Cost and Benefit Analysis Tool for Cycling Facilities

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1 Introduction

The primary objective of this project was to design and develop an interactive tool for estimating the economic returns, including costs and benefits, of cycling facility investments in the developing world where might have very limited transport data. The tool, referred to as the Cost and Benefit Analysis for Cycling Facilities (CBA_CF), is intended to enhance decision-making with respect to cycling facility investments. Built upon a comprehensive framework of proven methodologies for evaluating costs and benefits, the tool provides a user-friendly web-based interface with default and optional user-defined values to customize outputs for World Bank teams and clients. The comprehensive benefits incorporated in the tool include factors related to safety, health, travel time, and the environment, and the tool converts all benefits into monetized annual cash flow. For cost, the initial construction cost of the cycling facility along with the ongoing maintenance costs are considered by the tool. The overall cost-benefits are represented by the net present value (NPV) and interval return rate (IRR), providing evidence-based information for decision makers. The tool is designed to support policy dialog and project preparation. The tool will support World Bank teams and clients in estimating the economic returns of cycling facility construction or upgrading cycling infrastructure, protected bike lanes. It simplifies the process by considering both the necessary data and the wide range of economic advantages, striking a balance between detail and comprehensiveness.

2 Key Features

2.1 Use Cases

This tool is mainly intended to evaluate the benefits of newly constructed cycling facility which aims to provide an exclusive bikeway for cyclists at the project level. Although this tool can also be used to evaluate benefits for improving or upgrading existing facilities, cautions should be used while selecting the input parameters, since the parameters for new construction and improvement projects may differ significantly.

2.2 Measured Benefits

The CBA_CF tool provides an accounting of the benefits and costs of proposed cycling facilities, giving decision-makers an aggregated view of the positive effects of cycling infrastructure. We note that the installation of cycling facilities has a wide range of direct and indirect benefits described in future sections of this report; here, we have focused on those that can be reasonably estimated based on available research and data and that demonstrate opportunities for future benefits. The CBA_CF includes the following four benefit categories:

- **Safety**. CBA_CF calculates safety benefits for both traffic shifted from cars and existing cycling traffic, accounting for improved safety resulting from dedicated cycling lanes with road safety features.[1] The benefit from crashes avoided by car riders switching to cycling is estimated from the average cost of car crashes. Existing cyclists who travel in existing facilities (e.g., the roadway with no cycle lane or unprotected cycle lane before the cycling facility is installed) in a mixed traffic with cars will also benefit; this benefit is assessed using Crash Modification Factors and the average cost of bicycle crashes.

- **Emissions**. The emissions benefit is calculated from the reduction in CO_2 from the mode shift from cars to cycling. The CBA_CF extracts emission costs ($/g) from a lookup table based on World Bank data that extends to 2050.

- **Health**. The health benefit is calculated as the reduction in mortality due to increased exercise. Physical activity associated with cycling will lead to improved health and reduced mortality [2]. The cost savings are estimated based on the value of a statistical life (VSL), which is defined as how much individuals are willing to pay for a very small reduction in the probability of death [3].

- **Travel time savings**.[4] When calculating savings in travel time, the tool considers both time savings for traffic shifted from walking and additional time costs for traffic shifted from cars and public transit. Given that this tool was designed for use in developing countries, travelers will likely be switching from walking to cycling, resulting in travel time saving benefits. There are ongoing discussions on benefits of travel time savings due to mode shift from car to cycling. While mode shift from car to cycling typically leads to longer travel times, recent meta-analysis on value of time savings (VTTS) in developing countries suggest that VTTS for cycling

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[1] In this report, dedicated cycling lanes are cycling pathways that provide exclusive access to cyclists.

[2] https://www.who.int/europe/news/item/07-06-2022-cycling-and-walking-can-help-reduce-physical-inactivity-and-air-pollution--save-lives-and-mitigate-climate-change#:~:text=Many%20studies%20have%20specifically%20investigated,European%20Regional%20Obesity%20Report%20202

[3] Colmer J. *What is the meaning of (statistical) life? Benefit–cost analysis in the time of COVID-19*. Oxford Review of Economic Policy. 2020 Aug 29:graa022. doi: 10.1093/oxrep/graa022. PMCID: PMC7499700.

[4] This is an advanced option that advanced users must opt in to due to the required location-specific transit and transportation information.

and walking might be approximately twice as high as for cars[5]. This means that the perceived "negative benefit" of increased travel time could be offset by a much greater willingness to spend time cycling, potentially making it a significant benefit overall. Thus, to avoid overestimation of the benefits of travel time savings, the current tool focuses on the benefits from mode shift from walking to cycling.

2.3 Input and Default Parameters

The benefits and costs of a cycling facility depend strongly on the location. For example, the cost of crashes and the value of statistical life can vary dramatically from country to country. In addition to a comprehensive consideration of benefits from cycling facility construction, the CBA_CF tool incorporates flexible and customable settings for key parameters. Users can **input specific parameter values** based on the infrastructure under consideration and the local area.

The user can also opt to use the tool's **default parameter values**. For example, for time-varying parameters that depend on per capita Gross Domestic Product (GDP), such as the value of a statistical life, the tool extracts the most recent value from the World Bank using an API to ensure the calculation is up to date. For location-specific parameters, the tool provides reference default values from published studies. Users can customize any coefficients based on their own research. CBA_CF also allows administrators to add, modify, and delete reference values, allowing for future expansion of the tool.

As the analysis is primarily for new construction, the parameters should be carefully calibrated when used for facility improvements. For example, the percentage of induced cycling traffic and construction cost could differ substantially between new construction and facility improvements.

2.4 Key Outputs

Importantly, the CBA_CF tool outputs monetized metrics—the outputs include the total costs of construction and maintenance as well as annual benefits in the four benefit categories (safety, emission, health, and travel time savings) over the project evaluation period (multiple decades in the future or the number of years selected by the users). The tool also calculates the Net Present Value (NPV) and the Internal Rate of Return (IRR), two key metrics for cost-benefit analysis. These tangible and actionable outputs allow users to immediately grasp the cost-benefit of a project and make informed decisions about the economic viability of the investment.

The remainder of this report provides an overview of the background and related research, details of the methodologies used by CBA_CF, and information about the tool's structure, interface, parameters, and outputs.

[5] Wardman et al. *Meta-analysis of the Value of Travel Time Savings in Low-and Middle-Income Countries*, Mobility and Transport Connectivity Series, June, 2023.

3 Background and Related Studies

Dedicated cycling lanes[6] provide a safe and efficient environment for bicycle traffic. For example, multiple studies have shown that such facilities encourage more people to cycle. This increased cycling use can lead to less reliance on motorized vehicles, which in turn reduces traffic congestion and the associated environmental impacts. Additionally, cycling lanes can improve public health by promoting physical activity, reducing transportation costs for individuals, and creating a more livable urban environment through reductions in noise and improvements in air quality. Cycling facilities also contribute to safer roads for all users because they can reduce the likelihood of crashes involving cyclists and motor vehicles. Recognizing the benefits of cycling facilities, considerable research has been conducted to quantify the benefits from various aspects using a variety of models.[7,8,9,10] This chapter provides a review of the major categories of benefits: safety, emissions, health, and travel time.

3.1 Safety Benefits

Well-designed cycling facilities can substantially improve safety. Data from the city of Copenhagen has demonstrated that the construction of cycling facilities is associated with reduced rates of fatalities and injuries (Figure 1). Cycling facilities can improve safety in two major ways: 1) by inducing a shift from driving to cycling, thereby reducing motorized vehicle crashes; and 2) by improving the safety of existing cyclists (i.e., those who were previously riding with motor vehicles on existing roads without cycling facilities).

Dedicated cycling lanes can improve safety by providing protected spaces for cyclists, reducing the likelihood of crashes with motor vehicles, and encouraging safer and more predictable interactions between cyclists and drivers. By separating cyclists from motorized vehicles, cycling lanes can also reduce the exposure of cyclists to road hazards and improve overall traffic safety for all road users. The Australian Transport Assessment and Planning Guidelines use the difference between the baseline crash rate (i.e., the crash rate without the cycling project) and the crash rate after the installation of the cycling facility to estimate the reduction in crashes. A more commonly used approach is the Crash Modification Factor (CMF),[11] which is the ratio of the crash rate with the safety improvement to that without the safety improvement. In the case of a cycling facility, the CMF represents the crash rate ratio of the newly constructed cycling facility to the existing traffic lane. A CMF smaller than 1 indicates a lower crash rate after the installation of the cycling facility.

[6] https://en.wikipedia.org/wiki/Cycling_infrastructure

[7] World Health Organization. (2021). *Health Economic Assessment Tool (HEAT) for Walking and Cycling*. https://www.who.int/tools/heat-for-walking-and-cycling

[8] Institute for Transportation & Development Policy. (2022, October). *Protected Bicycle Lanes Protect the Climate*. https://itdp.org/publication/protected-bicycle-lanes-protect-the-climate/

[9] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*. https://www.atap.gov.au/mode-specific-guidance/active-travel/index

[10] University of California, Davis. (2022). UCDAVIS Active Transportation Resource Center Tool. https://activetravelbenefits.ucdavis.edu/

[11] AASHTO. (2010). *Highway Safety Manual*, Vol. 1.

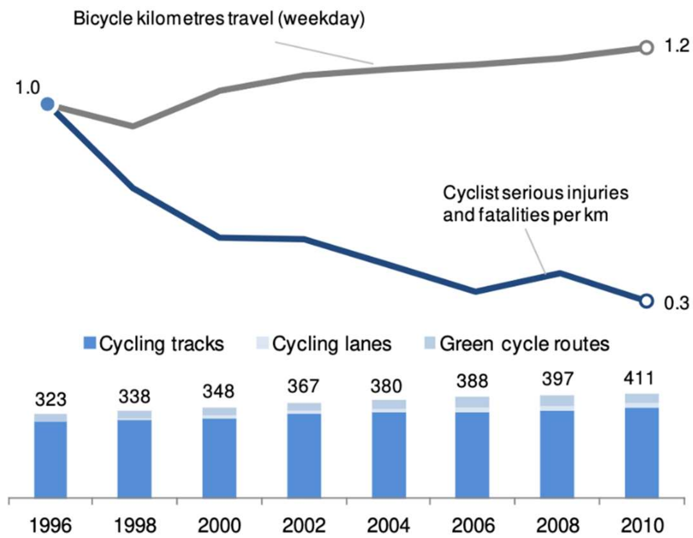

Figure 1: Cycling travel, per-kilometer cyclist casualties, and kilometers of cycling infrastructure in in Copenhagen.[12]

Safety impacts are mixed in terms of the reduction in crash rate resulting from cycling facilities; some studies found reduced crash rates, while others indicated increased crash rates.[13] The issue is further complicated by the cycling induced by the new facility. In general, unprotected inducted cycling could lead to increased cycling volume, which could contribute to increasing the crash rate; for example, high traffic volume could increase interactions and conflicts among riders, lead to more collisions.[14] Properly designed cycling lanes have been found to reduce fatalities by 25%–40%.[15] Properly designed cycling lanes should be safe and efficient for cyclists in terms of better design and management of intersections, roadsides, midblock, special treatment for vulnerable road users, as well as speed management and traffic calming devices. . In the absence of studies in LMICs, the following CMFs (Table 1) are suggested based on studies from the United States and Australia suggest CMFs[16], which are also adapted in the World Bank's Transport GP requirement assessment model.[17]

[12] https://read.oecd-ilibrary.org/transport/cycling-health-and-safety_9789282105955-en#page20

[13] Federal Highway Administration. (2021). *Developing Crash Modification Factors for Bicycle-Lane Additions While Reducing Lane and Shoulder Widths*. Washington DC, USA: FHWA; Federal Highway Administration. (n.d.). *Crash Modification Factor Clearing House*. https://www.cmfclearinghouse.org/userguide_CMF.php; iRAP. (2022). *iRAP Road Attribute Risk Factors: Facilities for Bicycles*. https://irap.org/irap-knowledge-base/category/methodology-fact-sheets/irap-road-attribute-risk-factors/fact-sheet-facilities-for-bicycles/

[14] B. Turner et al. (2009). *Review of iRAP Risk Parameters*. https://irap.org/2009/10/review-of-irap-risk-factors-2/

[15] iRAP. (2022). R*oad Safety Tool Kit: Bicycle Facilities*. https://toolkit.irap.org/safer-road-treatments/bicycle-facilities/

[16] iRAP. (2022). *iRAP Road Attribute Risk Factors: Facilities for Bicycles*.; D. Lynam. (2012). *Development of Risk Models for the Road Assessment Programme*. https://www.scribd.com/document/673802788/2012-iRAP-report-development-of-risk-models

[17] In October 2019, the World Bank launched a Good Practice Note (GPN) to address road safety. This GPN provides guidance to World Bank staff on how to support efforts to improve road safety on projects supported by Investment Project Financing (IPF) and thereby meet the requirements of the ESF road safety standards (ESS4). To support the use of the GPN, the World Bank Transport GP has developed a 'Road Safety Screening and Appraisal Tool (RSSAT), which is a tool to identify road safety performance and screen for opportunities for improvement in road and roadside infrastructure. https://www.worldbank.org/en/projects-operations/environmental-and-social-framework/brief/environmental-and-social-framework-resources

Table 1: Suggested CMFs for Cycling Lanes

Type of cycling facility	CMF (base = none)
Segregated cycling path with barrier (or separated from other traffic)	0.41
Non-protected dedicated cycling lane on the roadway (marking only)	0.82.
None	1.00

For induced cycling traffic, the crash reduction is calculated based on the mode shift from motorized vehicles to bicycles.[18] The safety benefit is calculated based on the reduction in crashes due to cyclists among both existing and induced cyclists, including road crashes involved in other road users such as motorized vehicles and pedestrians; thus, the individual crash risk should be decreased.[19]

Overall, the safety benefit of cycling facilities is well-documented. However, existing CMFs are primarily based on high-income countries. While these factors provide a good starting point, future research on CMFs and other coefficients for low- and middle-income counties can improve the estimation accuracy. The current tool incorporates the safety benefits of both induced and existing cycling traffic.

3.2 Emissions

The reduced reliance on motorized vehicles resulting from cycling facilities directly reduces the emissions of greenhouse gases (GHGs) and air pollution. The Health Economic Assessment Tool (HEAT) for walking and cycling developed by the World Health Organization (WHO)[20] calculates the differences in carbon emissions between cycling and other modes of transport across three categories: operational emissions, energy supply emissions, and vehicle lifecycle emissions. Operational emissions are determined by analyzing changes in travel demand, energy efficiency, and carbon intensity of the energy consumed. Energy supply emissions cover upstream emissions from the extraction, production, generation, and distribution of energy supplies, including emissions from fossil fuels and electric sources. Vehicle lifecycle emissions come from the manufacturing processes of vehicles and are based on aggregate carbon values for each vehicle type, considering factors like typical lifetime mileages, body mass weights, material composition, and material-specific emission and energy use. The monetary impact is calculated based on the Social Cost of Carbon (SCC).

The Institute for Transportation and Development Policy (ITDP) has created a model to estimate the climate impacts of installing protected cycling lanes.[21] This model calculates potential reductions in CO_2 emissions based on the local population size adjacent to protected cycling lanes and incorporates a user-specified percentage for mode shift to bicycles from other forms of transportation. The environmental benefits are quantified as a reduction in tons of CO_2 per annum, considering that bicycle travel generally emits less CO_2 compared to other transportation modes such as private vehicles. Furthermore, the ITDP tool incorporates essential data such as regional emission factors and the

[18] University of California, Davis. (n.d.). *California Active Transportation Benefit-Cost Tool*. https://activetravelbenefits.ucdavis.edu/tool; University of California, Davis. (2022). UCDAVIS Active Transportation Resource Center Tool. https://activetravelbenefits.ucdavis.edu/

[19] iRAP. (2022). *iRAP Road Attribute Risk Factors: Facilities for Bicycles*; D. Lynam. (2012). *Development of Risk Models for the Road Assessment Programme*. https://www.scribd.com/document/673802788/2012-iRAP-report-development-of-risk-models

[20] World Health Organization. (2021). *Health Economic Assessment Tool (HEAT) for Walking and Cycling*. https://www.who.int/tools/heat-for-walking-and-cycling

[21] Institute for Transportation & Development Policy. (2022, October). *Protected Bicycle Lanes Protect the Climate*. https://www.itdp.org/publication/protected-bicycle-lanes-protect-the-climate

person-kilometers traveled within specific areas.

The calculations of environmental benefits in the Australian Transport Assessment and Planning Tool and the California Active Transportation Benefit-Cost Tool[22] reflect the reductions in emissions and energy consumption from the reduced vehicle-distances traveled by motorized vehicles. Cycling facilities can induce demand for cycling and incentivize existing motorized vehicle users to shift to cycling.

The above review showcases the complexity and significance of the emissions-reduction benefits of active mobility infrastructure. Sophisticated models such as HEAT consider the lifecycle and energy supply emissions of vehicles, requiring extensive information as input. The targeted users of the current tool typically do not have such extensive information. In addition, tools such as HEAT intended for city- or country-level benefit evaluation do not align with the scope of the current tool (project-level evaluation). As such, the CBA_CF tool adopts a relatively straightforward approach based on reduced vehicle distance coupled with emission factors, as outlined in the subsequent Emissions section.

3.3 Health Benefit (Mortality)

Active mobility such as cycling involves physical activity that can significantly improve the health of the cyclist, thereby reducing mortality. Regular cycling enhances cardiovascular fitness, strengthens muscles, improves joint mobility, and decreases stress levels. By incorporating cycling into daily routines, individuals can achieve substantial health improvements that contribute to longer life expectancy and overall well-being. A systematic review indicates that active commuting by walking or cycling decreased all-cause mortality by 9% and cardiovascular mortality by 15%[23]. Well-designed cycling lane infrastructure would thus induce additional cycling traffic to reduce mortality. Multiple studies have considered the health benefits of cycling lanes.

The HEAT model developed by the WHO[24] comprehensively evaluates the effects of cycling facilities on mortality from three aspects. The physical activity benefit describes the positive impact of choosing active transportation modes such as cycling. The physical activity benefit is calculated by considering the local mortality rate and the duration of cycling activity. The benefit is reflected in the reduction in all-cause mortality. The HEAT model uses a coefficient of 0.9, indicating a 10% lower mortality rate for cyclists compared with non-cyclists.

According to a report published by the World Bank and IDTP, health is the largest monetized benefit of cycling infrastructure in Buenos Aires, Argentina and the second largest Lima, Peru, highlighting the importance of the health benefits of cycling facilities.[25] Similarly, the benefit assessment in the Australian Transport Assessment and Planning Guidelines[26] consider the increased physical activity from cycling, which leads to improved health outcomes and reduced healthcare costs. The Australian model uses public health data and existing studies to quantify physical

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[22] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*. https://www.atap.gov.au/mode-specific-guidance/active-travel/index

[23] Frédéric Dutheil et al. (2020). *Protective Effect on Mortality of Active Commuting to Work: A Systematic Review and Meta-Analysis*. *Sports Medicine*. https://doi.org/10.1007/s40279-020-01354-0

[24] World Health Organization. (2021). *Health Economic Assessment Tool (HEAT) for Walking and Cycling*. https://www.who.int/tools/heat-for-walking-and-cycling

[25] World Bank & IDTP. (2023). T*he Path Less Travelled: Scaling Up Active Mobility to Capture Economic and Climate Benefits*. https://itdp.org/publication/the-path-less-traveled-scaling-up-active-mobility-to-capture-economic-and-climate-benefits/

[26] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*; Queensland Department of Transport and Main Roads. (2022, September). *Active Transport Economic Appraisal Tool*. https://www.tmr.qld.gov.au/Travel-and-transport/Cycling/Cycling-investment-in-Queensland/Active-transport-economic-appraisal-tool

activity levels and determine health benefits. The California Active Transportation Benefit-Cost Tool[27] calculates the reduction in mortality risk based on the reduction in mortality rate resulting from additional cycling-related exercise and the original all-cause mortality rate in the area, similar to the literature discussed above.

While cycling in general is associated with positive effects, the WHO HEAT tool also includes two negative impacts. Air pollution risk is a negative effect stemming from cyclists' exposure to local PM2.5 concentrations. Opting for cycling as a mode of transportation can increase pollution-related mortality risk among cyclists. The extent of this increased risk is determined by factors including the local PM2.5 levels, cycling duration, the ventilation rate of the cyclist, and various adjustment parameters. The second negative effect is associated with crashes and is addressed under the safety benefit category.

As most existing studies only consider the benefit of cycling facilities in terms of reduced mortality, the current CBA_CF tool focuses on this aspect. One of the key parameters for accurately estimating the health benefit is the annual reduction in mortality. For example, the CBA_CF tool uses an 4.5% annual reduction in mortality for cycling facilities in the United States as suggested by the CALTRAN model.[28] We expect this rate to vary by country and region; accordingly, the CBA_CF webtool provides reference rates for other countries and regions that can be selected by the user. These mortality reduction rates were derived from existing studies, as shown in Appendix Table A2.

3.4 Travel Benefits

The travel benefits include multiple aspects, including travel time saving and reduction in congestion. Various studies have captured the time-saving benefits of cycling facilities. For example, case studies indicated that active mobility investments produced average travel-time savings of 15 minutes per metro trip and 2–4 minutes per bus trip in Tianjin, China and travel-time savings equivalent to USD2.6 billion in Lima, Peru.[29] The calculation of time-saving benefits appears to be simple. For example, the Australian Transport Assessment and Planning Guidelines[30] calculate the time saved by cyclists after the implementation of a cycling project by measuring the difference in travel time before and after the project is built. This time saving is then valued using the *Value of Time*, which assigns a monetary value to time based on average wages and other societal measures:

Time Saving Benefit = Number of Trips × *Time Saved per Trip* × *Value of Time.*

The main challenge in this calculation lies in the accurate estimation of the number of trips and time saved per trip (the current tool estimates the demand as the total cycling time). The time saved per trip depends heavily on the local transit system and motor vehicle infrastructure. Such information typically requires a detailed examination of multiple factors, including the waiting time for transit, connection time, location of parking facilities, and walking distance to and from the parking facilities to final destinations. For this reason, the travel benefit in terms of time saving is included as an advanced benefit calculation in the CBA_CF tool due to the difficulty in identifying default

[27] CALTRAN. (2024). *Cal-B/C AT Version 8.1*. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/data-analytics-services/transportation-economics/cal-bc/2022-cal-bc/guides/cal-bc-81-at-instructions-v1-a11y.pdf

[28] University of California, Davis. (n.d.). *California Active Transportation Benefit-Cost Tool*. https://activetravelbenefits.ucdavis.edu/tool

[29] World Bank & IDTP. (2023). T*he Path Less Travelled: Scaling Up Active Mobility to Capture Economic and Climate Benefits*. https://itdp.org/publication/the-path-less-traveled-scaling-up-active-mobility-to-capture-economic-and-climate-benefits/

[30] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*. https://www.atap.gov.au/mode-specific-guidance/active-travel/index

parameter values. Advanced users who have the expertise and resources to accurately estimate the related parameters can opt to include this benefit.

3.5 Other Benefit Categories

Several other benefit categories in literature were reviewed by the study team, including 1) Journey quality improvement; 2) Reduced emissions other than GHGs; 3) Reduced absenteeism; 4) Intersection safety improvements; 5) Decongestion; and 6) Other potential benefits. These benefit categories were not included in the CBA_CF tool for the following reasons:

1) **Journey quality improvement** is a relatively subjective measure that requires a preference matrix from the users to define the preferred index of different cycling facilities (cycling lane, cycling way, cycling path, etc.). The California tool includes the calculation of this benefit. However, this calculation is only applicable in situations where multiple types of cycling facilities will be built, and each type of facility has an existing and quantified preference level in the local community. Thus, it does not apply to the situations where the CBA_CF tool will be used.

2) **Air pollution benefits** are generally calculated in two categories: lifecycle emissions for vehicles and the emission cost for all pollutants (CO, NOx, PM2.5, and SOx) in the area. The life-cycle emission calculation involves operational emissions of all modes of travel, energy supply emissions (from the extraction, production, generation, and distribution of energy supplies), and vehicle lifecycle emissions (the emissions for manufacturing and disposing the vehicles). The WHO HEAT model includes this calculation based on an embedded database of lifecycle emissions for different modes (cars, trains, buses, etc.). The CALTRAN tool calculates the benefit of emission cost savings for all pollutants because they have the cost data of all the pollutants[31]. The CBA_CF tool does not include these two calculation categories because both involve extensive input parameters. The parameters from other locations are typically not transferrable – they are location specific and vary significantly from area to area.

3) **The absenteeism benefit** can be calculated as the decrease in the number of sick days resulting from the mode shift to cycling and the subsequent increase in exercise. This benefit is calculated by the California tool as a function of the following parameters: average absenteeism of employees, percentage covered by short-term sick leave, percentage of sick days reduced when active at least 30 minutes per day, value of reduced absenteeism per day, and cycling days per year. Due to the many uncertainties in these parameters, this benefit was excluded from the CBA_CF tool.

4) **Intersection safety improvement** can be calculated based on the effects of adding cyclist-friendly features at intersections, as done in the California tool. This calculation applies mainly to cycling facility improvement projects where intersection improvement countermeasures are specified (traffic signal for cyclists, stop bar for cyclists, or markers on the ground for cyclists, etc.) and the corresponding effects are well quantified. Due to the fact that such sophisticated data are highly unlikely available in developing countries, this benefit is not included in the CBA_CF tool.

5) **Impact local economic development and retail activity:** A review of studies on the impacts of local economy indicates that creating or improving active travel facilities generally has positive or non-significant

[31] University of California, Davis. (n.d.). *California Active Transportation Benefit-Cost Tool*. https://activetravelbenefits.ucdavis.edu/tool

economic impacts on retail and food service businesses located nearby.[32] There could be negative economic effects on businesses that are auto-centric. The quantification of impact of local economic requires detailed site-specific data and need to be considered for future extension of the tool.

6) The calculation method for **decongestion** is straightforward but requires considerable efforts to validate the input parameters, which include the benefit of decongestion ($/km). This parameter is provided by the users in the Australian tool. We believe this parameter is difficult to validate without a comprehensive traffic study that confirms the existing number of motor vehicle trips, a car ownership survey, and a detailed traffic fundamental diagram (with locally calibrated parameters including density, velocity, and traffic flow). Thus, the decongestion benefit is not calculated in the CBA_CF tool.

7) **Other benefits** may be added to the tool in the future if more studies are performed to validate the parameters needed to accurately calculate the benefits. For example, cycling lanes induce *more public transit trips,* which *stimulate local business,* and more cycling trips will help cycling-related business; *The operational costs (VOC) for cyclists* are significantly lower compared to those for car drivers. Therefore, switching from cars to bicycles can lead to substantial *savings in terms of depreciation, insurance, parking costs, fuel, and other expenses*; Another example is *increased accessibility* to cycling lanes. These benefits require additional information to supply the necessary input parameters and are not included in the CBA_CF tool currently.

3.6 Summary and Discussion

The above overview of cost-benefit analysis showcases the complexity of cost-benefit analysis for cycling facilities, which can be summarized as follows:

- *Benefits for society can be difficult to recognize or monetize:* The societal benefits of cycling projects, such as improved health outcomes, reduced environmental impacts, and enhanced quality of life, can be challenging to quantify and assign a monetary value. These benefits often accrue over time and may not be immediately apparent, making it difficult to capture their full impact in traditional cost-benefit analyses.
- *Applications at the project level are limited.* Cost-benefit analyses are often conducted at the city or country level. There is limited literature on comprehensive cost-benefit analyses at the project level. As a results, reference parameters and the associated methods are scarce.
- *The costs and benefits can vary substantially based on the location of the project*: The financial costs and benefits associated with a project may differ greatly depending on its geographical location. Factors such as local economic conditions, population density, existing infrastructure, and environmental conditions can all influence the outcomes of a cost-benefit analysis, leading to significant variability in results.
- *Studies using the typical cost-benefit framework with standard metrics are limited.* Few cost-benefit analyses of cycling facilities have been conducted using standardized frameworks and metrics such as the Internal Return Rate (IRR) and Net Present Value (NPV). The lack of consistent methodologies and metrics makes it challenging to compare and evaluate the outcomes of different projects accurately.
- *A user-friendly tool to facilitate benefit estimation is currently lacking:* There is a notable absence of accessible and easy-to-use tools designed to assist in estimating the benefits of projects. This makes it

[32] Volker, J. M. B., & Handy, S. (2021). Economic impacts on local businesses of investments in bicycle and pedestrian infrastructure: a review of the evidence. Transport Reviews, 41(4), 401–431. https://doi.org/10.1080/01441647.20

difficult for practitioners and decision-makers to conduct comprehensive benefit analyses, potentially leading to underestimation or misrepresentation of a project's true value.

The CBA-CF Cost and Benefit Analysis Tool for Cycling Facilities is intended to address or mitigate some of the above listed limitations by providing a user-friendly, flexible, and expandable webtool that is based on solid methodology. The detailed methodologies employed by the tool are introduced in the next chapter.

4 Methodology For the CBA-CF Tool

4.1 Cycling Facility Cost

The cost of a cycling facility includes two major components: the *initial construction* cost incurred before the facility opens to traffic and the *annual maintenance cost*, which is incurred each year for maintenance since the facility opens to traffic. This construction cost can vary significantly according to the local costs of construction materials and labor. Several studies have surveys of the costs of cycle lanes, providing reference values for estimating cost.[33] As users typically have an estimate of the project cost, the construction and maintenance costs are requested as inputs from the user in the input module. Figure 2 illustrates the cost of per kilometer for construction of cycle lane in a report by ITDP.[34]

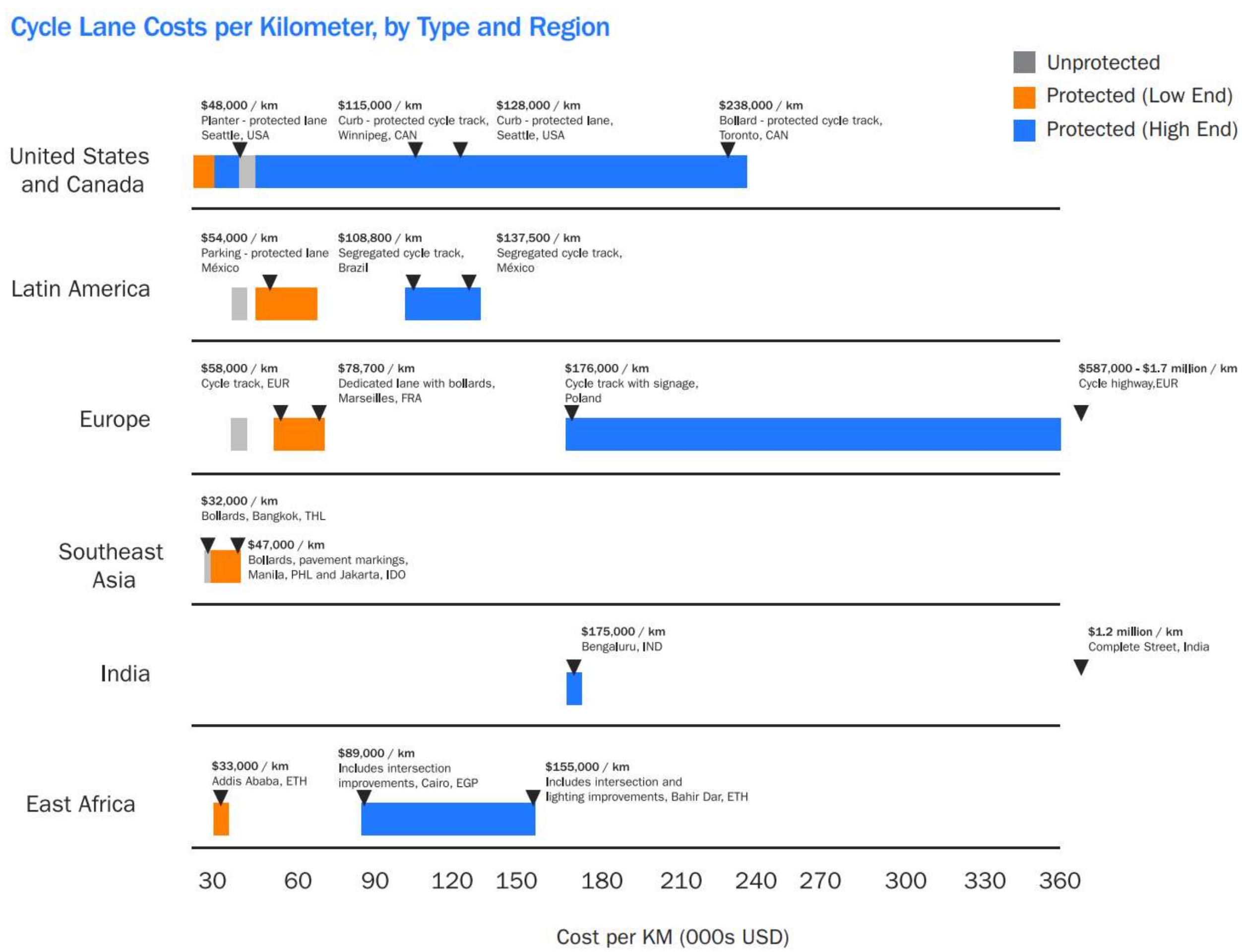

Figure 2: Cost of cycling lane per kilometer.[35]

[33] https://www.pedcyclinginfo.org/cms/downloads/Countermeasure_Costs_Summary_Oct2013.pdf

[34] mobiliseyourcity.net/sites/default/files/2022-08/Making-the-Economic-Case-for-Cycling_6-13-22.pdf

[35] mobiliseyourcity.net/sites/default/files/2022-08/Making-the-Economic-Case-for-Cycling_6-13-22.pdf

4.2 Cycling Demand Modeling

The demand for cycling traffic serves as critical input for assessing the benefits of cycling infrastructure. The volume of bicycle trips and their cumulative distance directly influence the benefits of a cycling facility, including the environmental, safety, and health benefits. Cycling demand is influenced by the location, type, and density of land use both along and within a specific radius of the bicycle facility. Various factors can lead to significant variations in cycling demand, including the following:

1) Cycling facility type: cycling lane (with or without a physical divider between the cycling lane and the lane for motor vehicles), exclusive cycling lane, on-street cycling route, etc.
2) Existing transportation modes and demand
3) Existing local economic development and land use around the cycling facility

Travel demand forecasting is well studied, and multiple methods for demand forecasting have been developed. In general, these demand forecasting models can be grouped into the following general categories:[36]

- *Trip-based four-step trip generation models*. These models predict traffic demand based on a sequence of tasks that includes trip generation, trip distribution, mode choice, and route assignment. The trip-based four-step model is the industry standard for forecasting future demand. However, this method requires extensive input and complex modeling. The inputs require surveys, comprehensive coefficient selection, network development for trip distribution and route assignment, and sensitivity analysis. Thus, forecasting using the four-step model is typically carried out through dedicated consulting efforts for each project.
- *Activity-based travel demand models*. These models improve upon the trip-based models by incorporating constraints related to time, space, and the linkages among activities and travel. Activity-based travel demand models have been increasingly adopted in recent years.
- *Strategic planning and sketching-planning models.* These models are based on high-level estimates of trip rate per individual, population size, percentage of shift from other traffic modes etc. Strategic planning and sketching-planning models typically require less information and less intensive modeling processes than trip- and activity-based models.

Although trip- and activity-based models show potential for cycling demand forecasting, both modeling approaches require significant investment for data collection, traffic network construction, utility function development, and model calibration. The associated costs are often prohibitively high for cycling demand forecasting. Consequently, most cycling infrastructure cost-benefit analyses employ variations of strategic planning and sketch-planning models, which require less information and less burdensome modeling. However, as for trip- and activity-based models, the outcomes are sensitive to the chosen parameters. Therefore, identifying accurate parameter values is essential for precisely estimating cycling demand. Another challenge arises from the fact that the targeted users for a project may lack access to sources for the key parameters. Therefore, providing reasonable default values is critical. A suggested approach based on strategic-planning and sketch-planning models is illustrated in Figure 3 below.

[36] J. Castiglione, M. Bradley, and J. Gliebe *Activity-Based Travel Demand Models: A Primer*. National Academies of Sciences, Engineering, and Medicine.

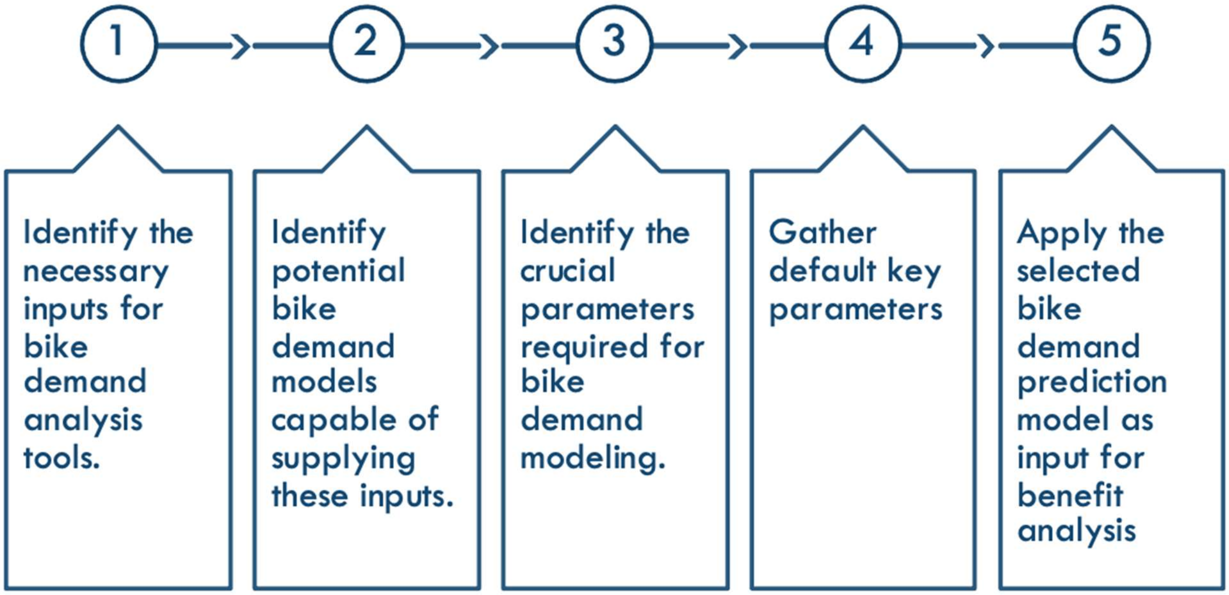

Figure 3. Approach for forecasting cycling demand.[37]

The CBA_CF tool estimates demand based on the population affected along the new cycling facility. A simple linear regression is used to estimate the total induced travel distance resulting from the new cycling facility Based on a sample of 8 Latin American cities. This regression model (R^2 = 0.88) concluded that for every person living within 300 m of a protected bicycle lane, roughly 315 km are cycled on protected lanes every year[38].

$$Induced\ Biking\ Length = Population * 315\ (km\ per\ year), \qquad (1)$$

where $Population$ is the population within 300 meters of the cycling facility.

According to a study by the National Institutes of Health (NIH) installing new bicycle lanes will induce increases in bicycle use by 59% (trips) and 88% (total distance traveled) relative to the situation without bicycle lanes.[39] Therefore, the existing cycling length is:

$$Existing\ Biking\ Length = \frac{Induced\ Biking\ Lengt}{0.88}\ (km\ per\ year). \qquad (2)$$

4.3 Benefit Modeling

The CBA_CF tool includes four categories of benefits: safety, health, environmental, and travel time saving. During the development of the CBA_CF tool, several existing tools were reviewed. From these existing tools, we incorporated into the CBA_CF the benefit categories we deemed to be most valuable for cycling facilities and applicable at the project level. We then added modeling modules that can best demonstrate the benefits. We omitted benefits that we believe need further research or that require parameters/input variables that are atypical

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[37] Created by the authors.

[38] Institute for Transportation & Development Policy. (2022, October). *Protected Bicycle Lanes Protect the Climate*. https://itdp.org/publication/protected-bicycle-lanes-protect-the-climate/

[39] M. Fosgerau et al. (2023). *Cyclingability and the Induced Demand for Cycling*. *Proceedings of the National Academy of Sciences.* https://doi.org/10.1073/pnas.2220515120

or inaccessible to users in developing countries. In this section, we discuss the calculation methods for all benefits considered in the CBA_CF tool and explain the rationale for the employed approaches. Note that all the parameters/variables discussed in this section are also listed in the Appendix. The reference number (*ref #*) of each parameter/variable indicated in the following sections is indexed in the Appendix for ease of identification. The rule of a half needs to be applied when assessing the impacts of induced traffic.[40]

Safety Benefits

The CBA_CF tool considers the safety benefits of a cycling facility in two parts: 1) the benefit from shifting modes from cars to cycling and 2) the benefit of improved safety for existing riders. These two components are detailed below.

1) Benefit from shifting modes from cars to cycling. In existing cost and benefit analyses of cycling facilities, the safety benefits are typically calculated based on the amount of traffic that shifts from cars to cycling. The mode shift from car to cycling enhances safety by avoiding potential car crashes. The associated benefit is estimated from the average cost of crashes, crash rate, and the total amount of induced cycling distance that is diverted from car travel. The calculation formula is similar to those applied in the CALTRAN and Australia models.[41] Note that a single car is likely to have more than one occupant; thus, *Vehicle Occupancy* is included as a parameter in the calculation to reflect the total number of cars instead of total number of cycling riders:

$$Safety\ Benefit\ from\ Mode\ Shift\ = Induced\ Cycling\ Length * (Trip\ Purpose\ Composition[1] + Trip\ Purpose\ Composition[2]) * Diversion\ from\ Cars\ /\ Vehicle\ Occupancy * Crash\ Rate * Average\ Serious\ Crash\ Cost * (Induced\ Benefit\ Factor), \tag{3}$$

where:

- $Induced\ Biking\ Length$ can be calculated from Equation (1);
- $Trip\ Purpose\ Composition[1]$ is the percentage of commuting in cycling traffic (*ref 1*);
  $Trip\ Purpose\ Composition[2]$ is the percentage of cycling traffic other than commuting and recreational trips (*ref 1*); Following common safety benefit calculation practice, recreational trips were not included as recreational bike trips are elastic demand and may expose to less risk [42,43]
- *Diversion from Cars* is the percentage of newly induced cycling trips that were originally taken by cars (*ref 15*);
- *Vehicle Occupancy* is the average number of people in each car (*ref 3*);
- *Crash Rate* is the motor vehicle traffic crash rate per billion vehicle KM traveled (*ref 7*);

[40] P. Mackie et al. (2005). *Treatment of Induced Traffic*. [World Bank Transport Notes Series]. http://hdl.handle.net/10986/11796

[41] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*; CALTRAN. (2024). *Cal-B/C AT Version 8.1*; University of California, Davis. (2022). *UCDAVIS Active Transportation Resource Center Tool*.

[42] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*. https://www.atap.gov.au/mode-specific-guidance/active-travel/index

[43] CALTRAN. (2024). *Cal-B/C AT Version 8.1*. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/data-analytics-services/transportation-economics/cal-bc/2022-cal-bc/guides/cal-bc-81-at-instructions-v1-a11y.pdf

- $Induced\ Benefit\ Factor$[44] adjusts for the effects of unaccounted factors and is given a value of 0.5; and
- $Average\ Serious\ Crash\ Cost$ is the cost per crash in USD (*ref 5*), which can be calculated as follows:

$$Average\ Cost\ of\ Serious\ Crash = (p_{fatal} * Cost\ per\ Fatal\ Crash + p_{injury} * Cost\ per\ Serious\ Injury\ Crash\ )/\ (\ (p_{fatal} + p_{injury}), \quad (4)$$

where:

$$Cost\ per\ Fatal\ Crash = \ 70\ *\ per\ capita\ GDP\ , \quad \text{and} \quad (5)$$

$$Cost\ per\ Serious\ Injury\ Crash = 17.5\ *\ per\ capita\ GDP \quad (6)$$

based on World Bank estimates,[45] and p_{fatal} and p_{injury} are the proportions of fatal and serious injury crashes, respectively.[46]

Along with the calculation of burden of road crash in LMICs in the iRAP's ec model,[47] the safety benefit will be calculated only includes fatal and serious injury based on a meta-analysis in LMICs. The Global Road Safety Facility study suggested that the ratio of fatal to serious injury crashes is 1:15 as country level[48]. However, as a logical assumption, this could vary by road infrastructure length. Suggested ratios could be: 1:2 for very short sections, 1:5 for short sections, 1:10 for medium-length sections, and 1:15 for long sections. The CBA_CF tool uses 1:15 as the default value, but users can adjust this ratio according to the specific project.

Fatal crash rates per billion kilometers traveled by cars are available for limited counties.[49] These data are only available for two developing counties: Mexico (27.5 fatal crashes per billion km traveled and Malaysia (16.2 per billion km traveled). Most developed counties have low rates between 3 and 9 fatal crashes per billion km traveled.

The CBA_CF tool estimates the default fatal and serious injury crash rates as follows:

a) The default fatal crash rate is set to 20 fatalities per billion km traveled by cars based on the average of the statistics available for Mexico and Malaysia.

b) The estimated rate of fatal and serious-injury crashes is set at $16 * 20 = 320$ per billion km traveled. The factor 16 comes from the 1:15 ratio of fatal to serious-injury crashes derived from World Bank research.

2) Benefit for existing cycling traffic. A second component of safety benefit (i.e., the safety benefits of the cycling facility for existing cycling traffic) was incorporated into the CBA_CF tool in consideration of previous safety-related research conducted based on the Highway Safety Manual (HSM). This benefit reflects the reduction in cycling crashes in existing cycling traffic due to the newly built cycling facility. Similar to the calculation method of the HSM, the CBA_CF tool calculates this benefit based on the existing cycling distance, existing crash rate, average cost of cycling

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[44] In the majority of situations, the calculation of the user benefit associated with induced traffic is relatively straightforward and relies on the "rule of the half" methodology: P. Mackie et al. (2005). *Treatment of Induced Traffic*. [World Bank Transport Notes Series]. http://hdl.handle.net/10986/11796

[45] World Bank. (2019). *Guide for Road Safety Opportunities and Challenges: Low- and Middle-Income Country Profiles*. https://doi.org/10.1596/33363

[46] https://crashstats.nhtsa.dot.gov/Apri/Public/ViewPublication/813369

[47] McMahon, K. & Dahdah, S. (2008) The True Cost of Road Crashes: Valuing Life and the Cost of a Serious Injury. International Road Assessment Programme.

[48] Wambulwa, W.M., Job, R.F.S., & Turner, B.M. (2020). *Guide for Road Safety Opportunities and Challenges : Low and Middle Income Country Profiles* (English). Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/447031581489115544/Guide-for-Road-Safety-Opportunities-and-Challenges-Low-and-Middle-Income-Country-Profiles

[49] https://en.wikipedia.org/wiki/List_of_countries_by_traffic-related_death_rate

crashes, and CMF of the newly built cycling facility:

$$Safety\ Benefit\ for\ Existing\ Cycling\ =\ Existing\ Cycling\ Length * Existing\ Cycling\ Crash\ Rate * (1 - CMF) * Cost\ of\ Cycling\ Crashes,$$
(7)

where:

- $Existing\ Cycling\ Length$ is calculated using Equation (2);
- $Existing\ Bike\ Crash\ Rate$ refers to the crash rate between cycling and motor vehicles in mixed traffic conditions (*ref 7*);
- $Cost\ of\ Cycling\ Crashes$ is the average cost of crashes (*ref 6*); and
- CMF is the crash modification factor (*ref 9*), which ranges from 0.41 to 0.92 based on existing studies, implying a reduction of 59% to 8% in crash rate.

The World Bank has suggested the CMFs shown in Table 1, which are also adapted in the World Bank's Transport GP assessment models.

The fatal and serious injury cycling crash rate is a critical parameter when determining the safety benefit. Unfortunately, virtually all availably cycling crash rates are for developed countries, and no fatal and serious-injury crash rates are available, even for developed countries. We derived the default value for developing countries using the following logic:

a) In United Kingdom, the fatal cycling crash rate is 36.8 per billion km traveled (23 per billion miles traveled) and fatal car crash rate is 4.8 per billion km traveled.[50] [51]

b) The ratio of the rate of fatal cycling crashes to the rate of fatal car crashes is 36.8/4.8.

c) The default value for the rate of fatal car crashes is 20 per billion km traveled, as discussed above in the "Benefit from shifting modes from cars to cycling" section.

Assuming a constant ratio between the rates of fatal cycling crashes to car crashes, the fatal cycling crash rate should be $20 * 36.8/4.8 = 153$ per billion km traveled. The corresponding fatal + serious injury crash rate should then be $16 * 153 = 2{,}448$ per billion km traveled.

Health

Cycling facilities improve health by inducing exercise when users shift from car travel to bicycle travel. The calculation of health benefits in the CBA_CF tool involves the value of a statistical life, percentage of cycling (aged 16–64) in the population, percentage of induced cycling traffic, and the reduction in mortality due to exercise. The modeling method used combines features of the CALTRAN model and WHO HEAT model.[52] However, instead of estimating the population affected by cycling exercise based on the estimated number of trips per traveler and average cycling distance of each trip, the CBA_CF tool asks users to provide the population as a direct input variable. This approach

[50] https://read.oecd-ilibrary.org/transport/cycling-health-and-safety_9789282105955-en#page41

[51] Reported road casualties Great Britain, annual report: 2022- Table 5. https://www.gov.uk/government/statistics/reported-road-casualties-great-britain-annual-report-2022/reported-road-casualties-great-britain-annual-report-2022#casualties-and-rates-by-road-user-type

[52] World Health Organization. (2021). *Health Economic Assessment Tool (HEAT) for Walking and Cycling*. https://www.who.int/tools/heat-for-walking-and-cycling; CALTRAN. (2024). *Cal-B/C AT Version 8.1*. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/data-analytics-services/transportation-economics/cal-bc/2022-cal-bc/guides/cal-bc-81-at-instructions-v1-a11y.pdf

is more accurate and direct since the local population and the percentage of cyclists are both known parameters in most areas of the world; it is much more difficult to estimate the number of cycling trips and cycling distances.

$$Health\ Benefit\ = Population\ within\ 300\ meters\ of\ the\ cycling\ facility * Percentage\ of\ Cyclist\ in\ the\ Population * (Induced\ Cycling\ Length\ )\ /\ (\ Induced\ Biking\ Length\ + Existing\ Cycling\ Length) * Annual\ Reduction\ of\ Mortality\ * Allcause\ Mortality * Value\ of\ a\ Statistical\ Life * (Induced\ Benefit\ Factor), \quad (8)$$

where:

- *Percentage of Cyclist in the Population* is the percentage of the population aged 16–64 (*ref 4*);
- *Annual Reduction of Mortality* is reduction in all-cause mortality due to cycling exercise (*ref 11*);
- *All-cause Mortality* is the local mortality rate (*ref 10*);
- $Induced\ Benefit\ Factor$: 0.5, which is a *discount* factor to adjust for the effect of unaccounted factors[53]; and
- *Value of Statistical Life* = 70 * per capita GDP *(ref 12).*

Environmental Benefits

The CBA_CF tool calculates environmental benefits in terms of the amount of carbon dioxide that would have been used by cars if that amount of traffic did not switch from cars to cycling. The emission per car distance traveled is aggregated with the cost of emissions. The formula used to calculate the environmental benefit is similar to the method used in the CALTRAN model.[54] However, rather than using a simple compound increasing rate to calculate the cost of emissions from year to year, CBA_CF uses a more accurate emission cost based on multiple previous studies with multiple years of data. The emission benefit in CBA_CF is calculated as:

$$Emission\ Benefit\ = (Induced\ Biking\ Length) * (Trip\ Purpose\ Composition[1] + Trip\ Purpose\ Composition[2]) * Diversion\ from\ Cars\ /\ Vehicle\ Occupancy * (Emission\ Cost * Vehicle\ Emission\ Rate)\ *\ (Induced\ Benefit\ Factor) \quad (9)$$

where:

- $Trip\ Purpose\ Composition[1]$ is the percentage of commuting in cycling traffic (*ref 1*);
  $Trip\ Purpose\ Composition[2]$ is the percentage of cycling traffic other than commuting and recreational trips (*ref 1*); Following common environmental benefit calculation practice, recreational trips were not included by default. For example, the Australian model does not include recreational trips, while California allows users to choose whether they should be included, which is likely due to which is likely due to the elastic natura of recreational bike demand.

[53] In the majority of situations, the calculation of the user benefit associated with induced traffic is relatively straightforward and relies on the “rule of the half” methodology: P. Mackie et al. (2005). *Treatment of Induced Traffic*. [World Bank Transport Notes Series]. http://hdl.handle.net/10986/11796

[54] CALTRAN. (2024). *Cal-B/C AT Version 8.1*. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/data-analytics-services/transportation-economics/cal-bc/2022-cal-bc/guides/cal-bc-81-at-instructions-v1-a11y.pdf

- .[55,56]
- *Diversion from Cars* is the percentage of newly induced cycling trips that were originally taken in cars (*ref 15*);
- *Vehicle Emission Rate* is the parameter (*ref 14*);
- $Induced\ Benefit\ Factor$: 0.5, which is a discount factor to adjust for the effect of unaccounted factors.[40]
- *Emission Cost* can be found in the lookup table (Table 2 below) from the World Bank, which provides lower and upper bounds of dollar per tonnage for present until 2050. Based on these data, the carbon cost is set to between US$40 and $80 in 2020 and increases to US$50 to $100 by 2030.

Table 2. Price of Carbon for the Estimation of Environmental Benefits[57]

Year	Lower Bound ($/ton)	Upper Bound ($/ton)
2022	42	84
2023	43	86
2024	44	87
2025	45	89
2026	46	91
2027	47	94
2028	48	96
2029	49	98
2030	50	100
2031	51	102
2032	52	105
2033	53	107
2034	55	109
2035	56	112
2036	57	114
2036	58	117
2038	60	120
2039	61	122
2040	63	125

[55] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*. https://www.atap.gov.au/mode-specific-guidance/active-travel/index

[56] CALTRAN. (2024). *Cal-B/C AT Version 8.1*. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/data-analytics-services/transportation-economics/cal-bc/2022-cal-bc/guides/cal-bc-81-at-instructions-v1-a11y.pdf

[57] The price adjustment using the Consumer Price Index (CPI) involves recalculating the shadow price of carbon from a past year to reflect current prices may be needed in case the inflation is extensive: World Bank. (2017). *Shadow price of carbon in economic analysis*. [Guidance note]. https://thedocs.worldbank.org/en/doc/911381516303509498-0020022018/original/2017ShadowPriceofCarbonGuidanceNoteFINALCLEARED.pdf

Year	Lower Bound ($/ton)	Upper Bound ($/ton)
2041	64	128
2042	65	131
2043	67	134
2044	68	137
2045	70	140
2046	71	143
2047	73	146
2048	75	149
2049	76	153
2050	78	156

Travel Time Savings

The CBA_CF tool considers travel time savings derived from a traveler switching from walking to cycling. The tool also considers increases in travel time resulting from mode shifts from cars or public transit to cycling. The travel time savings is calculated as the sum of all changes in travel time resulting from diversions from cars, walking, and public transit to cycling. The diversion rates and average travel speeds of these modes are advanced parameters that must be input by users. The modeling method used in CBA_CF is modified from the M4 method,[58] which calculates the travel time savings for existing cycling trips before and after a cycling facility is built. We believe that the time savings for such trips should not be significant if the travel distance is the same. In contrast, the difference in travel time resulting from switching to cycling from other modes will be significant given the different average travel speeds of these modes. Travel time savings (TTS) is calculated as follows:

$$TTS = Value\ of\ Time * [(Induced\ Cycling\ Distance * Diversion\ Rate\ from\ Walk\ / \\ Average\ Walk\ Speed - Induced\ Cycling\ Distance * Diversion\ Rate\ from\ Walk\ / \\ Average\ Cycling\ Speed) + (Induced\ Cycling\ Distance * Diversion\ Rate\ from\ Car\ / \\ Average\ Car\ Speed - Induced\ Cycling\ Distance * Diversion\ Rate\ from\ Car\ / Average\ Cycling\ Speed) + \\ (Induced\ Cycling\ Distance * Diversion\ Rate\ from\ Transit\ / \\ Average\ Transit\ Speed - Induced\ Cycling\ Distance * Diversion\ Rate\ from\ Transit\ / \\ Average\ Cycling\ Speed)] * (Induced\ Benefit\ Factor), \quad (10)$$

where:

- $Induced\ Cycling\ Distance$ is the induced total cycling distance due to the newly built facility and can be calculated from Equation (1);
- $Diversion\ Rate\ from\ Cars$ is the percentage of newly induced cycling trips that were originally taken in cars (*ref 15*);

[58] Australia Infrastructure and Transport Ministers. (2023, July). *Guidelines: M4 Active Travel*. https://www.atap.gov.au/mode-specific-guidance/active-travel/index

- $Diversion\ Rate\ from\ Walk$ is the percentage of newly induced cycling trips that were originally taken by walking (ref 15);
- $Diversion\ Rate\ from\ Transit$ is the percentage of newly induced cycling trips that were originally taken by walking (ref 15);
- $Average\ Cycling\ Speed$ is the average speed of cycling (km/h) (ref 16);
- $Average\ Car\ Speed$ is the average speed of driving (mph) including time spent on looking for parking, walking from parking to final destination, etc. (ref 16);
- $Average\ Transit\ Speed$ is the average speed of traveling by public transit including transfer and waiting time (km/h) (ref 16);
- $Induced\ Benefit\ Factor$: 0.5, which is a discount factor to adjust for the effect of unaccounted factors.[59]
- $Value\ of\ Time$ is calculated using Equation (11):

$$Value\ of\ Time = e^{-4.191} * per\ capita\ GDP^{0.696}. \quad (11)$$

4.4 Monetized Benefit Metrics

The tool calculates the annual cash flow based on the costs (e.g., construction and maintenance costs) and monetized benefits, as illustrated in Figure 4. NPV is then calculated using the following equation:

$$\boldsymbol{NPV} = \sum_{n=1}^{20} \frac{Cash\ Flow_n}{(1 + interest\ rate)^{n-1}}, \quad (12)$$

where:

- $Cash\ Flow_n = Benefit_n - Construction_n - Maintenance\ Cost_n$.
- IRR is estimated by solving the following equation:

$$\sum_{n=1}^{20} \frac{C_t}{(1+IRR)^t} = C_0, \quad (13)$$

where C_t is the cash flow at year t (not including the initial construction cost), and C_0 is the initial construction cost. IRR is the value when the NPV is equal to zero.

[59] P. Mackie et al. (2005). *Treatment of Induced Traffic*. [World Bank Transport Notes Series]. http://hdl.handle.net/10986/11796

5 CBA-CF Cost and Benefit Analysis Tool for Cycling Facilities

The CBA_CF is an online tool that includes three primary modules: the Input Module, Background Calculation Module, and Output Module (as shown in Figure 4).

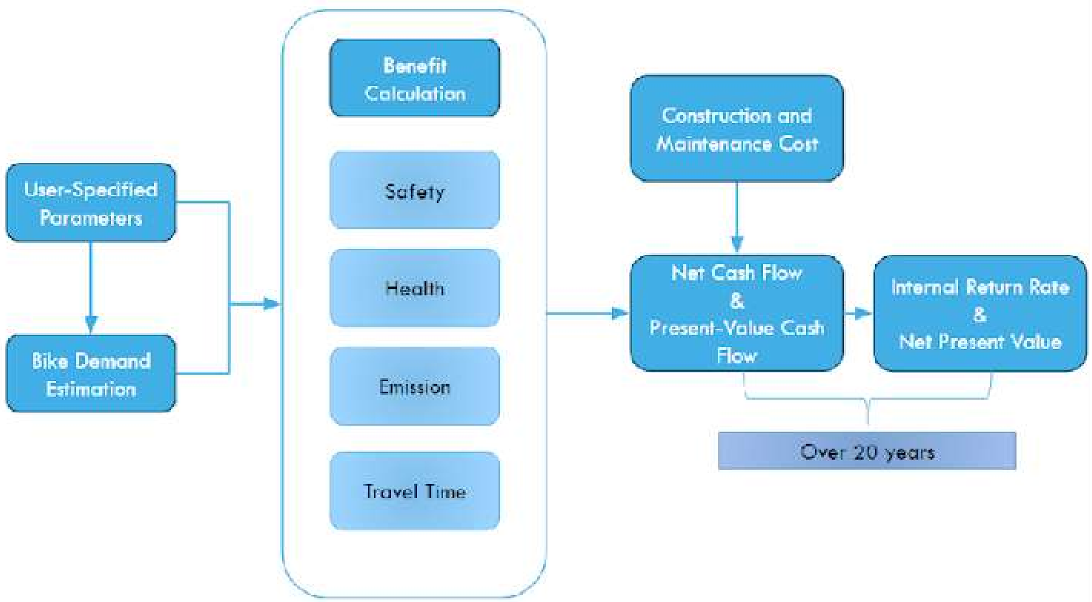


Figure 4: High-level structure of the World Bank CBA_CF tool.

5.1 Input Module

The input module (Figure 5) is the first interface that users encounter when accessing the tool. Users can select "Continue as a guest" or input login credentials. If users select "Continue as a guest", the webtool will allow users to select default parameters from dropdown menus, or input customized parameters, and calculate the benefits. If Users input login credentials as an administrator, the webtool will allow users to add input parameters to the dropdown menus as candidate parameters for future users. Following this page is the introduction page as shown in Figure 6. The users will be directed to the basic input information page after that (Figure 7). The input module requests three main inputs from the user:

1) **Select project location and input project name**. The input module first asks the user to select a project location for the new cycling facility. The project location is used by the tool to identify default values for location-specific parameters required for the benefits calculation, including the per capita GDP, the value of time (VOT), value of statistical life (VSL), and the cost of crashes. The tool then extracts these parameters from an online database (Figure 5).

2) **Input basic project information**. The input module requires the user to input basic information about the cycling facility (e.g., the length of the facility, construction cost, maintenance cost, population, etc.). The data entered by the user in this section is used to estimate cycling demand. For now, the construction is assumed to be accomplished within one year before the project opens to traffic (Figure 5).

3) **Click on "Next Step" to enter the parameter input interface.** Once the user clicked on the "NEXT STEP" button, the input module directs the user to a different interface (Figure 6) where they can define the values of the input parameters. This option empowers advanced users with more flexibility in determining the input variables.

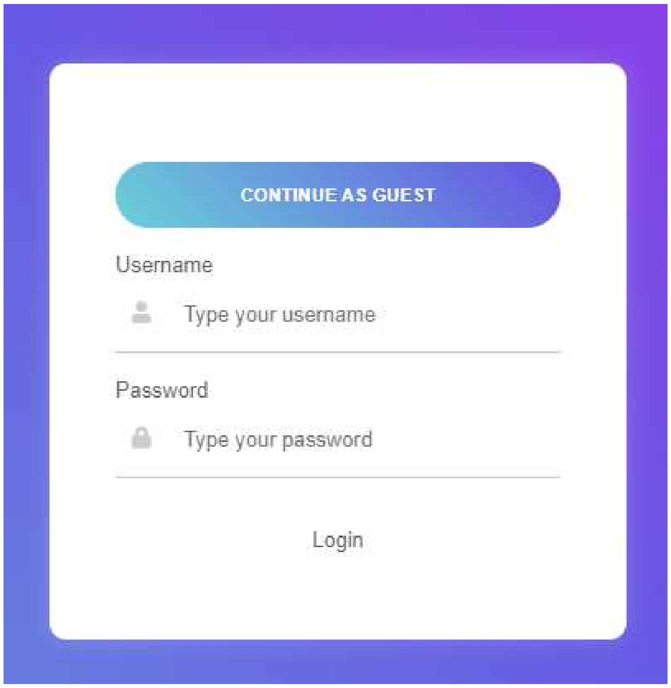


Figure 5: Landing page of the World Bank CBA_CF tool

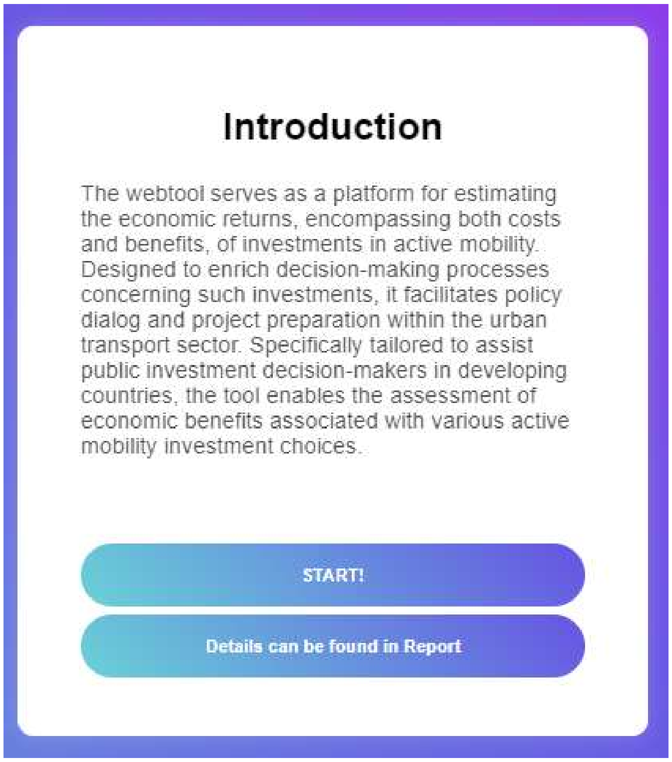


Figure 6: Introduction page of the World Bank CBA_CF tool

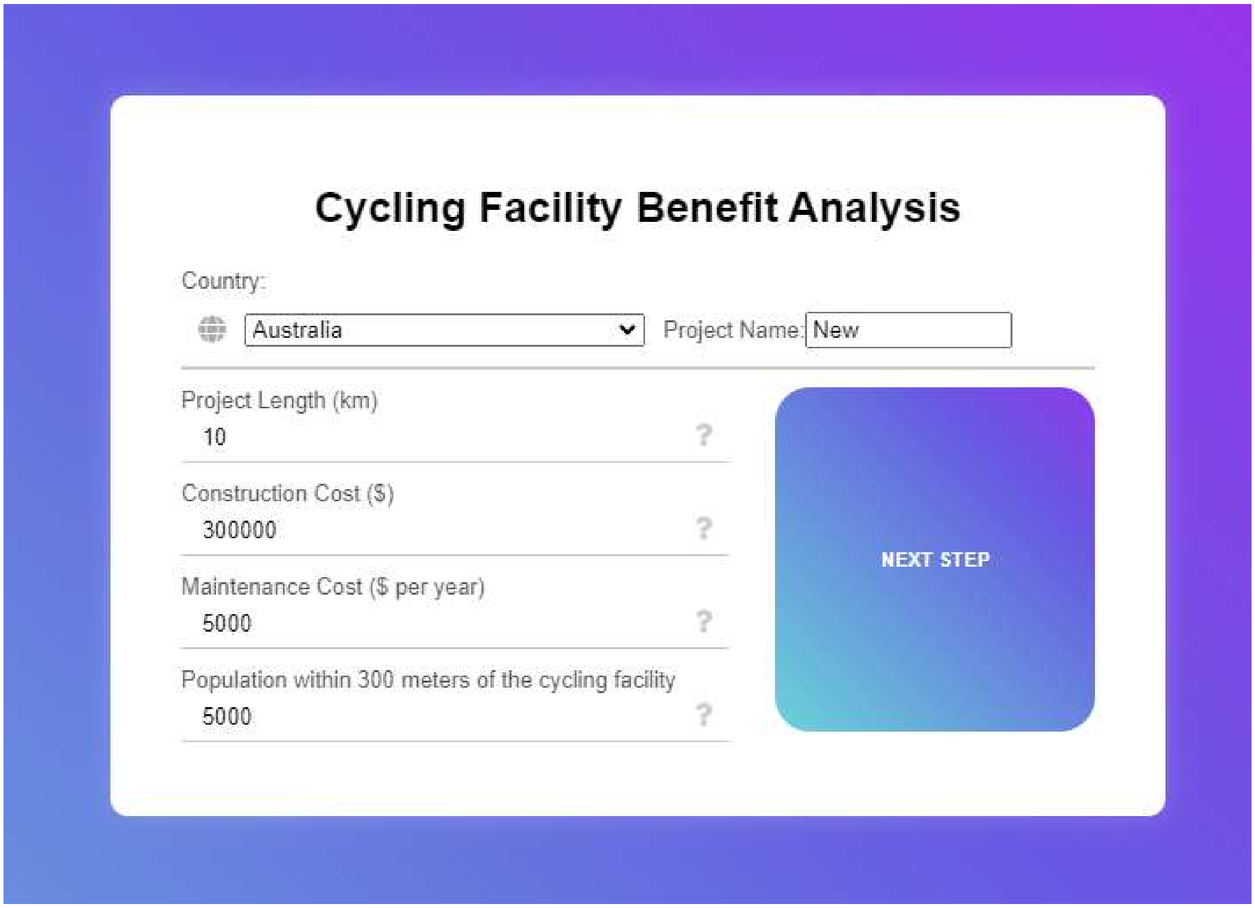


Figure 7: Image of the input module, which is the second interface encountered by the user when accessing the tool.

As shown in Figure 8, the input parameters included on the advanced scenario interface have pulldown menus with suggested values. The sources of the suggested values are listed in the Appendix. The sources of these suggested values are either existing cost and benefit analyses reported by various research institutes around the world or case studies conducted by the World Bank from different geographic locations worldwide. If these suggested values are not suitable for a specific project, CBA_CF allows users to input values for any parameter. Thus, if users choose to, they can specify the values for all the input parameters to best suit their local situation.

Note that the number of available suggested values varies from parameter to parameter. Studies that comprehensively collect and evaluate all the parameters considered in the CBA_CF tool are very limited; the current parameter selections in the tool represent all the relevant parameters identified in our review of the literature. If future users wish to provide other suggested values, they can use the “Advanced scenario” option and/or update the dropdown menu to include other candidate parameters.

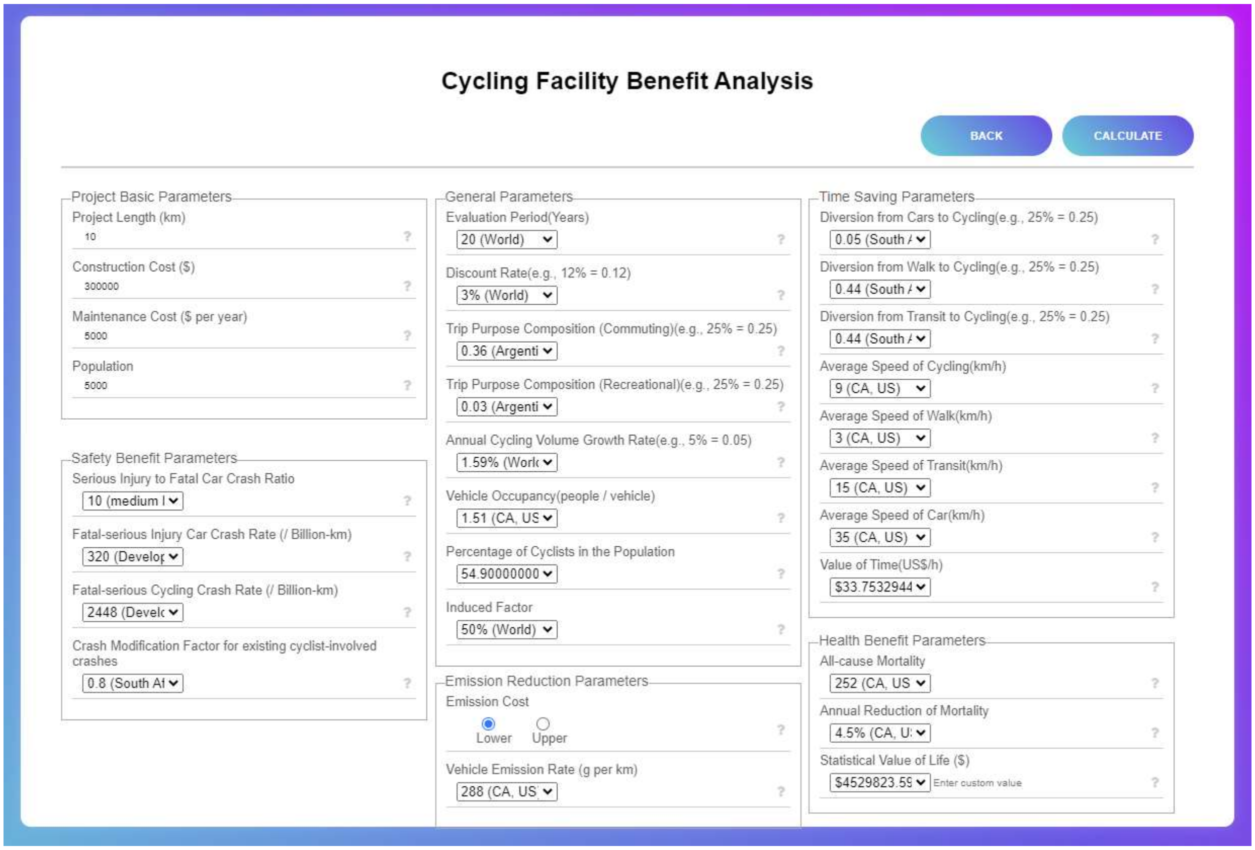
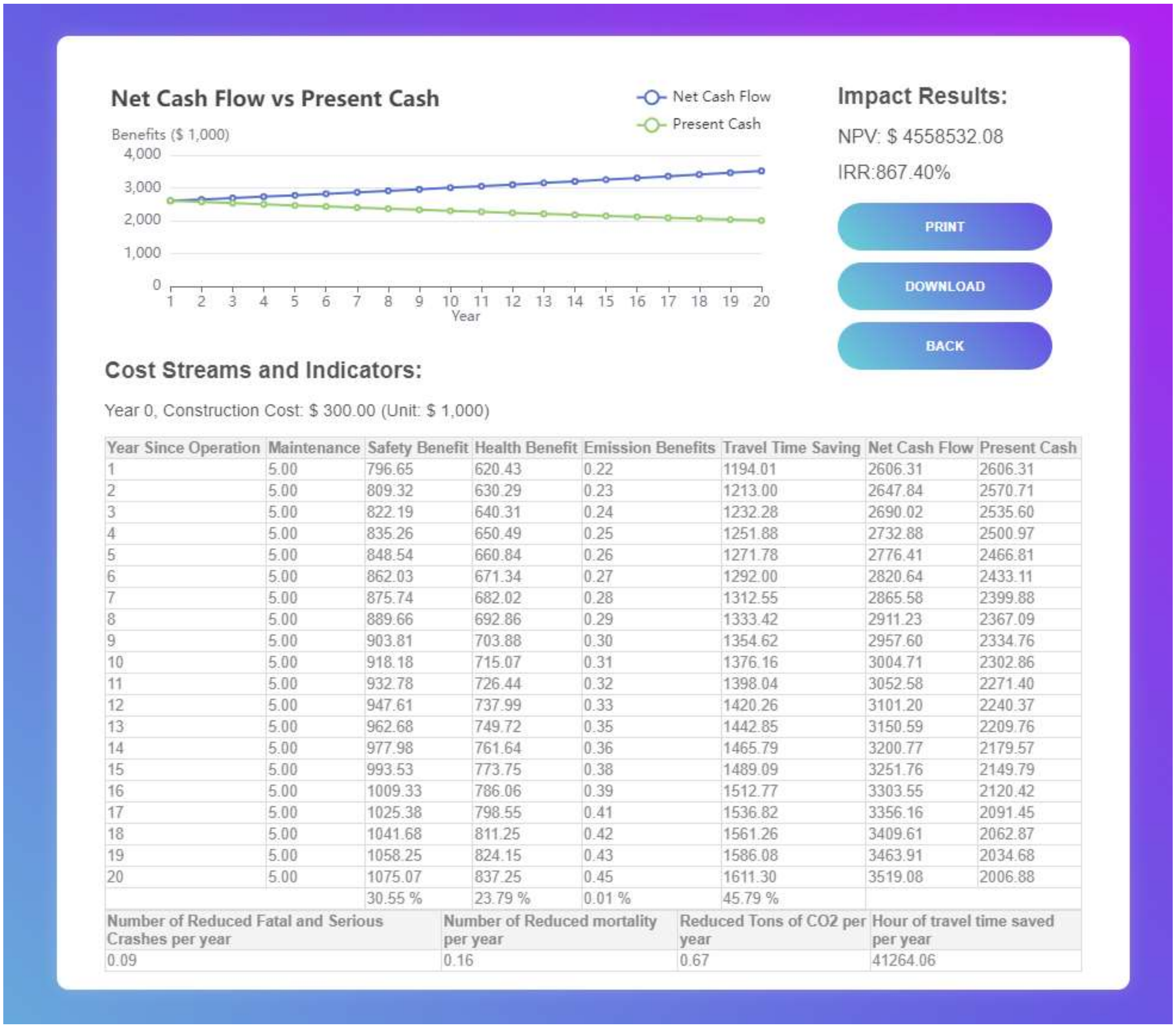


Figure 8. Interface for the advanced scenario where users can define the values of the input parameters.

5.2 Output Module

The CBA_CF tool calculates the annual cash flow associated with the cycling facility based on the cost, including both the construction and maintenance costs, and monetized benefits. The outputs (Figure 7) are provided as the net cash flow, present value cash flow, net present value (NPV), and internal return rate (IRR). Net cash flow is the difference between monetized benefits and cost by specific years. Present value cash flow is the current worth of a future cash flow discounted at a specific rate. Net present value (NPV) is the sum of the present values of incoming and outgoing cash flows over 20-year evaluation period. Internal rate of return (IRR) is the discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. The IRR and NPV provide a high-level summary of the overall benefit of the project.



Year Since Operation	Maintenance	Safety Benefit	Health Benefit	Emission Benefits	Travel Time Saving	Net Cash Flow	Present Cash
1	5.00	796.65	620.43	0.22	1194.01	2606.31	2606.31
2	5.00	809.32	630.29	0.23	1213.00	2647.84	2570.71
3	5.00	822.19	640.31	0.24	1232.28	2690.02	2535.60
4	5.00	835.26	650.49	0.25	1251.88	2732.88	2500.97
5	5.00	848.54	660.84	0.26	1271.78	2776.41	2466.81
6	5.00	862.03	671.34	0.27	1292.00	2820.64	2433.11
7	5.00	875.74	682.02	0.28	1312.55	2865.58	2399.88
8	5.00	889.66	692.86	0.29	1333.42	2911.23	2367.09
9	5.00	903.81	703.88	0.30	1354.62	2957.60	2334.76
10	5.00	918.18	715.07	0.31	1376.16	3004.71	2302.86
11	5.00	932.78	726.44	0.32	1398.04	3052.58	2271.40
12	5.00	947.61	737.99	0.33	1420.26	3101.20	2240.37
13	5.00	962.68	749.72	0.35	1442.85	3150.59	2209.76
14	5.00	977.98	761.64	0.36	1465.79	3200.77	2179.57
15	5.00	993.53	773.75	0.38	1489.09	3251.76	2149.79
16	5.00	1009.33	786.06	0.39	1512.77	3303.55	2120.42
17	5.00	1025.38	798.55	0.41	1536.82	3356.16	2091.45
18	5.00	1041.68	811.25	0.42	1561.26	3409.61	2062.87
19	5.00	1058.25	824.15	0.43	1586.08	3463.91	2034.68
20	5.00	1075.07	837.25	0.45	1611.30	3519.08	2006.88
		30.55 %	23.79 %	0.01 %	45.79 %		

Number of Reduced Fatal and Serious Crashes per year	Number of Reduced mortality per year	Reduced Tons of CO2 per year	Hour of travel time saved per year
0.09	0.16	0.67	41264.06

Figure 7. Output of the CBA_CF tool.

6 Future Work of CBA-CF

CBA-CF is a straightforward tool that is readily available for use by users who may or may not have all the needed parameters to calculate benefits and costs of cycling facilities. It needs to be noted that there are several aspects that the tool can be improved in the future if more resources become available to improve the tool. 1) E-bike; 2) More sophisticated demand modeling method; 3) Sensitivity analysis to model the impacts of varied demands of cycling.

Appendix: Parameter Values and Sources

Table A1. General Parameters

Ref #	Parameter	Description	Suggested Value	Location	Source
1	Trip Purpose Composition	The composition of the cycling traffic in [commute, others, and recreational]	[0.186,0.353,0.461]	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
			[0.36,0.61,0.03]	Argentina	Case study (Buenos Aires in 2024)[60]
2	Cycling Volume Growth Rate	The trip growth rate due to the newly built facility	1.59%	Multiple countries	Case study (Buenos Aires in 2024)[61]
			6%	Peru	A study reviewed [62]
			11.5%	Argentina	Case study (Lima in 2023)[63]
			2%	China	WB ICR (Tianjin in 2023)[64]
3	Vehicle Occupancy	The average number of people in each car	1.51	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
4	% of population ages 16-64	The percentage of cyclists among the population involved	54.9%	CA, US	Reviewed tools (UCDAVIS and CALTRAN)

[60] From "MASeV eng v1 44.xlsx" – "Other Parameters" – E41-E42

[61] From "MASeV eng v1 44.xlsx" – "Other Parameters" – E41-E42

[62] The bicycle trip market size is estimated to increase by 12.78% from 2024-2032: https://www.imarcgroup.com/bicycle-trip-market

[63] Republic of Peru Lima Traffic Management and Sustainable Transport MPA, Item 67 "increasing the modal share of bicycles from 8.2% to 14.2%"

[64] https://documents1.worldbank.org/curated/en/099062723124542429/pdf/BOSIB0167f32c00dd0988f02065523c3d82.pdf

Table A2. Accident Prevention Parameters

Ref #	Parameter	Description	Suggested Value	Location	Source
5	Average Cost of Car Crashes	The average cost per crash including fatal and serious injury crashes	US $126,400 (including all crashes, including property damage only crashes)	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
			(70 * per capita GDP + 17.5 * per capita GDP * 15) / 16 [in USD]	Low- and Middle-Income Countries	World Bank, GRSF
6	Average Cost of Cycling Crashes	The average cost per crash including fatal, injury, and property-only crashes	$126,400	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
		The average cost per crash including fatal and serious injury crashes	(70 * per capita GDP + 17.5 * per capita GDP * 15) / 16 [in USD]		
7	Crash Rate	Default *Fatal and Serious Injury* crash rate per billion-km-traveled	320	Developing countries	See estimation on Methodology chapter Safety Benefits section
8	Cycling Crash Rate	Fatal and Serious injury crash rate per billion-km-traveled.	2,448	Developing countries	See estimation on Methodology chapter Safety Benefits section
9	CMF	Segregated bicyclist path with barrier & without barrier from no lane	0.41	Low- and Middle-Income Countries	World Bank, CMF memo
		Dedicated bicyclist lane on roadway from no lane	0.82	Low- and Middle-Income Countries	World Bank, CMF memo
		Crash modification factor from no build	0.92	China	WB ICR (Tianjin in 2023)[65]

[65] https://documents1.worldbank.org/curated/en/099062723124542429/pdf/BOSIB0167f32c00dd0988f02065523c3d82.pdf

Table A3. Health Benefit Parameters

Ref #	Parameter	Description	Suggested Value	Location	Source
10	All-cause Mortality for cycling population	The rate of all-cause mortality per 0.1 million people	252	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
			446	India	Reviewed tools (WHO,HEAT)
			340	Argentina	Case study (Buenos Aires in 2024)[66]
11	Annual Reduction of Mortality	The reduced percentage of all-cause mortality due to exercise	4.5%	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
			21%	France	A Systematic Review [67]
			5.2%	Argentina	Case study (Buenos Aires in 2024)[68]
12	Value of Statistical Life	The statistical value of life	70 * per capita GDP [in USD]	Low- and Middle-Income Countries	

[66] From "MASeV eng v1 44.xlsx" – "Physical activity model" – H15

[67] F. Dutheil et al. (2020). Protective Effect on Mortality of Active Commuting to Work: A Systematic Review and Meta-analysis*.* *Sports Medicine*, 50(12), 2237-2250.

[68] From "MASeV eng v1 44.xlsx" – "Physical activity model" – row 39

Table A4. Emission Reduction Parameters

Ref #	Parameter	Description	Suggested Value	Location	Source
13	Emission Cost	The cost per ton of CO_2	Look up table	Low- and Middle-Income Countries	
14	Vehicle Emission Rate	The per-vehicle CO_2 emissions by driving cars	207 [in g/km at 40km/h]	CA, US (Model 2024)	Reviewed tools (UCDAVIS and CALTRAN)
			303 [in g/km]	Peru	Case study (Lima in 2023)[69]
			251 [in g/km]	Argentina	Case study (Buenos Aires in 2024)[70]
			294	USA	ITDP PBLPC tool[71]
			167	Europe	
			155	China	
			100	India	
			151	Brazil	
			168	Other Americas	
			139	Africa	
			117	Other Europe	

[69] Republic of Peru Lima Traffic Management and Sustainable Transport MPA, Item 63 Average distance 4.5 km reduction 843 tons of CO2 617128 cars, therefore 843/(617128*4.5) ton/km

[70] From “MASeV eng v1 44.xlsx” – “Emission factor(3)” – row 45

[71] Protected Bicycle Lanes Protect the Climate Tool: https://itdp.org/multimedia/the-compact-city-scenario/

Table A5. Time Savings Parameters

Ref #	Parameter	Description	Suggested Value	Location	Source
15	Diversion Rates	From cars to cycling	0.05	East Africa	ITDP case studies (Dar es Salaam, Addis Ababa)[72]
			0.15	Argentina	Case study (Buenos Aires in 2024)[73]
			0.36	Peru	Case study (Lima in 2023)[74]
			0.5	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
			0.29	China	WB ICR (Tianjin in 2023)[75]
			0.049	Bogota	ITDP PBLPC tool[76]
			0.016	Guangzhou	ITDP PBLPC tool
		From walking to cycling	0.44	East Africa	ITDP case studies (Dar es Salaam, Addis Ababa) 77
			0.27	China	WB ICR (Tianjin in 2023)[78]
			0.32	Bogota	ITDP PBLPC tool
			0.57	Guangzhou	ITDP PBLPC tool
		From public transit to cycling	0.44	East Africa	ITDP case studies (Dar es Salaam, Addis Ababa)[79]
			0.6	Argentina	Case study (Buenos Aires in 2024)[80]
			0.64	Peru	Case study (Lima in 2023)[81]

72 "Scenario stereotype for protected bicycle lanes"

73 InputVariableCyclingFacilityCBanalysis_Buenos Aires – Beunos Aires - B13"

74 InputVariableCyclingFacilityCBanalysis_Buenos Aires – Lima - B13"

75 https://documents1.worldbank.org/curated/en/099062723124542429/pdf/BOSIB0167f32c00dd0988f02065523c3d82.pdf

76 Protected Bicycle Lanes Protect the Climate Tool: https://itdp.org/multimedia/the-compact-city-scenario/

77 "Scenario stereotype for protected bicycle lanes" F12 (THEY ARE PROVIDED BY ITDP. PLEASE MODIFY AS NEEDED)

78 https://documents1.worldbank.org/curated/en/099062723124542429/pdf/BOSIB0167f32c00dd0988f02065523c3d82.pdf

79 "Scenario stereotype for protected bicycle lanes" F12

80 From "MASeV eng v1 44.xlsx" – "GHG model" – G13/G11

81 Copy of Copy of InputVariableCyclingFacilityCBanalysis_Buenos Aires – Lima - B14

Ref #	Parameter	Description	Suggested Value	Location	Source
16	Average Speed (Cycling, Walk, Car)	The average speed of different modes	(14,5.3,40) [in km/h]	CA, US	Reviewed tools (UCDAVIS and CALTRAN)
			(14,5.3, --) [in km/h]	Argentina	Case study (Buenos Aires in 2024)[82]
			(16.5,3.6,-) [in km/h]	Peru	Case study (Lima in 2023)[83]
			(22.3,--, --) [in km/h]	China	WB ICR (Tianjin in 2023)[84]
17	Value of Time	General cost of time/cost for business trips	$e^{-4.191} * per\ capita\ GDP^{0.696}$ [in USD/hour]	Low- and Middle-Income Countries	World Bank, Meta-analysis of the value of time

82 From “MASeV eng v1 44.xlsx” – “Travel time saving model”

83 Republic of Peru Lima Traffic Management and Sustainable Transport MPA, Item 51

84 https://documents1.worldbank.org/curated/en/099062723124542429/pdf/BOSIB0167f32c00dd0988f02065523c3d82.pdf

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