SAVi Sustainable Asset Valuation

A Sustainable Asset Valuation of the Sustainable Transport Strategy in Bogota, Colombia

TECHNICAL REPORT

IISD International Institute for Sustainable Development

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This report is part of a series of SAVi assessments on sustainable transport and mobility projects to raise awareness and inform decision-makers on the use of systemic approaches and simulation to support the transformation toward sustainable mobility.

More about the project: https://www.iisd.org/savi/using-systemic-approaches-and-simulation-to-support-transformation-toward-sustainable-mobility/

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Executive Summary

Purpose of This Assessment and the Sustainable Asset Valuation Methodology

This Sustainable Asset Valuation (SAVi) assessment of the Sustainable Transport Strategy in Bogota, Colombia is part of a series of SAVi assessments on sustainable transport and mobility projects.

The series aims to raise awareness on sustainable transport infrastructure investments and inform decision-makers on the use of systemic approaches in supporting the transformation toward sustainable mobility. The assessments also integrate the economic valuation of social and environmental impacts, such as health and carbon dioxide (CO_2) emissions, and aim to highlight their importance for the transport investment decision-making processes.

SAVi is an assessment methodology that provides policy-makers and investors with a comprehensive and customized analysis of the benefits and costs of infrastructure projects and portfolios throughout their life cycles. The approach purposefully considers risks and externalities that are overlooked in a traditional valuation. A SAVi assessment is built on a foundation that includes the following elements:

- modelling: Assessments involve a combination of systems thinking and different modelling methodologies, spatial modelling, economic multiplier/multicriteria assessments, system dynamics and financial models.
- customization: Assessments are customized to each individual infrastructure project, portfolio, or policy.
- collaboration: Assessments are co-created with decision-makers and stakeholders. This multistakeholder approach allows stakeholders to identify material risks and opportunities that are unique to the projects or alternatives. Through this process, the capacity of decision-makers and stakeholders is strengthened, which allows them to take a systemic approach to investments and increases the likelihood of uptake, use, and impact of the results of the analysis.
- data-driven approach: Assessments are based on project-level data (where available), the SAVi database (based on literature review and data from previous SAVi applications), and best-in-class climate data from the EU Copernicus Climate Data Store (built in to all SAVi models).

Sustainable Transport Strategy in Bogota

Bogota is the capital and largest city in Colombia, home to a rapidly growing population of more than 8 million inhabitants across an urban area of 400 km^2. The city's public transportation network has struggled to keep pace with this urban population growth over the past few decades. Bogota has topped the list of the most congested cities in the world, with an average person in Bogota losing 191 hours to traffic each year. Currently, 13.4 million transport trips are made daily, amounting to more than 16 million trips if all municipalities in the city's metropolitan area are considered. Public transport is responsible for 44.2% of trips, while private transport modes including cars, motorcycles, and taxis amount to 25.3% of trips. Active transport modes such as walking and cycling represent 24% and 6.5% of trips, respectively. As a result, Bogota experiences serious traffic congestion problems, long commuting times, high accident rates, and elevated levels of noise and air pollution. In addition, the city produces around 5% of Colombia's greenhouse gas (GHG) emissions, with the transport sector responsible for 48% of Bogota's emissions. A large share of the city's low-income population lives in the southern and western outskirts of the city, which have disproportionately low levels of accessibility to public transport links and, hence, to employment opportunities.

To address these issues, national and regional efforts to develop sustainable transport strategies and increase the implementation of sustainable transport projects have been undertaken. Transforming the transport sector in Bogota is crucial for reducing GHG emissions and addressing socio-economic disparities. The implementation and reorganization of public transport systems have the potential to deliver positive environmental impacts and social benefits.

This report provides a SAVi assessment of the Sustainable Transport Strategy in Bogota, which focuses on the three principal public transport systems in the city: the bus rapid transit (BRT), non-motorized transport (NMT) systems, and the mass-rapid transit (MRT) system (currently under construction and expected to be operational by 2028). The SAVi assessment aims to provide a comprehensive analysis by going beyond simply estimating the value of the investment costs (capital and operations and maintenance [O&M]) of the three public transport systems. Also included in the assessment are the environmental, social, and economic added benefits and avoided costs. The assessment includes two sustainable transport scenarios: the **current sustainable transport scenario** (which evaluates only the existing BRT and NMT systems from 2010 to 2022) and the **future sustainable transport scenario** (which also evaluates the MRT, in addition to the BRT and NMT systems, from 2010 to 2058).

The SAVi assessment of the Sustainable Transport Strategy in Bogota also consists of the following elements:

- a simulation of two sustainable transport scenarios for the implemented MRT, BRT, and NMT systems and the associated changes in transport use patterns in Bogota;
- a valuation of nine added benefits and avoided costs related to the public transport systems; and
- an integrated cost-benefit analysis of the MRT, BRT, and NMT systems including the added benefits and avoided costs, and a benefit-to-cost ratio public transport system.

Findings

The MRT, BRT, and NMT public transport systems have a wide range of economic, social, and environmental benefits that are typically overlooked in traditional transport infrastructure assessments. The public transport systems stimulate growth, either directly (through revenues or employment creation) or indirectly (through stimulated retail activity, property value increases, and fuel savings).

Moreover, the use of public transport systems leads to significant health benefits for Bogota's residents by encouraging physical activity and reducing air pollution. Other indirect benefits include the reduction of CO_2 emissions and fewer traffic accidents. The only negative values are found in the value of time saved, as increased cycling and walking to and from public transport stations leads to additional time spent commuting. Table ES1 summarizes the results of the integrated cost-benefit analysis (CBA) of the Sustainable Transport Strategy in Bogota across the two sustainable transport scenarios.

The net result of both sustainable transport scenarios is positive and, therefore, an attractive investment for the country.

Using different discount rates over time and for tangible or intangible indicators,[1] the current sustainable transport scenario shows cumulative discounted net results of COP 21,551 billion (USD 5,755 million) in the low estimate and COP 23,138 billion (USD 6,179 million) in the high estimate. Additionally, the future sustainable transport scenario shows cumulative discounted benefits of COP 45,821 billion (USD 12,237 million) and COP 36,379 billion (USD 9,715 million) in the low and high estimates, respectively.

Table ES1. Integrated CBA (discounted using different discount rates for the sustainable transport scenarios), in COP billion

	Sustainable transport scenarios			
	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Integrated CBA	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Total investment costs	**4,486**	**4,486**	**12,868**	**12,868**
Capital cost of the MRT system	**0**	**0**	**4,458**	**4,458**
O&M costs of the MRT system	0	0	3,412	3,412
Capital cost of the BRT system	3,822	3,822	3,822	3,822
O&M costs of the BRT system	423	423	936	936
Capital cost of the NMT system	241	241	241	241
O&M costs of the NMT system	0	0	0	0

[1] Discount rates used for tangible impacts: 6% from 2010 to 2018, 6.5% for 2019, 7% for 2020, 7.5% for 2021, and 8% from 2022 to 2058. Discount rate for intangible impacts: 3.5% from 2010 to 2058.

Integrated CBA	Sustainable transport scenarios			
	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
	Low estimate	High estimate	Low estimate	High estimate
Total revenues	**1,300**	**1,300**	**7,524**	**7,524**
Revenues from MRT use	0	0	3,282	3,282
Revenues from BRT use	1,300	1,300	4,242	4,242
Total added benefits	**23,752**	**25,203**	**46,899**	**36,380**
Income creation from employment*	571	577	1,398	1,405
Health impacts*	3,778	6,868	10,673	23,134
Value of time saved*	-1,166	-11,656	-3,587	-35,866
Retail revenues	11,725	11,725	29,124	29,124
Property prices*	8,844	17,688	9,291	18,583
Total avoided costs	**797**	**933**	**4,077**	**5,154**
CO_2 emissions	226	226	1,041	1,041
Fuel use	319	319	997	997
Accidents*	235	371	1,900	2,978
Noise pollution	17	17	138	138
Cumulative net benefits (discounted)	**21,551**	**23,138**	**45,821**	**36,379**
Benefit-cost ratio (BCR)	0.3	0.3	0.6	0.6
Sustainable BCR (S-BCR)	**5.8**	**6.1**	**4.5**	**3.8**

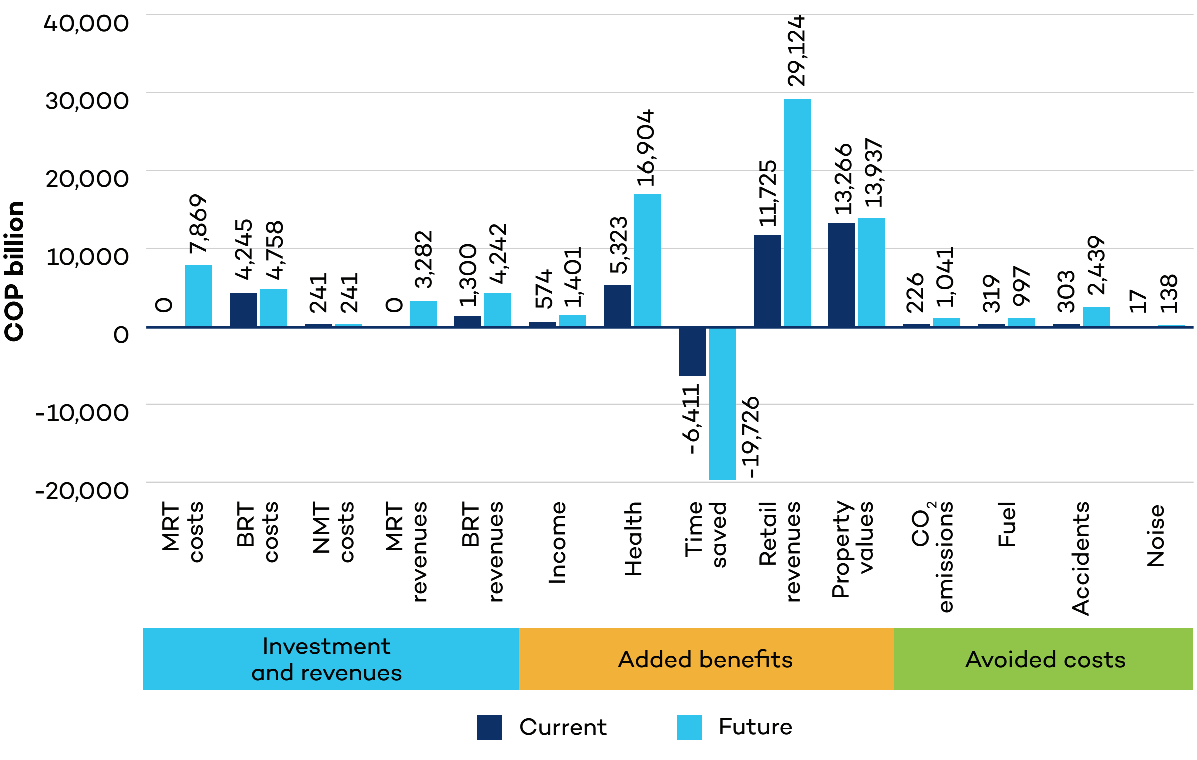
* Added benefits and avoided costs that are impacted by the different demand scenarios.

Source: Authors' calculations.

As Table ES1 demonstrates, the added benefits of the retail revenues resulting from the implementation of the public transport systems have the highest cumulative values, amounting to COP 11,725 billion in the current sustainable transport scenario and COP 29,124 billion in the future sustainable transport scenario. This is followed by health benefits resulting from increased physical activity and reduced air pollution. The SAVi results show discounted cumulative health benefits of COP 3,778 billion and COP 6,868 billion in the low and high estimates, respectively, for the current sustainable transport scenario and COP 10,673 billion and COP 23,134 billion in the low and high estimates, respectively, for the future sustainable transport scenario. The third most significant impact is the added benefit of property value increases around BRT, NMT, and MRT stations, amounting to COP 8,844 billion in the low estimate and COP 17,688 billion in the high estimate of the current sustainable transport scenario and COP 9,291 billion in the low estimate and COP 18,583 billion in the high estimate of the future sustainable transport scenario. Finally, the public transport systems will significantly increase active transport modes such as walking and cycling, resulting in time lost overall which is represented as negative values for time savings. Overall, the three public transport systems are expected to revitalize Bogota's economy in the form of increased retail revenues (especially in the central areas of the city) and deliver significant health benefits to Bogota's citizens. However, higher real estate prices—as a result of the public transport systems and the MRT in particular—will possibly increase the cost of living in Bogota's city centre and make properties less affordable.

The SAVi assessment results of the Sustainable Transport Strategy in Bogota, including investment costs, revenues, added benefits, and avoided costs of the three public transport systems that were evaluated, are shown in Figure ES1 below. Average values of low and high estimates have been calculated where appropriate.

Figure ES1. Monetary values of investment costs, revenues, added benefits, and avoided costs of the Sustainable Transport Strategy in Bogota



Source: Authors' calculations.

In addition, two different BCRs have been calculated: the conventional BCR and the sustainable BCR. The BCR determines the overall value for money of a project. It illustrates the return for every unit (COP) invested by comparing the project's total benefits with the total costs. The BCR is based on estimations of only tangible parameters and includes capital costs, O&M costs, and revenues. The S-BCR considers the project from a societal point of view and is based on an estimation of the full range of economic, social, environmental added benefits, and avoided costs. As indicated in Table ES2, the conventional BCR leads to a significantly lower BCR than the S-BCR.

Table ES2. Conventional BCR vs S-BCR (discounted using different discount rates)

	BCR				**S-BCR**			
Parameters considered	Investment costs, revenues				Investment costs, revenues, full range of economic, social, and environmental added benefits, and avoided costs			
Scenario	Current		Future		Current		Future	
	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate
BCR	0.3	0.3	0.6	0.6	5.8	6.1	4.5	3.8

Source: Authors' calculations.

Overall, the Sustainable Transport Strategy's benefits outweigh the investment costs by 4.5 in the sustainable transport scenario that considers all three MRT, BRT and NMT public transport systems. When a wide range of tangible and intangible economic, social and environmental impacts are valued, the benefits are approximately seven times higher.

This SAVi assessment provides benchmark values for policy-makers and public infrastructure planners when it comes to valuing the societal benefits and costs of the Sustainable Transport Strategy in Bogota. Table ES3 indicates how different stakeholders and decision-makers can use the results of this assessment to make more informed decisions.

Table ES3. How different stakeholders and decision-makers use the results of the Sustainable Transport Strategy in the Bogota SAVi assessment

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
Government	Design, implementation, and finance of the Sustainable Transport Strategy in Bogota	Urban and regional governments can use the assessment results to raise awareness of sustainable transport projects and to justify investments in sustainable transport strategies as well as make these assessments a standard and a requirement for investment decisions. Overall, the results of the assessment provide an integrated perspective on MRT, BRT, and NMT systems and the wide range of economic, social, and environmental benefits that they deliver. This can help urban authorities and governments provide funding and support for such projects, tapping into different capital sources. Policy-makers can use the assessment results to make decisions on sustainable transport projects and sustainable transport strategies, as well as on potential additional investments that may be required to realize additional benefits.
Private sector/ industry	Project developers	Businesses and private sector entities can use the assessment results for additional advocacy for sustainable transport projects and public transport systems, as well as for identifying new opportunities and business cases for additional investment in sustainable transport projects.
Donors and funders	Funding of sustainable transport strategies and public transport projects	Donors can include the assessment results in their reporting processes to show the impacts of their investments. The assessment results can also be used to raise awareness of the benefits of public transport systems in cities, including health benefits, avoided costs of air pollution and CO_2 emissions, and potential increases in retail and property prices. This can help to make the case for further sustainable transport projects and active transport schemes (e.g., by making these assessments a formal requirement).
Civil society organizations	Consultation with government on Sustainable Transport Strategy	Civil society organizations can use the assessment results and the valuation of the added benefits and the avoided costs of public transport projects to conduct more targeted advocacy for sustainable transport projects. Civil society organizations can also use the assessment results to promote integrated solutions for sustainable transport and to raise awareness of their value to society.

Source: Authors.

Integrated assessments such as this one, conducted using the SAVi methodology, can help to make a stronger case for sustainable transport strategies and public transport systems. Altogether, this assessment shows that the Sustainable Transport Strategy advances the realization of sustainable mobility targets in Bogota and will improve the quality of life of its residents.

Abbreviations and Acronyms

BAU	business as usual
BCR	benefit-cost ratio
BRT	bus rapid transit
CBA	cost-benefit analysis
CO	carbon monoxide
COP	Colombian peso
HC	hydrocarbons
HEAT	Health Economic Assessment Tool
LPG	liquified petroleum gas
MRT	mass-rapid transit
NO_x	nitrogen oxides
NMT	non-motorized transport
O&M	operations and maintenance
$PM_{2.5}$	particulate matter with a diameter of less than 2.5 micrometres
SAVi	Sustainable Asset Valuation tool
SCC	social cost of carbon
S-BCR	sustainable benefit-cost ratio
SITP	Sistema Integrado de Transporte Público (Integrated Public Transport System)
V-KM	vehicle-kilometre
VSL	value of a statistical life

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Glossary

Benefit-cost ratio: A ratio that determines the overall value for money of a project. It illustrates the return for every unit (USD or COP) invested by comparing a project's total benefits with the total costs.

Causal loop diagram: A schematic representation of key indicators and variables of the system under evaluation that shows the causal connections between them and contributes to the identification of feedback loops and policy entry points.

Discounting: A finance process to determine the present value of a future cash value.

Indicators: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Programme [UNEP], 2014a).

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used, as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014b).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014b).

Net benefits: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014b).

System dynamics: A methodology developed by Forrester in the late 1950s (Forrester, 1961) to create descriptive models that represent the causal interconnections between key indicators and indicate their contribution to the dynamics exhibited by the system as well as to the issues being investigated. The core pillars of the system dynamics method are feedback loops, delays and nonlinearity emerging from the explicit capturing of stocks and flows (UNEP, 2014b).

1.0 Introduction

1.1 Mobility Challenges and Transport Strategies in Bogota

Bogota is the capital of Colombia and its largest city, home to a rapidly growing population of more than 8 million inhabitants across an urban area of 400 km^2. The city's public transportation network is insufficient and has not been able to respond to urban population growth and mobility needs over the past few decades. As a result of the inefficient use of transport alternatives and resources, Bogota faces significant traffic congestion issues that affect the city's competitiveness and productivity. Traffic analytics data from 2020 show that Bogota was the most congested city in the world, with the average person in Bogota losing 191 hours to traffic each year (World Economic Forum, 2020).

In addition, Bogota produces around 5% of Colombia's greenhouse gas (GHG) emissions, with the transport sector responsible for 48% of that portion. The city also faces significant challenges related to air pollution, especially particulate matter, which has levels that often exceed World Health Organization (WHO) recommendations and national guidelines. It is estimated that air pollution leads to the death of at least 2,100 Bogatanos per year. At the same time, motorization rates in Bogota have been on the rise. The number of registered vehicles in the city has doubled in the last decade, which, together with outdated vehicle technologies, has significantly contributed to the increased GHG emissions. On the other hand, Bogota's Climate Action Plan aims to reduce GHG emissions by 15% by 2024 and 50% by 2030 and reach net-zero carbon emissions by 2050 (Viable Cities & UN Habitat, 2022).

Moreover, Bogota's low-income population lives mostly in the southern and the western outskirts of the city, which have disproportionately low levels of accessibility to public transport links and, hence, to employment opportunities. This is because economic activities in Bogota are highly concentrated in the eastern part of the city, in proximity to areas accommodating higher-income populations. As a result, travel time is up to 40% higher for low-income populations than for affluent ones (Guzman et al., 2018).

In order to address these issues, national and regional efforts to develop sustainable transport strategies and increase the implementation of sustainable transport projects have been undertaken, some of which are mentioned below.

According to the National Development Plan 2018–2022: Pact for Colombia Pact of Equity, the main transport sector objectives in Colombia are to

- modernize, simplify, and improve the efficiency of the institutional framework of the transport and logistics sector to achieve higher levels of efficiency, specialization, and articulation between national and territorial entities;
- modernize public transport systems with better technologies, greater accessibility for the disabled population, and affordable prices for all;
- reduce travel times and costs through the increased efficiency and integration of modes of transport; and
- identify new alternatives for the financing of transport infrastructure at the national and regional levels.

Moreover, in 2020, the District Development Plan 2020–2024: A New Social and Environmental Contract for the 21st Century was produced. The plan aims to "[c]hange living habits to green Bogota and adapt to and mitigate climate change" as well as "[m]ake Bogotá a model of multimodal, inclusive and sustainable mobility" (Viable Cities & UN Habitat, 2022). The plan promotes investment in sustainable mobility projects in the Bogota region (Secretariat of Mobility, 2020). Its general objective is to improve the travelling experience in Bogota through time savings and quality of transport (considering the more vulnerable segments of Bogota's population), as well as safety matters linked to gender.

The investment projects consider nine goals that total COP 105.8 billion of investment over 5 years of implementation (2020–2024). More specific objectives of the plan include

- increase the public transport offer of the Integrated Public Transport System (SITP) by 20%,
- increase the reliability of the SITP service,
- implement a strategy that improves the quality of urban public transport on a regional level
- ensure that the average travel time in the 14 main city corridors stays the same for all road users

Lastly, the Bogota Sustainable Mobility Plan (Plan integral de Movilidad Sostenible) and the Bogota Development Plan Bogota Better For All 2016–2020 (Bogota Mejor Para Todos 2016–2020), propose targets to address these challenges and gradually transform how the citizens of Bogota move around, encouraging more sustainable modes of transport. In addition, the Better Mobility for All program seeks to improve the quality and accessibility of mobility for all transport users in Bogota, including pedestrians, cyclists, and public and private transport users.

Overall, Bogota experiences serious traffic congestion problems, long commuting times, high accident rates, and elevated levels of noise and air pollution (Centre for Public Impact, 2016). These problems are projected to worsen with climate change and continued urban development. Transforming the transport sector in Bogota is, therefore, crucial for reducing GHG emissions and addressing socio-economic disparities. More specifically, the implementation and reorganization of public transport systems have the potential to deliver positive environmental impacts and social benefits, mainly from increased accessibility to employment opportunities and travel time savings. The following subsections explore Bogota's main public transport systems. They are divided into current public transport systems that have been operating in the city in the last 20 to 30 years and the public transport systems that are under construction and will expand transport options for Bogota's residents in the future.

1.1.1 CURRENT PUBLIC TRANSPORT SYSTEMS IN BOGOTA

Currently, the main form of public transport available in the city is the TransMilenio bus rapid transit (BRT) system. TransMilenio was implemented in the late 1990s and was, at least at the beginning of its operation, one of the largest and most successful BRT systems in the world. The BRT system has 12 interconnected lines that usually run in dedicated lanes, totalling 112 km. There are more than 3,500 buses in operation, providing service to 2.3 million people daily. At its peak load, it is the busiest BRT system in the world, carrying approximately 250,000 passengers per hour (Global infrastructure Hub, 2018). In addition, the TransMilenio BRT system has managed to considerably decrease car usage and average travel times, increase property values along the main line, enhance tax revenues, create employment opportunities, and improve the health and safety of many communities across Bogota. Despite all this, the TransMilenio currently experiences high levels of overcrowding in old and decaying buses, long walking and waiting times due to excessive queuing, and an overall poor quality of public transport service (Centre for Public Impact, 2016).

Additionally, since the late 1990s, the city of Bogota has constructed more than 600 km of dedicated bicycle paths, known locally as "ciclorrutas," which form part of an elaborate non-motorized transport (NMT) network. Also, the city has introduced programs that encourage active transport modes on "ciclovias," which are street spaces that become available to recreational cyclists and pedestrians on certain days, such as Sundays or public holidays. The NMT network has contributed to a significant increase in daily cycling trips in Bogota and it has led to positive environmental impacts, saving around 57,000 tons of carbon dioxide (CO_2) per year. Currently, the modal share for cycling in Bogota is 3.3%. However, Bogota's NMT networks are often fragmented, forcing cyclists to make use of busy and dangerous roads. Moreover, there are still major gaps in the city's NMT networks as well as numerous maintenance issues that negatively affect their overall usage (UN Environment, 2019).

1.1.2 FUTURE PUBLIC TRANSPORT SYSTEMS IN BOGOTA

The Metro Line 1 of the Metro de Bogota mass rapid transit (MRT) system, an elevated MRT line that will be fully automatic and driverless, is currently under construction. Upon completion, the MRT system will be the first modern metro system in Colombia. It will act as the main transit line for the public and will be a major passenger transport system in the city, connecting Bogota's city centre with the southern and northern districts (WSP, 2022). The MRT system is expected to accommodate 1.05 million passengers per day or 72,000 passengers per hour in each direction (Metro de Bogotá, 2022), covering a distance of almost 25 km. Construction of the MRT project began in 2020, and Line 1 is expected to be operational in 2028 (Construction Review Online, 2021). Finally, the system will integrate with the existing public transport network, including the TransMilenio BRT system (WSP, 2022). The project will also be complemented with improvements to 600,000 m^2 of public spaces dedicated to pedestrian use, civil works, and construction of new BRT stations. The MRT is projected to provide significant benefits to 2.92 million people across Bogota by reducing traffic congestion and increasing access to employment opportunities while contributing to time savings (although these benefits can be offset by the lower speed of NMT). It also aims to meet sustainable, low-carbon mobility targets (Railway Technology, 2020).

1.2 Purpose of a Sustainable Asset Valuation for the Sustainable Transport Strategy in Bogota

The city lies in central Colombia in a fertile upland basin 2,640 metres above sea level, and its metropolitan area extends for approximately 1,500 km^2. According to a 2019 mobility survey 13.4 million transport trips are made daily, amounting to more than 16 million trips if all municipalities in the city's metropolitan area are considered. Public transport is responsible for 44.2% of trips, while private transport modes, including cars, motorcycles, and taxis, account for 25.3%. Active transport modes, such as walking and cycling, represent 24% and 6.5% of trips, respectively (Secretariat of Mobility, 2020).

To address the mobility challenges mentioned in the previous section and reduce transportation-related GHG emissions, Bogota has been undertaking important efforts to develop sustainable transportation strategies and implement sustainable mobility projects. In 2011, the city held the Regional Sustainable Transport Forum (FTS), where best practices, challenges, and innovations in the sustainable transport sector in Latin America were shared and reviewed (Latin American National Transport and Environment Agencies, 2011). Nine countries agreed to adopt a declaration of sustainable transport principles and objectives. The Bogota Declaration of Sustainable Transport Objectives follows the "avoid, shift, and improve" approach (Crawford, 2012), which seeks to

- avoid unnecessary travel by private motorized vehicles,
- shift from private, motorized transport modes to safer, more efficient, and more environmentally-friendly transport modes, and
- improve transport infrastructure and management by adopting cleaner and more efficient transport technologies.

More recently, Bogota received the 2022 Sustainable Transport Award from the Institute for Transportation and Development Policy for its sustainable transport interventions that expanded safety and mobility for the city's most vulnerable populations. Bogota was one of the first cities in the world to establish cycling as a priority transport mode and create emergency bike lanes during the pandemic. The city created 84 km of emergency bike lanes, of which 28 km become permanent, and 46 km are still being used. In addition, Bogota assembled a fleet of 1,485 electric buses, 350 of which have been deployed so far, benefiting mostly low-income neighbourhoods. Additionally, the city created a program to incentivize carpooling as well as an initiative to reduce highway speed limits in order to reduce accidents and increase safety for children walking to school (Institute for Transportation and Development Policy, 2022).

Despite these actions, a quantitative analysis clearly demonstrating the benefits of different sustainable transport strategies in Bogota (and the extent to which such strategies can yield mobility improvements or emissions and energy consumption reductions) has not yet been undertaken. The environmental, social, and economic benefits and costs associated with different transport strategies that aim to meet sustainability targets in Bogota are currently merely anecdotal, based on evaluations of transport policies and strategies implemented in other countries or regions around the world. For this reason, and in order to encourage public authorities to invest in sustainable transport projects and develop sustainable mobility plans, it is important to estimate the value of the investment costs (capital and operations and maintenance [O&M]) that are captured in conventional transport infrastructure assessments and also the added benefits and avoided costs of sustainable transport strategies.

The SAVi model estimates and values the economic, social, and environmental indicators in order to develop an integrated cost-benefit analysis (CBA) of the Sustainable Transport Strategy in Bogota. It is an integrated analysis because, in addition to investments and costs, the indicators that are incorporated reflect a wide range of valued economic, social, and environmental added benefits and avoided costs. The SAVi assessment encourages public authorities to compare transport strategies in Bogota against a set of key economic, social, and environmental criteria, such as income creation, GHG emissions, air pollution, and number of accidents.

The SAVi assessment of the Sustainable Transport Strategy in Bogota will focus mainly on the three main public transport systems in Bogota: BRT, NMT, and MRT. As noted earlier, these three systems are crucial in addressing the city's overreliance on private vehicles, which has resulted in severe traffic congestion, high GHG emissions, and social equity issues. The SAVi assessment considers two sustainable transport scenarios: the current sustainable transport scenario (based on existing public transport systems in Bogota) and the future sustainable transport scenario (which includes both current and future public transport systems in the city). The former will assess only the BRT and NMT systems that have been and are currently operating in the city, and the latter will also include the MRT system, which is under construction and is expected to be operational in 2028. Naturally, the two sustainable transport scenarios will be assessed using different time horizons. The SAVi assessment will include investment and O&M costs of those public transport systems, as well as a wide range of economic, social, and environmental added benefits and avoided costs that are associated with them.

This SAVi assessment of the Sustainable Transport Strategy in Bogota, Colombia is part of a series of nine SAVi assessments on sustainable transport and mobility projects that aim to raise awareness on sustainable transport infrastructure and inform decision-makers on the use of systemic approaches in supporting the transformation toward sustainable mobility.

1.3 Structure

Section 2 of the report presents the methodology, including an overview of system dynamics and the causal loop diagram (CLD) (system dynamics model) that was created for this SAVi assessment. The section also includes a summary of the transport-related indicators, including the valued investment and costs, revenues, added benefits, and avoided costs of this assessment. The scenarios and assumptions used in the assessment are discussed in Section 3. This section summarizes the sustainable transport scenarios and presents the valuation methodologies and data sources of each indicator individually. Section 4 of the report presents the results. The results overview begins with an integrated CBA table that demonstrates the total cumulative monetary values generated by the sustainable transport scenarios. The values of the added benefits and avoided costs are integrated into the CBA that includes the investment and costs in order to better represent the societal value of the different scenarios used in the Sustainable Transport Strategy in Bogota. The last part of Section 4 includes the valuation results for the investment and costs, revenues, added benefits, and avoided costs used in the analysis. Section 5 concludes by illustrating how the results of the SAVi assessment make a stronger case for sustainable transport strategies and public transport systems, highlighting the added value of integrating economic, social, and environmental parameters into transport assessments.

2.0 Methodology

This section introduces the system dynamics methodology used for the SAVi assessment of the Sustainable Transport Strategy in Bogota. It provides an overview of the CLD as well as a summary of the transport impacts that are related to the Sustainable Transport Strategy from a system dynamics perspective. The second part of this section summarizes the investment and costs, added benefits, and avoided costs used in the assessment. A more elaborate description of the valuation process of these investments, costs, added benefits, and avoided costs is included in Section 3. Some of the limitations of the methodology used are discussed in the concluding Section 5.

2.1 System Mapping

2.1.1 SYSTEMS THINKING AND SYSTEM DYNAMICS

The underlying dynamics of the Sustainable Transport Strategy in Bogota, including driving forces and key indicators, are summarized in the CLD displayed in Figure 1. The CLD includes the main indicators analyzed during this SAVi assessment, their interconnections with other relevant variables, and the feedback loops they form. The CLD illustrates the interconnections of the economy with a wide range of social and environmental parameters while highlighting key dynamics and potential trade-offs emerging from different development strategies. The CLD is the starting point for the development of the mathematical stock and flow model.

2.1.2 READING A CAUSAL LOOP DIAGRAM

CLDs aim to capture causal relationships within a system accurately in order to increase the effectiveness of relevant solutions and interventions. CLDs establish causal links between variables using arrows with a sign (either + or −) on each link, indicating a positive or negative causal relationship (see Table 1).

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction.

Table 1. Causal relations and causality

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	−
↓	↑	−

Source: Authors.

Circular causal relations between variables form causal, or feedback, loops. These can be positive or negative. A negative feedback loop tends toward a goal or equilibrium, balancing the forces in the system (Forrester, 1961). A positive feedback loop can be found when an intervention triggers other changes that amplify the effect of that initial intervention, thus reinforcing it (Forrester, 1961). CLDs also capture delays and nonlinearity. In addition, reinforcing loops tend to increase and amplify everything happening in the system (i.e., action – reaction), whereas balancing loops represent a self-limiting process which aims at finding balance and equilibrium. A detailed description of all the reinforcing and balancing loops for the Sustainable Transport Strategy in Bogota is included in Appendix A.

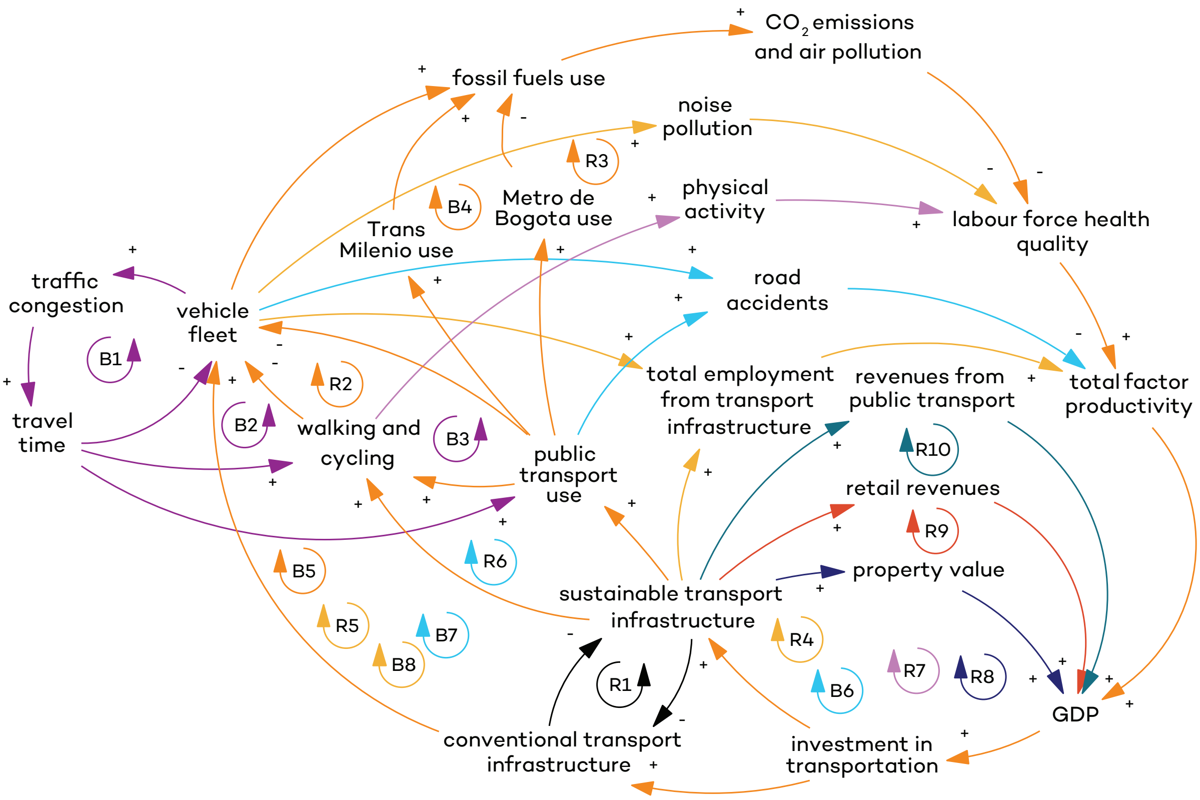
2.1.3 CAUSAL LOOP DIAGRAM FOR THE SUSTAINABLE TRANSPORT STRATEGY IN BOGOTA

The impacts of the Sustainable Transport Strategy in Bogota and its feedback mechanisms are represented in the CLD in Figure 1. The relationships are diverse, involving interrelated social, environmental, and economic variables.

One of the main dynamics of the system that represents sustainable transport in Bogota is the transport shift reinforcing loop (R1), which explains the shift from conventional to sustainable transport and vice versa and how one or the other can be reinforced and become self-sustaining. In Bogota, the largest share of transport modes includes conventional, road-based solutions, such as buses, cars, and motorcycles. Since 1999, Bogota has made considerable progress toward more sustainable transport, including through the creation of a BRT system (TransMilenio). This progress is evidenced (and can be further strengthened) by several dynamics noted in Figure 1, including a reduction of emissions generated from conventional transport modes (R2), emissions avoided from the Metro de Bogota MRT use (R3), employment from sustainable transport infrastructure (R4), avoided road traffic accidents (R6), increased physical activity (R7), increase in property value (R8), increase in retail revenues (R9), and revenues from public transport systems (R10). In the case of conventional transport, the main reinforcing loop that will enhance the dynamics is employment generation from conventional transport modes (R5).

Some balancing loops can counteract the reinforcing effects described above for both sustainable and conventional transport systems. For the case of sustainable transport systems, balancing loops include the effect of traffic congestion on walking, cycling and public transport (B2 & B3), fuel use from internal combustion engines on TransMilenio buses (B4), and accidents from public transport modes (B6). In the case of conventional transport, the side effects generated by its operation will create the balancing effects, such as traffic congestion (B1), fossil fuel use (B5), noise pollution (B8) and accidents from the vehicle fleet (B7).

Figure 1. Causal loop diagram of the Sustainable Transport Strategy in Bogota



Source: Authors' diagram.

The CLD presented in this section is described in more detail in Appendix A.

2.2 Added Benefits and Avoided Costs Valued by the SAVi Assessment

The SAVi assessment of the Sustainable Transport Strategy in Bogota provides the monetary valuation of strategy-related indicators, including investments and costs, revenues, added benefits, and avoided costs. Table 2 lists the indicators considered in this assessment, relevant stakeholders, and whether each of these indicators has economic, social, or environmental impacts. Section 3.2 explains in detail how each of these indicators is quantified and includes all data sources and assumptions.

Table 2. Added benefits and avoided costs considered in the SAVi assessment

Added benefit or avoided cost	Stakeholder of relevance (government, households, private sector)	Social, environmental, economic
Investment and costs		
Capital and O&M costs of the MRT system	Government	Economic
Capital and O&M costs of TransMilenio BRT system	Government	Economic
Capital and O&M costs of NMT infrastructure	Government	Economic
Revenues		
Revenues from the MRT system	Government	Economic
Revenues from the TransMilenio BRT system	Government	Economic
Added benefits		
Income creation from employment	Government, households	Economic
Health impacts	Households, government	Social
Value of time saved	Households, private sector	Economic
Retail revenues	Private sector, households	Economic
Property value	Government, private sector, households	Economic
Avoided costs		
CO_2 emissions	Households	Environmental
Fuel use	Households	Economic
Accidents	Households	Social
Noise pollution	Households	Social

Source: Authors.

3.0 Scenarios and Assumptions

This section introduces the scenarios simulated for the SAVi assessment of the Sustainable Transport Strategy in Bogota, including demand figures and shifting mobility patterns associated with the sustainable transport scenarios. Subsequently, it examines the underlying valuation methodologies of the SAVi assessment for these scenarios. This includes the assumptions, data sources, and valuation methodologies of the nine added benefits and avoided costs valued by the SAVi model. This is then followed by the SAVi assessment results of the Sustainable Transport Strategy in Bogota.

Concerning the baseline business-as-usual (BAU) scenario, the SAVi model assumes that transport mode shares will remain constant over time. Most of the added benefits and avoided costs are affected by trip demand per transport mode. The SAVi model predicts that daily trip demand in Bogota will increase in the future across all transport modes due to population growth and economic development.

There are multiple scenarios that could result in changes in transport modal shares over time or because of the implementation of specific transport policies. Two possible BAU scenarios focus on an increase in either the motorcycle or car use shares.

In the first case, if the share and number of motorcycles were to increase in Bogota, traffic congestion would decrease and transport efficiency would improve, as motorcycles occupy less space and are faster than cars. In addition, the increase in the number of motorcycles would result in reduced air pollution and fuel consumption when compared with cars. It would also improve access to jobs for users who can travel longer distances while decreasing travel time for current users. However, an increase in the number of motorcycles will also lead to negative impacts, such as more traffic accidents and noise pollution in Bogota.

In the second case, if the car share and number were to increase in the city, people would have greater access to more and further destinations, increasing job opportunities and boosting the local economy. However, this would also result in increased traffic congestion, accidents, air pollution, and urban sprawl (i.e., people live farther away from their workplaces).

It is challenging to predict future demand for different transport modes, especially when transport policy decisions are made within 4-year political cycles, and there is a lack of data regarding possible scenarios for transport mode shares in Bogota. Nevertheless, regardless of the scenarios mentioned above, the relative change in transport modal shares between BAU and alternative scenarios will be similar, as alternative scenarios are always compared to BAU scenarios.

3.1 Scenarios of the Sustainable Transport Strategy SAVi Assessment

This SAVi assessment of the Sustainable Transport Strategy in Bogota includes two sustainable transport scenarios: (i) a current sustainable transport scenario (2010–2022) and (ii) a future sustainable transport scenario (2010–2058). Table 3 provides a description of the scenarios simulated for the SAVi assessment. For each of the two sustainable transport scenarios, assumptions related to the modal share of different transport modes have been developed and are summarized in Table 4.

Table 3. Description of the scenarios simulated in the Sustainable Transport Strategy SAVi assessment

Scenario	Assumptions
Status quo	This is a no-action scenario in which the measures included in the Sustainable Transport Strategy have not been implemented, and the modal share of transportation in Bogota stays the same over the simulation period.
Current sustainable transport scenario	This scenario represents public transport systems that are currently in operation in Bogota and have been introduced during the last 20 to 30 years. This includes the TransMilenio BRT system and the NMT network, which includes cycling and walking infrastructure. The time period for this scenario starts in 2010 and ends in 2022, with no other actions implemented after that.
Future sustainable transport scenario	This scenario represents public transport systems that are currently in operation and public transport systems that are under construction and will be operational in the future. This includes the TransMilenio BRT system, the NMT network, which includes cycling and walking infrastructure, and the MRT system currently under construction. The latter will be the first metro system in Bogota and a major passenger transport system in the city. The time period for this scenario starts in 2010 and finishes in the 2058.

Source: Authors.

Table 4. Scenario assumptions for the Sustainable Transport Strategy SAVi assessment

Modal share of transportation	Current sustainable transport			Future sustainable transport scenario			
	2010	2018	2022	2028	2038	2048	2058
Car	14.7%	14.8%	14.9%	13.8%	11.0%	11.0%	11%
Motorcycle	0.7%	4.0%	5.5%	5.5%	5.5%	5.5%	5.5%
Taxi	3.7%	4.5%	4.9%	4.9%	4.5%	4.5%	4.5%
TransMilenio (BRT)	9.6%	16.0%	18.8%	18.8%	18.8%	18.8%	18.8%
Bus + SITP	53.9%	34.1%	25.4%	24.5%	21.7%	21.7%	21.7%
MRT	0%	0%	0.0%	2%	8%	8%	8%
Cycling	2.3%	5.3%	6.6%	6.6%	6.6%	6.6%	6.6%
Walking	15.1%	21.2%	23.9%	23.9%	23.9%	23.9%	23.9%

Source: Authors' calculations.

This SAVi assessment considers a project period of 48 years, from 2010 to 2058. The current sustainable transport scenario evaluates currently operational public transport systems from 2010 to 2022, and the future sustainable transport scenario assesses the existing and future public transport systems, considering the whole project period from 2010 to 2058. Naturally, different discount rates have been applied to the two sustainable transport scenarios.

For the **current sustainable transport scenario**, which evaluates past transport investments, four different discount factors have been applied to the conventional investment costs, revenues, and tangible added benefits, as well as avoided costs for different years. The discount rates used follow the historical rate of inflation in Colombia. The different discount factors that are applied over time are estimated, considering a wide range of parameters, including the historical rate of inflation over time in Colombia, economic growth, the impacts of COVID-19, and 10-year bond yields on government bonds in the country. Tangible added benefits and avoided costs include income creation from employment, retail revenues, property prices, and fuel use. For the social and environmental indicators of the assessment—in other words, the intangible added benefits and avoided costs, such as health impacts, value of time saved, CO_2 emissions, accidents, and noise pollution—the lower discount rate of 3.5% is applied for all years (UK Government, 2022).

For the **future sustainable transport scenario**, a discount factor of 8% is applied to the conventional investment costs and revenues as well as to tangible added benefits and avoided costs. The discount factor of 8% was also estimated considering the parameters mentioned above, including the current inflationary pressure. Similar to the current sustainable transport scenario, for the social and environmental indicators of the assessment, the lower discount rate of 3.5% is applied for all years. Table 5 demonstrates the different discount rates used in this SAVi assessment for different years and across both sustainable transport scenarios.

Table 5. Discount rates used for the Sustainable Transport Strategy SAVi assessment

	Future sustainable transport scenario					
Scenario	**Current sustainable transport scenario**					
Year	**2010–2018**	**2019**	**2020**	**2021**	**2022**	**2022–2058**
Discount rate for tangible indicators	6%	6.5%	7%	7.5%	8%	8%
Discount rate for intangible indicators	3.5%					

Source: Authors' calculations.

Box 1. Addressing uncertainty in transport modal shares

The SAVi model assumes that transport modal shares in the BAU scenario will remain constant over time. Most of the added benefits and avoided costs are affected by trip demand in different transport modes. The SAVi model predicts that daily trip demand in Bogota will increase in the future across all transport modes due to population growth and economic development. In other words, if trip demand increases, then infrastructure will also have to increase to accommodate that demand. However, since we do not know what infrastructure will be added, we avoid making assumptions about the rate of change of trips. As a result, we consider only the net impact of the investments implemented in the past, such as considering the BRT and NMT systems in Bogota or the net impact of the MRT project in the future.

There are multiple scenarios that could result in changes in transport modal shares over time or because of the implementation of specific transport policies. The following section analyzes two BAU scenarios, in which either the motorcycle or car shares increase.

In the first case, if the share and number of motorcycles were to increase in Bogota, traffic congestion would decrease and transport efficiency would improve, as motorcycles occupy less space and are faster than cars. In addition, the increase in motorcycles would result in reduced air pollution and fuel consumption when compared with cars, and it would improve access to jobs for users who can travel longer distances while decreasing travel time for current users. However, an increase in motorcycles will also lead to negative impacts such as more traffic accidents and noise pollution.

In the second case, if the car share and number were to increase in the city, people would have greater access to more and further destinations, increasing job opportunities and boosting the local economy. However, this would also result in increased traffic congestion, accidents, air pollution, and urban sprawl (i.e., people live farther away from their workplaces).

It is challenging to predict future demand for different transport modes, especially when transport policy decisions are made within 4-year political cycles, and there is a lack of data regarding possible scenarios for transport mode shares in Bogota. Nevertheless, regardless of the scenarios mentioned above, the relative change in transport modal shares between BAU and alternative scenarios will be similar, as alternative scenarios are always compared to BAU scenarios.

3.2 Valuation Methodologies of the Investment and Costs, Added Benefits, and Avoided Costs

3.2.1 INVESTMENT AND COSTS

The Sustainable Transport Strategy in Bogota includes investment and operation and maintenance (O&M) costs for three public transport systems in Bogota: MRT, BRT, and NMT.

Table 6. Construction rate in km per year for MRT, BRT, and NMT systems from 2010 to 2027

	Construction rate (km/year)		
Year	**MRT**	**BRT**	**NMT**
2010	0.00	83.00	0.00
2011	0.00	0.00	3.00
2012	0.00	22.00	26.00
2013	0.00	0.00	37.00
2014	0.00	0.00	2.00
2015	0.00	7.00	13.00
2016	0.00	0.00	70.00
2017	0.00	0.00	18.00
2018	0.00	2.40	0.00
2019	0.00	0.00	0.00
2020	0.00	0.00	8.00

	Construction rate (km/year)		
Year	**MRT**	**BRT**	**NMT**
2021	3.43	0.00	0.00
2022	3.43	0.00	13.00
2023	3.43	0.00	0.00
2024	3.43	0.00	0.00
2025	3.43	0.00	0.00
2026	3.43	0.00	0.00
2027	3.43	0.00	0.00
Total km	24.00	114.40	564.00

Source: Authors' calculations.

3.2.1.1 Capital and O&M Costs of the MRT system

The capital costs of the MRT system are estimated using the construction rate and the cost per km of MRT lines.

The construction of the MRT system started in 2021 and the first MRT line, which is 24 km long, is expected to be completed by 2028 (Zuber, 2016). The model assumes a constant construction rate of 3.43 km per year until 2027. The cost per km of the MRT system is calculated based on data on the total cost and total km of MRT infrastructure and amounts to COP 534.16 billion per km (Mazzoni et. Al, 2016).

The total O&M costs of the MRT are estimated considering the number of MRT wagons and the cost per wagon-km. The wagon-km is calculated using data of vehicle-kilometre (v-km) and wagons per MRT train. The O&M cost per wagon-km amounts to COP 17,898 (Zuber, 2016).

3.2.1.2 Capital and O&M Costs of the TransMilenio BRT System

For the TransMilenio BRT system in Bogota, total investment is also estimated using the construction rate and the cost per km of BRT lanes. By 2010, the BRT had 83 km of bus lanes built, adding 22 in 2012, 7 km in 2015 and 2.4 km in 2018 (Hidalgo, 2004; urban sustainability exchange, 2022; Global Infrastructure Hub, 2018; TransMilenio, 2019). Moreover, the cost per km of BRT infrastructure amounts to USD 12.5 billion per km or COP 46.8 billion per km (Carrigan, et al., 2013). Considering past investments in the BRT system in Bogota, one third of the investment required for the 83 of BRT lanes is used, based on the assumption that the BRT system has been in use for 10 years already, although it has a lifetime of 30 years.

The total O&M costs of the BRT system are calculated using the BRT system's v-km per year and the O&M cost per v-km. The former is calculated by the model based on trips demand data in Bogota, modal share data and trip distances. The latter is assumed to cost COP 1,872 per v-km (Rizelioğlu et al., 2019).

3.2.1.3 Capital and O&M Costs of NMT Infrastructure

Similar to the other public transport systems, investment for NMT infrastructure in Bogota considers the construction rate and the cost per km. The construction rate amounts to 3 km of permanent cycle lanes in 2011, 26 km in 2012 and 37 km from 2013 to 2022 (Estupiñan, Gómez & Avila, 2021; Secretaría de movilidad de Bogotá, 2020; Galeano, 2022). The cost per km of the NMT system amounts to COP 1.73 billion. In addition, COP 800 billion are going to be invested in 346 km of cycling lanes and 5,000 parking spaces for cyclists in Bogota in the future (Camacho, 2020).

To calculate the construction cost per km, the model assumes that COP 200 billion of the investment (25%) goes to the parking spaces and the rest goes for the 346 km of new and reconstructed cycle lanes (COP 600 billion). Due to the low requirement for O&M for permanent cycling lanes and the lack of local data, it is assumed that the NMT system does not have any O&M costs.

3.2.2 REVENUES

This section presents the revenues generated from both the BRT and MRT system in Bogota. The NMT system is not included in this section as it does not generate revenues.

3.2.2.1 Revenues From MRT Use

Revenues from the use of the MRT system simply represent the revenues from passengers' purchase of MRT tickets. Data for the MRT system shows that the average MRT ticket price of a trip is expected to be COP 3,216 in 2028. This value is calculated by the SAVi model based on TransMilenio prices in Bogota (TransMilenio, 2022). The average MRT ticket price was then multiplied by the number of trips per year through to 2058. The number of trips per year was calculated by using MRT demand projections and assumptions about the number of daily trips per person (1.9) based on current travel habits in Bogota. From 2029, daily trips per person (two) are based on population and trip demand projections for the city of Bogota (Bogota City Hall, 2019). Price projections of the MRT system are assumed to follow the TransMilenio price growth, which is estimated based on historical prices over the last 5 years—a 4.8% price increase per year (TransMilenio, 2022).

3.2.2.2 Revenues From TransMilenio BRT Use

Revenues from the use of the TransMilenio BRT represent the revenues from the purchase of BRT tickets. Revenues are calculated based on BRT trips per year, obtained by the model based on the modal share over time, total trip demand, trips per person in Bogota, and ticket price.

BRT trip share has increased from 9.6% in 2010 to 18.8% in 2022 (Bogota City Hall, 2019). After 2022, the BRT modal share is assumed to be constant. The TransMilenio BRT ticket price has increased from COP 1,600 in 2010 to COP 2,650 in 2022 (TransMilenio, 2022). The projection for future prices from 2022 onward assumes an annual rate of increase of 4.8%, which corresponds to the average of the last 5 years.

3.2.3 ADDED BENEFITS

3.2.3.1 Income Creation From Employment

Construction and O&M related to the different public transport systems in Bogota generate additional employment, which has beneficial socio-economic impacts, such as increased discretionary spending. Discretionary spending from labour income represents the amount of money that flows back into the economy in the form of additional consumption. The discretionary spending from income generation is valued as an added benefit of the Sustainable Transport Strategy.

For employment creation during the construction of the MRT system, a fixed amount of direct (8,000) and indirect (20,000) employment positions was assumed for the valuation based on an interview with Chinese Embassy representative Xu Wei (Capital, 2019). The total employment (direct and indirect) per year during the construction period (2021–2028) is 28,000 jobs. For O&M employment, a multiplier of 49.5 jobs per km was calculated based on the operation of the Metro in Medellin, Colombia's second-largest city, for which there are 1,708 persons employed for a network of 34.5 km (Metro de Medellin, 2022). Once the jobs from construction and O&M are calculated, the sum is multiplied by the average annual salary per person in Bogota, which is COP 31,876,781/person/year (Salary Expert, 2022). Subsequently, this is multiplied by the share of the income that is considered discretionary spending, which is 21.2% for Bogota (Numbeo, 2022).

For employment creation during construction of the TransMilenio BRT system, the BRT construction rate is multiplied by construction jobs per km, which is calculated as 17 jobs/km for the low estimate scenario and 21 jobs/km for the high estimate scenario. For the O&M costs, the cumulative BRT system in km is multiplied by the O&M cost per km, estimated as 23 jobs/km for the low-estimate scenario and 35 jobs/km for the high-estimate scenario (Carrigan et al., 2013).

Regarding the NMT system, based on the information available, job generation from cycling includes manufacturing, sale, and maintenance of bicycles, with a generation of 5,978 jobs for 410 km of infrastructure (Portafolio, 2019). This results in 15 jobs per km, which is multiplied by the cumulative km of the NMT network to obtain the total employment generation from the NMT network.

3.2.3.2 Health Impacts

This section estimates the aggregated effect of three impacts: (1) health benefits from increased physical activity, (2) health costs of air pollution, and (3) health costs from increased exposure to air pollution. The avoided costs of traffic accidents are considered in a separate section.

The benefits from **physical activity** come from the additional walking and cycling generated by the use of the three public transport systems. It is assumed that the use of the MRT, BRT, and NMT systems will lead to a shift from motorized transport to walking and cycling, which increases the overall time commuters spend being active and, hence, reduces their mortality. According to a BRT system study (Carrigan et al., 2013), every user will walk an additional 10 minutes per day on average. WHO has developed a Health Economic Assessment Tool (HEAT) to quantify and monetize health benefits from additional time spent on active modes of transport, such as walking and cycling (WHO, 2017). HEAT's methodology makes it possible to estimate the reduced risk of all-cause mortality due to increased physical activity. The reduction in relative risk of mortality is valued using the value of a statistical life (VSL). The VSL is derived from a method called willingness to pay, which considers the aggregated individual willingness to pay to reduce the risk of premature death in accordance with life expectancy. This includes factors such as consumption, inability to work, and health-care payments (WHO, 2017).

This methodology is applied to value the benefits of increased physical activity from additional walking by public transport users. To consider the national context in Colombia for the valuation of health benefits, a crude death rate of 4.33 people per 1,000 was used (Saludata, 2022), and a VSL for Colombia of USD 0.64 per life, based on a study in Chile and Latin American countries (Mardones et al., 2018).

Regarding **air pollution**, the shift from road fuel-based transport to public transport systems will significantly reduce air pollution levels. The avoided cost of air pollution is estimated based on each transport mode's air pollutants and the health costs associated with emitting 1 kg of a specific air pollutant. The Sustainable Transport Strategy SAVi model includes the valuation of $PM_{2.5}$, NO_x, CO, and HC. The difference in the total health cost of air pollutants between the baseline and the sustainable transport scenarios is calculated by multiplying the health cost per kg of each respective pollutant with the volume of air pollution avoided as a result of using the different public transport systems. A low- and a high-value estimate for the health cost of the pollutant $PM_{2.5}$ has been used in the analysis based on a study conducted for Indian cities (Rahul et al., 2013). Transport-related air pollution is likely to decrease over time as fossil fuel-powered vehicles will become more energy efficient and will be gradually replaced by electric vehicles. Table 7 summarizes these input parameters for the different transport modes that are part of the modal share of Bogota.

Table 7. Air pollutants (in g/km) per transport mode in Delhi and health cost valuation per emitted air pollutant

Emission factors (in g/km)	Unit	$PM_{2.5}$	NO_x	CO	HC
Car	g/km	0.05	0.243	3.595	0.469
Motorcycle	g/km	0.071	0.086	2.027	2.049
Taxi	g/km	0.05	0.243	3.595	0.469
BRT	g/km	2.672	21.38	11.92	3.311
Bus	g/km	2.672	21.38	11.92	3.311
MRT	g/km	0	0	0	0
Cycle	g/km	0	0	0	0
Walk	g/km	0	0	0	0
Valuation of emissions					
Health cost of pollutants (low value)	COP/kg	71,758.68	51.27	0.52	4.19
Health cost of pollutants (high value)	COP/kg	550,582.92	51.27	0.52	4.19

Source: Authors' calculations based on Rahul et al., 2013.

Lastly, the **additional walking** in urban environments with high background concentrations of air pollutants tends to have worse health effects. This is the case because the pollutant dose increases for people who walk or cycle due to direct exposure in traffic and higher inhalation rates during physical activity as opposed to sitting in vehicles (Rabl & Nazelle, 2012). These negative health effects caused by $PM_{2.5}$ with respect to all-cause mortality are considered in this SAVi assessment—they range from higher risks for strokes, heart diseases, lung cancer, and respiratory diseases.

The cost of increased exposure to air pollutants is estimated based on the health cost per km travelled (76.98 COP/km) as indicated by Rabl and Nazelle (2012) and the additional walking due to the use of the MRT, BRT, and NMT systems. The exposure and related negative health effects strongly depend on where the walking takes place and the pollution levels of those areas. Due to the lack of these contextual factors, the calculations are based entirely on the study by Rabl and Nazelle (2012).

3.2.3.3 Value of Time Saved

The value of time saved represents the economic value of improved mobility resulting from the MRT, BRT, and NMT systems. The SAVi assessment does not apply a growth rate to the value of time saved over time; therefore, the value of time saved is estimated in real terms. An average speed for each assessed transport mode has been assumed. The speeds of the different transport modes are shown below and are informed by different studies, local/regional reports, and consultations with the client (adjusted based on the context):

- Car: 20 km/h – (Secretaría de Desarrollo Económico, 2018)
- Motorcycle: 23 km/h – (Secretaría de Desarrollo Económico, 2018)
- Taxi: 23 km/h – (Secretaría de Desarrollo Económico, 2018)
- BRT: 25 km/h – (TransMilenio, 2013)
- Bus: 13 km/h – (Despacio, 2017)
- MRT: 43 km/h – (Metro de Bogota, 2018)
- Cycle: 16 km/h – (Despacio, 2017)
- Walking: 5 km/h – (WHO, 2017)

The shift from other transport modes to the MRT, BRT, and NMT systems will result in differing travel speeds. The use of the public transport systems will lead to either time savings or additional time spent commuting, depending on the current mode of transportation. The respective hourly figure of time saved is multiplied by the hourly salary of commuters to calculate the value of the hourly time saved. The hourly salary is based on assumed 2,511 annual working hours (UBS, 2018) and an average annual salary in Bogota amounting to COP 31,876,781 (Salary Expert, 2022). The analysis does not differentiate public transport users based on income and socio-economic background. If a dominant share of users is connected to a specific income class, this will impact the calculation of the economic value of time saved, which is based on average salary.

Moreover, a low estimate and a high estimate for the value of time saved have been assumed in the analysis. The high estimate for the value of time is considered as the maximum value possible, according to which all transport commuters will benefit from the reduction of travel time, assuming that 100% of the total value is taken for the calculation of the CBA. The low-value estimate, on the other hand, represents the minimum impact, according to which only 10% of transport commuters receive the benefits of travel time reduction, e.g., if only the transport and delivery companies benefit or only the public transport users and not the other commuters. Practically, in this low-value assumption, only the value of time that is tangible (e.g., for businesses working in delivery) is considered, because time in these sectors and activities is monetized (i.e., the faster the speed of travel, the higher the potential income and revenue generation).

Effectively, because active transport modes, such as walking and cycling, are significantly increased as a result of the implementation of the public transport system, it is possible that time is lost. This is not because of increased congestion but because more people are walking and, therefore, their average speed is lower.

3.2.3.4 Retail Revenues

Studies suggest that the mode of transport and commuting speed have an impact on retail spending. For instance, walking is associated with higher retail spending. If the walkability of an area improves, people tend to spend more time—and money—in that area (Rabl & Nazelle, 2012; Victoria Transport Policy Institute [VTPI], 2018). In this SAVi assessment, there will be additional walking time of 10 min/person/day (Carrigan et al., 2013). It is assumed that the number of trips per person per day will increase over time, with an average annual growth of 1.5%, based on the historical changes in trips per day and population (Bogota City Hall, 2019).

Additional retail sales are calculated based on the assumption that there is increased spending per additional trip that is shifted to the public transport systems, excluding the walking or cycling trips that were already taking place before these systems were implemented. The additional retail spending volume is based on the additional number of daily walking trips that occur as a result of the public transport systems. The number of trips is then multiplied by the average yearly retail spending in Bogota, which is COP 5,365,161 per person/year (BBVA, 2019), and the difference in spending that occurs when people are walking as opposed to when they are using any other means of transportation, which is approximately 42.2% higher (Rabl & Nazelle, 2012). The results show the total additional daily retail spending caused by improved walkability.

Lastly, while the public transport systems will increase retail revenues around their infrastructure, there will likely be a shift of retail spending from other areas in Bogota to areas with MRT and BRT infrastructure. However, there is a stronger economic multiplier, as smaller shops near MRT and BRT infrastructure will increase their retail revenues, which, coupled with reductions in vehicle and energy use, will contribute to the city's vibrancy.

3.2.3.5 Property Value

The implementation of the BRT and NMT systems and the future implementation of the MRT system will affect property prices in the areas where they will operate. Specifically, the real estate value of the properties surrounding the MRT and BRT stations will increase due to improved connectivity and walkability to stations. Research has shown that property values can increase from 5% to 15% as a result of newly constructed public transportation stations (Buchanan, 2007; Song & Knaap, 2003; VTPI, 2018). The scale of increase depends on both the degree of improved walkability and perceived improvements in safety.

The average property value per square metre in Bogota is COP 4,166,666 per m^2 (Habimeter, 2022). The total property value increase is estimated by multiplying the average property price per m^2 with the estimated cumulative area impacted by the public transport systems in square metres. This, in turn, is multiplied by the increased value of property due to improved walkability, which is assumed to be 5% for the lower-end valuation scenario and 10% for the higher-end valuation scenario. The results represent the total one-time increase in property values in the area affected by the public transport systems. The potential increase in property value is forecasted based on the direct impacts of the investment assessed. City-wide dynamics are not considered in the assessment.

3.2.4 AVOIDED COSTS

3.2.4.1 CO_2 Emissions

The replacement of road and fossil fuel-based transport modes by public transport systems is accompanied by a reduction of the transport sector's CO_2 emissions. The social cost of carbon (SCC) represents the economic cost of an additional ton of CO_2 or its equivalent (CO_2e). It can be regarded as the discounted value of economic welfare from an additional unit of CO_2 emissions. The SCC per kg of CO_2 is based on Nordhaus (2017) and amounts to 31 USD per ton of CO_2.[2] In this SAVi assessment, the SCC is multiplied by CO_2 emission values per transport mode (Sharma et al., 2014) as indicated in Table 8, which, in turn, is multiplied by the total avoided emission costs as a result of implementing the MRT, BRT, and NMT systems.

Table 8. CO_2 emission factor for Bogota per transport mode (based on Delhi values)

Emission factors	CO_2 (in g/km)
Bus, BRT	806.5
Car	134
Gasoline	*115*
Diesel	*153*
Motorcycle	24.4
Cycle	0
Walk	0
MRT	0
Valuation of emissions	
SCC	0.031
SCC in COP	116.07

Source: Authors' calculations.

[2] Values for the SCC for India can vary among studies. Nordhaus (2017) proposes a value for India of USD 2.93 per ton of CO_2, while for Ricke et al. (2017) the country-level SCC for India is USD 86 per tonne of CO_2. The approach taken was to use the global value of USD 31 per ton of CO_2 because it is close to the average of the two values mentioned.

3.2.4.2 Fuel Use

The shift of transport users to the MRT, BRT, and NMT systems will lead to a reduction in road transport and, hence, a reduction in fuel consumption. The number of trips by transport mode per v-km that have been shifted to the public transport systems is used to estimate the total amount of fuel saved through the shift. The average annual mileage by transport mode in km and the fuel efficiency by transport mode in km per litre are included in the calculation (Goel et al., 2016). A weighted average value is used based on fuel shares of diesel, petrol, and liquified petroleum gas (LPG) in Colombia (UPME, 2019). Where local data were not available, fuel per km values from case studies of SAVi assessments in India are used. The amount of fuel saved as a result of the shift to the public transport systems is multiplied by the price per litre of fuel in Colombia (Trading Economics, 2022). Information on fuel prices and types, transport modes, and case studies used is summarized in Table 9.

Table 9. Fuel prices per fuel type, mode, and case study used

Fuels shares in the transport sector in Colombia	Unit	Fuel shares
Diesel	%	47%
Petrol	%	48%
LPG	%	5%
Fuel use per km	**Unit**	**Fuel use**
Rajkot case study		
Diesel cars (all engine sizes)	ltr/km	0.074
Petrol cars	ltr/km	0.063
Petrol motorized two-wheelers	ltr/km	0.019
Diesel three-wheelers	ltr/km	0.042
Visakhapatnam case study		
Diesel cars (all engine sizes)	ltr/km	0.062
Petrol cars (all engine sizes)	ltr/km	0.067
Petrol motorized two-wheelers	ltr/km	0.021
Diesel three-wheelers	ltr/km	0.034

Fuels shares in the transport sector in Colombia	Unit	Fuel shares
Weighted average		
Diesel + petrol cars	ltr/km	0.066
Petrol motorized two wheelers (MTW)s	ltr/km	0.020
Average cars + MTWs	*ltr/km*	*0.043*
Diesel three-wheelers	ltr/km	0.038
Fuel prices		
Petrol (2021 Bogota prices)	COP/ltr	2,337

Source: Authors' calculations, based on Goel et al., 2016; Trading Economics, 2022; UPME, 2019.

3.2.4.3 Accidents

The shift from motorized transport modes to public transport systems will lead to a reduction in the number of traffic accidents. The valuation of traffic accidents is estimated using the number of accidents per v-km, which is calculated based on the annual v-km in Bogota and the annual number of accidents per severity (Observatorio de Movilidad de Bogota, 2022; Pachon, 2015) for the year 2010. Three degrees of accident severity are considered: fatal injuries, injuries, and car damage. The share of accidents per severity type in Bogota is then calculated and multiplied by the cost of accidents per severity in Colombia (Fasecolda, 2018).

The annual accident rates in Bogota prior to the implementation of the MRT, BRT, and NMT systems per accident severity are shown in Table 10, below. Annual accident rates following the implementation of the public transport systems are estimated based on changing accident risk levels. The number of accidents is assumed to decrease if the motorized road transport v-km is reduced.

Table 10. Annual accident rates in Bogota prior to the implementation of the public transport systems, in accidents/1,000 v-km

Type of accident severity	Accidents in Bogota (BAU)
Fatal injuries	0.00008
Injuries	0.00192
Car damages	0.00348
Total	0.00548

Source: Authors' calculations.

The next step in valuing the reduced accident costs is to estimate the economic value per accident, depending on accident severity. The cost per accident is calculated for all accident types, and there is a low-value and high-value estimation, as indicated in Table 11 (Fasecolda, 2018). Cost per accident values have changed between 2010 and 2016, as shown in the table. It is assumed that values stay the same from 2016 onwards.

The indicators considered for the cost valuation are human capital costs (consumption loss), resource costs (damages, administrative costs, medical costs) considered as public costs, and human suffering costs, considered as private costs.

Table 11. Valuation of accidents per accident severity, in COP/accident

Cost of accidents (all severity types)	Cost per accident (2010)	Cost per accident (2016)
Cost per accident (low value)	9,610,418	18,403,681
Cost per accident (high value)	16,818,231	28,805,761

Source: Authors' calculations, based on Fasecolda, 2018.

3.2.4.4 Noise Pollution

Noise emissions from various transport modes can cause negative health effects to humans exposed to the noise. These are usually stress-related health effects like hypertension and myocardial infarction (heart attacks) (Ricardo-AEA et al., 2014). The calculation of the cost of noise pollution follows a bottom-up approach that considers the number of people exposed to noise and the total cost of noise pollution. The latter is calculated by multiplying the cost of noise per person exposed by the total amount of people exposed. Finally, weighting factors are applied to account for differences in noise characteristics between different modes of transportation (van Essen et al., 2011).

In the SAVi assessment of the Sustainable Transport Strategy in Bogota, the avoided cost of noise pollution is estimated based on the replacement of individual transport modes with public transport systems, such as the MRT, BRT, and NMT systems, which are characterized by less noise. The total value is estimated based on the reduced noise emissions per v-km per transport mode (see Table 12) being replaced by public transport systems. The SAVi assessment also considers different noise costs per transport mode, influenced by peak and off-peak travel times.

Table 12. Noise cost per v-km by transport mode

Noise cost per v-km	Unit	in EUR	in COP
Bus and BRT	value/v-km	0.0016	7.0818
Car	value/v-km	0.0017	7.5244
Motorcycle	value/v-km	0.0144	63.7363
Cycle	value/v-km	0.0000	0.0000
Walk	value/v-km	0.0000	0.0000
Other & trucks	value/v-km	0.0063	27.8846
MRT	value/v-km	0.0012	5.3114
Railway	value/v-km	0.0010	4.4261

Source: Authors' calculations.

4.0 Results

This section describes the results of the SAVi Assessment of the Sustainable Transport Strategy in Bogota. It begins by presenting two CBA tables. The first, shown in Table 13, includes values that are discounted using different discount rates across both current and future scenarios (see Table 5 in Section 3.1). The second, shown in Table 14, includes values that are discounted at 3.5% alone. They are both integrated CBAs because, in addition to the Sustainable Transport Strategy's conventional investment costs (capital and O&M costs) and revenues, the valued economic, social, and environmental added benefits and avoided costs are integrated into the analysis.

The second part of this section examines the different parts of the integrated CBA independently, differentiating between the conventional project investment costs and revenues and the valued economic, social, and environmental added benefits and avoided costs. This section also examines and compares the benefit-cost ratios (BCRs) of the conventional project finance analysis with the sustainable benefit-cost ratios (S-BCR) of the integrated analysis in order to demonstrate the importance of integrating the multiple added benefits and avoided costs. Finally, the valuation results for the investment costs, revenues, and added benefits and avoided costs of the two sustainable transport scenarios are described independently in the last section.

4.1 Integrated Cost-Benefit Analysis

Table 13. Integrated CBA discounted using different discount rates tangible and intangible indicators (see Table 5 in Section 3.1), in COP billion

	Sustainable transport scenarios			
	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Integrated CBA	Low estimate	High estimate	Low estimate	High estimate
Total investment costs	**4,486**	**4,486**	**12,868**	**12,868**
Capital cost of the MRT system	**0**	**0**	**4,458**	**4,458**
O&M costs of the MRT system	0	0	3,412	3,412
Capital cost of the BRT system	3,822	3,822	3,822	3,822
O&M costs of the BRT system	423	423	936	936
Capital cost of the NMT system	241	241	241	241

	Sustainable transport scenarios			
	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Integrated CBA	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
O&M costs of the NMT system	0	0	0	0
Total revenues	**1,300**	**1,300**	**7,524**	**7,524**
Revenues from MRT use	0	0	3,282	3,282
Revenues from BRT use	1,300	1,300	4,242	4,242
Total added benefits	**23,752**	**25,203**	**46,899**	**36,380**
Income creation from employment*	571	577	1,398	1,405
Health impacts*	3,778	6,868	10,673	23,134
Value of time saved*	-1,166	-11,656	-3,587	-35,866
Retail revenues	11,725	11,725	29,124	29,124
Property prices*	8,844	17,688	9,291	18,583
Total avoided costs	**797**	**933**	**4,077**	**5,154**
CO_2 emissions	226	226	1,041	1,041
Fuel use	319	319	997	997
Accidents*	235	371	1,900	2,978
Noise pollution	17	17	138	138
Cumulative net benefits (discounted)	**21,551**	**23,138**	**45,821**	**36,379**
BCR	0.3	0.3	0.6	0.6
Sustainable BCR (S-BCR)	**5.8**	**6.1**	**4.5**	**3.8**

Source: Authors' calculations.

* Indicates where a different discount rate has been used for intangible indicators.

Table 14. Integrated CBA using the discount rate of 3.5% for all indicators, in COP billion

	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
	Low estimate	**High estimate**	**Low estimate**	**High estimate**
Total investment costs	**4,735**	**4,735**	**26,175**	**26,175**
Capital cost of the MRT system	0	0	7,939	7,939
O&M costs of the MRT system	0	0	12,021	12,021
Capital cost of the BRT system	3,912	3,912	3,912	3,912
O&M costs of the BRT system	547	547	2,027	2,027
Capital cost of the NMT system	275	275	275	275
O&M costs of the NMT system	0	0	0	0
Total revenues	**1,706**	**1,706**	**25,057**	**25,057**
Revenues from MRT use	0	0	13,235	13,235
Revenues from BRT use	1,706	1,706	11,822	11,822
Total added benefits	**28,429**	**31,045**	**88,120**	**79,115**
Income creation from employment*	676	683	2,566	2,572
Health impacts*	3,778	6,868	10,673	23,134
Value of time saved*	-1,166	-11,656	-3,587	-35,866
Retail revenues	15,132	15,132	67,663	67,663
Property prices*	10,009	20,018	10,805	21,610
Total avoided costs	**891**	**1,028**	**5,632**	**6,709**

	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
	Low estimate	High estimate	Low estimate	High estimate
CO_2 emissions	226	226	1,041	1,041
Fuel use	413	413	2,552	2,552
Accidents*	235	371	1,900	2,978
Noise pollution*	17	17	138	138
Cumulative net benefits (discounted)	**26,292**	**29,045**	**92,635**	**84,707**
BCR	0.4	0.4	1.0	1.0
S-BCR	**6.6**	**7.1**	**4.5**	**4.2**

Source: Authors' calculations.

* Indicates the variables for which the discount rate has not been changed.

An integrated analysis, as demonstrated in Tables 13 and 14, provides a more systemic and comprehensive view for assessing the different sustainable transport scenarios in Bogota. The analysis clearly identifies the extent to which the current and future sustainable transport scenarios generate benefits from an economic and a societal perspective. This is because the integrated CBA considers both conventional costs and revenues found in traditional transport infrastructure assessments as well as added benefits and avoided costs. Each sustainable transport scenario uses a different project time period: the current sustainable transport scenario evaluates public transport systems in Bogota (from 2010 to 2022), and the future sustainable transport scenario assesses the existing and future public transport systems (from 2010 to 2058).

According to the SAVi assessment of the Sustainable Transport Strategy in Bogota, the cumulative undiscounted benefits of the current sustainable transport scenario amount to COP 34,798 billion in the low estimate and COP 36,965 billion in the high estimate. Furthermore, the low estimate of the future sustainable transport scenario yields cumulative benefits of COP 235,748 billion, and the high estimate of the same scenario yields cumulative benefits of COP 211,295 billion. The BCR of the low and high estimates of the current sustainable transport scenario is 8.2 and 8.6, respectively. Similarly, the BCR of the low estimate of the future sustainable transport scenario is 5.1, and the BCR of the high estimate of the same scenario is 4.6. The undiscounted net results of the Sustainable Transport Strategy across both sustainable transport scenarios can be found in Appendix C.

Once a discount factor is applied to future costs and benefits, the SAVi net results are naturally lower. In this section, two integrated CBAs are presented. Table 13 provides an integrated CBA analysis, which includes different discount factors. More information on the discount factors used per time period can be found in Table 5. In this integrated CBA, different discount factors have been applied to the conventional investment costs and revenues as well as to tangible added benefits and avoided costs, such as income creation from employment, retail revenues, property prices, and fuel use. The different discount factors applied were estimated by considering the historical inflation rate changes over time in Colombia, which is based on parameters such as economic growth, the impacts of COVID-19, and the 10-year yields on government bonds in the country. The higher discount rate is also used to compensate for country risk specificities associated with investing in Colombia. For the social and environmental indicators of the assessment (i.e., the intangible added benefits and avoided costs such as health impacts, value of time saved, CO_2 emissions, accidents, and noise pollution), the lower discount rate of 3.5% is applied (UK Government, 2022).

Table 14 shows an integrated CBA, which applies only the discount rate of 3.5% to all economic, social, and environmental indicators of this assessment, including investment and costs, revenues, added benefits, and avoided costs, as per the Green Book guidance (UK Government, 2022). Using a lower discount rate across all indicators in the SAVi analysis and assigning a higher value to the benefits that the Sustainable Transport Strategy in Bogota can have in the future aims to emphasize the importance of addressing climate change impacts, which are likely to worsen in the coming decades. In other words, a lower discount rate aims to give a higher value to the future impacts of the project. Given that the positive impacts of the sustainable transport scenarios outweigh the negative impacts, it is expected that with a lower discount rate, their economic performance will improve over time.

This SAVi analysis will elaborate on the results of the Sustainable Transport Strategy in Bogota that are discounted using the different discount rates shown in Table 13. Following the application of the different discount rates, the low and high estimates of the current sustainable transport scenario amount to COP 21,363 billion and COP 22,950 billion, respectively. Additionally, the low estimate of the future sustainable transport scenario amounts to COP 45,632 billion, and the high estimate of the same scenario shows values of COP 36,190 billion.

The next subsections will examine the different parts of the integrated CBA independently, differentiating between the conventional project investment costs and revenues and the valued economic, social, and environmental added benefits and avoided costs.

4.2 Summary of Investment Costs and Benefit-Cost Ratios

The SAVi assessment of the Sustainable Transport Strategy in Bogota starts with the conventional investment costs and revenues. As shown in the first part of the integrated CBA in Table 13, the investment costs—including capital and O&M expenditures—and revenues are always incorporated in a conventional transport infrastructure assessment. Table 15 displays only the capital expenditures, the O&M costs, and the revenues of the public transport systems in Bogota for both sustainable transport scenarios.

Table 15. Capital, O&M costs, and revenues of the sustainable transport scenarios, in COP billion

CBA	Current sustainable transport scenario (2010–2022)	Future sustainable transport scenario (2010–2058)
Investment and costs	**4,486**	**12,868**
Capital cost of the MRT system	0	4,458
O&M costs of the MRT system	0	3,412
Capital cost of the BRT system	3,822	3,822
O&M costs of the BRT system	423	936
Capital cost of the NMT system	241	241
O&M costs of the NMT system	0	0
Revenues	**1,300**	**7,524**
Revenues from MRT use	0	3,282
Revenues from BRT use	1,300	4,242

Source: Authors' calculations.

Furthermore, two different BCRs have been calculated, the conventional BCR and the S-BCR. The BCR determines the overall value for money of a project. It illustrates the return for every unit (in COP) invested by comparing the project's total benefits with the total costs. The BCR is based on estimations of only tangible parameters and includes capital costs, O&M costs, and revenues. The S-BCR considers the project from a societal point of view and is based on an estimation of the full range of economic, social, and environmental added benefits and avoided costs. As indicated in Table 16, the conventional BCR leads to a significantly lower BCR than the S-BCR. The next subsection examines the valuation of the added benefits and avoided costs in more detail.

Table 16. Conventional BCR vs S-BCR (discounted using different discount rates)

	BCR				**S-BCR**			
Parameters considered	Investment costs, revenues				Investment costs, revenues, full range of economic, social, and environmental added benefits and avoided costs			
Scenario	Current		Future		Current		Future	
	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate
BCR	0.3	0.3	0.6	0.6	5.8	6.1	4.5	3.8

Source: Authors' calculations.

4.3 Summary of Added Benefits and Avoided Costs

The SAVi assessment of the Sustainable Transport Strategy in Bogota calculates monetary values for a range of added benefits and avoided costs, arising from the use of different public transport systems in the two sustainable transport scenarios. Table 17 shows the cumulative monetary values of the added benefits and the avoided costs for both scenarios. A high-valuation and a low-valuation estimate are presented for some added benefits and avoided costs (shown with an asterisk in Tables 13, 14, and 17) where literature and available data showed diverging figures to arrive at a customized and appropriate monetary valuation. For instance, the increase in property values resulting from improved walkability caused by the increased use of public transport systems in Bogota, is considered as a one-time increase.

The discounted net benefits of the added benefits and avoided costs of the low estimate and the high estimate of the current sustainable transport scenario amount to COP 24,549 billion and COP 26,136 billion, respectively. In addition, the low estimate of the future sustainable transport scenario shows values of COP 50,976 billion and the high estimate of the same scenario amounts to COP 41,534 billion. For each value-added benefit or avoided cost, the table shows which stakeholders are the most relevant (government, households, and/or the private sector) and whether social, environmental, or economic indicators are the most suitable. In the next section, the valuation results for each added benefit and avoided cost are demonstrated in more detail.

Table 17. Value-added benefits and avoided costs of the sustainable transport scenarios (discounted using different discount rates), in COP billion

Integrated CBA	Sustainable transport scenarios				Stakeholder of relevance (G, H, P)**	Social, environmental, economic
	Current (2010–2022)		Future (2010–2058)			
	Low estimate	High estimate	Low estimate	High estimate		
Total added benefits	**23,751**	**25,203**	**46,899**	**36,380**		
Income creation from employment*	570	577	1,398	1,404	G, H	Economic
Health impacts*	3,778	6,868	10,673	23,134	G, H	Social
Value of time saved*	-1,166	-11,656	-3,587	-35,866	H, P	Economic
Retail revenues	11,725	11,725	29,124	29,124	H, P	Economic
Property prices*	8,844	17,688	9,291	18,583	G, P, H	Economic
Total avoided costs	**797**	**933**	**4,077**	**5,154**		
CO_2 emissions	226	226	1,041	1,041	H	Environmental
Fuel use	319	319	997	997	H	Economic
Accidents*	235	371	1,900	2,978	H	Social
Noise pollution	17	17	138	138	H	Social
Cumulative net benefits (discounted)	**24,549**	**26,136**	**50,976**	**41,534**		

Source: Authors' calculations.

* Indicates where high-valuation and low-valuation estimates have been used to arrive at a customized and appropriate monetary valuation.

** G = government, H = households, P = private sector

4.4 Valuation Results for Investment and Costs, Revenues, Added Benefits, and Avoided Costs

4.4.1 INVESTMENT AND COSTS

4.4.1.1 Capital and O&M Costs of the MRT System

The SAVi assessment of the Sustainable Transport Strategy in Bogota considers the investment and O&M costs of the three different public transport systems assessed. For the MRT system, which is currently under construction and is expected to be operational in 2028, the capital costs are estimated using the construction rate and the cost per km of MRT lines. The MRT system's O&M costs are estimated using the number of MRT wagons and cost per wagon-km. Table 18 shows cumulative discounted values of the capital and O&M costs of the MRT system for the future sustainable transport scenario (2010–2058). The current sustainable transport scenario (2010–2022) does not consider the MRT system, which is currently under construction.

Table 18. Cumulative values of capital and O&M costs of the MRT system (discounted at 8%), in COP billion

	Future sustainable transport scenario (2010–2058)
Scenarios	**Both estimates**
Total capital and O&M costs of the MRT system	7,869
Capital costs	4,458
O&M costs	3,412

Source: Authors' calculations.

4.4.1.2 Capital and O&M Costs of the TransMilenio BRT System

The TransMilenio BRT system in Bogota is currently the largest public transport system in the city, serving approximately 2.3 million people daily. Similar to the MRT system, capital costs of the TransMilenio BRT system in Bogota are estimated using the construction rate and cost per km of BRT lanes. The calculation of the O&M costs of the BRT system considers v-km per year and cost per v-km. Table 19 shows cumulative discounted values of the capital and O&M costs of the BRT system across the current and future sustainable transport scenarios.

Table 19. Cumulative values of capital and O&M costs of the BRT system (discounted at 6%, 6.5%, 7%, 7.5%, and 8% for different years), in COP billion

	Current sustainable transport scenario (2010–2022)	**Future sustainable transport scenario (2010–2058)**
Scenarios	**Both estimates**	**Both estimates**
Total capital and O&M costs of the BRT system	4,245	4,758
Capital costs	3,822	3,822
O&M costs	423	936

Source: Authors' calculations.

4.4.1.3 Capital and O&M Costs of NMT Infrastructure

NMT infrastructure in Bogota includes walking and cycling lanes and parking spaces for cyclists. NMT infrastructure has been increasing steadily in the city over the last decade. The estimation of the capital costs of NMT infrastructure in Bogota also considers the construction rate and cost per km of NMT. Table 20 shows cumulative discounted values of the capital costs of NMT infrastructure across the two sustainable transport scenarios. NMT systems usually have negligible O&M costs; therefore, the O&M costs of NMT infrastructure in this SAVi assessment are assumed to be zero.

Table 20. Cumulative values of capital and O&M costs of NMT infrastructure (discounted at 6%, 6.5%, 7%, 7.5%, and 8% for different years), in COP billion

		Current sustainable transport scenario (2010–2022)	**Future sustainable transport scenario (2010–2058)**
Scenarios	**Unit**	**Both estimates**	**Both estimates**
Total capital and O&M costs of NMT infrastructure	**COP billion**	**241**	**241**
Capital costs	COP billion	241	241
O&M costs	COP billion	0	0

Source: Authors' calculations.

4.4.2 REVENUES

4.4.2.1 Revenues From MRT Use

The implementation of the MRT system in Bogota will lead to increased revenues through the purchase of MRT tickets by MRT users. Average MRT ticket prices in the future are estimated using the yearly increase in ticket prices of the TransMilenio BRT system in Bogota over the last decade. Demand projections of yearly MRT trips are also considered in the calculation, based on current travel habits, population, and current daily trips. The MRT demand projections after the first year of operation of the MRT system (2028), increase gradually up to 8% until 2030, from which point onward they stay the same.

Table 21 shows the cumulative discounted values of the revenues from the use of the MRT system for the future sustainable transport scenario, which amount to COP 3,282 billion for both low and high estimates. The current sustainable transport scenario does not consider the MRT system, which is currently under construction.

Table 21. Cumulative values of revenues from MRT use (discounted at 8%), in COP billion

	Future sustainable transport scenario (2010–2058)
Scenarios	**Both estimates**
Revenues from MRT use	3,282

Source: Authors' calculations.

4.4.2.2 Revenues From TransMilenio BRT Use

Revenues from the use of the TransMilenio BRT system in Bogota represent the revenues from the purchase of BRT tickets by BRT users. Revenues from the use of the BRT system are estimated using BRT trips per year, trips per person in Bogota, and ticket prices. Changes in BRT trip share over the years are also taken into account. Table 22 shows the cumulative discounted values of the revenues from the use of the TransMilenio BRT system across the current and future sustainable transport scenarios, which amount to COP 1,300 billion in the former scenario and to COP 4,242 billion in the latter scenario.

Table 22. Cumulative values of revenues from TransMilenio BRT use (discounted at 6%, 6.5%, 7%, 7.5%, and 8% for different years), in COP billion

	Current sustainable transport scenario (2010–2022)	Future sustainable transport scenario (2010–2058)
Scenarios	**Both estimates**	**Both estimates**
Revenues from TransMilenio BRT use	1,300	4,242

Source: Authors' calculations.

4.4.3 ADDED BENEFITS

4.4.3.1 Income Creation From Employment

Construction and O&M of the public transport systems will lead to employment creation, which has beneficial socio-economic impacts, such as increased discretionary spending. The latter represents the amount of labour income that flows back into the economy in the form of additional consumption. This SAVi assessment values the employment creation from the MRT, BRT, and NMT public transport systems individually. First, the MRT system will lead to the creation of 28,000 construction jobs (Capital, 2019). In addition, a multiplier of 49.5 jobs per km is used for O&M jobs based on data from the Metro in Medellin. Secondly, the construction rate and construction jobs per km are used to estimate the number of construction jobs created for the TransMilenio BRT. Then, O&M cost per km data are used to calculate the O&M jobs for the BRT system. Finally, NMT jobs per km and the length of the NMT network in Bogota are used to estimate total employment generation from NMT. The cumulative discounted values of the income creation of the total amount of employment positions created for all three public transport systems across both sustainable transport scenarios are included in Table 23. They amount to COP 571 billion and COP 577 billion in the low and high estimates of the current sustainable transport scenario, respectively, and COP 1,398 billion and COP 1,405 billion in the low and high estimates of the future sustainable transport scenario, respectively.

Table 23. Cumulative values of income creation from increased employment (discounted at 6%, 6.5%, 7%, 7.5%, and 8%), in COP billion

	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Scenarios	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Income creation from employment	571	577	1,398	1,405

Source: Authors' calculations.

4.4.3.2 Health Impacts

The implementation of the MRT, BRT, and NMT systems in Bogota will lead to a shift from motorized transport modes to public transport systems and, therefore, will deliver significant health benefits. This SAVi assessment values and aggregates three different health impacts under this category: (i) health benefits from increased physical activity, (ii) health costs of air pollution, and (iii) health costs from increased exposure to air pollution. The total cumulative net health benefits are shown in Table 24 and amount to COP 3,778 billion and COP 6,868 billion in the low and high estimates of the current sustainable transport scenario, respectively, and COP 10,673 billion and COP 23,134 billion in the low and high estimates of the future sustainable transport scenario, respectively.

Primarily, the three public transport systems lead to increased levels of physical activity as public transport users spend additional time walking to and from MRT and BRT stations in Bogota and NMT users spend additional time cycling or walking by default. The additional daily minutes walked and the reduction in the relative risk of mortality using the VSL are considered in the estimation of the health benefits from increased physical activity. The total health benefits from increased physical activity in the current sustainable transport scenario amount to COP 3,818 billion and in the future sustainable transport scenario, they amount to COP 10,776 billion. In the case of the MRT system that is under construction, these benefits only emerge after the construction period, once the MRT is in operation.

In addition, the shift of transport users from motorized, fuel-based transport modes to public transport systems will reduce the number of vehicles on the road and thus reduce air pollution levels. The avoided cost of air pollution is estimated based on each transport mode's air pollutants and the health costs associated with emitting 1 kg of a specific air pollutant. More details on the health cost assumptions of air pollutants per different transport modes are indicated in Table 7. The use of a low- and a high-value estimate for the health cost of the pollutant $PM_{2.5}$ in the analysis is based on a study conducted for Indian cities (Rahul et al., 2013). Avoided costs of air pollution for the current sustainable transport scenario amount to COP 466 billion in the low estimate and COP 3,557 billion in the high estimate; for the future sustainable transport scenario, they amount to COP 1,878 billion in the low estimate and COP 14,340 billion in the high estimate.

Lastly, the negative health effects of air pollution ($PM_{2.5}$) are increased for MRT, BRT, and NMT users, who spend more time walking in urban environments with high background concentrations of air pollutants. This is the case because the pollutant dose increases for people who walk or cycle due to direct exposure in traffic and higher inhalation rate during physical activity as opposed to sitting in vehicles (Rabl & Nazelle, 2012). These negative health effects caused by $PM_{2.5}$, with respect to all-cause mortality, are considered in this SAVi assessment. As increased exposure to air pollution is considered as an additional cost compared to the baseline (and hence a cost resulting from using the public transport systems), values showing this cost are negative. The results in the current sustainable transport scenario amount to COP -506 billion, and the results in the current sustainable transport scenario amount to COP -1,982 billion. All of the above results are summarized in Table 24.

Table 24. Cumulative values of health impacts (discounted at 3.5%), in COP billion

	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Scenarios	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Total health impacts	**3,778**	**6,868**	**10,673**	**23,134**
Benefits from increased physical activity	3,818	3,818	10,776	10,776
Costs of air pollution	466	3,557	1,878	14,340
Costs from increased exposure to air pollution	-506	-506	-1,982	-1,982

Source: Authors' calculations.

4.4.3.3 Value of Time Saved

The value of time saved represents the economic value of improved mobility resulting from the MRT, BRT, and NMT systems. Because the shift from other transport modes to these public transport systems will result in differing travel speeds, it will lead to either time savings or additional time spent commuting. The value of time in this SAVi assessment is estimated based on average speeds of different transport modes, the hourly salary of commuters, and the value of the hourly time saved. The assumption used is that the average speed of walking is 5 km/h. Even if a car is in traffic, its average speed is around 15 km/h. On the other hand, the public transport systems, such as the MRT, reduce the time of travel. However, in this case it does not reduce the time of travel enough to fully offset the time lost by increased walking and cycling; therefore, the value of time saved is negative across all estimates and scenarios.

The cumulative value of time saved is COP -1,166 billion and COP -11,656 billion in the low and high estimates of the current sustainable transport scenario, respectively, and COP -3,587 billion and COP -35,866 billion, for the low and high estimates of the future sustainable transport scenario. These results are summarized in Table 25.

Table 25. Cumulative values of time saved due to improved mobility (discounted at 3.5%), in COP billion

		Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Scenarios	**Unit**	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Value of time saved	COP billion	-1,166	-11,656	-3,587	-35,866

Source: Authors' calculations.

4.4.3.4 Retail Revenues

The shift from motorized transport to the three public transport systems will result in additional time spent walking to and from MRT and BRT stations and additional time spent walking and cycling as a result of NMT infrastructure. Increased walkability is associated with higher retail spending because as the walkability of an area improves, people tend to spend more time and money in the area (Rabl & Nazelle, 2012; VTPI, 2018). Therefore, the increased walkability of MRT, BRT, and NMT users in retail establishments located near public transport infrastructure implies higher retail spending for those users. The additional number of daily walking trips and the average yearly retail spending in Bogota are considered in the calculation. As shown in Table 26, the cumulative increase in retail revenues due to additional retail spending expected from public transport users in Bogota amounts to COP 11,725 billion in the current sustainable transport scenario and COP 29,124 billion in the future sustainable transport scenario.

Table 26. Cumulative values of additional retail spending (discounted at 6%, 6.5%, 7%, 7.5%, and 8%), in COP billion

	Current sustainable transport scenario (2010–2022)	Future sustainable transport scenario (2010–2058)
Scenarios	**Both estimates**	**Both estimates**
Retail revenues	11,725	29,124

Source: Authors' calculations.

4.4.3.5 Property Value

The implementation of the three public transport systems will affect property prices in the areas where they will operate. Because of increased connectivity and walkability toward the stations, the real estate value of the properties surrounding MRT and BRT stations and NMT infrastructure will increase. To calculate the potential increase in the real estate values of the properties surrounding the public transport stations, the average property value per square metre in Bogota and the total area impacted were considered. In addition, the increased value of property prices according to literature indicates a potential increase of between 5% and 15% (Buchanan, 2007; Song & Knaap, 2003; VTPI, 2018). In this SAVi assessment, a 5% increase in property prices is assumed for the low estimate and a 10% increase in property prices is assumed for the high estimate of both sustainable transport scenarios; the final results represent the total one-time increase in property values in the area affected by the public transport systems. As Table 27 indicates, the cumulative net benefits of increases in property value as a result of the MRT, BRT, and NMT systems amount to COP 8,844 billion in the low estimate and COP 17,688 billion in the high estimate of the current sustainable transport scenario, and COP 9,291 billion and COP 18,583 billion in the low and high estimates of the future sustainable transport scenario, respectively.

Table 27. Cumulative property value increase (discounted at 6%, 6.5%, 7%, 7.5%, and 8%), in COP billion

		Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Scenarios	**Unit**	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Property value	COP billion	8,844	17,688	9,291	18,583

Source: Authors' calculations.

4.4.4 AVOIDED COSTS

4.4.4.1 CO_2 Emissions

The shift of users to the MRT, BRT, and NMT systems and away from road, fossil fuel-based transport modes will lead to a reduction of the transport sector's CO_2 emissions in Bogota. The calculation of the avoided costs of CO_2 emissions is based on the amount of carbon per kg of CO_2 (Nordhaus, 2017). According to the SAVi model, the cumulative discounted avoided costs of CO_2 emissions in the current sustainable transport scenario amount to COP 226 billion and, in the future sustainable transport scenario, they are valued at COP 1,041 billion. The results are summarized in Table 28.

Table 28. Cumulative values of avoided CO_2 emissions costs (discounted at 3.5%), in COP billion

	Current sustainable transport scenario (2010–2022)	Future sustainable transport scenario (2010–2058)
Scenarios	**Both estimates**	**Both estimates**
CO_2 emissions	226	1,041

Source: Authors' calculations.

4.4.4.2 Fuel Use

The shift of transport users to the MRT, BRT, and NMT systems will lead to a reduction in use of road transport. This will result in a reduction of fuel consumption, which is used to estimate the avoided costs of fuel use in this SAVi assessment. To estimate the total avoided costs of fuel use, the following are considered: each transport mode's number of trips shifted, average annual mileage and fuel efficiency, and the price of fuel in Colombia. For the latter, a weighted average value is used, based on fuel shares of diesel, petrol, and LPG in Bogota. As Table 29 demonstrates, the avoided costs of fuel use in the current sustainable transport scenario amount to COP 319 billion, and in the future sustainable transport scenario, they amount to COP 997 billion.

Table 29. Cumulative values of avoided fuel costs (discounted at 3.5%), in COP billion

	Current sustainable transport scenario (2010–2022)	Future sustainable transport scenario (2010–2058)
Scenarios	**Both estimates**	**Both estimates**
Fuel use	319	997

Source: Authors' calculations.

4.4.4.3 Accidents

The shift from motorized transport modes to the public transport systems will lead to a reduction of vehicles circulating on the roads of Bogota and, therefore, to a reduction in the number of traffic accidents. The avoided costs of accidents in this SAVi assessment are estimated using the number of accidents per v-km in Bogota and the annual number of accidents per severity. The latter includes three different categories: fatal injuries, injuries, and car damages. Annual accident rates following the implementation of the MRT, BRT, and NMT systems are estimated based on changing accident risk levels and the economic value per accident, depending on accident severity. The cumulative values of the avoided costs of accidents in the current sustainable transport scenario are COP 235 billion and COP 371 billion, in the low and high estimates, respectively. Similarly, in the future sustainable transport scenario, the low estimate amounts to COP 1,900 billion and the high estimate to COP 2,978 billion. The results are summarized in Table 30.

Table 30. Cumulative values of avoided accident costs (discounted at 3.5%), in COP billion

	Current sustainable transport scenario (2010–2022)		Future sustainable transport scenario (2010–2058)	
Scenarios	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Accidents	235	371	1,900	2,978

Source: Authors' calculations.

4.4.4.4 Noise Pollution

Noise emissions from various transport modes can have negative health effects on humans, mostly related to stress, including hypertension and myocardial infraction (heart attacks) (Ricardo-AEA et al., 2014). The shift from motorized transport modes to the MRT, BRT, and NMT systems will lead to a reduction of vehicles and, therefore, to a reduction of noise pollution. To estimate the avoided costs of noise pollution, the following are considered: number of people exposed to noise, total cost of noise pollution, and noise characteristics of different modes of transport. As shown in Table 31, the avoided costs of noise pollution for both low and high estimates in the current sustainable transport scenario amount to COP 17 billion, while in the future sustainable transport scenario they are valued at COP 138 billion.

Table 31. Cumulative values of avoided noise pollution costs (discounted at 3.5%), in COP billion

	Current sustainable transport scenario (2010–2022)	Future sustainable transport scenario (2010–2058)
Scenarios	**Both estimates**	**Both estimates**
Noise pollution	17	138

Source: Authors' calculations.

5.0 Discussion and Conclusions

This SAVi assessment shows that the benefits arising from the three public transport systems in Bogota are considerably higher when the value-added benefits and avoided costs are integrated into the CBA. This is shown by the comparison of the conventional BCR, which is established using only the parameters used in conventional transport assessment (e.g., the different transport systems' investment costs and revenues) and the S-BCR, which includes the full range of economic social and environmental benefits and costs.

This SAVi assessment shows that the BCR is 0.3 in both the low and the high estimate of the current sustainable transport scenario and 0.6 in the low and high estimates of the future sustainable transport scenario. On the other hand, the S-BCR is 5.8 in the low estimate of the current sustainable transport scenario and 6.1 in the high estimate of the same scenario, and 4.5 and 3.8 in the low and high estimates of the future sustainable transport scenario, respectively.

Both sustainable transport scenarios of the Sustainable Transport Strategy in Bogota yield positive results. The results also provide evidence that the economic viability of the MRT, BRT, and NMT systems in Bogota increases significantly when the multiple environmental, social, economic added benefits, and avoided costs are considered.

Overall, the MRT, BRT, and NMT public transport systems stimulate growth, either directly (through revenue or employment creation) or indirectly (by stimulating retail and property value increases and leading to fuel savings). Moreover, the use of public transport systems leads to significant health benefits for Bogota's residents by encouraging physical activity and reducing air pollution. Other indirect benefits include a reduction of CO_2 emissions and traffic accidents. The only negative values are found in the value of time saved, as increased cycling and walking to and from public transport stations leads to additional time spent for commuting.

Furthermore, the SAVi assessment of the Sustainable Transport Strategy in Bogota supports the city's transport objectives included in the national and regional development plans. The public transport systems improve accessibility to job opportunities for Bogota's residents, stimulates economic and business growth, and leads to positive health impacts.

The limitations of the methodology used for this SAVi assessment are related to the valuation and quantification of some qualitative indicators. While the CLD (qualitative model) can identify a wide range of impacts, not all can be quantified due to the lack of data and literature that supports their valuation, or limitations in their scope. This is the case for indicators such as GDP and labour force health quality. However, it is possible to link SAVi to another model and determine other indicators or dynamics where the feedback loops can be represented more explicitly (e.g., macroeconomic/dynamic model to estimate GDP).

The application of SAVi allows for diverse performance assessments beyond what has been applied for valuing the Sustainable Transport Strategy in Bogota and provides insights to government, citizens, and investors on the different value creation elements of public transport systems that were assessed.

This analysis can inform future sustainable mobility strategies, help make the case for better transport investments in cities, and identify sources of funding/financing that match the different financial and social returns of the project.

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Appendix A. CLD Description of the Sustainable Transport Strategy in Bogota

Reinforcing loops (R)

R1 – Transport shift dynamics: An increase in the demand for sustainable transport generates a decrease in the demand for conventional transport modes, which in turn generates an increase in the demand for sustainable transport modes. On the contrary, an increase in the demand for conventional transport generates a decrease in the demand of sustainable transport, which increases the demand for conventional transport.

R2 – Sustainable transport infrastructure driven by CO_2 emissions from the private vehicle fleet: An increase in sustainable transport infrastructure decreases the use of the private vehicle fleet, which decreases fuel use, CO_2 emissions, and air pollution, increasing labour force health quality, total factor productivity, and GDP as a consequence. An increase in GDP leads to an increase in investment in transportation and, hence, an increase in sustainable transport infrastructure.

R3 – MRT system use driven by CO_2 emissions from the Metro system: An increase in MRT use decreases the use of fossil fuels and, hence, CO_2 emissions and air pollution, which increases labour force health quality, total factor productivity, and GDP as a consequence. An increase in GDP leads to an increase in investment in transportation and, hence, sustainable transport infrastructure increases, increasing MRT use.

R4 – Sustainable transport infrastructure driven by employment from sustainable transport: An increase in sustainable transport infrastructure increases employment from transport, which increases total factor productivity and GDP. An increase in GDP increases investment in transportation, increasing sustainable transport infrastructure.

R5 – Conventional transport infrastructure driven by employment from conventional transport: An increase in conventional transport infrastructure, increases private vehicle fleet use and employment from transport, which increases total factor productivity and GDP. An increase in GDP increases investment in transportation, increasing conventional transport infrastructure.

R6 – Sustainable transport infrastructure driven by road accidents from the private vehicle fleet: An increase in sustainable transport infrastructure will decrease the use of the private vehicle fleet due to the use of public transport modes, walking, and cycling. A decrease in private vehicle fleet use generates a decrease in road accidents, which increases total factor productivity. This increases GDP, increasing investment in transport and sustainable transport Infrastructure next time around.

R7 – Sustainable transport infrastructure driven by additional physical activity: An increase in sustainable transport infrastructure generates an increase in walking and cycling, and additional walking is generated due to increased BRT and MRT use. This increases the physical activity of public transport users, increasing labour force health quality, total factor productivity, and GDP, which consequently increases investment in transportation and sustainable transport infrastructure.

R8 – Sustainable transport infrastructure driven by property value: The increase in sustainable transport infrastructure increases the value of properties surrounding public transport stations and NMT infrastructure. This increases GDP, which leads to more investment in transportation and more sustainable transport infrastructure.

R9 – Sustainable transport infrastructure driven by retail revenues: An increase in sustainable transport infrastructure increases the distance walked by public transport users, which increases retail revenues for retail establishments located near public transport stations and NMT infrastructure. This increases GDP, which leads to increased investment in transportation and, hence, increased sustainable transport infrastructure.

R10 – Sustainable transport infrastructure driven by revenues from public transport: An increase in sustainable transport infrastructure increases public transport system use and, hence, revenues from public transport systems. This increases GDP, which leads to increased investment in transportation and, hence, increased sustainable transport infrastructure.

Balancing Loops (B)

B1 – Direct effect of traffic congestion on vehicle fleet: An increase in private vehicle fleet use increases traffic congestion, leading to higher travel time and, consequently, a decrease of private vehicle fleet use.

B2 – Effect of traffic congestion on private vehicle fleet through walking and cycling: An increase in private vehicle fleet use increases traffic congestion, leading to longer travel times. A longer travel time for road transport encourages transport users to use other alternatives, such as walking and cycling, which decreases private vehicle fleet use.

B3 – Effect of traffic congestion on private vehicle fleet through public transport: An increase in private vehicle fleet use increases traffic congestion, leading to longer travel times. An increase in travel times will decrease the use of road transport and increase alternatives such as public transport (BRT and MRT), which results in a decrease in the private vehicle fleet.

B4 – Effect of CO_2 emissions and air pollution from the BRT system on sustainable transport infrastructure: An increase in sustainable transport infrastructure increases the use of the BRT system, which (because buses are not electrified) increases fuel use, CO_2 emissions, and air pollution. This generates a decrease in labour force health quality, total factor productivity, and GDP. A decrease in GDP leads to a decrease in investment in transportation, resulting in a decrease of sustainable transport investment.

B5 – Effect of CO_2 emissions and air pollution from vehicle fleet on conventional transport infrastructure: An increase in conventional transport infrastructure increases the private vehicle fleet, which increases fuel use, CO_2 emissions, and air pollution. This generates a decrease in labour force health quality, total factor productivity, and GDP. A decrease in GDP leads to a decrease in investment in transportation, resulting in a decrease in conventional transport investment.

B6 – Effect of road accidents from public transport use on sustainable transport infrastructure: An increase in sustainable transport infrastructure increases the use of public transport and accidents due to public transport operations. An increase in road accidents decreases total factor productivity and GDP, which leads to a decrease in investment in transportation, decreasing sustainable transport infrastructure.

B6 – Effect of road accidents from the private vehicle fleet on conventional transport infrastructure: An increase in conventional transport infrastructure increases the private vehicle fleet and, hence, road accidents. An increase in road accidents decreases total factor productivity and GDP, which leads to a decrease in investment in transportation, decreasing conventional transport infrastructure.

B7 – Effect of noise pollution on conventional transport infrastructure: An increase in conventional transport infrastructure increases the vehicle fleet and, hence, the amount of noise pollution, which reduces labour force health quality and total factor productivity. This, in turn, reduces GDP and, hence, investment in transportation, reducing conventional transport infrastructure.

Appendix B. System Dynamics/ Excel-Based Model

This approved methodology for infrastructure valuation is based on multistakeholder engagement techniques, the use of systems thinking, and project finance modelling to capture the life-cycle costs of environmental, social, economic, and governance risks. Moreover, SAVi calculates the monetary value of environmental, social, and economic added benefits and avoided costs that result from deploying infrastructure projects. The SAVi assessment for sustainable transport in Bogota focuses on this latter element.

This SAVi assessment uses a spreadsheet-based modelling approach that integrates data from project-specific documents, peer-reviewed research, and scientific reports to estimate infrastructure performance and related externalities. In the case of sustainable transport in Bogota, data on demand for transport, vehicle mix, and the expected reduction in v-km and passenger-km were obtained from project feasibility studies (and the project ambition in km and investments). The added benefits and avoided costs analyzed were identified in collaboration with local stakeholders. Where required, in most cases due to the presence of strong causality but lack of location-specific data, additional data sources were used to quantify variables that served to measure and monetize added benefits and avoided costs in Bogota.

The SAVi approach quantifies and monetizes the costs and benefits of the assessed infrastructure projects. For example, the cost of air pollution is estimated based on the v-km travelled and the emissions factors of air pollutants per km of various transport modes. The v-km travelled with motorized vehicles are affected by the number of people that shift to NMT, reducing system-wide air pollution, which leads to lower health costs in return. All value-added benefits and avoided costs and the results are discussed in detail in Sections 2, 3, and 4 of this report. Each added benefit and avoided cost is calculated and valued separately and contributes to estimating the net benefits of the NMT network.

It is worth noting that a causes tree does not indicate the sense of causality (i.e., direct or inverse relation) that connects two variables. This is only captured in the mathematical model through the use of specific equations. For instance, in the case of "costs of accidents," it is assumed that a shift from motorized v-km travelled to km travelled by NMT modes contributes to a reduction in accidents. This, in turn, reduces the health costs incurred from accidents. A similar causal relation is made for the cost of air pollution: the more people shift from motorized modes of transport to NMT, the higher the reduction in air emissions such as $PM_{2.5}$ or NO_x. The reduction in emissions leads to a reduction in emission-related health impacts and hence reduces health costs. Similar impacts are considered for the increased ridership of BRT and MRT.

SAVi estimates the net difference of biophysical parameters between a baseline scenario and an intervention scenario (e.g., kilogram of reduced NO_x emissions due to the use of the NMT network instead of motorized vehicles). These biophysical parameters and their changing values between scenarios are the underlying elements for determining the economic value of an added benefit and avoided cost (e.g., a reduction of health costs due to lower air pollution and fewer health implications for citizens). The valuation of added benefits and avoided costs is based on peer-reviewed scientific literature providing an economic value linked to a specific biophysical parameter. These multipliers are applied and customized to the local context to the furthest extent possible, using studies conducted in Bogota.

Appendix C. Undiscounted CBA With Undiscounted Values

Table C1. Overview of undiscounted CBA with undiscounted values, in COP billion

Integrated CBA (undiscounted)	Sustainable transport scenarios			
	Current sustainable transport scenario (2010–2021)		Current sustainable transport scenario (2022–2058)	
	Low estimate	High estimate	Low estimate	High estimate
Total investment costs	**4,847**	**4,847**	**58,128**	**58,128**
Capital cost of the MRT system	**0**	**0**	**12,820**	**12,820**
O&M costs of the MRT system	0	0	36,494	36,494
Capital cost of the BRT system	3,947	3,947	3,947	3,947
O&M costs of the BRT system	731	731	4,699	4,699
Capital cost of the NMT system	168	168	168	168
O&M costs of the NMT system	0	0	0	0
Total revenues	**2,304**	**2,304**	**79,054**	**79,054**
Revenues from MRT use	0	0	45,067	45,067
Revenues from BRT use	2,304	2,304	33,987	33,987
Total added benefits	**36,146**	**38,131**	**200,113**	**172,755**
Income creation from employment	837	844	5,049	5,055
Health impacts*	4,818	8,947	24,138	53,752
Value of time saved*	-1,557	-15,571	-7,792	-77,920

Integrated CBA (undiscounted)	Sustainable transport scenarios			
	Current sustainable transport scenario (2010–2021)		Current sustainable transport scenario (2022–2058)	
	Low estimate	High estimate	Low estimate	High estimate
Retail revenues	20,185	20,185	165,569	165,569
Property prices*	11,863	23,727	13,149	26,299
Total avoided costs	**1,194**	**1,376**	**14,709**	**17,614**
CO_2 emissions	302	302	2,559	2,559
Fuel use	553	553	6,644	6,644
Accidents*	316	498	5,133	8,037
Noise pollution	23	23	374	374
Cumulative net benefits (undiscounted)	**34,798**	**36,965**	**235,748**	**211,295**
BCR	0.5	0.5	1.4	1.4
Sustainable BCR (S-BCR)	**8.2**	**8.6**	**5.1**	**4.6**

Source: Authors' calculations.

Appendix D. Main Assumptions and Data Sources Used for the SD Model

Table D1. Overview of key assumptions used in the Sustainable Transport Strategy, Bogota SAVi Assessment

Parameters for calculating added benefits and avoided costs				Level of data collection			
Added benefit or avoided cost	**Indicator**	**Value**	**Data source**	**Project-specific**	**Urban/ regional**	**National**	**International**
Capital and O&M costs of the MRT system	MRT cost per km	COP 534.16 billion per km	Mazzoni et al., 2016			X	
	MRT O&M cost per wagon	COP 17,898	Zuber, 2016	X			
Capital and O&M costs of the TransMilenio BRT system	Cost per km of BRT	USD 12.5 million	Carrigan et al., 2013				X
	O&M costs per v-km	1,872 per v-km	Rizelioğlu & Arslan, 2019				X
Revenues from MRT use	Average MRT ticket price	COP 3,216	TransMilenio, 2022	X			
	MRT ticket price annual increase	4.8%	TransMilenio, 2022	X			
Revenues from TransMilenio BRT use	BRT trip share	9.6% in 2010; 18.8% in 2022	Bogota City Hall, 2019	X			
	Average BRT ticket price	COP 1,600 in 2010; COP 2,650 in 2022	TransMilenio, 2022	X			

Parameters for calculating added benefits and avoided costs				Level of data collection			
Added benefit or avoided cost	**Indicator**	**Value**	**Data source**	**Project-specific**	**Urban/ regional**	**National**	**International**
Income creation from employment	Employment creation during MRT construction	8,000 direct and 20,000 indirect jobs	Capital, 2019	X			
	O&M jobs per MRT km	49.5 jobs	Metro de Medellin, 2022		X		
	Average annual salary in Bogota per person	COP 31,876,781	Salary Expert, 2022		X		
	Share of income considered as discretionary spending	21.2%	Numbeo, 2022		X		
	BRT construction jobs per km	17 jobs/km (low estimate); 21 jobs/km (high estimate)	Carrigan, et al., 2013				X
	BRT O&M jobs per km	23 jobs/km (low estimate); 35 jobs/km (high estimate)	Carrigan, et al., 2013				X
	NMT jobs per km	15	Portafolio, 2019		X		

Parameters for calculating added benefits and avoided costs				Level of data collection			
Added benefit or avoided cost	**Indicator**	**Value**	**Data source**	**Project-specific**	**Urban/ regional**	**National**	**International**
Health impacts	Average walking time for MRT users	10 mins per day	Carrigan, et al., 2013				X
	Crude death rate	4.33 people per 1,000	Saludata, 2022			X	
	Value of Statistical Life (VSL) in Colombia	USD 0.64 million per life	Mardones et al., 2018				X
	Cost of different air pollutants	COP/1 kg of air pollutant	Rahul et al., 2013			X	
	Cost of exposure to air pollution per person	EUR 20/year	Rabl & Nazelle, 2012				X
	Cost of exposure to air pollution per km travelled	COP 76.98 per km	Rabl & Nazelle, 2012				X

Parameters for calculating added benefits and avoided costs				Level of data collection			
Added benefit or avoided cost	**Indicator**	**Value**	**Data source**	**Project-specific**	**Urban/ regional**	**National**	**International**
Value of time saved	Value of average speed per transport mode	Walking – 5 km/h	WHO, 2017			X	
		Bus=13 km/h Cycle=16 km/h	Despacio, 2017		X		
		Car=20 km/h Motorcycle=23 km/h Taxi=23 km/h	Secretaría de Desarrollo Económico, 2018		X		
		BRT system – 18 km/h	TransMilenio, 2013		X		
		MRT system – 43 km/h	Metro de Bogotá, 2018		X		
	Hourly salary	2,511 annual working hours	UBS, 2018				X
	Average annual salary in Bogota	COP 31,876,781	Salary Explorer, 2022		X		
Retail revenues	Average yearly retail spending in Bogota per year per person	COP 5,365,161	BBVA, 2019		X		

Parameters for calculating added benefits and avoided costs				Level of data collection			
Added benefit or avoided cost	**Indicator**	**Value**	**Data source**	**Project-specific**	**Urban/ regional**	**National**	**International**
	Average added retail spending from walkability	42.2%	Rabl & Nazelle, 2012				X
	Average annual growth of MRT trips per person	1.5%	Mayor of Bogota, 2019		X		
Property value	Increased value of property due to increased walkability	5%-15%	Buchanan, 2007; Song & Knaap, 2003; VTPI, 2018				X
	Average property value in Bogota	COP 4,166,666 per m^2	Habimeter, 2022		X		
CO_2 emissions	SCC	0.031 USD/kg	Nordhaus, 2017				X
	Amount of CO_2 emitted by transport mode	4-wheeler (134 g/km), Bus (806 g/km), 2-wheeler (24.4 g/km)	Sharma et al., 2014		X		
Fuel use	Fuel efficiency by transport mode	14.9-16.2 km/L	Goel et al., 2016			X	
	Average annual mileage by transport mode	7,255 – 12,804 km	Goel et al., 2016			X	

Parameters for calculating added benefits and avoided costs				Level of data collection			
Added benefit or avoided cost	**Indicator**	**Value**	**Data source**	**Project-specific**	**Urban/ regional**	**National**	**International**
	Price per litre of fuel in Colombia	Petrol (2,337 COP/L),	Trading Economics, 2022			X	
Accidents	Annual vehicle km in Bogota		Pachon, 2015; Observatorio de Movilidad de Bogota, 2022		X		
	Annual number of accidents per severity		Pachon, 2015; Observatorio de Movilidad de Bogota, 2022		X		
	Rate of accidents/ 1000 v-km per severity	Fatal (0.00008), Injury (0.00192), Car damages (0.00548)	Fasecolda, 2018			X	
	Cost per accident	Low value= COP 18,403,681 high value= COP 28,805,761	Fasecolda, 2018			X	
Noise pollution	Cost of noise pollution per v-km	Car (COP 7.5244) Motorcycle (COP 63.7363), Bus & BRT (COP 7.0818)					X

Source: Authors' calculations.

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