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SOCIAL COST - BENEFIT ANALYSIS OF ACTIVE MOBILITY PROJECTS IN CONTEXTS WITH STEEP TERRAIN. A CASE STUDY IN COLOMBIA

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Abstract: Active mobility projects can potentially initiate paradigm shifts in population and urban planning decision-makers. This paper aims to conduct a social cost-benefit analysis of an active mobility project in a Colombian city. The increase of physical activity, reduction of CO_2 emissions, and traffic crashes were measured in an area with suitable slopes to promote bicycles for commuting. A social cost-benefit ratio of 1.14 was found, with physical activity and road safety as the most important outcomes of the active mobility infrastructure. Furthermore, a big room for the increase and promotion of cycling as a mode of transport is addressed.

Key words: social cost-benefit analysis, steep terrain, active mobility, walking, cycling, modal shift

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INTRODUCTION

From the perspective of active mobility projects, many authors have documented the benefits to society generated by cycling and walking. An increase in physical activity and a reduction of premature deaths (Mueller et al., 2015), a reduction of air pollutants (Espinosa et al., 2018), traffic congestion (Rabl and de Nazelle, 2012), an increase in road safety (Prato et al., 2016), and accessibility (Oviedo and Sabogal-Cardona, 2022). Several methods, such as balance sheet calculations (BSC), cost-effectiveness analysis (CEA), and multi-criteria analysis (MCA) have been popular for evaluating active mobility projects (Ruffino and Jarre, 2020). Nevertheless, cost-benefit analysis (CBA), also known as social cost-benefit analysis (S-CBA) (Ruffino and Jarre, 2020), has been the most used technique in the last two decades because it assesses the return on societal welfare. For instance, the World Health Organization (WHO) developed the Health Economic Assessment Tool (HEAT) to support the evaluation of active mobility (walking and cycling) projects, considering S-CBA.

The tool conducts an S-CBA in four categories: physical activity, air pollution, crash risk, and carbon emissions (Kahlmeier et al., 2017). Similarly, Sælensminde (2004) evaluated the implementation of active mobility networks in three Norwegian cities using a S-CBA. Traffic congestion, road safety, health, and external costs due to a modal shift from cars to active mobility were considered. The modal shift calculation considered the average distances of cycling and walking trips, resulting in a benefit-cost ratio of 4 to 5 times the initial investment. Later, a study conducted by Woodcock et al. (2009) compared the effects on health (physical activity, air pollution, and road crashes) of hypothetical scenarios of public policy implementations in London (UK) and New Delhi (India), where car traffic decreased, and technology improved to reduce air pollution, and active mobility grew. Health effects were measured through disability-adjusted life-years [DALYs], finding significant benefits of up to 7,332 DALYs avoided in London and 12,516 DALYs avoided in Delhi. A mixed approach was considered between increased active travel and lower emissions. Gotschi (2011) carried out an S-CBA of three different future investment plans (basic, 80%, and world-class) in bicycling infrastructure in Oregon (US). Health benefits were monetised via two methods: the value of statistical life savings and healthcare cost savings. The benefit-cost ratio reached 3.8 for the basic plan, 2.3 for the 80% plan, and 1.3 for the world-class plan when healthcare and fuel savings were considered. The ratio increased to 53.3, 33.1, and 20.1, respectively, when the value of saved statistical lives was considered.

Similarly, Macmillan et al. (2014) simulated the societal costs and benefits due to public policies implemented to increase the use of cycling as a commute mode in Auckland (New Zealand). A benefit-cost ratio between 6 and 20 was found. The highest benefits came from reducing all-cause mortality due to increased physical activity. In a case study of a

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6-mile recreational and commuting bikeway connecting two cities (Wilmington and New Castle) in Delaware, USA, Li and Faghri (2014) developed a comprehensive framework to support the construction of new cycling facilities through S-CBA. This study involved the analysis of social benefits due to traffic reduction (fuel and parking cost savings, congestion decrease), health improvement, road safety, and emissions and noise reduction. A net benefit-cost ratio of 1.92 was found when a 10% active mobility mode share was reached. In Flanders (Belgium), the impact of two bicycle superhighways was studied by Buekers et al. (2015). The effect on health was considered from a modal shift from car to cycling and walking. The number of cyclists and distances cycled were used to create future scenarios of private and active modal shares.

Health was measured through DALYs, and noise and CO_2 were considered for the environment and congestion in the model. The study found a benefit-cost ratio above 1 in all 22 evaluated scenarios, except for two where higher average construction costs were assumed. Brey et al. (2017) evaluated an S-CBA of cycling promotion policies in Seville (Spain) using questionnaires applied to private and public bike-share-system users, detecting an internal rate of return of 130%. Furthermore, Maizlish et al. (2017) quantified the health benefits and decrease in greenhouse gas emissions due to California's regional transportation plan with a high level of active transportation in the future.

Ambitious scenarios increased physical activity among the population by up to 283 minutes per week and reduced 2.5 to 12 deaths and DALYs compared to preferred scenarios. Similarly, Chapman et al. (2018) conducted an S-CBA of the ACTIVE (Activating Communities to Improve Vitality and Equality) program in New Zealand, comparing the net benefits for health and the environment between two cities where the program was implemented comparing with two control cities where it was not. The results indicated a benefit-cost ratio of 11:1.

In the Latin American context, few studies have applied S-CBA or evaluated health impacts related to active mobility projects and public policies. de Sá et al. (2015) evaluated the modal shift from car to active mobility in Sao Paulo (Brazil) and its impact on physical activity. Three hypothetical scenarios were considered, using the household travel survey and trip distance as a data source. Walking was identified as the most probable substitute for car trips in short distances (less than 1,000 meters). In contrast, public transport (i.e., subways, trains, and buses) was identified as the preferred mode for long distances (more than 1,000 meters). This resulted in increased physical activity levels from 19.4 to 26.7 minutes per capita while reducing private vehicle use. Moreover, de Sá et al. (2017) modelled the health impact of physical activity, air pollution, and road injuries in Sao Paulo (Brazil). A comparison between the current travel patterns of the city (2012 baseline year) with four counterfactual scenarios were conducted: Sao Paulo's central business district, London (2012), highly motorised Sao Paulo (as California), and 2040 Sao Paulo's vision.

Results showed a notable rise in health gains of 64,000 DALYs avoided. In the Colombian context, Espinosa et al. (2018) estimated the CO_2 emissions for two cities (Cali and Villavicencio), considering a hypothetical scenario of a 10% bicycle modal share for 2030. This situation will generate a cumulative avoidance between 2015 and 2030 of 83,245 CO_2 tons in Villavicencio and 445,976 CO_2 tons in Cali. Although Latin American studies have examined the health and emissions benefits of active mobility but have not utilized cost-benefit analyses.

Table 1 presents a brief summary of the reviewed research on evaluations of active mobility projects: i) The scenarios are categorized as infrastructure projects, implementation of public policies, and hypothetical scenarios; ii) The calculations consider the active mode of transport (cycling or walking); iii) The assessments take into account variables such as traffic, health, noise, pollution, and road safety; iv) The modal shift variables are based on trip distances for cycling and walking (percentages extracted from literature reviews) and are calculated for the city or area of influence; v) The research calculates the benefit-cost ratio (Yes/No); vi) Whether the topography of the case study region was considered (Yes/No).

Table 1. Synthesis of some contributions related to evaluations of active mobility projects. Source: authors

Autor	Types of scenarios	Modes of transport		Variables					Variables of modal shift and cycling share			BCR	Topo	City	Income level by World bank	
		B	W	T	H	P	N	RS	D	LR	R				HIC	LMIC
Sælensminde (2004)	IP	X	X	X	X	X		X	X		C	Yes	No	Hokksund, Hamar and Trondheim	X	
Woodcock et al. (2009)	HS	X	X		X	X		X	X		C	No	No	London, New Delhi	X	X
Gotschi (2011)	IP	X		X	X						C	Yes	No	Oregon	X	
Macmillan et al. (2014)	SPP	X	X	X	X	X		X		X	C	Yes	No	Auckland	X	
Li and Faghri (2014)	IP	X		X	X	X	X	X		X	C	Yes	No	Delaware	X	
Buekers et al. (2015)	IP	X	X	X	X	X	X	X			C	Yes	No	Flandes	X	
de Sá et al. (2015)	HS		X	X	X				X*		C	No	No	Sao Paulo		X
Brey et al. (2017)	SPP	X		X	X	X		X			C	Yes	No	Seville	X	
Maizlish et al. (2017)	SPP	X	X		X	X		X			C	No	No	California	X	
de Sá et al. (2017)	HS	X	X		X	X		X			C	No	No	Sao Paulo		X
Espinosa et al. 2018)	HS	X	X			X					C*	No	No	Cali and Villavicencio		X
Chapman et al. (2018)	SPP	X	X		X	X		X			C	Yes	No	New Plymouth and Hastings	X	
Rodrigues et al. (2020)	HS	X	X		X	X		X			C*	Yes	No	Porto	X	

IP: Infrastructure project; HS: Hypothetical scenario; SPP: Scenarios of public policy; B: Bike; W: Walk; T: Traffic; H: Health; P: Pollution; N: Noise; RS: Road Safety; D: Distance; LR: Literature review; R: Analysis resolution; C: City; AI: Area of influence *Consider projected modal shares of cycling and walking in government plans; BCR: Calculate the benefit-cost ratio Topo: Topography was considered? HIC: High Income Country; LMIC: Lower and Middle Income Country

As shown in Table 1, the literature presents several studies related to active mobility, which evaluate public policy implementations and hypothetical scenarios. Hypothetical scenarios often assess future transport mode shares with higher rates of active mobility among residents (de Sá et al., 2015, 2017; Espinosa et al., 2018; Rodrigues et al., 2020; Woodcock et al., 2009). In contrast, most studies assess modal shifts and benefits at the city level. Only Buekers (2015) estimated the benefits of the area of influence near the project. A common approach is to calculate the benefit-cost ratio; however, this is only possible if infrastructure or public policy implementation costs are available (e.g., Buekers et al., 2015; Gotschi, 2011; Li and Faghri, 2014). In Latin America, the reviewed articles calculated health benefits or pollutant reductions without implementing an S-CBA mainly because they are related to hypothetical scenarios and do not contemplate infrastructure projects with a detailed budget (de Sá et al., 2015, 2017; Espinosa et al., 2018). On the other hand, only Rodrigues et al. (2020) discuss the importance of steep topographies in the impact of active mobility projects, especially for increasing the use of the bicycle as a transport mode; however, they did not use it as a variable for the S-CBA. Additionally, all the reviewed articles measured the impacts at the city level. For example, the social well-being benefits and modal shift were calculated based on the overall impact on the population in the city, without considering specific effects on the project's area of influence where there is a greater potential for modal shift from private vehicles to active modes.

Therefore, this article aims to address these gaps by conducting an S-CBA in a medium-sized Colombian city where steep topography affects the construction of infrastructure for mobility projects and the popularisation of cycling as a transport mode. The project's impact will be measured by focusing on the most used variables in the literature: health, environmental, and road safety. Open-source programs like QGIS and programming languages like Python will be used for calculations. Furthermore, transportation data such as the Household Travel Survey and the Origin-Destination Matrix, geography data like Digital Elevation Model (DEM) and crowd-sourced data associated with cycling commutes will be used. This research can be replicated in other contexts where topography is an important variable in calculating the project's impact and data on modal shift and health are scarce.

The most important contributions of this research can be outlined as follows: i) The topography was a crucial variable in delimiting the area of influence of the active mobility infrastructure project. Steep topography affects the construction of new transport infrastructure due to the negotiation of public space with private vehicles and the popularisation of bicycles as a mode of transport; ii) The modal shift calculation considers trips within the area of influence and the average trip distance per mode of transport, estimated from the household travel survey. Furthermore, indicators from the World Health Organization about the percentage of shifted trips were used to avoid overstatement in the measures (Kahlmeier et al., 2017); iii) Social benefits were estimated regarding health, pollution, and road safety. A proposed method to estimate road safety benefits is presented, considering vision zero and safe road infrastructure approaches in the design and public policy implementations. This method reduces the probability of road crashes, calculating the Social Cost Saved due to fatalities and injuries prevented; iv) This research focuses on S-CBA in terms of health, environment, and road safety in a medium-sized Colombian city where the steep topography limits the use of the bike as a mode of transport. Studies on active mobility projects and S-CBA are scarce in the Global South, and Latin America and the Caribbean.

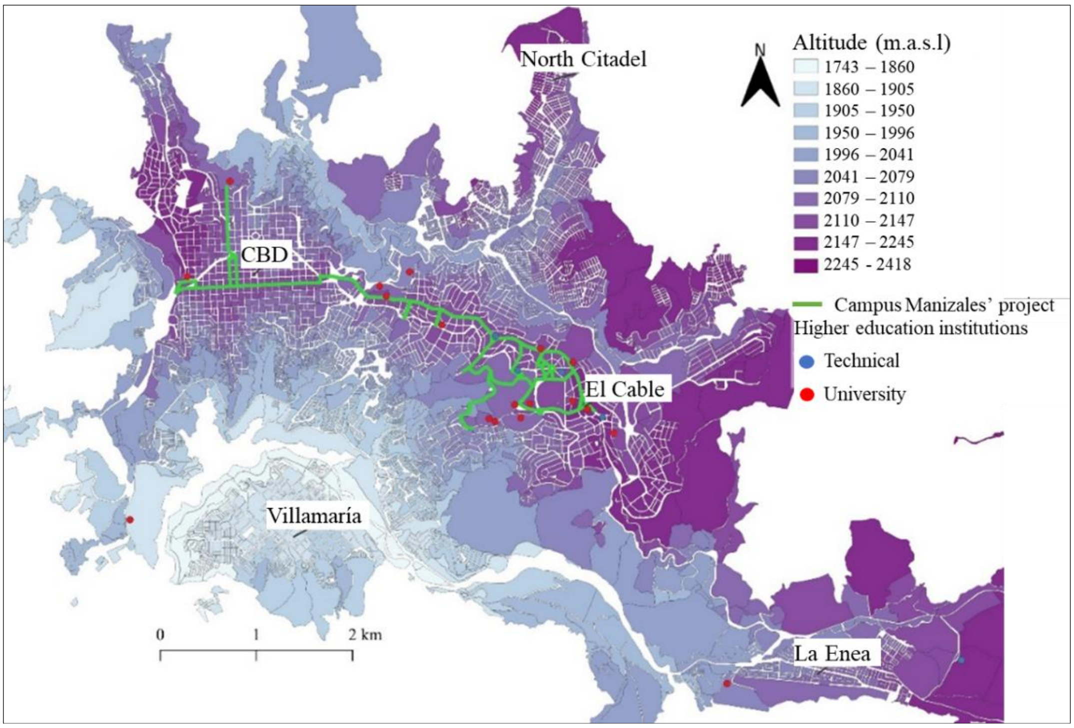

Figure 1. Case study location and Manizales' topography (Source: authors)

In Colombian medium-sized cities, infrastructure projects aimed at promoting active mobility (cycling and walking) are highly criticised and difficult to sustain due to the prevailing mobility status quo, where cars are the most dominant factor on the streets (Nello-Deakin, 2019; Oldenziel and Albert de la Bruhèze, 2011). Consequently, governments, practitioners, and academics have shown a growing interest in developing active mobility projects appropriately (Ruffino and Jarre, 2020). Campus Manizales (CM) is an infrastructure project that seeks to improve the active mobility network (cycling and walking) in the city of Manizales (Colombia) through the construction of boulevards, parks, and bike paths. This city is in the Andes Mountains in the centre-west of Colombia (Figure 1). CM aims to consolidate Manizales as Colombia's higher education capital by connecting 20 facilities (16 university campuses and 4 technical campuses) through an active mobility network. CM considers the intervention of 136,000 m^2 of public space (44% of boulevards and 37% of parks) (see green lines in Figure 1), including the provision of 16 km of separated bike paths (9 km in one direction and 7 km bidirectional) following a focus on designing road infrastructure for safety and vision zero in road crashes.

Moreover, it seeks integration with the city's mobility system through direct connections with aerial-cable car stations, public bike-sharing system stations, and bus stops. In Latin American contexts, where social inequalities, poverty, and urban segregation constantly affect inhabitants, boosting this kind of project is essential. Manizales City has a population of 450,000, and has steep topography, hindering the urbanisation processes and increasing the use of the bike as a mode of transport. As shown in Figure 1, the altitude of Manizales ranges from 1,743 to 2,418 meters above sea level (masl), with an average of 2,150 masl. CM is the first active mobility infrastructure project in the city where traditionally, mobility paradigm projects have been prioritized, investing most of the transport municipality budget in increasing the operational speeds and connections of private vehicles (cars, motorcycles, and taxis). These projects include new roads and intersections, widening of lanes, bridges, and roundabouts. Detailed designs included the project cost is USD 25.5 million.

MATERIALS AND METHODS

The methodology (Figure 2) was designed to be replicated in any context if the necessary data is available. Firstly, the required materials are described in detail. Then, the area of influence proposal and modal shift calculations are explained. Finally, the social cost-benefit assessment is described.

Phase 1 – Input Data: The transport network represents roads and intersections in a GIS environment. The road network for private vehicles and active mobility (walking and cycling) was obtained from previous investigations in the study area (Escobar et al., 2021). Researchers can download and use transport networks from OpenStreetMaps in absence of official data. GPS data for cycling commutes were collected through the Strava application to calculate average speeds, considering road slopes in the city. More than 20,000 GPS points were collected. In addition, Transport Analysis Zones (TAZ), Origin-Destination Matrix (ODM), and Household Travel Surveys (HTS) were obtained from the data collected in Manizales' Mobility Master Plan (Alcaldía de Manizales, 2017). This data is typically used for transport planning and is periodically collected by local governments. Besides, the National Administrative Department of Statistics collected sociodemographic information at various geographic resolutions (DANE, 2018). Finally, georeferenced data for road crashes were obtained from local authorities upon request. Information on crashes from 2013 to 2020 was registered, including crash severity (simple, injured, and fatal) and people involved (age, gender). Additionally, road crash data were validated with the National Agency of Road Safety (ANSV, 2022) information available for all municipalities in Colombia.

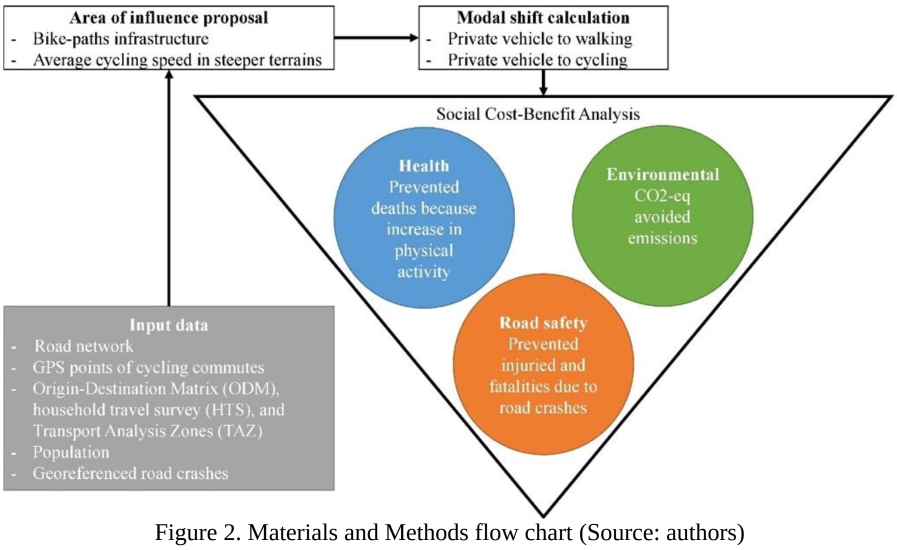

Figure 2. Materials and Methods flow chart (Source: authors)

Phase 2 – Area of influence proposal. Previous studies have assessed the S-CBA of active mobility projects based on their benefits for the entire city. However, this research considers proximity to define the area of influence. It is expected that most trips shifting from private vehicles to cycling or walking will occur near the infrastructure provided. The influenced area was estimated as the minimum coverage of 5 min. from bike infrastructure considering a bikeable distance in the most challenging topography conditions, i.e., the road slopes higher than 6% (Romanillos and Gutiérrez, 2020). Finally, coverage distances were analysed by grouping different average cycling speeds per slope percentage and using a 90% confidence interval (z = ±1.65) to broaden the range of analysis, to define the area of influence, i.e., the zone where modal shift calculations and social benefits will be concentrated.

Phase 3 – Modal shift calculation. Modal shift resulting from the active mobility project is estimated based on the ODM and HTS, considering the following constraints and assumptions: i) Sociodemographic groups: The age groups recommended by the World Health Organization (WHO) for cycling are people between 20 and 60 years, and for walking, people between 20 and 74 years (Kahlmeier et al., 2017); ii) Potential trips by distance: The potential trips for a modal shift from private vehicles (cars, motorcycles, and taxis) to active mobility are restricted to distances shorter than the average trip distance for bikes and walking in the current ODM. The ODM reflects the mobility dynamics built throughout a household survey where sociodemographic characteristics are recorded. For each mode of transport and purpose, trips are grouped between pairs of origin-destination zones represented in TAZs. The distance between each pair of TAZs using its centroid as a reference was calculated using the private vehicle road network and the QNEAT3 plugin of QGIS 3.16. The modal shift assumes that most of the trips to cycling and walking come from private vehicles (car, motorcycle, and taxi), considering their similar recent trips in the mobility system (Oviedo and Sabogal-Cardona, 2022); iii) Shifted trips: Finally, the shifted trips to cycling and walking were calculated as the product of the potential trips for a modal shift from private vehicles and the changeable default values defined by the WHO as 30% for cycling and 20% for walking (Kahlmeier et al., 2017). This study used a conservative approach; therefore, shifted trips from public transport were not considered.

Phase 4 – Social cost-benefit analysis. To calculate the benefits, two scenarios were studied: one without an active mobility project and the other with the project. The project was 2023, and a projection period of 10 years was considered. The scenario without the project corresponded to the current mobility dynamics extracted from the ODM. The scenario with the active mobility project involved the modal shift calculation. Health benefits are connected to increased physical activity, such as using bicycles and walking as modes of transport (Kahlmeier et al., 2017: 15). Table 2 shows the parameters defined by the WHO in the HEAT tool for health benefits. For instance, for people between 20 and 60 years, a relative risk reduction of 10% (i.e., the relative risk of 90%) was obtained if they ride at least 1,213 km/year-person as a commute. Using Equation 1 as an example, if the study zone registers an average distance of 750 km/year-person using a bike, this translates to a relative risk reduction of 6.2% (i.e., the relative risk of 93.8%) (Kahlmeier et al., 2017). In Equation 1, RRr represents the relative risk reduction in the study area, Dsz is the distance travelled per person per year in the study zone, Dref is the distance travelled per person per year in the reference zone established as Denmark by WHO, and RR is the relative risk.

Table 2. Basic parameters for health benefits assessment (Source: authors)

Mode of transport	Relative risk (RR)	Relative risk (RRr)	Distance travelled (person/year) in Denmark (Dref)	Age group (years) to measure health benefits
Cycling	90 %	10%	1213 km	20 to 60
Walking	89 %	11%	700 kms	20 to 74

$$RRr = \left(\frac{D_{sz}}{D_{ref}}\right) * (1 - RR) \tag{1}$$

The distance covered by walking or cycling per person per year ($D_{bike\ or\ walk}$) (used as *Dsz* in equation 1) is computed using Equation 2 (Source: authors); where $\overline{d_{bike\ or\ walk}}$ is the average distance of the trips by cycling or walking, $P_{bike\ or\ walk}$ is the people using each mode of transport, and *P* is the total number of people commuting in the study zone. Finally, the distance is calculated for a whole year, considering five working days per week and 52 weeks/year.

$$D_{bike\ or\ walk} = \frac{\left(\overline{d_{bike\ or\ walk}} * 5 * 52\right) * P_{bike\ or\ walk}}{P} \tag{2}$$

Prevented deaths in the study zone are calculated as the product of the relative risk reduction and the total fatalities for all causes. The Value of Statistical Life (VSL) was used to estimate the social cost of safety due to the prevention of premature deaths. According to the calculations of Mardones and Riquelme (2018), the VSL in Colombia was 640,000 USD.

On the other hand, the Environmental benefits refer to the reduction of CO_2 equivalent (CO_2-eq) emissions per year in the study zone considering the modal shift from private vehicles (motorcycle, car, and taxi) to active mobility (walking and cycling). The emissions were calculated using methodologies used in transport inventories (Escobar et al., 2022b; Espinosa et al., 2018). This method calculates the activity factor, the efficiency factor, and the emission factor.

The activity factor is based on the distance covered per type of vehicle in the study zone. This research calculated the number of trips per mode of transport, the distance between TAZs obtained from ODM (explained in phase 2), and an occupancy factor per mode of transport. The efficiency factor describes the distance covered per volume of fuel consumed (mainly expressed in km/gallon or km/m^3); this factor is specific to each vehicle or mode of transport. Finally, the emission factor expresses the number of pollutants per type of fuel considering pollutants per gallon (in this case, in CO_2-eq); it was obtained from the most recent calculations of Colombian fuel types (Amell Arrieta et al., 2016). Changes in emissions between the baseline and projected scenarios are monetised using the social cost of carbon, which is a value in USD for each ton of CO_2-eq saved due to the project (Griffiths et al., 2012). Following WHO's suggestion, the social cost of carbon in Colombia was estimated to be 78 USD in 2014 and is expected to increase to 103 USD in 2032.

Traditional road safety assessments in S-CBA of active mobility projects consider the increased distance travelled by commuters as a rise in exposure to road crashes (Kahlmeier et al., 2017). Two assumptions were adopted: i) the rise of active mobility reduces the probability of use of motorised traffic; ii) Active mobility projects must be designed with a vision zero and road infrastructure safety management focus (Belin et al., 2012). A value per each prevented road crash involving fatalities or injured is given to monetise road safety benefits. The Years of Potential Life Saved (YPLS) and the Social Cost Save (SCS_y) per year were used for fatalities. This is a similar method to estimating the social cost lost due to fatalities, but, in this case, we compute the social cost saved (Roselli, 2018). The YPLS estimations in the study zone (see eq. 3) considered the life expectancy (LE), the average age of fatalities ($\overline{A_f}$) and the prevent fatalities per year, calculated as the difference between the average number of fatalities ($\bar{F}$) and the projected fatalities when the project is finished (F_i). On the other hand, the prevented injured person (PIP) by road crashes was estimated using Equation 4, where the difference between the average number of injured people ($\bar{I}$) and the projected injured people when the project is finished (I_i) was computed.

$$YPLS = \left(LE - \overline{A_f}\right) * \sum_{i=1}^{n} (\bar{F} - F_i) \quad (3) \qquad PIP = \sum_{i=1}^{n} (\bar{I} - I_i) \quad (4)$$

Finally, the social cost saved due to road safety (SCS_{rs}) is achieved by monetizing the values of prevented fatalities (SCS_y) and injured (SCS_p) by road crashes (see Equation 5). To monetize fatalities, a value of three times of the Gross Domestic Product (GDP) per capita is given per YPLS (Instituto de Evaluación Tecnológica en Salud, 2014; Roselli, 2018) (USD $5,085 in the Caldas department in 2023). To monetize the injured person, we used the estimation of Gómez-Restrepo et al. in 2014, where health system costs were considered (USD 430 for 2023 per injured person).

$$SCS_{rs} = YPLS * SCS_y + PIP * SCS_p \quad (5)$$

RESULTS AND DISCUSSION

This area was defined by the proximity to the CM project and average cycling speeds per road slope for commute trips in Manizales. More than 20 thousand GPS points were collected before and during the Covid-19 pandemic. Speeds were calculated and added to the road cycling network through Python 3.7. This network had road slopes calculated using the Manizales' Digital Elevation Model (DEM), like Romanillos and Gutierréz (2020), who analysed cycling speeds in Madrid. The average speed decrease with higher ascent slopes (higher than 0%) because people need more power to maintain the speed; the study area evidences the steeper terrain with road slopes up to 25%. Table 3 shows average cycling speeds grouped by road slope and the distance coverage (in meters) for different cycling speeds. Average speeds for descent terrains (slopes less than 0%) resulted in higher than 20 kph, while the speeds for ascent terrains with slopes higher than 6 % are near 10 kph. Considering uncertainty in the average cycling speed results, Table 3 presents the minimum and maximum speed for a confidence interval of 90% (z = 1.65). Finally, the distance coverage was calculated for a maximum travel time of 5 minutes to the new cycle infrastructure project. We observe that coverage is huge sensible to the change of speeds and slopes; consequently, we decided to delimit the area of influence to 500 meters (Figure 3) considering the steeper terrains in the study area, high road slopes (more than 6%) and an average cycling speed of 6 kph.

Table 3. Average cycling speeds per road slope groups and distance coverage (Source: authors)

Slope (%)	Cycling speed (kph)				Distance coverage (meters) in five minutes		
	Avg	Std	90% (z = 1.65)		Avg	90% (z = 1.65)	
			min	max		min	max
< -10	23.01	10.82	5.16	40.86	1,918	430	3,405
- 8 - -10	22.23	7.57	9.74	34.72	1,853	812	2,893
-6 - -8	24.16	7.98	10.99	37.33	2,013	916	3,111
-4 - -6	25.39	8.40	11.53	39.25	2,116	961	3,271
-2 - -4	23.36	7.47	11.03	35.69	1,947	920	2,974
0 - -2	24.06	7.06	12.41	35.71	2,005	1,034	2,976
0 - 2	14.71	4.80	6.79	22.63	1,226	566	1,886
2 - 4	15.38	6.39	4.84	25.92	1,282	403	2,160
4 - 6	12.19	4.18	5.29	19.09	1,016	441	1,591
6 - 8	10.70	2.77	6.13	15.28	892	511	1,273
8 - 10	10.65	3.29	5.22	16.09	888	435	1,340
> 10	9.60	2.58	5.34	13.86	800	445	1,155
Avg: Average; Std: Standard deviation; min: minimum; max: maximum							

The area of influence intervened by CM project covers 101,604 inhabitants, nearly 20.4% of the total inhabitants in Manizales and Villamaría (498,943 inhabitants). On the other hand, 178,052 trips are made within the TAZ in area of influence (Figure 3), especially between the Central Business District (CBD) and El Cable sector. Moreover, walking is the most used mode of transport with 46.4%, followed by a car as a private vehicle (19.3%) and public transport (16.6%). Cycling has a minimum use with 0.6% of all trips, although the zone's topography characteristics allow bike mobility compared with other zones with higher slopes. Gender has been established as an important variable for transportation studies because mobility dynamics between males and females are nearly different (Rodas-Zuleta et al., 2022). The population covered is 54.5% female (55,345 inhabitants), ten per cent more than male. Furthermore, age groups are very important for social benefits assessments. For instance, for cycling, 57,833 inhabitants (56.9% of the total) between 20 and 60 years lived around the CM project, while for walking, 74,659 inhabitants (73.4% of the total) between 20 and 74 years were covered.

Since modal shift assessment is a difficult stage in mobility projects, we defined a conservative approach to avoid bloated results. Table 4 shows the total trips for private vehicles, the potential trips to shift and the shifted trips to walking and cycling. Regarding private vehicles, the use of cars (34,431 trips) doubles the use of motorcycles (17,238 trips) and triples the use of taxis (9,957 trips). An analysis of trip distance per the mode of transport shows that walking registers the shortest average distance at 1.71 km. Meanwhile, cycling has an average distance of 2.54 km; this result is equal to the average distance of a motorcycle (2.54 km) and close to a taxi (2.58 km) and car (2.65 km). The potential trip to shift from private vehicles was obtained using waking and cycling average trip distance and the age constraint. In this case, cars represent a similar proportion of the total trips while motorcycles reduce their participation in the total potential trips for walking and cycling. Taxis have a lower percentage of potential cycling trips than walking, which can be explained by age. Finally, considering a modal shift from private vehicle to cycling and walking of 30% and 20% respectively, the trips shifted to cycling is 7,284 (11.8% of total private vehicle trips) and walking 4,128 (6.7% of total private vehicle trips).

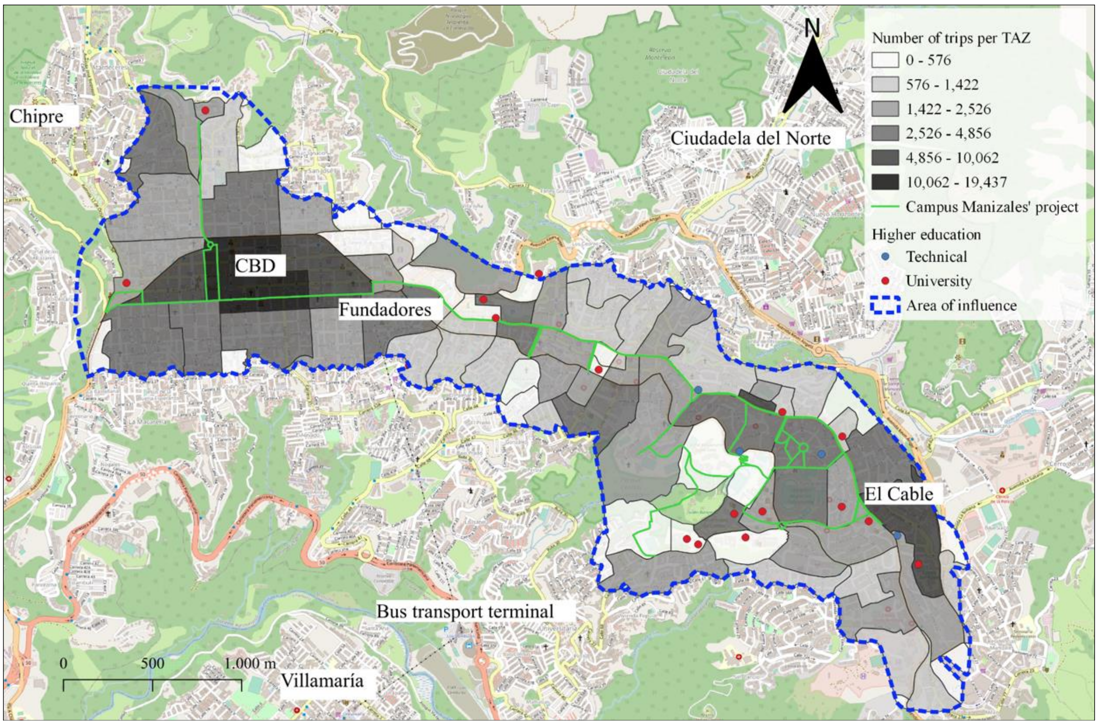

Figure 3. Trips per TAZ in the area of influence (Source: authors)

Table 4. Modal shift analysis for private vehicles to active mobility (Source: authors)

Mode of transport	Trips	Cycling (Age 20 - 60 years and average distance of 2.5 km)		Walking (Age 20 - 74 years and average distance of 1.7 km)	
		Potential trips to shift	Shifted trips	Potential trips to shift	Shifted trips
Car	34,431 (55.9%)	15,252 (62.8%)	4,576	12,377 (59.9%)	2,475
Motorcycle	17,238 (27.9%)	6,403 (26.4%)	1,921	4,853 (23.5%)	971
Taxi	9,957 (16.2%)	2,625 (10.8%)	788	3,412 (16.6%)	682
Total	61,626	24,280	7,284	20,642	4,128

The health benefits assessment considers relative risk reduction due to increased physical activity caused by cycling and walking. In the current scenario, the area of influence registers a walking distance of 144.59 km per person per year, while cycling reaches 3.17 km. This result shows the low use of cycling as a mode of transport (achieved only 0,6% of all trips in Manizales) and an opportunity to increase their use. The CM project stimulated a shift in transportation modes within the population, resulting in an average of 27.87 km of cycling per person per year.

This represents a remarkable increase of 779% compared to the base scenario. Moreover, this increase in cycling led to a relative risk reduction of 0.23% per year in premature deaths, as demonstrated in Table 5. Due to walking being the primary mode of transportation in the area of influence (accounting for 46.4% of all trips), the increase in its usage resulting from the modal shift leads to a 7.19% rise in the distance covered per person per year. Additionally, this increase in walking contributes to a 0.08% reduction in the risk of premature deaths attributed to physical inactivity.

Table 5. Distance covered and relative risk reduction for cycling and walking (Source: authors)

Mode of transport	Base scenario		Project scenario		Relative risk reduction
	Distance (km-person/year)	Relative risk	Distance (km-person/year)	Relative risk	
Cycling	3.17	99.97%	27.87	99.77%	0.23%
Walking	144.59	98.80%	155.00	98.72%	1.28%

Involving the number of deaths because of different causes (some types of cancer, mental health, coronary heart disease, lung disease, and high blood pressure, among others.) in the study zone, reaching 843 deaths in 2019, and using time-series data of deaths, a linear regression (35.06*x + 69848. $R^2 = 0.85$) was performed to define the number of deaths in the long term. A total of 35 premature deaths are prevented in a ten-year projection (2023 – 2032) because of increased physical activity (walking and cycling) in the area of influence.

Regarding to the environment factor, emissions of CO_2-eq in the base scenario result in 7,665 tons/year, showing a geographical pattern (Figure 4) like the number of trips per TAZ. CBD (823 CO_2-eq tons/year) and El Cable (736 CO_2-eq tons/year) registered the highest emissions in the area of influence. Most zones record emissions between 115 and 274 CO_2-eq and are located around the CM project. On the other hand, the CM project boosted a modal shift producing a drop in the emissions near to 8% per year (618 CO_2-eq tons/year) due to transport. Figure 5 shows the percentage of saved CO_2-eq per TAZ, finding a high reduction near universities (up to 43% of emission reduction) located in the west of the influenced area. In this case, the CBD register savings of around 7.41% despite having the highest emissions and trips.

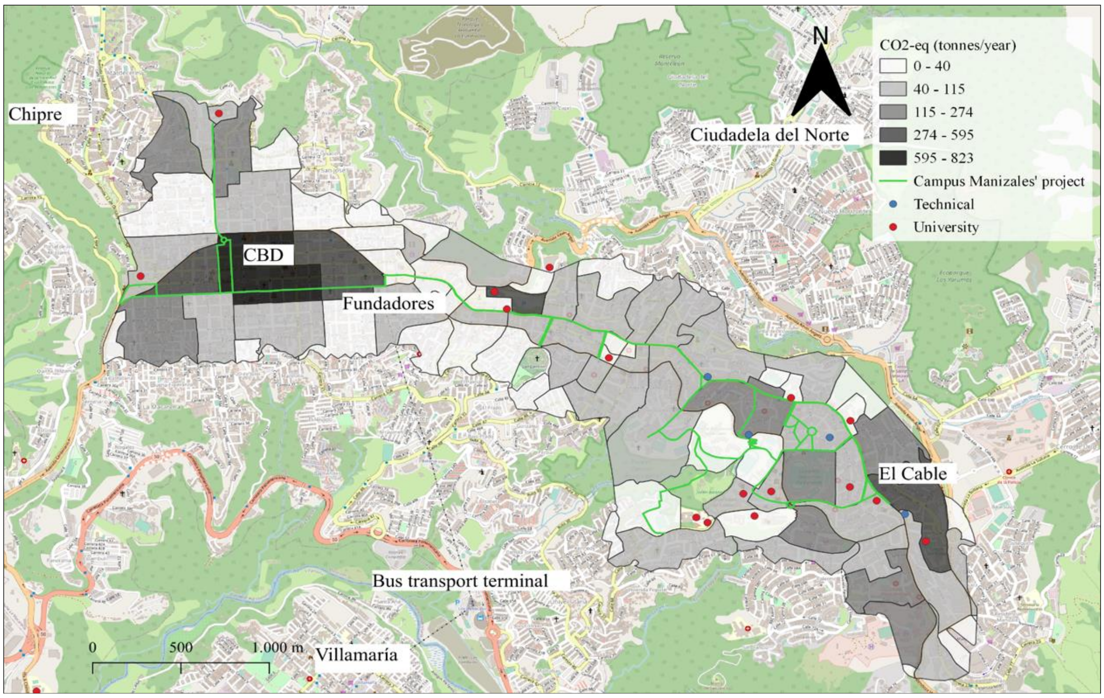

Figure 4. CO_2 -eq (ton/year) in the base scenario (Source: authors)

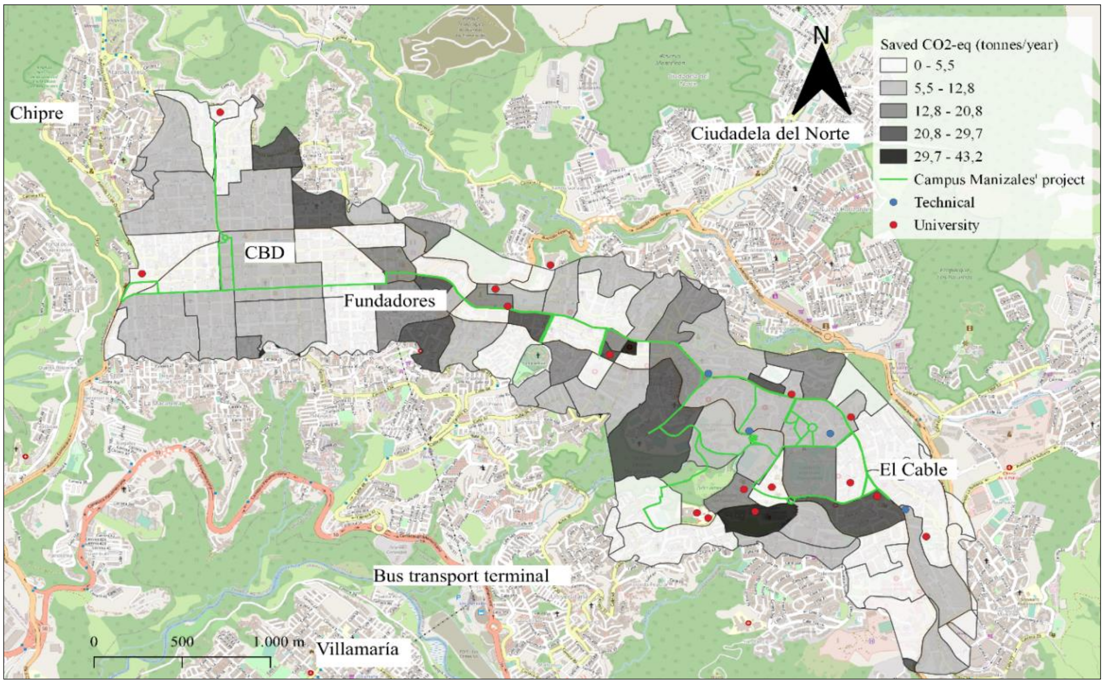

Figure 5. Saved CO_2 -eq (%) with CM project (Source: authors)

Finally, road crashes in the area of influence are analysed to define the benefits of the CM project. Following road safety recommendations in Manizales, some infrastructure and human behaviour interventions have worked to reduce road crashes, showing a decreasing trend in road crashes between 2013 and 2019 (Linear regression -18.74*x + 38174. R2 = 0.78). The five-year period generates 69.2% of simple crashes, 30.1% of them with injured and 0.7% with fatalities involved (2020 and 2021 were excluded). The CM project might avoid 624 injured and 19 fatalities, near 608 years of potential life saved (YPLS), in the ten-year projection. Table 6 presents the final S-CBA, where health, environment and road safety benefits were monetized.

Prevented deaths due to an increase in physical activity because of walking have the highest impact (USD 15,779,861), followed by years of potential life saved (YPLS) because of prevented road crashes with fatalities involved (USD 9,442,616). Finally, the S-CBA ratio is 1.14; consequently, the project shows a positive social impact in the study zone during the ten years.

This research concentrates on the benefits of the CM project up to 500 meters from the intervened road network. We defined the proximity to the project as the key to boosting a modal shift from private vehicle to active mobility because the provision of bicycle infrastructure increases the probability of bike use for commuting. This zone has the potential to obtain the highest benefits related to physical activity, environmental, and road safety related to CM project. Nevertheless, as other authors express (Brey et al., 2017; Chapman et al., 2018; Sælensminde, 2004), active mobility impacts could be translated to the entire city. In this case, we prefer to keep a conservative approach to mitigate the impact of some assumptions related to modal shifts, health benefits and the city's steep topography. High ascent road slopes affect the cycling speed among commuters limiting the accessibility and the increase of the bike in the modal share (Romanillos and Gutiérrez, 2020); however, its inclusion as an analysed variable in social cost-benefit analysis is scarce. E-bikes and e-scooters have the potential to minimize the ascent slope effects; nevertheless, recent studies shows that e-scooters have a minimum benefit on physical activity and air pollution and a high negative impact on road crashes (Félix et al., 2023). On the other hand, recently literature has paid particular attention to the differences in the travel patterns between women and men to design infrastructure (Montoya-Robledo et al., 2020) considering factors such as gender-based violence (Rodas-Zuleta et al, 2022).

Table 6. Summary of social cost-benefit analysis of Campus Manizales' project. (Source: authors)

Year	Health: Walking		Health: Cycling		Emissions		Road Safety				
	PD	(USD)	PD	(USD)	CO2-eq (tonnes)	(USD)	PIP	(USD)	PD	YPLS	Value (USD)
2023	2.74	$ 1,481,907	0.49	$ 266,280	618	$ 55,002	37.07	$ 15,942	1.33	42.62	$ 650,386
2024	2.78	$ 1,503,258	0.50	$ 270,117	618	$ 55,002	42.71	$ 18,366	1.47	46.90	$ 715,692
2025	2.82	$ 1,524,609	0.51	$ 273,953	618	$ 55,002	48.35	$ 20,790	1.60	51.18	$ 780,997
2026	2.86	$ 1,545,960	0.51	$ 277,790	618	$ 55,002	53.99	$ 23,215	1.73	55.46	$ 846,303
2027	2.90	$ 1,567,311	0.52	$ 281,626	618	$ 55,002	59.62	$ 25,639	1.87	59.73	$ 911,609
2028	2.94	$ 1,588,662	0.53	$ 285,463	618	$ 55,002	65.26	$ 28,063	2.00	64.01	$ 976,914
2029	2.98	$ 1,610,013	0.54	$ 289,299	618	$ 55,002	70.90	$ 30,487	2.13	68.29	$ 1,042,220
2030	3.02	$ 1,631,364	0.54	$ 293,136	618	$ 55,002	76.54	$ 32,911	2.27	72.57	$ 1,107,526
2031	3.06	$ 1,652,714	0.55	$ 296,972	618	$ 55,002	82.18	$ 35,335	2.40	76.85	$ 1,172,832
2032	3.10	$ 1,674,065	0.56	$ 300,809	618	$ 55,002	87.81	$ 37,760	2.54	81.13	$ 1,238,137
Total	29	$ 15,779,861	5	$ 2,835,444	6180	$ 550,020	624	$ 268,508	19	619	$ 9,442,616
PD = Prevented deaths; PIP = Prevented injured person; YPLS = Year potential live saved											

Modal shift is a problematic measure in mobility projects, especially when it considers the modal shift from private vehicles (car, motorcycle, and taxi) to active mobility (walking and cycling or public transport) (Kahlmeier et al., 2023; Kahlmeier et al., 2017; Oviedo and Sabogal-Cardona, 2022; Rodrigues et al., 2020). Several factors (supply infrastructure, accessibility, road safety, socioeconomic level, environment awareness, age, sex, trip purpose, distance, topography, among others) could determine the number of trips translated (De Vos et al., 2022). In this research, we constrain the modal shift to the area of influence and consider three assumptions based on age group, mode of transport and distance of commute. The first assumption related to the age group relates to the health benefits assessment, where only people between 20 and 60 years and 20 and 74 years are considered for cycling and walking by recommendations of WHO (Kahlmeier et al., 2017). The second assumption is related to the modes of transport we want to attract to active mobility projects. In this case, sustainable mobility and the potential use of walking and cycling are crucial. For example, Oviedo and Sabogal-Cardona (2022) argue the potential of cycling as a mode of transport for private vehicle commutes, considering the last one as the least wanted in urban mobility due to its negative externalities like traffic jams, road crashes, and the environment. Finally, the average distance per mode of transport is defined as the threshold for potential trips of modal shift (De Vos et al., 2022; Sælensminde, 2004). This conservative framework provides us with the certainty of not overstretching the effects of active mobility projects in a modal shift from private vehicles to walking and cycling.

Furthermore, the S-CBA considered three perspectives: health, environment, and road safety. Those are generally used in S-CBA analysis of cycling and walking projects (Ruffino and Jarre, 2020; Tainio et al., 2021). However, other benefits related to traffic jams, travel time savings or noise are more challenging to measure. Consequently, this study considers only the benefits that could be calculated with common built-in data for transport planning, such as the household travel survey and origin-destination matrix (de Sá et al., 2015, 2017). For instance, a previous work related to the impact of the CM project on private vehicle accessibility concluded that the impact is less than 3%, and it could be concentrated in the high socioeconomic groups of the population, promoting their shift to active modes of transport.

On the other hand, environmental impacts of 618 CO_2-eq tons/year avoided are less than reported by Espinosa et al. (2018) for Cali (29,731 CO_2-eq tons/year) and Villavicencio (5,540 CO_2-eq tons/year). In this article, the study zone was limited, while the other studies considered the entire city and future modal shares in Cali and Villavicencio regarding optimistic bike use for commutes. Road safety is an essential dimension of active mobility projects because people feel more comfortable cycling and walking when they have proper infrastructure or traffic is pacified (Macmillan et al., 2014; Montoya-Robledo et al., 2020; Escobar et al., 2022a). This innovative approach to measuring S-CBA related to road safety must be considered in future scenarios to create a safe transport system for everyone. Active mobility projects evaluated through S-CBA generally use the cost-benefit ratio as an economic appraisal; nevertheless, it is difficult to compare the results throughout studies because of their heterogeneity. For example, the CM project has a benefit-cost ratio of 1:1.14, mainly because the benefits are related to increased physical activity and road safety.

CONCLUSION

The research conducted in Latin America regarding the social benefit of active mobility projects or public policy has traditionally overlooked economic appraisal through the benefit-cost ratio. The presented method, based on existing literature on Social Cost-Benefit Analysis (S-CBA) in active mobility projects, can be adapted to cities where data is limited and hard to obtain. Additionally, the delineation of the area of influence using proximity and cycling speeds, considering road slopes, represents an improvement in evaluating active mobility projects, especially in areas with challenging topography that affects distance coverage and cycling speeds. The CM project in Manizales demonstrates a social cost-benefit ratio of 1.14 over a ten-year projection, highlighting its positive impact on the entire population of Manizales, even though the benefits are calculated based on the area of influence. This study represents the first S-CBA conducted in a city with limited bike usage for commuting due to steep topography and high road slopes.

However, the research does have limitations concerning the assumptions made for modal shift calculations and health benefits. The percentage of modal shift from private vehicles to cycling and walking is based on existing literature, and it is crucial to have demand estimation to provide objective certainty to the modal shift. Health benefits assessments related to increased physical activity also require further discussion in the context of Latin American settings, as the assumptions made in studies conducted in developed and high-income countries may not necessarily apply. These limitations were beyond the scope of this study and could be addressed in future research. Moreover, it is essential to implement this method in Latin American contexts, where active mobility projects face challenges due to a strong focus on the mobility paradigm centred around cars among decision-makers and politicians.

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