SAVi Sustainable Asset Valuation

A Sustainable Asset Valuation of the Mass Rapid Transit System in Bogota, Colombia

TECHNICAL REPORT

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This report is part of a series of Sustainable Asset Valuation (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.

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Executive Summary

Purpose of this Assessment and the Sustainable Asset Valuation Methodology

This Sustainable Asset Valuation (SAVi) assessment of the mass rapid transit (MRT) system in Bogota, Colombia, is part of a series of SAVi assessments on sustainable transport and mobility projects.

The assessments' aim is to raise awareness of 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 transport investment decision-making processes.

SAVi is an assessment methodology that provides policy-makers and investors with a comprehensive and customized analysis of how much their infrastructure projects and portfolios will cost throughout their life cycles. The approach purposefully considers risks and externalities that are overlooked in traditional valuations. 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: Assessments are based on project-level data (where available), the SAVi database (based on a literature review and data from previous SAVi applications), and best-in-class climate data from the EU Copernicus Climate Data Store (built into all SAVi models).

The MRT System in Bogota

Bogota, the capital and largest city in Colombia, is home to a rapidly growing population of over 8 million inhabitants. The city's public transportation network has struggled to keep pace with this rapid urban population growth in recent decades. Despite numerous attempts by various administrations to implement a metro system over the past 50 years, the primary form of public transportation in Bogota remains the TransMilenio bus rapid transit (BRT) system. As a result, Bogota has been ranked as one of the most congested cities in the world, with the average person 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 used for 36% of trips, while private transport modes, including cars, motorcycles, and taxis, account for 26% of trips. Active transport modes such as walking and cycling represent 24% and 6.6% of trips, respectively. Due to the above, Bogota experiences serious traffic congestion problems, long commuting times, high accident rates, and elevated levels of noise and air pollution.

To address these challenges, the City of Bogota introduced Metro Line 1 of the MRT system. The Metro Line 1 project is the first modern metro system in Colombia and is currently under construction. It will consist of an elevated MRT line that will connect Bogota's city centre with the southern and northern districts. The MRT will be fully electric and automatic and aims to meet sustainable, low-carbon mobility targets while reducing traffic congestion and increasing access to employment opportunities across Bogota. The MRT system is expected to accommodate 1.05 million passengers per day or 72,000 passengers per hour in each direction. It will be located within a 1-km distance of 80% of Bogota's population and will be integrated with the existing TransMilenio BRT system. Construction of the MRT project began in 2020, and it is expected to be operational in 2028. The total investment costs of the MRT system amount to approximately USD 5 billion.

This report discusses the results of a systemic valuation of the MRT system in Bogota, applying IISD's SAVi methodology to illustrate the value of the economic, social, and environmental outcomes of the MRT and how they impact the financial performance of the project.

The SAVi assessment uses a variety of models to estimate not only the investment costs (i.e., capital, operation and maintenance [O&M] costs and revenues) but also the environmental, social, and economic added benefits and avoided costs under a scenario where demand shifts from other transport modes to public transport. The assessment includes two MRT scenarios: 8% MRT and 16% MRT. Both scenarios have a low and a high estimate for some added benefits and avoided costs in the case that underlying data and assumptions about these indicators differ. Naturally, the higher the demand for using the MRT system, the higher the added benefits and avoided costs. The SAVi assessment for the MRT system in Bogota consists of the following elements:

- a simulation of two MRT scenarios (8% MRT and 16% MRT) for the implemented MRT system and the associated changes in transport use patterns in Bogota;
- a valuation of nine added benefits and avoided costs related to the MRT system; and
- an integrated cost-benefit analysis (CBA) of the MRT system, including the added benefits and avoided costs, and a benefit-cost ratio (BCR) for the MRT system.

Findings

According to the analysis, the MRT system in Bogota has a wide range of economic, social, and environmental benefits that are typically overlooked in traditional transport infrastructure assessments. The results from the SAVi assessment demonstrate that the MRT system will stimulate economic growth, either directly through MRT revenues and employment creation or indirectly through stimulating retail and property value increases and fuel savings. In addition, it will deliver considerable social benefits to Bogota's citizens, such as health benefits in the form of increased physical activity and reduced air pollution, as well as a diminishing number of traffic accidents. Lastly, the MRT system will be electric and will therefore deliver environmental benefits in the form of reduced CO_2 emissions.

Table ES1 summarizes the results of the integrated CBA of the MRT system across both 8% and 16% MRT scenarios. According to the SAVi MRT model, the total net value of both MRT scenarios is positive and is therefore profitable from both macroeconomic and societal perspectives. The integrated CBA shows cumulative discounted values over the project period of 35 years (2022–2058) of COP 7,682 billion[1] (USD[2] 2,051 million) in the low estimate and COP 20,283 billion (USD 5,412 million) in the high estimate of the 8% MRT scenario. The 16% scenario shows cumulative discounted benefits of COP 23,130 billion (USD 6,177 million) and COP 46,941 billion (USD 12,537 million) in the low and high estimates, respectively.

Table ES1. Integrated CBA (discounted values in COP billion) for the MRT scenario based on a project period of 35 years)

Integrated CBA (discounted at 8% and 3.5%)	MRT scenario: 2022–2058			
	MRT 8%		MRT 16%	
	Low estimate	High estimate	Low estimate	High estimate
Total investment costs	**16,909**	**16,909**	**24,357**	**24,357**
Capital cost	9,543	9,543	9,543	9,543
O&M cost	7,366	7,366	14,814	14,814
Total revenues	**7,085**	**7,085**	**14,217**	**14,217**
Revenues from MRT use	7,085	7,085	14,217	14,217
Total added benefits	**14,763**	**26,456**	**27,601**	**49,628**

[1] In this assessment, "billion" corresponds to the short scale, which is equivalent to 10e9 (1,000,000,000), which would correspond to a thousand million for Colombia.

[2] The exchange rate used is 3,744 COP/USD

Integrated CBA (discounted at 8% and 3.5%)	MRT scenario: 2022–2058			
	MRT 8%		MRT 16%	
	Low estimate	High estimate	Low estimate	High estimate
Income creation from employment	1,044	1,044	1,044	1,044
Health impacts*	3,829	5,306	7,711	10,852
Value of time saved*	1,029	10,287	1,992	19,920
Retail revenues	7,904	7,904	15,897	15,897
Property prices*	957	1,915	957	1,915
Total avoided costs	**2,743**	**3,650**	**5,668**	**7,452**
CO_2 emissions	316	316	583	583
Fuel use	702	702	1,472	1,472
Accidents*	1,606	2,513	3,157	4,941
Noise pollution	119	119	455	455
Cumulative net benefits (discounted)	**7,682**	**20,283**	**23,130**	**46,941**
BCR	0.4	0.4	0.6	0.6
S-BCR	**1.5**	**2.2**	**1.9**	**2.9**

* Added benefits and avoided costs that have a low and a high estimate.

Source: Authors.

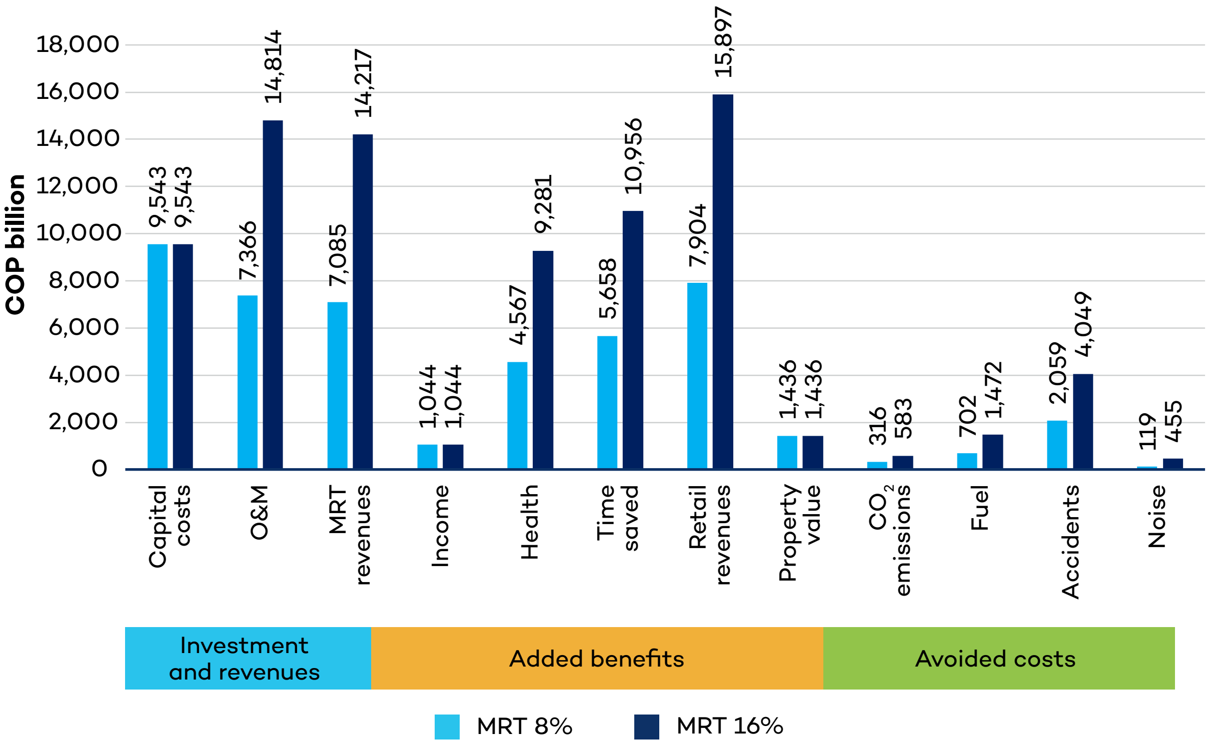
As Table ES1 demonstrates, the added benefits of the retail revenues resulting from the implementation of the MRT system show the highest discounted cumulative values, amounting to COP 7,904 billion in the 8% MRT scenario and COP 15,897 billion in the 16% MRT scenario.

The economic value of time savings ranges between COP 1,029 billion and COP 10,287 billion in the 8% MRT scenario and COP 1,992 billion and COP 19,920 billion in the 16% scenario. Health benefits resulting from increased physical activity and reduced air pollution amount to a value between COP 3,829 billion and COP 5,306 billion in the 8% MRT scenario and between COP 7,711 billion and COP 10,852 billion in the 16% MRT scenario.

Despite the high added benefits, the MRT system has O&M costs of COP 7,366 billion in the 8% scenario and COP 14,814 billion in the 16% scenario. However, revenues from MRT use are also high, amounting to COP 7,085 billion in the 8% scenario and COP 14,217 billion in the 16% scenario. Overall, the MRT system is expected to revitalize Bogota's economy in the form of increased retail revenues—especially in the central areas of the city—as well as deliver significant economic benefits to citizens from time savings and health benefits.

The SAVi assessment results for the MRT system, including investment costs, revenues, added benefits, and avoided costs of the MRT system, are shown in Figure ES1. Average values of low and high estimates have been calculated where appropriate.

Figure ES1. Investment costs, revenues, added benefits, and avoided costs of the MRT system in Bogota



Source: Authors.

In addition, two different BCRs have been calculated for the SAVi assessment of the MRT system in Bogota. 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. In this case, the conventional BCR considers only capital costs, O&M costs, and revenues from the use of the MRT system, whereas the S-BCR examines the project from a societal point of view and considers the full range of economic, social, and environmental added benefits and avoided costs. As indicated in Table ES2 below, the conventional BCR leads to a significantly lower BCR than the S-BCR across low and high estimates of both MRT scenarios.

Table ES2. Conventional BCR vs. S-BCR (discounted at 3.5%)

	BCR				S-BCR			
Parameters considered	Investment costs, revenues from MRT use				Investment cost, full range of economic, social and environmental added benefits and avoided costs			
Scenario	MRT 8%		MRT 16%		MRT 8%		MRT 16%	
	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate
BCR	0.4	0.4	0.6	0.6	1.5	2.2	1.9	2.9

Source: Authors.

The SAVi assessment of the MRT system in Bogota shows that the project's benefits outweigh the investment costs by 1.5 times if the modal shift from private transport to the MRT system is 8% and by almost two times if the modal shift is 16%. Overall, the benefits of the MRT outweigh the investment costs by four times in both demand scenarios. When a wide range of tangible and intangible economic, social, and environmental impacts are valued, the benefits are approximately four times higher.

The SAVi assessment provides benchmark values for policy-makers and public infrastructure planners when it comes to valuing the societal benefits and costs of MRT. 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 can use the results of the MRT SAVi assessment

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
Government	Design, implementation, and finance of the MRT system in Bogota	Urban and regional governments can use the assessment results to raise awareness for sustainable transport projects and to justify investments in MRT. They can also make these assessments a standard and a requirement for investment decisions. Overall, the results of the assessment provide an integrated perspective on MRT 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 MRT systems in particular, as well as on potential additional investments that may be required to realize additional benefits.

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
Private sector/ industry	Project developers	Businesses and private sector entities can use the assessment results for additional advocacy for sustainable transport projects and MRT systems, as well as for identifying new opportunities and business cases for additional investment in sustainable transport projects.
Donors and funders	Funding of MRT 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 for raising awareness of the benefits of MRT projects in cities, such as health benefits, avoided costs of air pollution and CO_2 emissions, and increases in retail revenues and property value. 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 MRT projects	Civil society organizations can use the assessment results and the valuation of the added benefits and the avoided costs of MRT 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 MRT infrastructure. Overall, this assessment shows that the MRT system advances the realization of sustainable mobility targets in Bogota and improves the quality of life of its residents.

Abbreviations

BAU	business as usual
BCR	benefit-cost ratio
BRT	bus rapid transit
CBA	cost-benefit analysis
CO	carbon monoxide
CO_2	carbon dioxide
GDP	gross domestic product
HC	hydrocarbons
HEAT	health economic assessment tool
LPG	liquefied petroleum gas
MRT	mass rapid transit
NO_x	nitrogen oxide
O&M	operation and maintenance
p-km	passenger kilometres
$PM_{2.5}$	particulate matter with a diameter of less than 2.5 micrometres
SAVi	Sustainable Asset Valuation tool
SCC	social cost of carbon
S-BSR	sustainable benefit-cost ratio
SITP	Integrated Public Transport System
UNEP	United Nations Environment Programme
v-km	vehicle kilometre
VSL	value of a statistical life
WHO	World Health Organization
WRI	World Resources Institute

Glossary

Benefit-cost ratio (BCR): 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.

Indicator: 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 Program [UNEP], 2014).

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

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, 2014).

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, 2014).

System dynamics (SD): A methodology developed by J. 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 non-linearity emerging from the explicit capturing of stocks and flows (UNEP, 2014).

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1.0 Introduction

1.1 Mobility Challenges and Transportation Strategies in Bogota

Bogota, the capital and largest city in Colombia, is home to a rapidly growing population of over 8 million inhabitants. The city is home to a deficient public transportation network, which has struggled to keep up with a surge in urban population growth in recent decades. According to traffic analytics data from 2020, Bogota ranked as the most congested city in the world, with the average person losing 191 hours to traffic each year (Kopf, 2020). Despite numerous attempts by various administrations to implement a metro system over the past 50 years, the primary form of public transportation in Bogota remains the TransMilenio bus rapid transit (BRT) system. Consequently, the city faces significant transportation challenges, including severe traffic congestion, lengthy commuting times, high accident rates, and elevated levels of noise and air pollution (Centre of Public Impact, 2016). These problems are anticipated to worsen with the impacts of climate change and ongoing urban development.

To address these challenges and gradually transform its transportation landscape toward more sustainable modes of transport, the city has established the Bogota Sustainable Mobility Plan (Plan integral de Movilidad Sostenible) and the Bogota Development Plan Bogota Better for All (Bogotá Mejor Para Todos 2016–2020). These initiatives set targets for improving the transportation system and encouraging sustainable mobility practices. Additionally, the Better Mobility for All program aims to enhance the quality and accessibility of mobility for pedestrians, cyclists, and users of both public and private transportation in Bogota.

Furthermore, in 2011, Bogota hosted the Regional Sustainable Transport Forum, a gathering where Latin American countries shared and evaluated best practices, challenges, and innovations in the sustainable transport sector (Latin American national transport and environment agencies, 2011). During this event, nine countries reached an agreement to adopt a declaration on sustainable transport principles and objectives known as the Bogota Declaration of Sustainable Transport Objectives. The declaration follows an "Avoid, Shift, and Improve" approach (Crawford, 2012), meaning it aims 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.

In addition, the District Development Plan 2020–2024—entitled *A New Social and Environmental Contract for the 21st Century*—was introduced in 2020. The plan focuses on fostering investment in sustainable mobility initiatives within the Bogota region (Secretariat of Mobility, 2020). Its primary objective is to improve the overall travel experience in Bogota by reducing travel time and improving the quality of transportation, particularly for the more vulnerable segments of the city's population. Additionally, the plan emphasizes the importance of addressing safety concerns related to gender. The investment projects outlined in the plan encompass nine specific goals totalling an investment of COP 105.8 billion over a 5-year implementation period (2020–2024). The plan's more detailed objectives are to

- increase the public transport offer of the Integrated Public Transport System (SITP) by 20%;
- increase the reliability of the SITP service;
- formulate and implement a comprehensive strategy to improve the quality of regional urban public transport; and
- maintain the average travel time in the 14 main corridors of the city for all road users.

To meet the above objectives and reduce dependence on the TransMilenio BRT system and private vehicles, Bogota has introduced Metro Line 1 of the Metro de Bogota as part of the mass rapid transit (MRT) system. This project represents Colombia's first modern metro system and is currently under construction. It will consist of an elevated MRT line that will connect Bogota's city centre with the southern and northern districts. With its fully electric and automatic operation, the MRT aims to promote sustainable and low-carbon mobility practices while alleviating traffic congestion and improving access to employment opportunities throughout Bogota.

1.2 Purpose of a Sustainable Asset Valuation for Bogota's MRT System

Bogota is situated in a fertile upland basin at an elevation of 2,640 m above sea level. Its metropolitan area spans approximately 1,500 km^2, and it serves as the vibrant heart of South America's second most populous nation. According to a 2019 Mobility Survey, Bogotanos undertake a staggering 13.4 million transport trips on a daily basis, which escalates to over 16 million trips when considering all municipalities within the city's metropolitan area. Of these trips, public transport accounts for 36%, while private modes of transportation, including cars, motorcycles, and taxis, contribute to 26%. Active modes of transport, such as walking and cycling, represent 24% and 6.5% of trips, respectively (Secretariat of Mobility, 2020).

To tackle these mobility challenges, the city has introduced Metro Line 1 of the Metro de Bogota MRT system. The elevated MRT line, which will be fully automated and driverless, forms part of a comprehensive plan to enhance Bogota's MRT network and improve connectivity between the city centre and the northern and southern districts. The MRT system will integrate with the existing public transport network, particularly the TransMilenio BRT system. Once completed, the Bogota MRT is expected to serve as the primary transit line for the public and a major passenger transport system within the city (WSP, 2022). It will accommodate 1.05 million passengers per day or 72,000 passengers per hour in each direction, with each driverless train having a capacity of approximately 1,800 passengers. By 2030, the MRT stations will be located within a 1-km radius of 80% of Bogota's population (Metro de Bogota, 2022). The trains will travel at an average speed of approximately 42.5 km/h, with intervals as short as 90 seconds. Journeys from the northern to the southern end of the line, and vice versa, will take as little as 27 minutes, with stops at 16 stations along the route (WSP, 2022). Construction of the MRT project began in 2020, and Line 1 is scheduled to be operational by the fourth quarter of 2025 (Railway Technology, 2020).

Following an international bidding process in October 2019, the APCA Transmimetro Consortium, which is comprised of the China Harbour Engineering Company, Xi'an Metro Company, and Bombardier, won the contract and is responsible for the construction of the MRT project. The project will cost USD 5.01 billion over a franchise period of 29 years and will be implemented by Metro de Bogotá (Bogota Metro Company), a state-owned company. It will be developed under the design–finance–build–operate–maintain–transfer model. The project will be executed in three phases. The first phase involves the construction of Metro Line 1, connecting Portal de las Américas with Avenida Caracas (Calle 1), covering a distance of nearly 25 km and elevated to a height of 13.5 m (Construction Review Online, 2021). This phase also includes the installation of 22 km of bike lanes and certain interventions in the BRT system. The second phase will extend the MRT system from Avenida Caracas (Calle 1) to Calle 72, while the third phase will further extend the Metro Line from Calle 72 to Calle 127 (Metro de Bogotá, 2021).

The implementation of the MRT system in Bogota is expected to have a significant positive impact on the city's economic, social, and environmental development. By increasing productivity and improving access to employment opportunities, the project will contribute to the overall growth of the city. It will also play a crucial role in reducing traffic congestion and providing high-quality transit options for public transportation users, as it is expected to encourage a shift from private motorized transport modes to a cleaner public transport network powered by electricity. This shift will also result in a substantial reduction in carbon dioxide (CO_2) emissions. Estimates suggest that the MRT system will reduce approximately 938,000 tonnes of greenhouse gas emissions by 2049 (Railway Technology, 2020). In addition to its environmental benefits, the MRT system incorporates various sustainable practices, such as the reuse of rainwater and 30% of its construction waste, as well as the implementation of energy-efficient measures such as LED lighting and natural ventilation in stations. These initiatives align with the goal of creating a greener and more sustainable transport system. The MRT system is projected to provide significant benefits to approximately 2.92 million people in Bogota (Railway Technology, 2020).

Moreover, the integration of the MRT system with TransMilenio is expected to significantly reduce travel time and increase demand for public transport. This integration will be complemented with improvements to 600,000 m² of public spaces for pedestrian use, civil works, and the construction of new BRT stations, further enhancing the overall mobility experience in the city.

To fully comprehend the extensive economic, social, and environmental benefits and costs of the MRT system in Bogota, a comprehensive quantitative analysis is required. This analysis should not only consider the investment costs (capital and operation and maintenance [O&M]) typically assessed in conventional transport infrastructure evaluations but also incorporate the additional benefits and avoided costs resulting from the MRT system. These may include the value of time saved, potential property and retail changes, health impacts, reduced accident costs, and environmental benefits, such as CO_2 emissions reductions. Integrating these factors into a cost-benefit analysis (CBA) will provide a comprehensive assessment of the societal value of investing in the MRT system. Given the difficulty in forecasting demand for transformative MRT projects, the assessment considers two potential scenarios: an 8% shift from motorized transport modes to the MRT system and a 16% shift.

This will enable public authorities to make informed decisions regarding investments in public transport systems, particularly MRT systems.

This Sustainable Asset Valuation (SAVi) assessment of the MRT system 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 this report presents the methodology of the SAVi assessment, including an overview of system dynamics, a causal loop diagram (CLD) (using a system dynamics model, which was created for this assessment), and a summary of the value-added benefits and avoided costs. The scenarios and assumptions used in the assessment are indicated in Section 3, which summarizes demand figures and shifting mobility patterns associated with the MRT demand scenario. Section 3 also presents the valuation methodologies and data sources used for the revenues and for each added benefit and avoided cost.

Section 4 of the report presents the results, starting with an integrated CBA table, which demonstrates the total cumulative monetary values generated by the two MRT demand scenarios. The values of the added benefits and avoided costs are integrated into the CBA, which includes the capital and operational expenditures for the MRT system, in order to better represent the societal value of the MRT system in Bogota. Both parameters are also summarized separately. The last part of Section 4 includes the valuation results for the revenues and for each added benefit and avoided cost. Section 5 concludes by illustrating how the results of the SAVi assessment make a stronger case for MRT by 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 this SAVi assessment, including an overview of the CLD and a summary of the impacts of the MRT system in the city of Bogota from a systemic perspective. The methodology section also summarizes the added benefits and avoided costs used in the assessment (a more extensive description and valuation process can be found in Section 3). Some of the limitations of the methodology used in the assessment are discussed in the conclusion (Section 5).

2.1 System Mapping

2.1.1 SYSTEMS THINKING AND SYSTEM DYNAMICS

The underlying dynamics of the MRT system in Bogota, including driving forces and key indicators, are summarized in the CLD displayed in Figure 1. The CLD includes the main indicators analyzed, 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 envisaged for the MRT system. The CLD is the starting point for the development of the mathematical stock and flow model.

2.1.2 READING A CLD

CLDs aim to capture causal relationships within a system accurately in order to increase the effectiveness of relevant solutions and interventions. Therefore, CLDs establish causal links between variables. CLDs include variables and arrows, with the latter linking the variables together 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 to find balance and equilibrium. A detailed description of all the reinforcing and balancing loops for the MRT system in Bogota is included in Appendix A.

2.1.3 CLD FOR THE MRT SYSTEM IN BOGOTA

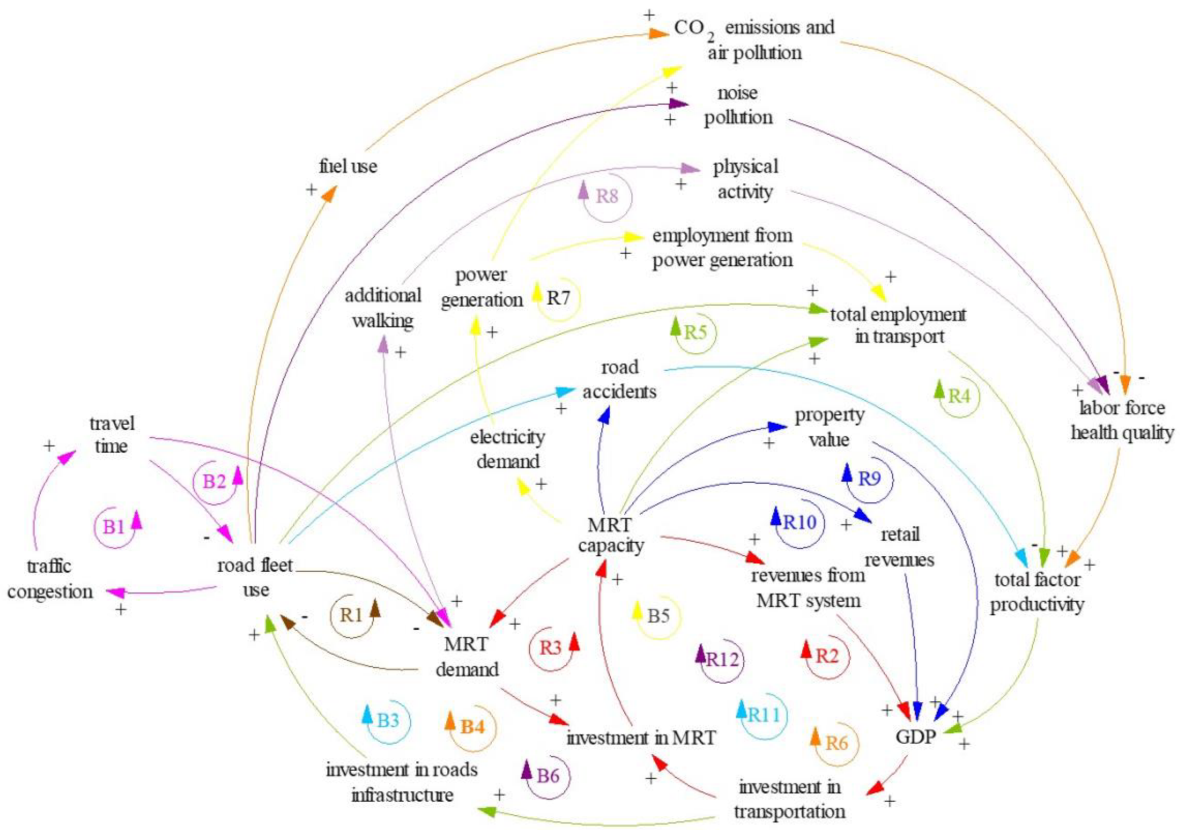
The impacts of the MRT system implementation in the city of Bogota and its feedback mechanisms are represented in the CLD in Figure 1. The relationships are diverse and involve social, environmental, and economic variables that are interconnected.

One of the main dynamics of the system is the shift from road transport to MRT and vice versa, which is represented by a reinforcing loop (R1) that is strengthened or weakened by the rest of the loops. As an urban population grows, more transport solutions are required. In the case of Bogota, road transport, including private and public modes, has been leading the mobility solutions, resulting in severe traffic congestion, higher CO_2 emissions, noise pollution, accidents, and other side effects. These outcomes impact both roads and MRT demand and use in different ways by either reinforcing them or balancing them. The feedback loops that can positively or negatively reinforce MRT investment and use are the revenues from the MRT system (R2), MRT demand (R3), employment (R4 & R7), fuel use from the road vehicle fleet (R6), additional physical activity (R8), property value around MRT stations (R9), retail revenues due to MRT infrastructure (R10), road accidents (R11), and noise pollution from the road vehicle fleet (R12). In addition, there is a reinforcing loop that directly impacts the investment in road infrastructure through the employment generated from the road vehicle fleet use (R5).

Two balancing loops can counteract the effects of the reinforcing loops in the MRT system use, specifically, the ones representing the impact of travel time as a result of the MRT use (B2) and the impact of CO_2 emissions from power generation (B5). In the case of road vehicle fleet use, several impacts offset its growth, including the impact of traffic congestion (B1), accidents (B3), CO_2 emissions from fuel use (B4), and noise pollution (B6).

In general, it can be concluded that MRT can enhance social outcomes (employment, physical activity), mitigate environmental impacts (reducing fuel use and CO_2 emissions), and improve economic outcomes (GDP, property values, retail revenues).

Figure 1. CLD for the MRT system in Bogota



Source: Authors.

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 provides the monetary valuation of project-related added benefits and avoided costs of an implemented MRT system. Table 2 lists all added benefits and avoided costs considered in this assessment, as well as stakeholders and indicators of relevance.

Table 2. Added benefits and avoided costs considered in the SAVi assessment of the MRT system in Bogota

Added benefit or avoided cost	Relevant stakeholders (government, households, private sector)	Social, environmental, economic
Income creation from employment	Government, households	Economic
Health impacts	Households, government	Social
Value of time saved	Households, private sector	Economic

Added benefit or avoided cost	Relevant stakeholders (government, households, private sector)	Social, environmental, economic
Retail revenues	Private sector, households	Economic
Property value	Government, private sector, households	Economic
CO_2 emissions	Households	Environmental
Fuel use	Households	Economic
Number of accidents	Households	Social
Noise pollution	Households	Social

Source: Authors.

2.3 Pre-Financial Analysis for MRT Projects

The pre-financial analysis provides an overview of the performance of MRT projects before the evaluation of the financing and the related investor financial return requirements. This analysis moves from the total life-cycle integrated CBA to the time-based analysis, equivalent to flow-based financial analysis (profit and loss and cash flows).

The viability of the BRT projects is assessed on the integrated value statement, which includes the net present value, internal rate of return, and present value analysis.

3.0 Scenarios and Assumptions

This section primarily introduces the scenarios simulated for the SAVi assessment of the MRT system in Bogota, including demand figures and shifting mobility patterns associated with the two MRT scenarios. Subsequently, it examines the underlying valuation methodologies of the SAVi assessment for the MRT scenarios. This includes the assumptions, data sources, and valuation methodologies of the MRT revenues and the nine added benefits and avoided costs valued by the SAVi MRT model.

3.1 Scenarios of the MRT SAVi Assessment

The SAVi assessment of the MRT system in Bogota consists of a status quo scenario and two MRT scenarios. The status quo scenario is considered the baseline scenario, and the two MRT scenarios are considered the "action" scenarios, which include the construction of MRT infrastructure and changes in modal share by 8% and 16% by the end of the project lifetime, compared to the status quo scenario. In addition, both MRT scenarios include a low and a high estimate based on sensitivity analyses of three added benefits and avoided costs—namely health impacts, property prices, and number of accidents. Table 3 provides an overview of the scenarios simulated for the SAVi assessment and related assumptions of the two MRT scenarios.

Table 3. Overview of scenarios of the MRT SAVi assessment

Scenario	Assumptions
Status quo	No action is undertaken. The modal shares of the business-as-usual (BAU) scenario are assumed to be constant over the entire project period, as the MRT system is not implemented in Bogota.
8% MRT scenario	The MRT system is implemented, operating starting in 2028, with a shift potential of 8% of the daily trips of the city of Bogota, based on an average capacity of 36,000 passengers per hour (Metro de Bogotá, 2018).
16% MRT scenario	The MRT system is implemented, operating from 2028, with a shift potential of 16% of the daily trips of the city of Bogota, based on a maximum capacity of 72,000 passengers per hour (Metro de Bogotá, 2018).

Table 4. Scenario assumptions for the MRT Bogota SAVi assessment

	BAU scenario	8% MRT scenario			16% MRT scenario		
Modal share of transportation	**2022–2058**	**2022**	**2028**	**2030–2058**	**2022**	**2028**	**2030–2058**
Car	14.9%	14.9%	13.8%	11%	14.9%	11.8%	8.5%
Motorcycle	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.0%
Taxi	4.9%	4.9%	4.9%	4.5%	4.9%	4.9%	4.5%
TransMilenio (BRT)	18.8%	18.8%	18.8%	18.8%	18.8%	18.8%	18.8%
Bus + SITP	25.4%	25.4%	24.5%	21.7%	25.4%	23.5%	17.5%
MRT	0.0%	0.0%	2%	8%	0.0%	5%	16%
Cycling	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%
Walking	23.9%	23.9%	23.9%	23.9%	23.9%	23.9%	23.9%

Source: Authors.

Table 4 shows the different mobility shifts in the BAU and MRT scenarios and, more importantly, the shift from other transport modes to the MRT system. An occupancy rate for each transport mode is assumed in order to calculate the passenger kilometres (p-km) per transport mode. The number of kilometres shifted to the MRT system is also considered in the analysis, as well as the amount of transport km that are avoided per vehicle mode thanks to the MRT system. Both the p-km shifted to the MRT system and the vehicle kilometres (v-km) avoided per transport mode are calculated in order to quantify and value various added benefits and avoided costs appropriately, as explained in the previous sections. The modal shares of the BAU scenario are assumed to be constant over the entire project period. For the MRT scenarios, a change that is linear over time is assumed up until the end of the construction year (2028), from which point onward, values are assumed to remain constant up to 2058.

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 added benefits and avoided costs are affected by the trip demand of 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 have to increase as well 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 only consider the net impact of the investments implemented in the past, such as considering the BRT and non-motorized transport systems in the Sustainable Transport Strategy in Bogota or, in this case, the net impact of the MRT project in the future.

Many scenarios 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 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 serious 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 will 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 Methodology of Revenues

3.2.1 REVENUES FROM MRT USE

Revenues from the use of the MRT system simply represent the revenues from the purchase of MRT tickets that passengers buy. Data for the MRT system shows that the average MRT ticket price of a trip is COP 3,216 for 2028. This value is calculated by the SAVi model based on TransMilenio BRT prices in Bogota (TransMilenio, 2022). The average MRT ticket price was then multiplied by the number of trips per year until 2050 for both MRT scenarios. 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 (2) are based on population and trip demand projections for the city of Bogota (Mayor of Bogota, 2019).

Price projections of the MRT are assumed to follow TransMilenio's price growth, which is estimated based on TransMilenio's historical prices during the last 5 years. The SAVi model considers a 4.8% price increase per year based on the annual price increases of TransMilenio (Transmilenio, 2022).

For the 8% MRT scenario, MRT demand projections from three different periods were considered, with a proportional growth of MRT demand. At the end of the first year of operation (2028), there is a projected 2% shift from private cars to MRT, and the new yearly trips for the MRT system are 102,376,804. For the second year of operation (2029), the projected shift is 5%, which amounts to 255,942,010 trips per year for the MRT system. Finally, for the third year of operation (2030) and until the end of the project period (2058), there is an 8% projected shift from other transport modes to MRT. This amounts to 409,507,217 trips per year for the MRT system, and the yearly value is assumed to stay constant until the end of the project period.

Similarly, for the 16% MRT scenario, in the first year of operation (2028), there is a 5% projected shift to MRT, which represents 255,942,010 new annual trips. In the second year of operation (2029), a 10% projected shift would lead to 511,884,021 new trips for the MRT system. For the third year of operation (2030), a 16% shift is assumed, resulting in 819,014,433 new annual trips. This level of trip demand for the MRT systems is assumed to stay constant until the end of the project period (2058).

3.3 Valuation Methodologies of the Added Benefits and Avoided Costs

3.3.1 INCOME CREATION FROM EMPLOYMENT

Construction and O&M of the MRT system 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 the income generation is valued as an added benefit of the MRT system.

For employment creation during construction, a fixed amount of direct (8,000) and indirect (20,000) employment positions was assumed for the valuation based on an interview with the 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 the 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, which employs 1,708 persons in a 34.5-km network (Metro de Medellín, 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/year/person (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).

3.3.2 HEALTH IMPACTS

Three impacts are aggregated to estimate the overall health impacts of the project: (i) health benefits from increased physical activity, (ii) health costs of air pollution, and (iii) health costs from increased exposure to air pollution. The avoided costs of traffic accidents are considered in a separate section.

IMPACT 1: The benefits from physical activity come with the additional walking generated from the use of the MRT system. It is assumed for this assessment, based on a BRT system study (Carrigan et al., 2013), that on average, every user will walk an additional 10 minutes per day. The World Health Organization (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). The HEAT 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, health-care payments, etc. (WHO, 2017).

This methodology is applied to value the benefits of MRT users' increased physical activity (additional walking). 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 million 0.64 per life, based on a study in Chile and other Latin American countries (Mardones & Riquelme, 2018).

IMPACT 2: Regarding air pollution, the shift from road fuel-based transport to the MRT system, which will be electric, 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 SAVi MRT model includes the valuation of particulate matter with a diameter of less than 2.5 ($PM_{2.5}$), nitrogen oxide (NO_x), carbon monoxide (CO), and hydrocarbon (HC). The difference in the total health cost of air pollutants between the baseline and the MRT scenario 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 MRT system. A low- and 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 & Verma, 2013). Transport-related air pollution is likely to decrease over time as fossil fuel-powered vehicles become more energy efficient and are gradually replaced by electric vehicles. Table 5 summarizes these input parameters for the different transport modes that are part of the modal share of Bogota.

Table 5. 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
Cycling	g/km	0	0	0	0
Walking	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: Rahul & Verma, 2013.

IMPACT 3: Lastly, 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 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 include higher risks for strokes, heart disease, lung cancer, and respiratory diseases.

The estimated cost of increased exposure to air pollutants is 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 MRT system use. The exposure—and hence the 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 entirely based on the study by Rabl and Nazelle (2012).

3.3.3 VALUE OF TIME SAVED

The value of time saved represents the economic value of improved mobility resulting from the MRT system. Because the SAVi assessment does not apply a growth rate to the value of time saved over time, value is estimated in real terms, and an average speed for each assessed transport mode has been assumed. The speeds of the different transport modes used in the model are informed by different studies, local/regional reports, and consultations with the client (with adjustments made based on 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 (Pardo, 2017)
- MRT: 43 km/h (Metro de Bogotá, 2018)
- Bicycle: 16 km/h (Pardo, 2017)
- Walking: 5 km/h (WHO, 2017)

The shift from other transport modes to MRT will result in differing travel speeds. The MRT system 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 an 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 MRT 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.

Additionally, 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 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—for instance, if only transportation and delivery companies benefit, or only the MRT users benefit and not the other type of commuters.

3.3.4 RETAIL REVENUES

Studies suggest that the mode of transport and commuting speeds 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 (Litman, 2003; Rabl & Nazelle, 2012). In this SAVi assessment, there will be additional walking of 10 minutes/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 (Mayor of Bogota, 2019).

Additional retail sales are calculated based on the assumption that there is increased spending per additional trip that is shifted to MRT, excluding the walking or cycling trips that were already taking place before the MRT system was implemented. The additional retail spending volume is based on the additional number of daily walking trips that occur as a result of the MRT. 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—approximately 42.2% higher (Rabl & Nazelle, 2012). The results show the total additional daily retail spending caused by improved walkability.

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

3.3.5 PROPERTY VALUE

The implementation of an MRT system will affect the property prices of the areas where it will operate. Specifically, the real estate value of the properties surrounding the MRT stations will increase due to improved connectivity and walkability to the stations. Research has shown that property values can increase from 5% to 15% (Buchanan, 2007; Song & Knaap, 2003; VTPI, 2018). The scale of increase depends on the degree of improved walkability but also on perceived improvements in safety.

The average property value in Bogota is COP 4,166,666 per m² (Quevedo, 2022). The total property value increase is estimated by multiplying the average property price per square metre with the estimated cumulative area impacted by the MRT system 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 MRT system. The forecasted potential increase in property value is based on the direct impacts of the investment assessed. City-wide dynamics are not considered in the assessment.

3.3.6 CO_2 EMISSIONS

The replacement of road-based fossil fuel-based transport modes by the MRT system is accompanied by a reduction of the transport sector's CO_2 emissions. The social cost of carbon (SCC) per kg of CO_2 is based on Nordhaus (2017) and amounts to 31 USD per tonne of CO_2.[3] The social cost of carbon is multiplied by CO_2 emission values per transport mode (Sharma et al., 2014), as indicated in Table 6. This, in turn, is then multiplied by the total avoided emission costs as a result of implementing the MRT system.

Table 6. CO_2 emission factor for Bogota per transport mode (based on Delhi values)

Emission factors (in g/km)	Unit	CO_2
Bus, BRT	g/km	806.5
Car	g/km	134
Gasoline	g/km	115
Diesel	g/km	153
Motorcycle	g/km	24.4
Cycling	g/km	0
Walking	g/km	0
MRT	g/km	0
Valuation of emissions		
SCC	USD/kg	0.031
SCC in COP	COP/kg	116.07

Source: Sharma et al., 2014.

3.3.7 FUEL USE

The shift in transport users to the MRT system 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 MRT is used to estimate the total amount of fuel saved through the shift. The average annual mileage by transport mode in kilometres and the fuel efficiency by transport mode in kilometres 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 liquefied petroleum gas (LPG) in Bogota. Where local data were not available, fuel per kilometre values from case studies of SAVi assessments in India were used. The amount of fuel saved as a result of the

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

shift to MRT 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 7.

Table 7. Fuel prices per fuel type, mode and case study used

Fuels shares in the transport sector in Colombia	**Fuel shares**
Diesel	47%
Petrol	48%
LPG	5%
Fuel use per kilometre	**Fuel use (L/km)**
Diesel cars (all engine sizes)	0.074
Petrol cars	0.063
Petrol motorized two-wheelers	0.019
Diesel three-wheelers	0.042
Visakhapatnam case study	
Diesel cars (all engine sizes)	0.062
Petrol cars (all engine sizes)	0.067
Petrol motorized two-wheelers (MTWs)	0.021
Diesel three-wheelers	0.034
Weighted average	
Diesel + petrol cars	0.066
Petrol MTWs	0.020
Average cars + MTWs	*0.043*
Diesel three-wheelers	0.038
Fuel prices	
Petrol (2021 Bogota prices)	COP 2,337/L

Source: Goel et al., 2016; Trading Economics, 2022.

The shift from motorized transport modes to MRT 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 degree of severity (Observatorio de Movilidad de Bogotá, 2022; Pachón, 2015) for the year 2010. Three degrees of accident severity are considered: fatal injuries, injuries, and car damages. 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 system per accident severity are shown in Table 8. Annual accident rates following the implementation of the MRT system 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 8. Annual accident rates in Bogota prior to the implementation of the MRT system (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: Pachón, 2015.

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 are low-value and high-value estimations, as indicated in Table 9.

Table 9. Valuation of accidents per accident severity (COP/accident)

Cost of accidents (all severity types)	Cost per accident (2016)
Cost per accident (low value)	18,403,681
Cost per accident (high value)	28,805,761

Source: Fasecolda, 2018.

3.3.9 NOISE POLLUTION

Noise emissions from various transport modes can have negative health effects on 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 this SAVi assessment, the avoided cost of noise pollution is estimated due to the reduced use of road transport in the MRT scenario. The total value is estimated based on the reduced noise emissions per v-km per transport mode (see Table 10) being replaced by the MRT system. The estimation also considers different noise levels per transport mode, influenced by peak and off-peak travel times.

Table 10. Noise cost per v-km by transport mode

Noise cost per v-km	EUR	COP
Bus and BRT	0.0016	7.0818
Car	0.0017	7.5244
Motorcycle	0.0144	63.7363
Cycling	0.0000	0.0000
Walking	0.0000	0.0000
Other and Trucks	0.0063	27.8846
MRT	0.0012	5.3114
Railway	0.0010	4.4261

Source: Authors.

4.0 Results

The results of the SAVi assessment of the MRT system in Bogota are presented here in two parts: a summary and analysis of two integrated CBA tables, followed by a summary of investment costs and benefit-cost ratios (BCRs). The first integrated CBA, shown in Table 11, includes values that are discounted using two different discount rates (8% for tangible indicators and 3.5% for intangible indicators). The second integrated CBA, shown in Table 12, includes values that are discounted at 3.5% only. They are both integrated CBAs because, in addition to the MRT system'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. A comparison of the BCRs between the conventional project finance analysis and the integrated analysis is also included to demonstrate the importance of valuing the multiple added benefits and avoided costs. The last part of this section provides a summary of the valuation results for the revenues and for each added benefit and avoided cost of the MRT demand scenarios.

4.1 Integrated CBA

An integrated analysis provides a more holistic view for assessing whether the MRT system generates net benefits and, thus, can be considered a worthwhile investment from a societal perspective. This SAVi assessment considers a project period of 35 years to demonstrate the MRT system's net benefits and provide a reference point for the overall investments required for the wider MRT infrastructure.

The undiscounted net results of the MRT system for the low and high estimate across both the 8% and 16% MRT scenarios can be found in Appendix D. The low estimate of the 8% MRT scenario yields cumulative benefits of COP 56,060 billion, and the high estimate of the 8% MRT scenario yields cumulative benefits of COP 82,377 billion. Furthermore, the low estimate of the 16% MRT scenario yields cumulative benefits of COP 122,691 billion, and the high estimate of the same scenario yields cumulative benefits of COP 173,061 billion. The BCRs of the low and high estimates of the MRT 8% scenario are 2.1 and 2.7, respectively. Similarly, the BCR of the low estimate of the MRT 16% scenario is 2.4, and the BCR of the high estimate of the same scenario is 3.

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 11 provides an integrated CBA analysis, which includes two discount factors (8% for tangible indicators and 3.5% for intangible indicators). In this integrated CBA, a discount factor of 8% is 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 discount factor of 8% was estimated considering a wide range of parameters, including inflation rate changes over time, economic growth in Colombia, the impacts of

COVID-19, and 10-year bond yields on government bonds in Colombia. 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—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 (UK Government, 2022).

Table 11. Integrated CBA discounted at 8% and 3.5% over 35 years

Integrated CBA (discounted at 8% and 3.5%)	MRT scenario: 2022–2058			
	MRT 8%		MRT 16%	
	Low estimate (COP billion)	High estimate (COP billion)	Low estimate (COP billion)	High estimate (COP billion)
Total investment costs	**16,909**	**16,909**	**24,357**	**24,357**
Capital cost	9,543	9,543	9,543	9,543
O&M cost	7,366	7,366	14,814	14,814
Total revenues	**7,085**	**7,085**	**14,217**	**14,217**
Revenues from MRT use	7,085	7,085	14,217	14,217
Total added benefits	**14,763**	**26,456**	**27,601**	**49,628**
Income creation from employment	1,044	1,044	1,044	1,044
Health impacts*	3,829	5,306	7,711	10,852
Value of time saved*	1,029	10,287	1,992	19,920
Retail revenues	7,904	7,904	15,897	15,897
Property prices*	957	1,915	957	1,915
Total avoided costs	**2,743**	**3,650**	**5,668**	**7,452**
CO_2 emissions	316	316	583	583
Fuel use	702	702	1,472	1,472
Accidents*	1,606	2,513	3,157	4,941
Noise pollution	119	119	455	455

Integrated CBA (discounted at 8% and 3.5%)	MRT scenario: 2022–2058			
	MRT 8%		MRT 16%	
	Low estimate (COP billion)	High estimate (COP billion)	Low estimate (COP billion)	High estimate (COP billion)
Net results				
Cumulative net benefits (discounted)	**COP 7,682 billion**	**COP 20,283 billion**	**COP 23,130 billion**	**COP 46,941 billion**
BCR	0.4	0.4	0.6	0.6
S-BCR	**1.5**	**2.2**	**1.9**	**2.9**

Source: Authors.

* Added benefits and avoided costs that have a low and a high estimate.

Table 12 shows an integrated CBA analysis, 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 MRT system in Bogota can have in the future aims to emphasize the importance of addressing climate change impacts that are likely going to worsen in the coming decades.

Table 12. Integrated CBA discounted at 3.5% over 35 years

Integrated CBA (discounted 3.5%)	MRT scenario: 2022–2058			
	MRT 8%		MRT 16%	
	Low estimate (COP billion)	High estimate (COP billion)	Low estimate (COP billion)	High estimate (COP billion)
Total investment costs	**28,156**	**28,156**	**45,229**	**45,229**
Capital cost	11,198	11,198	11,198	11,198
O&M cost	16,957	16,957	34,030	34,030
Total revenues	**18,669**	**18,669**	**37,406**	**37,406**
Revenues from MRT use	18,669	18,669	37,406	37,406

	MRT scenario: 2022–2058			
	MRT 8%		MRT 16%	
Integrated CBA (discounted 3.5%)	**Low estimate (COP billion)**	**High estimate (COP billion)**	**Low estimate (COP billion)**	**High estimate (COP billion)**
Total added benefits	**25,460**	**37,320**	**48,628**	**70,820**
Income creation from employment	1,282	1,282	1,282	1,282
Health impacts*	3,829	5,306	7,711	10,852
Value of time saved*	1,029	10,287	1,992	19,920
Retail revenues	18,198	18,198	36,520	36,520
Property prices*	1,123	2,247	1,123	2,247
Total avoided costs	**3,654**	**4,562**	**7,577**	**9,361**
CO_2 emissions	316	316	583	583
Fuel use	1,613	1,613	3,381	3,381
Accidents*	1,606	2,513	3,157	4,941
Noise pollution	119	119	455	455
Net results				
Cumulative net benefits (discounted)	**COP 19,628 billion**	**COP 32,395 billion**	**COP 48,382 billion**	**COP 72,359 billion**
BCR	0.7	0.7	0.8	0.8
S-BCR	**1.7**	**2.2**	**2.1**	**2.6**

Source: Authors.

* Added benefits and avoided costs that have a low and a high estimate

This SAVi analysis elaborates on the results of the MRT system in Bogota that are discounted using the two different discount rates (8% and 3.5%), shown in Table 11. Following the application of both discount rates, the low estimate of the 8% MRT scenario yields cumulative benefits of COP 7,682 billion, and the high estimate of the 8% MRT scenario amounts to COP 20,283 billion. In addition, the low estimate of the 16% MRT scenario yields cumulative benefits of COP 23,130 billion, and the high estimate of the same scenario amounts to COP 46,941 billion.

Subsequent subsections 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 BCRs

The SAVi assessment of the MRT system in Bogota starts with the investment costs and revenues. As shown in the first part of the integrated CBA in Table 11, the investment costs (including capital and O&M expenditures) and the revenues are always incorporated in a conventional transport infrastructure assessment. Table 13 displays only the capital expenditures, the O&M costs, and the revenues of the MRT system as cumulative values over the project period (2022–2058).

Table 13. Capital, O&M costs, and revenues of the MRT scenarios (in COP billion, discounted at 8% and 3.5%)

CBA	MRT 8%	MRT 16%
Total investment and costs (2022–2052)	**16,909**	**24,357**
Capital cost of the MRT system	9,543	9,543
O&M cost of the MRT system	7,366	14,814
Total revenues (2022–2052)	**7,085**	**14,217**
Revenues from MRT use	7,085	14,217

Source: Authors.

Two different BCRs have been calculated: a conventional BCR and a sustainable BCR (S-BCR). The conventional BCR considers only capital costs, O&M costs, and revenues from the use of the MRT system—similar to conventional transport infrastructure assessments. The S-BCR examines the project from a societal point of view and considers the full range of economic, social, and environmental added benefits and avoided costs. As indicated in Table 14, the conventional BCR leads to a significantly lower BCR than the S-BCR across low and high estimates of both MRT scenarios. Section 4.3 examines the valuation of the added benefits and avoided costs in more detail.

Table 14. Conventional BCR vs. sustainable S-BCR (discounted at 8% and 3.5%)

	BCR				S-BCR			
Parameters considered	Investment costs, revenues from MRT use				Investment costs, revenues, full range of economic, social, and environmental added benefits and avoided costs			
Scenario	MRT 8%		MRT 16%		MRT 8%		MRT 16%	
	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate
BCR	0.4	0.4	0.6	0.6	1.5	2.2	1.9	2.9

Source: Authors.

4.3 Summary of Added Benefits and Avoided Costs

The SAVi assessment of the MRT system in Bogota calculates monetary values for a range of added benefits and avoided costs arising from the implementation and use of the MRT system. Table 15 examines the cumulative discounted monetary values of the added benefits and the avoided costs over the 35-year project period. High-valuation and low-valuation estimates are presented for some added benefits and avoided costs for both 8% and 16% MRT scenarios, 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 the MRT system, and hence from improved walkability, is considered 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 8% MRT scenario amount to COP 17,506 billion and COP 30,107 billion, respectively. In addition, the low estimate of the MRT 16% scenario shows values of COP 33,269 billion, and the high estimate of the same scenario amounts to COP 57,080 billion. For each valued-added benefit or avoided cost, Table 15 shows which stakeholders are the most relevant (G for government, H for households, and/or P for 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 15. Valued-added benefits and avoided costs of the MRT scenarios (in COP billions, discounted at 8% and 3.5%)

Integrated CBA (discounted at 8% and 3.5%)	MRT scenario (2022–2058)				Stakeholder of relevance	Social, environmental, economic
	MRT 8%		MRT 16%			
	Low estimate	High estimate	Low estimate	High estimate		
Total added benefits	**14,763**	**26,456**	**27,601**	**49,628**		
Income creation from employment	1,044	1,044	1,044	1,044	G, H	Economic
Health impacts*	3,829	5,306	7,711	10,852	H, G	Social, Environmental
Value of time saved	1,029	10,287	1,992	19,920	H, P	Economic
Retail revenues	7,904	7,904	15,897	15,897	H, P	Economic
Property prices*	957	1,915	957	1,915	G, P, H	Economic
Total avoided costs	**2,743**	**3,650**	**5,668**	**7,452**		
CO_2 emissions	316	316	583	583	H	Environmental
Fuel use	702	702	1,472	1,472	H	Economic
Accidents*	1,606	2,513	3,157	4,941	H	Social
Noise pollution	119	119	455	455	H	Social
Net results of valued-added benefits and avoided costs						
Cumulative net benefits (discounted)	**17,506**	**30,107**	**33,269**	**57,080**		

Source: Authors.

* Added benefits and avoided costs that have a low and a high estimate.

Note: G = government, H = households, P = private sector

4.4 Valuation Results for Revenues

4.4.1 REVENUES FROM MRT USE

The implementation of the MRT system will lead to increased revenues through the purchase of MRT tickets by users. The average MRT ticket price for a trip in 2028 is estimated at COP 3,216, based on TransMilenio values. The MRT ticket price is then multiplied by demand projections and assumptions about the number of daily trips per person based on current travel habits in Bogota. Cumulative MRT revenues in the 8% MRT scenario are valued at COP 7,085 billion, and cumulative MRT revenues in the 16% scenario are valued at COP 14,217 billion, as shown in Table 16.

Table 16. Annual and cumulative values of revenues from MRT use (in COP billion/year, discounted at 8%)

Year	8% MRT scenario	16% MRT scenario
2028 (1st year of operation)	95.93	239.83
2038	269.90	539.80
2048	197.63	395.25
2058	145.81	291.62
Cumulative (2022–2058)	7,085	14,217

Source: Authors.

4.5 Valuation Results Per Added Benefit and Avoided Cost

4.5.1 INCOME CREATION FROM EMPLOYMENT

Construction and O&M of the MRT system will create employment, 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. Based on the SAVi assessment, during the construction period of the MRT system (2021–2028), an estimated 8,000 direct and 20,000 indirect jobs will be created (Capital, 2019). In addition, a multiplier of 49.5 jobs per km is used to calculate additional O&M jobs based on the experience of the metro in Medellin (Colombia's second-largest city). The calculation considers both types of jobs mentioned above, the average annual salary per person in Bogota, and the share of that income that is considered discretionary spending in Bogota.

The total cumulative income creation from employment from 2022 to 2058 is the same in both 8% and 16% MRT scenarios since employment creation is the same regardless of MRT demand and amounts to COP 1,044 billion. Table 17 presents the income creation for the construction years (2022–2027) for two of the operation years (including 2028, the first year of operation) and the cumulative income creation for the entire simulation period (2022–2058).

Table 17. Annual and cumulative values of income creation from increased employment (COP billion/year, discounted at 8%)

Year	Both 8% MRT and 16% MRT scenarios
2022	162.2
2023	150.2
2024	139.1
2025	128.7
2026	119.2
2027	115.1
2028 (1st year of operation)	4.3
2058	0.4
Cumulative (2022–2058)	1,044

Source: Authors.

4.5.2 HEALTH IMPACTS

The implementation of the MRT system leads to three different health impacts that are valued in this SAVi assessment: (i) health benefits from increased physical activity, (ii) health costs of air pollution, and (iii) health costs from increased exposure to air pollution as a result of using the MRT system. The total cumulative net health benefits amount to COP 3,829 billion in the low estimate and COP 5,306 billion in the high estimate of the 8% MRT scenario. The 16% MRT scenario shows values of COP 7,711 billion in the low estimate and COP 10,852 billion in the high estimate.

IMPACT 1: Primarily, the MRT system leads to increased levels of physical activity for MRT users who spend additional time walking to and from MRT stations in Bogota. The additional daily minutes walked and the reduction in the relative risk of mortality using the VSL are considered in the estimate of health benefits from increased physical activity. The total health benefits from increased physical activity in the 8% MRT scenario amount to COP 3,784 billion; for the 16% MRT scenario, they amount to COP 7,594 billion for both low and high estimates. The above values represent the cumulative net health benefits resulting from the new mobility patterns compared to the baseline over the project period. Importantly, these benefits only emerge after the construction period, once the MRT is in operation.

IMPACT 2: In addition, the shift of transport users from motorized, fuel-based transport modes to the use of the MRT system (which will be electric) will reduce the number of vehicles on the road and will therefore 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 5. Low- and high-value estimates for the health cost of the pollutant $PM_{2.5}$ have been used in the analysis based on a study conducted for Indian cities (Rahul & Verma, 2013). Avoided costs of air pollution for the 8% MRT scenario are valued at COP 223 billion, according to the low estimate, and COP 1,700 billion, according to the high estimate. Avoided costs of air pollution for the 16% MRT scenario amount to COP 473 billion and COP 3,615 billion for the low and high estimates, respectively.

IMPACT 3: Lastly, the negative health effects of air pollution ($PM_{2.5}$) will be experienced to an increased degree by MRT commuters who spend more time walking in urban environments with high background concentrations or air pollutants. This is the case because the pollutant dose increases for people who walk due to direct exposure to traffic and a higher inhalation rate during physical activity, as opposed to those 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. Increased exposure to air pollution is considered an additional cost compared to the baseline (and hence a cost from using the MRT system). Therefore, values showing this cost are negative. The results in the 8% MRT scenario amount to COP 178 billion, and the results in the 16% MRT scenario amount to COP 357 billion.

All of the above results are summarized in Table 18.

Table 18. Annual and cumulative values of health impacts, including health benefits from increased physical activity and avoided air pollution costs (COP billion/year, discounted at 3.5%)

Health impacts	Scenarios	Estimate	2028 (1st year of operation)	2038	2048	2058	Cumulative (2022–2058)
Benefits from physical activity	8% MRT	Both estimates	53.97	145.91	102.66	72.78	3,784
	16% MRT	Both estimates	134.93	291.82	205.33	145.56	7,594
Avoided costs of air pollution	8% MRT	Low estimate	3.01	8.65	6.13	4.34	223
		High estimate	23.05	66.05	46.82	33.19	1,700
	16% MRT	Low estimate	6.91	18.31	12.98	9.20	473
		High estimate	52.84	139.90	99.17	70.30	3,615
Avoided costs of increased exposure to air pollution	8% MRT	Both estimates	-2.53	-6.85	-4.82	-3.42	-178
	16% MRT	Both estimates	-6.34	-13.71	-9.65	-6.84	-357

Health impacts	Scenarios	Estimate	2028 (1st year of operation)	2038	2048	2058	Cumulative (2022–2058)
Total health impacts	8% MRT	Low estimate	54.45	147.70	103.97	73.70	3,829
		High estimate	74.49	205.10	144.66	102.55	5,306
	16% MRT	Low estimate	135.50	296.42	208.66	147.92	7,711
		High estimate	181.43	418.00	294.85	209.03	10,852

Source: Authors.

4.5.3 THE VALUE OF TIME SAVED

The value of time saved represents the economic value of improved mobility resulting from the MRT system. The shift from other transport modes to MRT will result in differing travel speeds; therefore, the MRT system will lead to either time savings or additional time spent commuting. The value of time in this SAVi assessment is estimated based on the average speed considerations of different transport modes, the hourly salary of commuters, and the value of the hourly time saved. In the 8% MRT scenario, the cumulative value of time saved is COP 1,029 billion in the low estimate and COP 10,287 billion in the high estimate. In the 16% MRT scenario, the cumulative value of time saved is valued at COP 1,992 billion in the low estimate and COP 19,920 billion in the high estimate. Table 19 summarizes the select annual values of benefits from time saved due to improved mobility as a result of the MRT system.

Table 19. Annual and cumulative values of benefits from time saved due to improved mobility (COP billion/year, discounted at 3.5%)

	8% MRT scenario		16% MRT scenario	
Year	Low estimate	High estimate	Low estimate	High estimate
2028 (1st year of operation)	4.67	46.70	40.56	405.61
2038	39.74	397.46	76.81	768.17
2048	8.17	81.77	54.45	544.57
2058	9.97	99.75	38.60	386.05
Cumulative (2022–2058)	1,029	10,287	1,992	19,920

Source: Authors.

4.5.4 RETAIL REVENUES

The shift from motorized transport to MRT will result in additional time spent walking to and from MRT stations. 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 (Litman, 2003; Rabl & Nazelle, 2012). Therefore, the increased walkability of MRT users in retail establishments that are located near MRT stations implies higher retail spending for MRT users. The additional number of daily walking trips and the average yearly retail spending in Bogota are considered in the calculation.

The increase in retail revenues reflects the total additional retail spending in both MRT scenarios over the project period. Naturally, the higher the demand for the MRT system, the higher the total amount of additional retail spending. The cumulative increase in retail revenues due to additional retail spending expected from MRT users over the project period amounts to COP 7,904 billion in the 8% MRT scenario and COP 15,897 billion in the 16% MRT scenario. Selected annual values of additional retail spending are also included in Table 20 below.

Table 20. Annual and cumulative values of additional retail spending (COP billion/year, discounted at 8%)

Year	8% MRT scenario	16% MRT scenario
2028 (1st year of operation)	177.06	442.65
2038	328.05	656.10
2048	151.95	303.90
2058	70.38	140.76
Cumulative (2022–2058)	7,904	15,897

Source: Authors.

4.5.5 CHANGES IN PROPERTY VALUE

The implementation of the MRT system will affect property prices located near MRT stations. The MRT system is expected to improve connectivity and walkability and increase safety in those areas. To calculate the potential increase in real estate values of the properties surrounding MRT stations, the average property value per square metre in Bogota and the total area impacted by the MRT system were considered. In addition, the increased value of property prices, according to the 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 MRT scenarios. The results represent the total one-time increase in property values in the area affected by the MRT system. 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.

Cumulative net benefits of increases in property value as a result of the MRT system amount to COP 957 billion in the low estimate and COP 1,915 billion in the high estimate of the 8% MRT scenario. Results for the 16% MRT scenario are the same across low and high estimates because rising property prices are irrespective of MRT demand projections. Cumulative and annual values of rising property values as a result of MRT infrastructure are summarized in Table 21. Table 21 includes select annual values for years before 2028, the first year of operation, since the increase in property prices takes place before the implementation of the MRT system. From 2028 to 2058, the annual values are 0.

Table 21. Annual and cumulative property value increase (COP billion/year, discounted at 8%)

	Both 8% MRT and 16% MRT scenarios	
Year	**Low estimate**	**High estimate**
2022	157.50	315.01
2024	135.03	270.07
2026	115.77	231.54
2028 (1st year of operation)	-	-
Cumulative (2022–2058)	957	1,915

4.5.6 CO_2 EMISSIONS

The implementation of the MRT system will lead to a shift from individual, motorized transport to the MRT system and, hence, to a reduction in vehicles circulating on the roads of Bogota. This will be accompanied by a reduction of CO_2 emissions generated from the transport sector in Bogota. The calculation of the avoided costs of CO_2 emissions is based on the social cost of carbon per kg of CO_2 (Nordhaus, 2017) and CO_2 emission values per transport mode (Sharma et al., 2014).

The cumulative avoided costs of CO_2 emissions in the 8% MRT scenario amount to COP 316 billion; in the 16% MRT scenario, they are valued at COP 583 billion, as indicated in Table 22.

Table 22. Annual and cumulative values of avoided CO_2 emissions costs (COP billion/year, discounted at 3.5%)

Year	8% MRT scenario	16% MRT scenario
2028 (1st year of operation)	4.41	11.67
2038	12.22	22.48
2048	8.66	15.94
2058	6.14	11.30
Cumulative (2022–2058)	316	583

Source: Authors.

4.5.7 FUEL USE

The implementation of the MRT system will lead to a shift from motorized, fossil fuel-based transport modes to the MRT system and, hence, to a reduction of road transport. This will result in a reduction in fuel consumption, which is used to estimate the avoided costs of fuel use in this SAVi assessment. The estimate of the avoided costs of fuel use is based on the number of trips per transport mode per v-km that are shifted to MRT, the average annual mileage by transport mode, the fuel efficiency by transport mode, and the price of fuel in Colombia. A weighted average value is used, based on fuel shares of diesel, petrol, and LPG in Bogota. Where local data were not available, fuel per kilometre values from a case study of a SAVi assessment in India were used. As Table 23 demonstrates, the avoided costs of fuel use in the 8% MRT scenario and the 16% MRT scenario amount to COP 702 billion and COP 1,472 billion, respectively.

Table 23. Annual and cumulative values of avoided fuel costs (COP billion/year, discounted at 8%)

Year	8% MRT scenario	16% MRT scenario
2028 (1st year of operation)	16.21	44.68
2038	28.99	60.72
2048	13.42	28.12
2058	6.21	13.02
Cumulative (2022–2058)	702	1,472

Source: Authors.

4.5.8 ACCIDENTS

The shift from motorized transport modes to MRT will lead to a reduction in vehicles circulating on the roads of Bogota and, therefore, 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 broken down into levels of severity. The latter includes three different categories: fatal injuries, injuries, and vehicle damage. Annual accident rates following the implementation of the MRT system are estimated based on changing accident risk levels and the economic value per accident, depending on accident severity. Finally, the cost per accident is calculated for all accident severity types and is divided into low and high estimates across both MRT scenarios (Fasecolda, 2018). The SAVi results for the avoided costs of accidents are shown in Table 24. The cumulative values of the avoided costs of accidents in the 8% MRT scenarios are COP 1,606 billion and COP 2,513 billion in the low and high estimates, respectively. Similarly, in the 16% MRT scenario, the low estimate is COP 3,157 billion, and the high estimate is COP 4,941 billion.

Table 24. Annual and cumulative values of avoided accident costs (COP billion/year, discounted at 3.5%)

	8% MRT scenario		16% MRT scenario	
Year	Low estimate	High estimate	Low estimate	High estimate
2028	22.73	35.58	63.23	98.97
2038	62.05	97.12	121.79	190.62
2048	43.99	68.85	86.33	135.13
2058	31.18	48.81	61.20	95.80
Cumulative (2022-2058)	1,606	2,513	3,157	4,941

Source: Authors.

4.5.9 NOISE POLLUTION

The shift from motorized transport modes to MRT will lead to a reduction of vehicles and, therefore, to a reduction of noise pollution. Noise emissions from various transport modes can cause negative health effects on humans exposed to it, mostly related to stress, including hypertension and myocardial infarction (heart attacks) (Ricardo-AEA et al., 2014). To estimate the avoided cost of noise pollution as a result of the implementation of the MRT system, three variables are considered: the number of people exposed to noise, the total cost of noise pollution, and noise characteristics between different modes of transportation. As indicated in Table 25, the avoided costs of noise pollution in the 8% MRT scenario amount to COP 119 billion; in the 16% MRT scenario, they are valued at COP 455 billion.

Table 25. Annual and cumulative values of avoided noise pollution costs (COP billion/year, discounted at 3.5%)

Year	8% MRT scenario	16% MRT scenario
2028 (1st year of operation)	1.69	4.70
2038	4.61	17.73
2048	3.27	12.57
2058	2.31	8.91
Cumulative (2022–2058)	119	455

Source: Authors.

5.0 Discussion and Conclusions

The SAVi assessment of the Metro de Bogotá MRT system offers a comprehensive range of results to inform transport infrastructure planners about the positive impacts associated with the MRT system. These results go beyond conventional transport infrastructure assessments, as they include the economic, social, and environmental added benefits, in addition to avoided costs. They clearly demonstrate the societal value of the project.

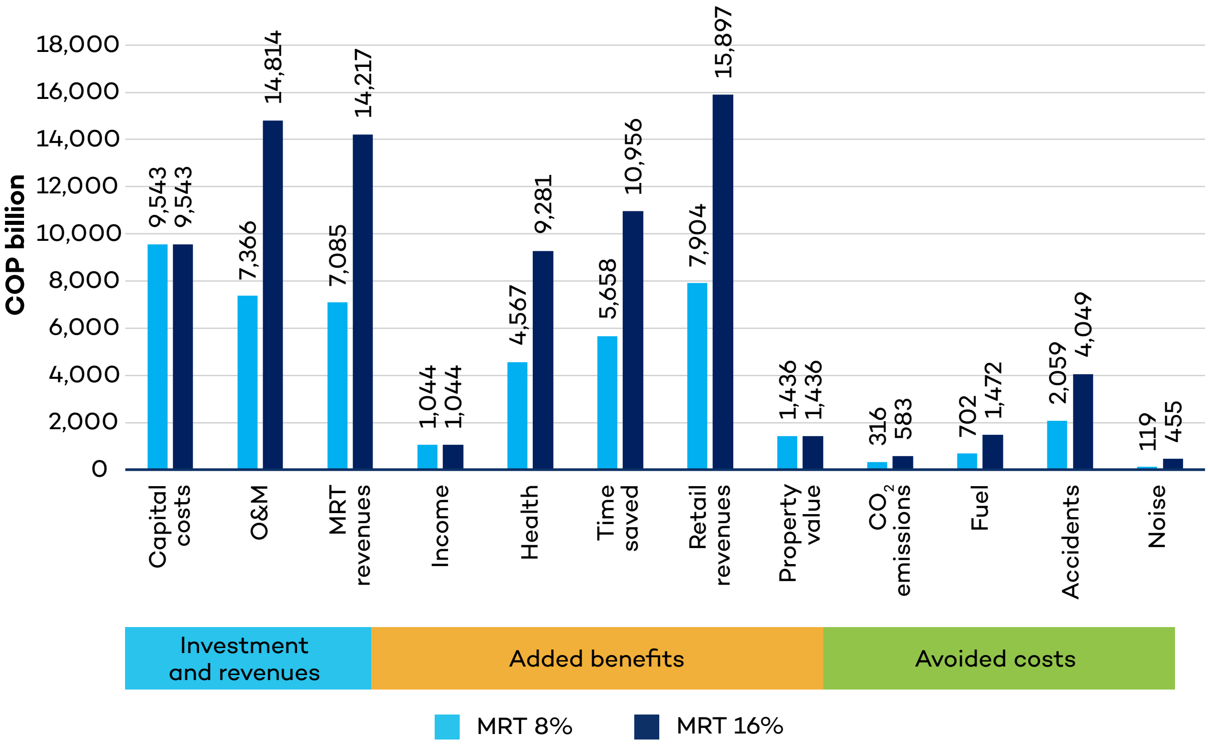
When the value-added benefits and avoided costs are incorporated into the CBA, the benefits resulting from the implementation of the MRT system in Bogota far exceed those calculated based solely on conventional parameters, such as investment costs and MRT revenues. This is evident in the disparity between the conventional BCR and the S-BCR. The BCR is 0.4 in the 8% MRT scenario and 0.6 in the 16% MRT scenario, whereas the S-BCR ranges from 1.5 to 2.9 in different estimates across both scenarios.

Furthermore, the SAVi assessment reveals positive outcomes for both MRT scenarios over the project period (2022–2058). When applying discount rates of 8% and 3.5%, the 8% MRT scenario shows cumulative discounted net results ranging from COP 7,682 billion to COP 20,283 billion in low and high estimates, respectively. The 16% MRT scenario yields cumulative discounted benefits ranging from COP 23,130 billion in the low estimate to COP 46,941 billion in the high estimate. Consequently, **this analysis demonstrates that the MRT system in Bogota is economically viable when the multiple environmental, social, and economic benefits and avoided costs are considered, thus making a compelling case for investing in the project**.

In summary, the MRT system in Bogota will have a positive impact on economic growth, both directly through MRT revenues and job creation and indirectly through the stimulation of retail and property value increases, as well as fuel savings. Moreover, it brings significant social benefits to the citizens of Bogota, such as improved health due to increased physical activity, reduced air pollution, and a decrease in traffic accidents. Furthermore, as an electric system, the MRT contributes to environmental benefits by reducing CO_2 emissions.

The SAVi assessment shows that the MRT system in Bogota contributes to achieving the city's mobility targets and provides access to job opportunities, particularly for residents in the southern and northern suburbs. Figure 2 presents the results of the SAVi assessment, including investment costs, revenues, added benefits, and avoided costs. The figure provides an average estimate of the low and high scenarios for both MRT scenarios.

Figure 2. Monetary values of the investment costs, revenues, added benefits, and avoided costs of the MRT system in Bogota



Source: Authors.

- **Economic benefits:** The implementation of the MRT system in Bogota will generate economic benefits for the government through MRT revenues and for businesses located near MRT stations through increased retail activity. Cumulative discounted revenues from MRT use over the project period (2022–2058) amount to COP 7,085 billion in the 8% MRT scenario and COP 14,217 billion in the 16% MRT scenario. In addition, retail revenues are expected to yield benefits of COP 7,904 billion in the 8% MRT scenario and COP 15,897 billion in the 16% MRT scenario.
- **Health effects:** The implementation and use of the MRT system in Bogota will have significant health benefits, including benefits from increased physical activity and avoided costs of air pollution. The discounted cumulative health benefits over the project period are valued at COP 3,829 billion and COP 5,306 billion in the low and high estimates of the 8% MRT scenario, respectively. In the 16% MRT scenario, these benefits are valued at COP 7,711 billion and COP 10,852 billion in the low and high estimates, respectively.
- **Efficient, convenient, and safe transport:** The use of the MRT system will enhance transportation efficiency in Bogota in terms of time saved. This time translates into a value of COP 1,029 billion and COP 10,287 billion in the low and high estimates, respectively, of the 8% MRT scenario. When looking at the 16% MRT scenario, these numbers are COP 1,992 billion and COP 19,920 billion in the low and high estimates, respectively, over the project period. Moreover, the MRT system will lead to

a reduction in traffic accidents, resulting in savings of COP 1,606 billion and COP 2,513 billion in the low and high estimates, respectively, of the 8% MRT and COP 3,157 billion and COP 4,941 billion in the low and high estimates, respectively, of the 16% MRT scenario.

- **Reduced emissions:** The SAVi assessment reveals that the transition from motorized transport to the MRT system contributes to a decrease in CO_2 emissions from private vehicles. The results show that 5.85 million tonnes of CO_2 emissions (valued at COP 316 billion) will be avoided in an 8% MRT scenario and that 10.79 million tonnes (valued at COP 583 billion) will be avoided in a 16% MRT scenario.

Limitations of the methodology employed in 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 of them can be quantified due to insufficient data, a lack of supporting literature for 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 integrate SAVi with another model to explore additional indicators or dynamics where the feedback loops can be explicitly represented. For example, a macroeconomic or dynamic model could be used to estimate GDP.

The results of the SAVi assessment of the MRT system in Bogota are directly linked to the evaluation of the Sustainable Transport Strategy in Bogota, demonstrating the importance of using integrated approaches at both infrastructure asset and policy levels. The long-term value of the MRT system will be enhanced by the growth of other public transport systems in the city, including the TransMilenio BRT system and the non-motorized transport system. By promoting sustainable intermodal transportation, it is possible to improve the efficiency of travel in Bogota and increase the economic benefits of all three public transport systems. A more detailed analysis of the above is provided in the SAVi assessment of the Sustainable Transport Strategy in Bogota.[4]

The application of SAVi facilitates a wide range of performance assessments beyond those currently employed in valuing the MRT system in Bogota. It offers valuable insights to government, citizens, and investors regarding the various elements that contribute to the creation of value in MRT systems. This can inform future strategies for sustainable mobility and support the case for improved transportation investments in cities. Additionally, it aids in identifying sources of funding and financing that align with the diverse financial and social returns of the project.

It is crucial that policy-makers design and implement processes that enable the recognition and accounting of the wider benefits of sustainable mobility infrastructure so that decisions are made in favour of transport investments that provide the greatest benefits to society while minimizing the environmental impacts.

[4] The SAVi assessment of the Sustainable Transport Strategy in Bogota can be found in the following link <to be added>.

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Appendix A. Causal Loop Diagram Description of the Mass Rapid Transit System in Bogota

Reinforcing loops (R)

R1 – Transportation shift dynamics: An increase in the demand for mass rapid transit (MRT) generates a decrease in the demand for road transport, which in turn generates an increase in the MRT demand. On the other hand, an increase in the demand for road transport generates a decrease in the demand for MRT, which increases the demand for road transport.

R2 – Investments in MRT driven by revenues from bus rapid transit: An increase in the investment in MRT leads to more MRT capacity and use and, hence, generates more revenues and more GDP, which increases the investment in transportation and investment in MRT.

R3 – Investment in MRT driven by MRT demand: The more the investment in MRT, the more MRT capacity and the more MRT demand, which will increase MRT investment as a result.

R4 – Investment in MRT driven by employment in transport: The increase in MRT investment increases MRT capacity and increases total employment in transport. The increase in the total employment in transport increases total factor productivity and GDP, which increases the investment in transportation and, again, the investment in MRT.

R5 – Investment in road infrastructure driven by employment in transport: The increase in investment in road infrastructure increases road vehicle fleet use, which generates an increase in total employment in transport. The increase in the total employment in transport increases total factor productivity and GDP, which increases the investment in transportation and, hence, the investment in road infrastructure.

R6 – Investment in MRT driven by fuel use from the road vehicle fleet: As investment in MRT increases, MRT capacity and demand also increase, which reduces the road vehicle fleet size. A reduction of the road vehicle fleet reduces fuel use, carbon dioxide (CO_2) emissions, and air pollution while increasing labour force health quality and total factor productivity. Increasing total factor productivity increases GDP, which increases investment in transportation and investment in MRT.

R7 – Investment in MRT driven by employment from power generation: The increase in MRT investment increases MRT capacity and increases electricity demand. The increase in electricity demand increases power generation, which increases total employment in transport, total factor productivity and GDP, which in turn increases the investment in transportation and the investment in MRT.

R8 – Investment in MRT driven by additional physical activity: An increase in MRT investment increases MRT demand, which leads to additional walking to and from MRT stations (physical activity), increasing labour force health quality, total factor productivity, and GDP, which increases investment in transport and MRT.

R9 – Investment in MRT driven by property valorization: An increase in MRT investment increases the MRT capacity and demand, which increases the value of the properties impacted by the MRT infrastructure. Property valorization increases GDP and leads to more investment in transportation and MRT as a result.

R10 – Investment in MRT driven by retail revenues: An increase in MRT investment increases MRT capacity and demand, leading to an increase in retail revenues in retail establishments around MRT stations. Increases in retail revenues increase GDP, investment in transportation, and, finally, investment in MRT.

R11 – Investment in MRT driven by traffic accidents: The increase in investment in MRT leads to more MRT demand and less road vehicle fleet use, which translates into fewer traffic accidents. A decrease in traffic accidents generates an increase in the total factor productivity, increasing GDP and investment in transportation and, finally, increasing investment in MRT.

R12 – Investment in MRT driven by noise pollution from road transport: An increase in MRT investment generates an increase in the MRT demand and a decrease in road vehicle fleet use, which results in less noise pollution and a higher labour force health quality. A higher labour force health quality results in an increase in total factor productivity and GDP, which increases investment in transportation and investment in MRT.

Balancing loops (B)

B1 – Impact of traffic congestion on-road vehicle fleet use: An increase in road vehicle fleet use increases traffic congestion and time spent on transportation, which reduces the use of road transportation.

B2 – Impact of MRT demand on travelling time: As MRT demand increases, road vehicle fleet use and traffic congestion are reduced, leading to reduced time spent on transportation and reduced MRT demand.

B3 – Impact of accidents on investment in roads: An increase in the investment in road infrastructure increases road vehicle fleet use, which increases traffic accidents, decreasing total factor productivity and GDP. A decrease in GDP decreases the investment in transportation, decreasing the investment in road infrastructure.

B4 – Impact of fuel use and CO_2 emissions on investment in roads: An increase in the investment in road infrastructure increases road vehicle fleet use, which increases fuel use, CO_2 emissions, and air pollution while decreasing labour force health quality, total factor productivity, and GDP. A decrease in GDP leads to a decrease in the investment in transportation, decreasing the investment in road infrastructure.

B5 – Impact of CO_2 emissions from power generation on investment in MRT: An increase in MRT investment leads to an increase in MRT capacity, resulting in an increase in electricity demand and power generation. Increased power generation results in more CO_2 emissions and air pollution, depending on the energy source, which decreases labour force health quality, total factor productivity, and GDP. A decrease in GDP reduces investment in transportation and investment in MRT.

B10 – Impact of noise pollution on investment in roads: An increase in investment in road infrastructure leads to an increase in road vehicle fleet use, generating more noise pollution, which decreases labour force health quality, total factor productivity, and GDP. A decrease in GDP decreases investments in transportation and road infrastructure.

Appendix B. Methodology

The Sustainable Asset Valuation (SAVi) 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.

This 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 the MRT system in Bogota, data on demand for transport, vehicle mix and the expected reduction in vehicle-km and passenger-km, project ambition in km, and investments were obtained from project feasibility studies. 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 a lack of location-specific data, additional data sources from other locations were used to quantify variables that served to measure and monetize added benefits and avoided costs.

To quantify the variables, SAVi estimates the net difference of biophysical parameters between a baseline scenario and an intervention scenario (e.g., a kilogram of reduced NO_x emissions due to the use of the MRT system 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 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 or other geographies.

Appendix C. Main Assumptions and Data Sources Used for the Model

Table C1. Overview of key assumptions used in the mass rapid transit (MRT) 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**
Income creation from employment	Employment creation during MRT construction	8,000 direct and 20,000 indirect jobs	Capital (2019)	X			
	Operation and maintenance jobs per km of MRT	49.5 jobs	Metro de Medellín (2022); company reports		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	

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**
Revenues from MRT use	Average MRT ticket price	COP 3,216	TransMilenio (2022)		X		
	MRT ticket price annual increase	4.8%	TransMilenio (2022)		X		
Health impacts	Average walking time for MRT users	10 minutes per day	Carrigan et al. (2013)				X
	Crude death rate	4.33 people per 1,000	Saludata (2022)			X	
	Value of a statistical life in Colombia	USD 0.64 million per life	Mardones & Riquelme (2018)				X
	Cost of different air pollutants	COP/1 kg of air pollutant	Rahul & Verma (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;	World Health Organization (2017)			X	
		Bus = 13 km/h; Cycling = 16 km/h	Pardo (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		
	Working hours in Bogota	2,511 annual working hours	UBS (2018)				X
	Average annual salary in Bogota	COP 31,876,781	Salary Explorer (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**
Retail revenues	Average yearly retail spending in Bogota per year per person	COP 5,365,161	BBVA (2019)		X		
	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, P. (2007); Song & Knaap (2003)				X
	Average property value in Bogota	COP 4,166,666 per m^2	Quevedo (2022)		X		
CO_2 emissions	Social cost of carbon	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		

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**
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	
	Price per litre of fuel in Colombia	Petrol (2,337 COP/L)	Trading Economics (2022)			X	
Accidents	Annual vehicle-km in Bogota		Pachón (2015)		X		
	Annual number of accidents per severity		Pachón (2015)		X		
	Rate of accidents/ 1,000 vehicle-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 vehicle-km	Car (COP 7.5244); Motorcycle (COP 63.7363); Bus & BRT (COP 7.0818)	van Essen et al. (2011)				X

Source: Authors.

Appendix D. Integrated Cost-Benefit Analysis With Undiscounted Values

Table D1. Integrated cost-benefit analysis (undiscounted values of the MRT scenarios based on a project period of 35 years)

	MRT scenario: 2022–2058			
	MRT 8%		MRT 16%	
Integrated CBA (undiscounted)	**Low estimate (COP billion)**	**High estimate (COP billion)**	**Low estimate (COP billion)**	**High estimate (COP billion)**
Total investment costs	**49,314**	**49,314**	**85,960**	**85,960**
Capital cost	12,820	12,820	12,820	12,820
O&M cost	36,494	36,494	73,140	73,140
Total revenues	**45,067**	**45,067**	**90,224**	**90,224**
Revenues from MRT use	45,067	45,067	90,224	90,224
Total added benefits	**52,451**	**76,817**	**102,148**	**148,686**
Income creation from employment	1,581	1,581	1,581	1,581
Health impacts*	8,210	11,392	16,512	23,267
Value of time saved*	2,211	22,109	4,277	42,775
Retail revenues	39,163	39,163	78,491	78,491
Property prices*	1,286	2,572	1,286	2,572
Total avoided costs	**7,953**	**13,086**	**16,533**	**27,120**
CO_2 emissions	679	679	1,252	1,252
Fuel use	3,468	3,468	7,266	7,266
Accidents*	3,451	5,402	6,780	10,612
Noise pollution	257	257	982	982

	MRT scenario: 2022–2058			
	MRT 8%		**MRT 16%**	
Integrated CBA (undiscounted)	**Low estimate (COP billion)**	**High estimate (COP billion)**	**Low estimate (COP billion)**	**High estimate (COP billion)**
Net results of valued-added benefits and avoided costs				
Cumulative net benefits (COP billion, undiscounted)	**56,060**	**82,377**	**122,691**	**173,061**
BCR	0.9	0.9	1.0	1.0
S-BCR	**2.1**	**2.7**	**2.4**	**3.0**

Source: Authors.

* Added benefits and avoided costs that have a low and a high estimate

SAVi Sustainable Asset Valuation

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