SAVi Sustainable Asset Valuation

Sustainable Asset Valuation (SAVi) of a Public Bicycle Sharing System in Dwarka, New Delhi, India

A focus on the environmental, social and economic impacts of non-motorized transport infrastructure

SUMMARY OF RESULTS

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Written by Laurin Wuennenberg, Andrea M. Bassi and Georg Pallaske

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About SAVi

SAVi is a simulation service that helps governments and investors value the many risks and externalities that affect the performance of infrastructure projects.

The distinctive features of SAVi are:

- Valuation: SAVi values, in financial terms, the material environmental, social and economic risks and externalities of infrastructure projects. These variables are ignored in traditional financial analyses.
- Simulation: SAVi combines the results of systems thinking and system dynamics simulation with project finance modelling. We engage with asset owners to identify the risks material to their infrastructure projects and then design appropriate simulation scenarios.
- Customization: SAVi is customized to individual infrastructure projects.

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This SAVi assessment was commissioned by the Centre for Green Mobility, India.

centre for green mobility

Executive Summary

This report presents the results of the Sustainable Asset Valuation (SAVi) applied to the Public Bicycle Sharing (PBS) system in Dwarka, Delhi.

The city district Dwarka is located in Delhi, India, and—like many large cities in India and other parts of the world—is coping with a range of urban mobility and development challenges. These challenges include long commuting times, rising numbers of private motorized vehicles, resulting in high traffic volumes and congestion, safety concerns, air pollution, health impairments and economic inefficiencies.

Dwarka is foreseen as a pilot area for implementing a PBS system that promises to be an important element for realizing sustainable and multi-modal transport infrastructure in Delhi. The Centre for Green Mobility, the concept developer of the PBS system, invited the International Institute for Sustainable Development (IISD) to customize the Sustainable Asset Valuation (SAVi) methodology for assessing the suggested PBS system in Dwarka. The developed SAVi PBS model serves to estimate and value the environmental, social and economic co-benefits and avoided costs generated by different demand scenarios for the PBS system. The SAVi assessment consists of the following elements that are presented in this report:

- A calculation of three demand scenarios for the implemented PBS system and associated changes in transport use patterns in Dwarka.
- A valuation of nine externalities resulting from a successfully implemented PBS system.
- A scenario comparison of the valued externalities.
- An integrated cost–benefit analysis of the PBS system, including valued externalities defined as added benefits and avoided costs per PBS demand scenario.

Table ES 1 summarizes the results of the valued environmental, social and economic externalities. The results for each of the nine externalities are indicated as daily monetary values. Externalities are categorized into "Added Benefits" and "Avoided Costs," and results are presented per PBS demand scenario. Moreover, the SAVi results are separated into a high-value and a low-value estimate for several externalities because underlying data and assumptions for the valuation of an externality can differ.

The total net value of each scenario is positive. The higher the demand for using the PBS system, the higher the benefits and avoided costs. Consequently, the two positive net values of the high-demand scenario are higher than the net values of the medium- and low-demand scenarios. The two bottom lines of Table ES 1 present cumulative net values over a project period of 20 years. Results are indicated as undiscounted and discounted numbers. The discounted net value of the high-value estimation for the high-demand scenario amounts to more than INR 12.4 billion. The high-value estimate for the medium-demand scenario is around 16 per cent lower, and the respective net result for the low-demand scenario is more than 25 per cent lower. The discounted low-value estimate for the high-demand scenario amounts to only slightly more than INR 5 billion, while the comparable results for the medium- and low-demand scenarios are more than 19 per cent and almost 30 per cent lower, respectively.

Table ES 1. Summary table of valued externalities (in Rs): Added benefits and avoided costs per PBS demand scenario

Costs and benefits	Unit	PBS low demand		PBS medium demand		PBS high demand	
		Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate
Added benefits							
Benefits from physical activity	INR/day	38,550		54,744		78,104	
Value of time saved	INR/day	168,910		239,865		363,532	
Increases in retail revenues	INR/day	101,049		143,498		217,481	
Increase in property values	INR/day	487,397	1,457,123	487,397	1,457,123	487,397	1,457,123
Total added benefits	**INR/day**	**795,906**	**1,765,632**	**925,504**	**1,895,230**	**1,146,514**	**2,116,240**
Avoided and added costs							
Avoided cost of air pollution	INR/day	33,415	339,093	47,452	481,538	71,917	729,805
Cost of increased exposure to air pollution	INR/day	(54,181)		(76,941)		(116,610)	
Avoided social cost of carbon	INR/day	2,003		2,845		4,311	
Avoided cost of accidents	INR/day	1,891	16,784	2,685	23,834	4,070	36,122
Avoided cost of noise pollution	INR/day	15,100		21,443		32,498	
Total avoided costs	**INR/day**	**(1,772)**	**318,799**	**(2,516)**	**452,719**	**(3,814)**	**686,126**

Costs and benefits	Unit	PBS low demand		PBS medium demand		PBS high demand	
		Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate
Net results of valued externalities							
Total net value per day	INR/day	794,134	2,084,431	922,988	2,347,949	1,142,700	2,802,366
Total net value per year	INR million/year	289.9	760.8	336.9	857.0	417.1	1,022.9
Total net value over 20 years	INR million	5,797.2	15,216.3	6,737.8	17,140.0	8,341.7	20,457.3
Total net value over 20 years (discounted*)	INR million	3,524.1	9,250.1	4,096.0	10,419.5	5,071.0	12,436.1

**Discount factor: 6 per cent*

The added benefits and avoided costs valued in this SAVi assessment are also incorporated into a cost–benefit analysis of the PBS system in Dwarka. Table ES 2 presents these results. Compared to the conventional net results of the PBS system, which indicate a deficient project under all demand scenarios, the SAVi net results are more convincing. These results highlight that when integrating externalities into the assessment, the PBS system can be considered beneficial from a societal point of view and hence should be rated a worthwhile investment. This holds true across the three demand scenarios, while the higher the demand for the PBS system, the higher the net benefits of the project.

Table ES 2. Integrated CBA, daily values per PBS scenario (in INR) based on a project period of 20 years

Costs and benefits	Unit	PBS low demand		PBS medium demand		PBS high demand	
		Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate
Conventional costs & revenues							
Total costs	INR/day	121,270		121,270		121,270	
Total revenues	INR/day	30,138		42,801		64,869	
Conventional net results	**INR/day**	**(91,132)**		**(78,468)**		**(56,401)**	
Valued externalities							
Total added benefits	INR/day	795,906	1,765,632	925,504	1,895,230	1,146,514	2,116,240
Total avoided costs	INR/day	(1,772)	318,799	(2,516)	452,719	(3,814)	686,126
Added benefits + avoided costs	**INR/day**	**794,134**	**2,084,431**	**922,988**	**2,347,949**	**1,142,700**	**2,802,366**
SAVi net results							
SAVi net results per day	**INR/day**	**703,002**	**1,993,299**	**844,520**	**2,269,481**	**1,086,299**	**2,745,965**
Total SAVi results over 20 years	**INR million**	**5,131.9**	**14,551.1**	**6,165.0**	**16,567.2**	**7,930.0**	**20,045.5**
Total SAVi results over 20 years (discounted*)	**INR million**	**3,143.6**	**8,869.6**	**3,764.5**	**10,088.0**	**4,824.9**	**12,190.0**

**Discount factors: 8 per cent for conventional costs and revenues, 6 per cent for added benefits and avoided costs (based on Institute of Economic Growth, 2018)*

It is important to analyze the SAVi net results in the context of sustainable transport infrastructure development in Dwarka. Deploying the PBS system successfully, achieving the demand figures estimated by the Centre for Green Mobility (CGM) and realizing the added benefits and avoided costs as calculated in this SAVi assessment build on the premise that required bicycle infrastructure will be provided by the municipality. This includes the construction of bicycle lanes and adjustment of existing road infrastructure, new street lighting and traffic light systems to improve safety, street furniture, planting of trees to provide shade and better ambience for cyclists and pedestrians. The SAVi net results in Table ES 2 can thus be considered as benchmark values for policy-makers and public infrastructure planners. By carefully assessing the SAVi net results of the different demand scenarios over a period of 20 years enables policy-makers to determine the scale of investment that could be earmarked for deploying the above-mentioned infrastructure components. Even if conservative demand numbers for the PBS system and low estimates for the valuation of externalities are assumed, discounted lifecycle costs for the additional infrastructure components can still be up to INR 3.143 billion. If these investment decisions are made, it will become more likely that high demand numbers for the PBS system can be achieved. This would again increase co-benefits resulting from increased use of the PBS system and the corresponding replacement of motorized transport.

Integrated assessments such as this one conducted using the Sustainable Asset Valuation (SAVi) methodology can help to make a stronger case for bicycle sharing and other forms of sustainable mobility solutions. Altogether, this assessment has shown that the PBS system advances the realization of sustainable mobility targets in Dwarka, improves the quality of life and therefore delivers the transport policy objectives defined in the Delhi Master Plan 2021.

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Abbreviations

Capex	capital expenditure
CGM	Centre for Green Mobility
CBA	cost–benefit analysis
CO	carbon monoxide
CSR	corporate social responsibility
HC	hydrocarbons
HEAT	health economic assessment tool
NO_x	nitrogen oxides
Opex	operational expenditures
PBS	public bicycle sharing
pkm	passenger kilometre
$PM_{2.5}$	Particulate matter with a diameter of less than 2.5 micrometres
SAVi	sustainable asset valuation tool
SCC	social cost of carbon
SD	system dynamics
vkm	vehicle kilometre
VSL	value of statistical life

Glossary

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

Feedback loop: "Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts et al., 1983).

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 (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 both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and allow to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (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 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).

Stock and flow variables: "A *stock* variable represents accumulation and is measured at one specific time. A *flow* variable is the rate of change of the stock and is measured over an interval of time" (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).

1.0 Introduction

1.1 Mobility Challenges and New Transport Strategies in Delhi

New Delhi, like many other densely populated cities in India and around the world, faces urban mobility and transport challenges. It is being forced to cope with issues such as long commuting times, rising numbers of private motorized vehicles that result in high traffic volumes and congestion, safety concerns and air pollution. Economic inefficiencies and negative health impacts are only two of the many negative consequences of urban transport planning that is centred around the automobile. Moreover, other modes of transport, including non-motorized and public transport systems, are negatively affected and cannot be used to their full potential.

The Master Plan of Delhi 2021 defines targets for transformative changes in the city's transport system to ensure safe, equitable, convenient, affordable, energy-efficient and environmentally friendly commuting for the residents of Delhi. The mobility transition is meant to address the population's needs and enhance their quality of life (CGM, 2015; DDA, 2017). The Master Plan highlights seven major transport policy objectives (DDA 2017, p. 12-2):

- "80:20 modal share, favouring public transport (excluding walking trips) by 2021.
- Reduction in vehicular emissions to meet the National Ambient Air Quality Standard.
- Achieving zero fatalities through an uncompromising approach to the reduction of fatalities of all road and transport users.
- Safety and accessibility for everyone through safe, convenient, comfortable and barrier-free movement for all users.
- Bringing about a more equitable allocation of road space with people, rather than vehicles, as its main focus.
- Affordability, by providing a range of mobility options for all users.
- Efficiency in the movement of people and goods."

Mobility strategies to achieve these objectives include implementation of integrated and mutually complementary multi-modal transportation infrastructure, provision of safe facilities for pedestrians and cyclists (with particular attention to women, children, elderly and differently abled), restructuring of arterial roads and street network to optimize public transport and non-motorized transport use as well as to reduce the use of private transport modes to minimize pollution and congestion (DDA 2017).

One method of encouraging the use of non-motorized transport and enhancing the use of public transport options is the implementation of a public bicycle sharing (PBS) system. The IBI Group (2016, p. xiii) describes the typical PBS system as a

> high-quality bicycle-based public transport system in which bicycles, stored in a closely spaced network of stations, are made available for short-term shared use.

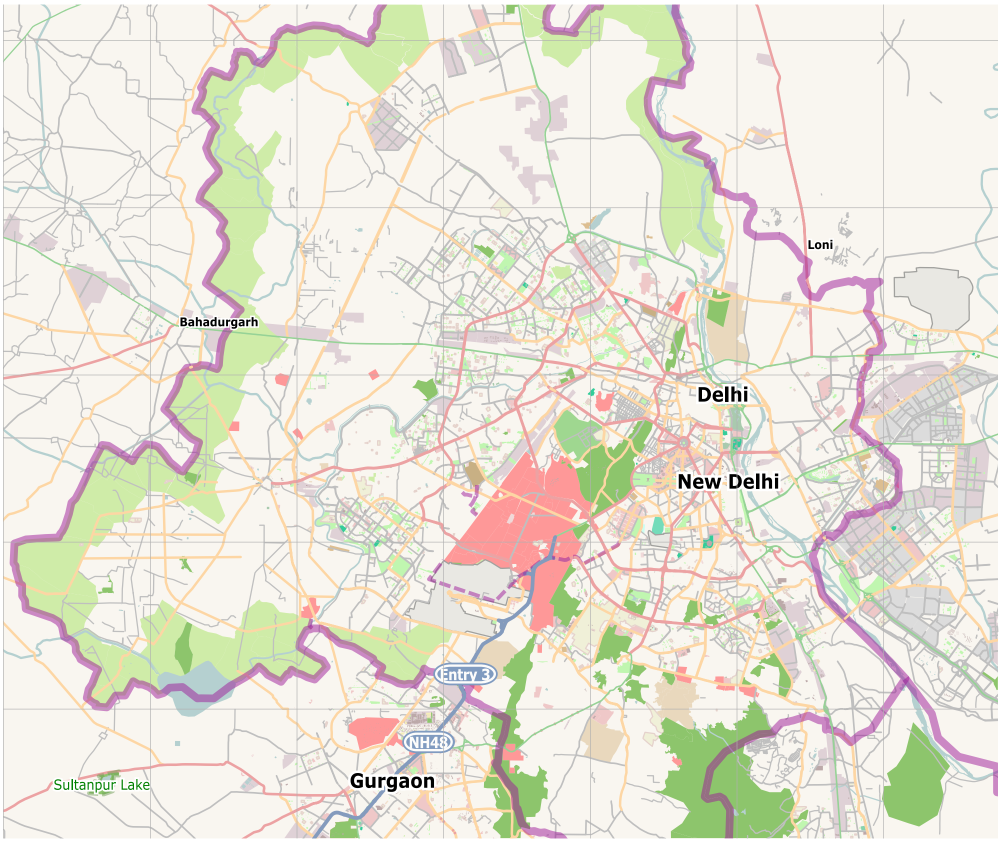
> Bicycle sharing programs involve installing multiple bicycle stations at several different key locations. A user checks out the bicycle from one location, rides to his or her destination, and drops off the bicycle to another location. The operators coordinate the redistribution of bicycles and ensure availability of the vehicles at locations with the highest demand at any given time.

PBS systems are often set up close to public transit stations to provide an alternative, non-motorized transport solution for last-mile connectivity. Also, PBS stations are provided in locations where people need a convenient transport mode for short trips to reach their workplaces or other places of interest (IBI Group, 2016).

1.2 Purpose of a Sustainable Asset Valuation for Dwarka's Public Bicycle Sharing System

Dwarka sub-city covers an area of more than 56 square kilometres and is located in the south-west district of the National Capital Territory of Delhi, in proximity to the Indira Gandhi International Airport (see Figure 1). It is home to roughly 700,000 people, many of whom live and work within Dwarka, while additional people commute to it from other districts.

Figure 1. Location of sub-city Dwarka in the National Capital Territory of Delhi



Source: Wikimedia, n.d.

Given the mobility and urban development challenges that Dwarka is coping with, it is considered an appropriate pilot area for implementing and testing a PBS system. Piloting a PBS system allows the collecting of evidence to show how the broader implementation of PBS systems can contribute to realizing the objectives of the Delhi Master Plan.

The key objectives of the PBS system in Dwarka are (CGM, 2015, p. 2):

- "To provide economical mobility options to the citizens: To provide an economical and convenient mode of transport for short trips as an alternative to motorized forms of transit that cost more.
- To serve last-mile connectivity: To bridge the gap in public transportation for end-to-end journeys; this would attract high ridership.
- To minimize adverse effects on the environment: To reduce the negative impacts that motorized vehicles have on the environment by encouraging people to opt for cycling.
- To reduce the congestion on roads: To reduce the number of vehicles on the road by catering to short trips through PBS which will help in reducing the number of active vehicles on the roads and hence serve as a long-term strategy to improve transport scenario."

The CGM has analyzed secondary data on the transport system's status quo, mobility strategies and the socioeconomic characteristics of Dwarka. It also conducted surveys to collect primary data on mobility patterns and transport needs in the sub-city. Based on its findings, the CGM has developed a detailed PBS implementation program for Dwarka, including system design and distribution, an operational model, demand forecasts from daily commuters and households, cost calculations for implementing and operating the PBS system as well as branding and marketing strategies to acquire revenues beyond user fees. The research results and strategies are presented in a detailed project report (CGM, 2015), which laid the basis for issuing a public tender in 2019 to select the project developer and operator of the PBS system in Dwarka. CGM's research also promoted the ongoing construction of bicycle lanes in the sub-city.

Despite this significant—and implementable—project concept, CGM's analysis does not yet demonstrate the multiple benefits of a well-implemented PBS system for Dwarka and to what extent such a system can yield mobility improvements as set forth in the Delhi Master Plan. As of yet, environmental, social and economic benefits and costs associated with a successfully implemented PBS system in Dwarka are merely anecdotal, based on evaluations of PBS systems implemented in other cities around the world. To strengthen the business case for the PBS system in Dwarka and encourage public authorities to invest in providing the baseline bicycle and safety infrastructure, it is vital to estimate and value the co-benefits, avoided costs and additional costs expected from this particular PBS system.

For this purpose, CGM invited the International Institute for Sustainable Development (IISD) to customize the Sustainable Asset Valuation (SAVi) methodology for assessing the suggested PBS system in Dwarka. The developed SAVi PBS model serves to estimate and value the environmental, social and economic co-benefits and avoided costs generated by a successfully implemented PBS system, as its use implies a shift from other transport modes to cycling. The co-benefits and avoided costs generated by changing mobility patterns can be termed the "externalities" of the PBS system. As part of this assessment, their monetary values will be integrated into a cost–benefit analysis of the PBS system. Because demand for new and transformative public transportation projects is difficult to forecast, the SAVi assessment includes three different demand scenarios and compares the results to a baseline scenario that does not include a PBS system.

Section 2 of the report presents assumptions, data sources and valuation methodologies of the nine externalities assessed by the SAVi PBS model. It also summarizes demand figures and shifting mobility patterns associated with the three demand scenarios. The valuation results per externality are explained in detail in Section 3 of the report. They are also summarized in a table that presents daily monetary values generated by each demand scenario. In Section 4, the daily values of these externalities are integrated into a cost–benefit analysis that includes the capital and operational expenditures for the PBS system as well as its revenue streams per demand scenario. The SAVi net results represent the societal value of the PBS system in Dwarka. The results also indicate benchmark values for policy-makers and city planners to determine the maximum investment volume for additional bicycle and road safety infrastructure (in addition to expenditures for the PBS system implementation and operation). Section 5 concludes by illustrating how the results of the SAVi assessment underscore the PBS system's contribution toward achieving the transport policy objectives defined in the Delhi Master Plan 2021. The valuations calculated by SAVi demonstrate the real value added of new transport systems—in doing so, they can increase the political will for widespread implementation of sustainable and transformative public transport concepts in Delhi and other parts of the world.

2.0 Externalities, Assumptions and Scenarios

This chapter introduces the underlying valuation methodologies of this SAVi assessment and definitions of the three demand scenarios. It begins by presenting the assumptions, data sources and valuation methodologies of the nine externalities valued by the SAVi PBS model. This is followed by a summary of demand figures and shifting mobility patterns associated with the three demand scenarios. The chapter is followed by the SAVi assessment results of the PBS system in Dwarka.

2.1 Externalities Valued by the SAVi Assessment

The SAVi assessment provides the monetary valuation of project-related externalities. This includes monetized added benefits, external costs and avoided costs of an implemented PBS system and provided infrastructure to use the system. Table 1 lists all externalities considered for this assessment.

Table 1. Externalities considered in the SAVi assessment

Externalities	• Benefits from physical activity • Value of time saved • Changes in retail revenues • Changes in property values • Cost of air pollution • Cost of increased exposure to air pollution • Cost of CO_2 emissions • Cost of accidents • Cost of noise pollution

2.1.1 Benefits From Physical Activity

Physical activity, such as walking and cycling, has beneficial health effects. 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 (WHO, 2017). The methodology of HEAT 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 methodology is also applied in this SAVi assessment to value the benefits for people in Dwarka switching from motorized transport modes to cycling through the provision of the PBS system. To consider the national context in India for the valuation of health benefits, a crude death rate in Delhi of 3.6 people per 1,000 was used (MHA 2017), and a VSL of INR 28 million was obtained from a recent report of The Energy and Resources Institute (TERI, 2018). The report summarized estimations of the overall benefits of increased cycling rates in India using the methodology of HEAT.

The calculation of benefits from physical activity in this SAVi assessment assumes a shift from walking to cycling, which reduces the overall time spent active for that specific group and hence adds to increased mortality of those affected. This is due to the fact that cycling the same distance can be achieved in a shorter period of time compared to walking and hence results in fewer minutes of physical activity per day for those that used to walk. All other transport users switching to cycling will benefit from reduced mortality. The weighted average reduction in mortality represents the net impact of the shift in mobility from all indicated modes toward cycling. This value differs depending on the calculated PBS demand scenario.

The valuation of health benefits further assumes a build-up period of five years. Health benefits (= reduced mortality) from increased physical activity only start materializing after this build-up period. To arrive at a daily health benefit value, a time period of 20 years was used for the calculations.

2.1.2 Value of Time Saved

The value of time saved represents the economic value of improved mobility resulting from the PBS system. The value of time saved is estimated in real terms, which means this assessment does not apply a growth rate to the value of time saved over time. It is estimated by assuming an average speed for each assessed transport mode. TERI (2018) estimates the speed of cycling in Delhi as 12 km/h. The assumed speeds of the other transport modes are informed by literature and consultations with the client. They are as follows:

- Walking: 5 km/h (WHO, 2014)
- 4-wheel: 26 km/h
- 2-wheel: 23 km/h
- 3-wheel auto rickshaw: 16 km/h
- 3-wheel pedal rickshaw: 10 km/h
- Buses: 12 km/h

The shift from other transport modes to cycling will result in differing travel speeds. Consequently, the PBS system will lead to either time savings or additional time spent for commuting, depending on the current mode of transportation. The respective hourly figure of time saved/spent is multiplied by the hourly salary of commuters to calculate the value of the hourly time saved/spent. The hourly salary is based on assumed 2,511 annual working hours in Delhi (UBS 2018) and an average annual salary in Delhi amounting to INR 365,529 (*Times of India,* 2019).

2.1.3 Changes in Retail Revenues

Studies suggest that the mode of transport and commuting speed have an impact on retail spending. If the walkability of an area improves, people tend to spend more time—and money—in that area (Rabl & Nazelle, 2012; Victoria Transport Policy Institute [VTPI], 2018).

We assume for this assessment that an implemented PBS system will be complemented by improved cycling and walking infrastructure such as cycling lanes and street lighting. Both modes of non-motorized transport are associated with higher retail spending. The approach for quantifying additional retail sales assumes increased spending of approximately 42.2 per cent (VTPI, 2018) per transport user that shifts to the PBS system, excluding the people who used to walk or cycle before the PBS system was implemented. The additional retail spending volume per PBS demand scenario was calculated using the baseline average minimum daily retail spending in Delhi (Statista, 2019) multiplied by the assumed 42.2 per cent retail spending increase and the number of defined PBS users per demand scenario.

2.1.4 Changes in Property Values

The shift from motorized transport to active forms of transportation tends to have positive impacts on property values. The shift implies changes in provided transport and safety infrastructure which improves walkability in affected areas. Other impacts such as the reduction in air pollution, reduction in noise pollution and higher retail spending can also have positive effects on real estate values.

In this SAVi assessment, we consider only the impact of improved walkability on property value—assuming the implementation of the PBS system will be accompanied by cycling and pedestrian infrastructure that enables safe cycling and associated co-benefits for improved walking. Research has shown that improved walkability in a city can increase property values by 5 per cent to 15 per cent (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 valuation of property value increases in Dwarka is based on the total hectares of residential and commercial property in the area where the PBS system is implemented. Together, this totals 3,263 hectares, or 32.63 million m^2 (CGM 2015). The average baseline value per m^2 of property in Dwarka is obtained from Makaan (2019). The total property value increase is then estimated by multiplying the average property price per m^2 of the estimated area being affected by 5 per cent (lower end valuation) and 15 per cent (higher-end valuation). The results represent the total one-time increase in property values in the area affected by the PBS system.

It is important to note that we forecast the potential increase in property value based on the direct impacts of the investment assessed, but we do not consider city-wide dynamics. For instance, if, as a result of the project, Dwarka becomes more attractive than other parts of Delhi, demand for apartments in Dwarka may grow faster than in neighbouring areas. This will likely lead to a stronger increase in property valuation than forecast for Dwarka.[1]

[1] In addition, this increase in property value may create housing pressure on low-income families, possibly resulting in migration to other parts of Delhi due to the gentrification and higher quality of life of Dwarka. While we do not consider these dynamics, it is important to mention that social housing could represent a solution in this scenario, limiting the negative impact of rising costs for the current population of Dwarka.

2.1.5 Cost of Air Pollution

The shift from motorized, fuel-based transport modes to the use of a non-polluting PBS system in Dwarka will reduce the transport sector's air pollution. The avoided cost of air pollution is estimated based on each transport mode's air pollutants and the health costs associated with emitting one less kg of a specific air pollutant. The SAVi PBS model includes the valuation of $PM_{2.5}$, NO_x, CO and HC. The difference in the total cost of air pollution between the baseline and the different PBS scenarios is calculated by multiplying the health cost of each respective pollutant per transport mode with the volume of air pollution avoided due to using the PBS system. Air pollutants per transport mode in Delhi are based on Goel & Guttikunda (2015), and the respective health costs of each air pollutant are captured by a low-cost and a high-cost factor estimated by CE Delft et al. (2011) for $PM_{2.5}$ and by Sengupta & Mandal (2005) for the remaining three air pollutants. Table 2 summarizes these input parameters for the motorized transport modes that are partly replaced by using the PBS system.

Table 2. Air pollutants (in g/km) per transport mode in Delhi and health cost valuation per emitted air pollutant

Transport mode	Unit	$PM_{2.5}$	NO_x	CO	HC
Bus	g/km	2.672	21.38	11.92	3.311
4-wheeler	g/km	0.05	0.243	3.595	0.469
2-wheeler	g/km	0.071	0.086	2.027	2.049
Auto rickshaw	g/km	0.108	0.329	2.958	5.137
Valuation of emissions	**Unit**	**$PM_{2.5}$**	**NO_x**	**CO**	**HC**
Low value	INR/kg	3,912	7.37	0.05	0.6
High value	INR/kg	69,884	108.26	0.46	6.73

2.1.6 Cost of Increased Exposure to Air Pollution

Cycling in urban environments—such as Delhi's—with high background concentrations of air pollutants, tends to have worse health effects than using motorized forms of transport. This is the case because the pollutant dose increases for cyclists due to direct exposure in traffic and higher inhalation rates during the physical activity as opposed to sitting in vehicles (Rabl & Nazelle, 2012). The other exposure factor is the ambient air pollution concentration faced by cyclists. Depending on traffic volumes, location of the cycle path and filter technologies used in vehicles, the ambient concentration of air pollutants can vary for cyclists compared to vehicle users. However, given the extremely high concentration of air pollution in Delhi and the effects of higher inhalation rates, we assume an increased exposure for transport users that switch from motorized transport to cycling. The negative health effects caused by PM2.5 with respect to all-cause mortality are considered in this SAVi assessment—they range from higher risks for strokes, heart diseases, lung cancer and respiratory diseases.

The cost of increased exposure to air pollution is estimated based on the health cost per km travelled per person as indicated by Rabl and Nazelle (2012) and the total vehicle kilometre (vkm) shifted from motorized to non-motorized transport in Dwarka. The health costs calculated by Rabl and Nazelle (2012) are based on 23 ug/m^3 background concentrations of $PM_{2.5}$ observed as an average value in different European cities.[2]

Even though significantly higher background concentrations of $PM_{2.5}$ are found in Delhi—for example, 113.5 ug/m^3 was the average $PM_{2.5}$ concentration in 2018 (AirVisual 2019)—we lack local information about estimated health cost occurring during physical activity under such polluted conditions. In addition, the exposure and hence the negative health effects strongly depend on where cycling takes place. If it takes place on a separate cycling path next to the road with motorized traffic, the negative health effects will be much lower compared to cycling on the main street behind cars and buses. Due to the lack of these contextual factors, we base our calculations entirely on Rabl and Nazelle (2012).

We note that given the significantly higher $PM_{2.5}$ background concentration in Delhi compared to the European context, we are likely underestimating the negative health costs from a switch from driving to cycling in Dwarka. However, we also include the number of people switching from walking to cycling (representing almost 36 per cent of the people switching to cycling under each PBS demand scenario) into the group of people experiencing higher air pollution exposure and hence negative health effects. This can be justified by the fact that cyclists have a higher ventilation rate compared to pedestrians and will thus experience increased negative health effects from air pollution. However, this negative impact might not be as high as that for people switching from driving to cycling: our calculations assume full impacts for those pedestrians switching to cycling. Consequently, we likely overestimate the added negative health effect for pedestrians switching to cycling.

2.1.7 Cost of CO_2 Emissions

The replacement of motorized, fossil fuel-based transport modes by a PBS system and increased volumes of cycling is accompanied by a reduction of the transport sector's CO_2 emissions. The reduced cost of CO_2 emissions is computed by multiplying the avoided emissions of each replaced motorized vkm by the social cost of carbon per ton of CO_2. The social cost of carbon per ton of CO_2 is based on Nordhaus (2017) and amounts to USD 31. The social cost of carbon in the SAVi PBS model is assumed to remain constant over time.

The CO_2 emission values per transport mode (Sharma et al., 2014) in Table 3 are used to calculate the total avoided social cost of carbon as a result of implementing the PBS system.

[2] The WHO recommends a PM2.5 annual mean concentration of up to 10 ug /m3 and a 25 µg/m3 24-hour mean (WHO, 2018).

Table 3. CO_2 emissions per transport mode in Delhi

Transport mode	Unit	CO_2
Bus	g/km	806.5
4-wheeler (average)	g/km	134
Gasoline	g/km	115
Diesel	g/km	153
2-wheeler	g/km	24.4
Auto rickshaw	g/km	77.7
Pedal rickshaw	g/km	0
Cycle	g/km	0
Walk	g/km	0
Metro	g/km	0
Railway	g/p-km	1.27
Transport mode	**Unit**	**CO_2**
Social cost of carbon (SCC)	USD/g	0.000031
SCC in INR	INR/g	0.002197

2.1.8 Cost of Accidents

The valuation of traffic accidents is calculated using several factors. The number of annual accidents recorded in Delhi (Ministry of Road Transportation & Highways 2017) is used to estimate the number of annual accidents in Dwarka under baseline conditions. The SAVi PBS model considers three different degrees of accident severity: minor, major and fatal. The annual accident rates in Dwarka prior to and after the implementation of the PBS system per accident severity are estimated based on changing accident risk levels. The number of accidents are assumed to decrease if the number of motorized vkm are reduced. Table 4 presents the number of reduced accidents per accident severity category and per PBS demand scenario.

Table 4. Annual number of accidents in Dwarka prior to the implementation of the PBS system and reduced accidents per PBS demand scenario

Accident severity	Unit	Accidents in Dwarka (baseline)	Accident reduction		
			Low PBS demand	Medium PBS demand	High PBS demand
Minor	Accidents/ year	149.0	0.22	0.31	0.46
Major	Accidents/ year	103.3	0.41	0.58	0.88
Fatal	Accidents/ year	78.7	0.28	0.40	0.61

The next step in valuing the reduced accident costs is to estimate the economic value per accident, depending on accident severity. Fatal accidents imply that a human life is lost and are consequently valued the highest among the three accident categories. Table 5 provides a low estimate (Bora, Landge, & Dalai, 2018) and a high estimate (TERI, 2018) for the monetary value of fatal accidents. Values for minor and major accidents are based on Bora et al. (2018). This reference also provides details about the various cost items and amounts associated with each respective accident severity level.

Table 5. Valuation of accidents per accident severity

Accident severity	Unit	Low estimate	High estimate
Minor	INR/accident	36,953	36,953
Major	INR/accident	217,924	217,924
Fatal	INR/accident	2,838,768	28,000,000

2.1.9 Cost of Noise Pollution

Noise emissions from various transport modes can cause negative health effects to humans exposed to the noise. These are usually stress-related health effects like hypertension and myocardial infarction (heart attacks) (Ricardo-AEA et al., 2014). A bottom-up approach using three steps is applied to estimate the cost of noise. First, the total number of people exposed to noise is determined using noise map data. The total cost of noise pollution is then calculated by multiplying the cost of noise per person exposed by the total amount of people exposed.[3] Finally, weighting factors are applied to account for differences in noise characteristics between different modes of transportation (CE Delft et al., 2011).

[3] An exchange rate of 77.7608 INR / Euro was applied to calculate the INR equivalent of the noise costs indicated in Euro in CE Delft et al. (2011).

In this SAVi assessment, the avoided cost of noise pollution is estimated as the PBS demand scenarios increase the use of cycling which, as a transport mode, is characterized by zero noise pollution. The total value is estimated based on the reduced noise emissions per vkm per transport mode being replaced by the PBS system. The estimation also considers different noise levels per transport mode influenced by peak and off-peak travel times. Since cycling will replace only short trips, the SAVi assessment generates noise costs for the following transport modes:

- Pedal rickshaw: 0.0398 INR/vkm
- Auto rickshaw: 1.1198 INR/vkm
- 4-wheel: 0.1322 INR/vkm
- 2-wheel: 1.1198 INR/vkm
- Bus: 0.1244 INR/vkm

2.2 Demand Scenarios for the PBS System

Table 6 provides an overview of the scenarios simulated for the SAVi assessment and related assumptions for each scenario. The assessment consists of a baseline and three demand scenarios that assume different scales of demand for an implemented PBS system.

Table 6. Scenarios simulated for the PBS SAVi assessment

Scenario	Assumptions
Baseline	• Transport infrastructure and transport use patterns of commuters in and to Dwarka remain as they are today.

Scenario 1: PBS low demand	• Bicycle infrastructure and supporting safety infrastructure is provided.
	• The PBS system is implemented and fully operational from the year 2020 onwards.
	• Demand – low PBS uptake. The following number of daily trips per user group will shift from other transport modes to cycling:
	  • Metro users (last-mile connectivity): 5,273
	  • Bus users (last-mile connectivity): 1,162
	  • Household trips: 4,713
	  • **Total trips replaced by bicycle per day: 11,147**

Scenario	Assumptions

Scenario 2: PBS medium demand	• Bicycle infrastructure and supporting safety infrastructure is provided.
	• The PBS system is implemented and fully operational from the year 2020 onwards.
	• Demand – medium PBS uptake. The following number of daily trips per user group will shift from other transport modes to cycling:
	  • Metro users (last-mile connectivity): 7,660
	  • Bus users (last-mile connectivity): 1,601
	  • Household trips: 6,570
	  • **Total trips replaced by bicycle per day: 15,831**

Scenario 3: PBS high demand	• Bicycle infrastructure and supporting safety infrastructure is provided.
	• The PBS system is implemented and fully operational from the year 2020 onwards.
	• Demand – high PBS uptake. The following number of daily trips per user group will shift from other transport modes to cycling:
	  • Metro users (last-mile connectivity): 11,899
	  • Bus users (last-mile connectivity): 2,091
	  • Household trips: 10,003
	  • **Total trips replaced by bicycle per day: 23,993**

Table 6 shows in detail the different mobility shifts under the three demand scenarios. Demand numbers for the PBS system and shifts from other transport modes to cycling (using the PBS system) are based on CGM (2015). We assumed an occupancy rate for each transport mode to calculate the passenger kilometres (pkm) per transport mode. Pkm hence serve to calculate the amount of kilometres shifted to cycling, i.e., the additional number of kilometres cycled through the use of the PBS system under each of the three demand scenarios. The vkm number represents the amount of transport km that are avoided per vehicle mode thanks to the PBS system. Both indicators are presented per transport mode per scenario in Table 7. It is crucial to calculate both the pkm shifted to cycling and the vkm avoided per transport mode in order to quantify and value various externalities appropriately as explained in the previous sections. It is important to note that the composition of demand indicated in Table 7 also highlights that some current cyclists will shift to using the PBS rather than their private bicycles. This intra-mode shift does not have an impact on transport-related externalities. These demand numbers from current cyclists are hence deducted within this SAVi assessment for the purpose of accurately calculating and valuing externalities for the different demand scenarios.

To calculate the number of trips shifted from other transport modes to cycling, we assume that the PBS system will only be used for distances up to 7 km. This determines the potential number of trips that can be shifted from other transport modes to cycling. For example, trips made by metro and train are longer than 7 km and hence will not be replaced by cycling. Table 6 indicates the average trip distance per transport mode. This number serves to calculate the total pkm shifted to cycling per scenario and the total avoided vkm per transport mode per scenario.

Table 7. Total trips shifted to cycling per PBS demand scenario

Transport mode	Km/ Trip	Vehicle occupancy (passenger per mode)	PBS low demand		
			PBS demand (trips/ day)	pkm/day shifted to PBS cycling	vkm/day avoided per mode
Bus	7	20	1,416	9,913	496
4-wheeler	7	2	97	679	339
2-wheeler	7	1	1,531	10,711	10,711
Auto rickshaw	4	1	660	2,641	2,641
Pedal rickshaw	4	1	270	1,082	1,082
Cycling	3	1	83	248	248
Walking	2	1	7,091	14,183	14,183
Metro	-	-	0	0	0
Railway	-	-	0	0	0
Total across all modes			**11,147**	**39,457**	**29,700**

Transport mode	Km/ Trip	Vehicle occupancy (passenger per mode)	PBS medium demand		
			PBS demand (trips/ day)	pkm/day shifted to PBS cycling	vkm/day avoided per mode
Bus	7	20	2,011	14,077	704
4-wheeler	7	2	138	964	482
2-wheeler	7	1	2,173	15,211	15,211
Auto rickshaw	4	1	938	3,750	3,750
Pedal rickshaw	4	1	384	1,536	1,536
Cycling	3	1	117	352	352

Transport mode	Km/ Trip	Vehicle occupancy (passenger per mode)	PBS medium demand		
			PBS demand (trips/ day)	pkm/day shifted to PBS cycling	vkm/day avoided per mode
Walking	2	1	10,070	20,141	20,141
Metro	-	-	0	0	0
Railway	-	-	0	0	0
Total across all modes			**15,831**	**56,031**	**42,176**

Transport mode	Km/ Trip	Vehicle occupancy (passenger per mode)	PBS high demand		
			PBS demand (trips/ day)	pkm/day shifted to PBS cycling	vkm/day avoided per mode
Bus	7	20	3,048	21,334	1,067
4-wheeler	7	2	209	1,460	730
2-wheeler	7	1	3,293	23,053	23,053
Auto rickshaw	4	1	1,421	5,684	5,684
Pedal rickshaw	4	1	582	2,329	2,329
Cycling	3	1	178	534	534
Walking	2	1	15,262	30,525	30,525
Metro	-	-	0	0	0
Railway	-	-	0	0	0
Total across all modes			**23,993**	**84,919**	**63,922**

3.0 Results of Valued Externalities

This section describes the results of the SAVi assessment. It includes the valuation results of each externality for the three PBS demand scenarios accompanied by details on why the value of each externality changes when mobility patterns shift to cycling. The second part of this section presents a summary table of all valued externalities.

3.1 Valuation Results per Externality

3.1.1 Valuation of Health Benefits From Cycling

The implementation of the PBS system leads to higher cycling rates in Dwarka and results in an overall increased level of physical activity within the commuter group that leads to health benefits. The SAVi assessment values these benefits in terms of reduced mortality.

Table 8 indicates the valued net health benefits per day for each PBS demand scenario. Values represent the cumulative net health benefits resulting from the new mobility pattern per scenario compared to the baseline. The build-up period for realizing health benefits from increased cycling is five years (WHO 2017). To account for this build-up period, the average daily monetary value of health benefits is estimated based on an assessed period of 20 years. Compared to all other commuter groups that are shifting to PBS, former pedestrians will experience an overall health impairment effect because they are expected to reduce their overall physical activity. The daily monetary value of health impairment for this commuter group as well as the health benefits for all other commuter groups and the net health benefits of each PBS demand scenario are displayed in Table 8. While the health impairment is the highest for the high-demand scenario (since it implies the biggest shift of former pedestrians to cycling) the health benefits in this scenario are also the highest. This is because of the large number of commuters previously using motorized modes of transport or other service transport and now using the PBS system. Consequently, the daily net health benefits of this scenario amount to more than INR 78,000 and hence are more than twice as high as the net health benefits associated with the low-demand scenario.

Table 8. Valued health benefits from increased cycling per PBS demand scenario

	Unit	PBS low demand	PBS medium demand	PBS high demand
Health benefits from increased cycling (excl. switched pedestrians)	INR/day	122,493	173,949	267,120
Health impairment from reduced physical activity for pedestrians switching to PBS	INR/day	-83,943	-119,205	-189,016
Net health benefits from increased cycling	**INR/ day**	**38,550**	**54,744**	**78,104**

3.1.2 Value of Time Saved

Results in Table 9 present the time saved (positive values) or additional time spent (negative values) per PBS demand scenario. The results are itemized per transport mode based on the pkm shifted to cycling. The total value of time saved per PBS scenario is translated into the value of time saved. Assumptions for calculating the physical value and the monetary value of time saved/spent are explained in Section 2.1.2.

Despite the higher speed of motorized transport modes compared to cycling, each PBS scenario yields a saved amount of time for commuting per day because a high number of trips are currently being walked and will be replaced by cycling. The higher the PBS demand, the higher the value of time saved—emphasized by the results of the "PBS high-demand" scenario that yields a monetary value more than twice as high as the "PBS low-demand" scenario.

Table 9. Time saved/spent per transport by using bicycles and total value of time saved per PBS demand scenario

Transport mode	Unit	Time saved/spent by using bicycles		
		PBS low demand	PBS medium demand	PBS high demand
Bus	hours/ day	0.00	0.00	0.00
4-wheeler	hours/ day	-30.45	-43.24	-65.53
2-wheeler	hours/ day	-426.91	-606.24	-918.80
Auto rickshaw	hours/ day	-55.02	-78.13	-118.41
Pedal rickshaw	hours/ day	18.03	25.61	38.81
Walking	hours/ day	1,654.66	2,349.75	3,561.21
Total time saved	**hours/ day**	**1,160.32**	**1,647.75**	**2,497.28**
Total daily value of time saved	**INR/ day**	**168,910**	**239,865**	**363,532**

3.1.3 Changes in Retail Revenues

Table 10 indicates the number of people shifted to cycling per PBS demand scenario and the amount of additional retail spending expected from PBS users. As explained in Section 2.1.3, the improved walkability due to better cycling infrastructure implies higher retail spending by people that use the PBS system but have not cycled or walked before. Neither of these groups causes additional retail spending. The table indicates the total daily additional retail spending per PBS demand scenario. Naturally, the higher the PBS demand and associated number of people shifting from motorized modes of transport to cycling, the higher the total amount of additional retail spending. The varying results of the three demand scenarios provide evidence for that causal relation. Additional tax revenues resulting from the increased retail spending will accrue to the South Delhi Municipal Corporation.

Table 10. Additional retail spending per day per PBS demand scenario

	Unit	PBS low demand	PBS medium demand	PBS high demand
People shifting to cycling compared to the baseline, excluding shifted pedestrians	people/ day	1,987	2,822	4,276
Total additional retail spending	**INR/ day**	**101,049**	**143,498**	**217,481**

3.1.4 Changes in Property Values

Property values in Dwarka will be affected by a successfully implemented PBS system. The provided bicycle paths and improved safety infrastructure associated with the PBS system in Dwarka will improve the overall walkability of the area. More and safer spaces will be available for pedestrians and cyclists, and motorized transport will be reduced.

Existing studies indicate an increase in property values if walkability is improved in a neighbourhood. The impact on property values found in the literature indicates a potential increase of between 5 per cent and 15 per cent. The SAVi PBS model assumes that walkability improves through the implementation of the PBS infrastructure. However, the scale of the increase in property value due to improved walkability is assumed to be independent of the scale of PBS demand. Accordingly, Table 11 presents two valuation estimates for net property value increases in Dwarka (5 per cent and 15 per cent), while it is assumed that the positive effect of the PBS system on property values remains the same between the different demand scenarios. Additional property tax revenues resulting from the increased property values in Dwarka will accrue to the South Delhi Municipal Corporation.

Table 11. Net changes in property values in Dwarka resulting from an implemented PBS system

	Unit	PBS low demand	PBS medium demand	PBS high demand
Change in property value (low estimate)	Million INR	3,558	3,558	3,558
Change in property value (high estimate)	Million INR	10,637	10,637	10,637

3.1.5 Avoided Cost of Air Pollution

If transport users in Dwarka shift from motorized, fuel-based transport modes to the use of fuel-free bicycles due to the provided PBS system, the level of air pollutants emitted by vehicles will decrease. The SAVi PBS model takes into account the reduced emission levels of $PM_{2.5}$, NO_x, CO and HC. The reduced level of air pollution is valued by estimating the avoided health cost of air pollution. The reduced health costs resulting from reduced kilograms of air pollutants are differentiated into a low and a high-value estimate. More details on the health cost assumptions are indicated in Section 2.1.5. Table 12 provides an overview of the avoided health cost per demand scenario caused by the shift from fossil fuel-based transport to cycling. Only emissions from fuel combustion are assessed and valued not emissions originating from upstream supply chain stages for fuel production.

Consequently, certain transport modes such as metro and railway are not associated with any health cost since no fuel combustion takes place during transport use. Likewise, the use of pedal rickshaw or walking does not cause any emissions. Shifting from these transport modes to cycling does not result in reduced air pollution costs.

In each scenario, more than 50 per cent of avoided air pollution cost—the greatest extent—stems from the replacement of motorized 2-wheel transportation by cycling, followed by reduced air pollution cost from replacing auto rickshaw transport trips. The highest reduction in total air pollution cost can be achieved by a high-demand scenario for the PBS system. Compared to the baseline, the high-demand scenario yields a reduction of air pollution cost across all transport modes of approximately 0.8 per cent.

Table 12. Avoided cost of air pollution per PBS demand scenario

		Avoided air pollution costs					
		PBS low demand		PBS medium demand		PBS high demand	
Transport mode	Unit	Low value	High value	Low value	High value	Low value	High value
Bus	INR/ day	6,414	53,705	9,109	76,265	13,805	115,585
4-wheeler	INR/ day	222	2,142	315	3,042	478	4,610
2-wheeler	INR/ day	17,158	179,979	24,366	255,584	36,928	387,356
Auto rickshaw	INR/ day	9,621	103,267	13,662	146,647	20,705	222,254
Pedal rickshaw, walking, metro, railway	INR/ day	0	0	0	0	0	0
Cost of air pollution avoided across all modes	**INR/ day**	**33,415**	**339,093**	**47,452**	**481,538**	**71,917**	**729,805**
Percentage of avoided cost of air pollution compared to baseline	%	**0.37**	**0.38**	**0.53**	**0.54**	**0.80**	**0.81**

3.1.6 Cost of Increased Exposure to Air Pollution

The negative health effects of air pollution ($PM_{2.5}$) are being experienced to an increased degree by commuter groups when switching from motorized or service transport to the use of bicycles provided by the PBS system. This negative health effect is considered and valued in this SAVi assessment. The cost of increased exposure to air pollution is estimated based on the health cost per km travelled by bicycle per person, as indicated by Rabl and Nazelle (2012) and the total vkm shifted newly to cycling. Details on assumptions are explained in Section 2.1.6 of this report. Since the increased exposure to air pollution is considered an additional cost compared to the baseline (and hence a negative externality from using the PBS system) values indicated in Table 13 are negative. The results per PBS demand scenario demonstrate that by far the highest health costs are caused by the high-demand scenario amounting to a daily cost of INR 116,610.

Table 13. Cost of increased exposure to air pollution per PBS demand scenario

	Unit	PBS low demand	PBS medium demand	PBS high demand
Cost of increased exposure to air pollution compared to baseline	INR/day	(54,181)	(76,941)	(116,610)

3.1.7 Avoided Cost of CO_2 Emissions

The replacement of motorized, fossil fuel-based transport modes by a PBS system and increased volumes of cycling is accompanied by a reduction of the transport sector's CO2 emissions. These emissions are valued in terms of their social cost of carbon, described in more detail in Section 2.1.7. Table 14 indicates that by far the highest reductions in the social cost of carbon are achieved by an increased cycling demand replacing bus trips, followed by replaced 2-wheeler and replaced auto rickshaw trips. This is due to the high carbon footprint of bus transportation in Dwarka. Naturally, the higher the demand for the PBS system, the more motorized transport trips are replaced, and the higher are the reductions in the social cost of carbon. The high-demand scenario reduces the social cost of carbon each day by more than INR 4,300 and hence more than twice as much as the low-demand scenario.

Table 14. Avoided social cost of carbon per PBS demand scenario

		Avoided social cost of carbon		
Transport mode	**Unit**	**PBS low demand**	**PBS medium demand**	**PBS high demand**
Bus	INR/ day	878	1,247	1,890
4-wheeler	INR/ day	100	142	215
2-wheeler	INR/ day	574	815	1,236
Auto rickshaw	INR/ day	451	640	970
Railway	INR/ day	0	0	0
Pedal rickshaw, walking, metro	INR/ day	0	0	0
Cost of air pollution avoided across all modes	**INR/ day**	**2,003**	**2,844**	**4,311**
Percentage of avoided cost of air pollution compared to baseline	**%**	**0.28**	**0.40**	**0.60**

3.1.8 Avoided Cost of Accidents

The SAVi PBS model distinguishes between three levels of accident severity: minor, major and fatal. For the monetary valuation of fatal accidents, a low estimate (Bora et al., 2018) and a high estimate (TERI, 2018) are used: only one value is applied for the other accident types (Bora et al., 2018). More details on accident statistics and risk levels in Dwarka are explained in Section 2.1.8 of this report. Table 15 presents the valuation results for the three PBS demand scenarios. All scenarios slightly lower the number of annual accidents in Dwarka. SAVi results indicate that the more vkm travelled by motorized transport are replaced by cycling, the fewer accidents happen. This holds true for all accident categories. Consequently, the PBS high-demand scenario yields the highest avoided accident costs among all scenarios.

The SAVi PBS model considers three different degrees of accident severity: minor, major and fatal. The annual accident rates in Dwarka before and after the implementation of the PBS system per accident severity are estimated based on changing accident risk levels. The number of accidents is assumed to decrease if total motorized vkm are reduced. The total avoided accident costs per day of the high-demand scenario are for both, the low (INR 4,069) and high-value estimate (INR 36,122), more than twice as high compared to the daily avoided accident costs of the low-demand scenario and more than 50 per cent higher compared to the daily avoided accident costs of the medium-demand scenario.

Table 15. Avoided accident costs per day per PBS demand scenario

		Avoided accident costs					
		PBS low demand		PBS medium demand		PBS high demand	
Accident severity	Unit	Low value	High value	Low value	High value	Low value	High value
Minor	INR/day	41	41	59	59	89	89
Major	INR/day	169	169	240	240	364	364
Fatal	INR/day	1,680	16,573	2,386	23,535	3,616	35,669
Total avoided accident costs	**INR/day**	**1,890**	**16,783**	**2,685**	**23,834**	**4,069**	**36,122**

3.1.9 Avoided Cost of Noise Pollution

The avoided cost of noise pollution is estimated based on the noise emissions and the resulting negative health effects per transport mode. Avoided costs stem from replacing one additional vkm of noise emitting transport modes by using a bicycle for the respective vkm. Because motorized transport is partly replaced by the PBS system, all scenarios are associated with a reduced cost of noise pollution. Table 16 displays the reduced cost per replaced transport mode per PBS demand scenario. Next to bicycles, no noise pollution is caused by walking. Moreover, vkm of metro and railway will not be reduced when a PBS system is implemented. Hence, for all these transport modes a value of 0 is indicated in Table 16. Consequently, these transport modes will not contribute to avoided cost of noise pollution associated with an implemented PBS system. The highest value of avoided noise pollution is achieved by the PBS high-demand scenario amounting to a daily value of almost INR 32,500. This value is higher compared to the other demand scenarios since the majority of motorized vkm are replaced by cycling in the high-demand scenario. The daily value of avoided noise pollution is more than twice as high as the value achieved by the low PBS demand scenario.

Table 16. Avoided cost of noise pollution per day per transport mode and PBS demand scenario

Transport mode	Unit	Avoided noise pollution costs		
		PBS low demand	PBS medium demand	PBS high demand
Bus	INR/ day	61.67	87.57	132.72
4-wheeler	INR/ day	44.85	63.69	96.52
2-wheeler	INR/ day	11,994.19	17,032.65	25,814.19
Auto rickshaw	INR/ day	2,957.15	4,199.38	6,364.45
Pedal rickshaw	INR/ day	42.07	59.74	90.53
Walking, metro, railway	INR/ day	0	0	0
Cost of noise pollution avoided across all modes	**INR/ day**	**15,099.92**	**21,443.03**	**32,498.41**

3.2 Summary of Valued Externalities

The SAVi assessment of the PBS system in Dwarka calculates monetary values for a range of significant positive externalities and one negative externality arising from the implementation and use of the PBS system. Table 17 summarizes the results as daily monetary values. Externalities are categorized into "Added Benefits" and "Avoided Costs" and results are presented per PBS demand scenario. In fact, the scale of added benefits and avoided costs mostly depends on the extent of demand for the PBS system, as demonstrated by the varied results among the three scenarios. A high-valuation and a low-valuation estimate are presented for externalities where literature and available data showed diverging figures in order to arrive at a customized and appropriate monetary valuation.

The increase in property values resulting from improved walkability and less noise pollution is treated differently than other externalities. It is considered as a one-time increase in property values. It is not an externality that is occurring daily due to less motorized transport trips. However, to arrive at a daily value, the total net value increase in property values is divided by 365 days and 20 years. The latter is assumed to be the lifetime of the bicycle infrastructure as explained below.

The total net value of each scenario is positive as indicated in Table 17. The higher the demand for using the PBS system, the higher the benefits and avoided costs. Consequently, the positive net value of the high-demand scenario is higher than the net value of the medium- and low-demand scenarios. The discrepancies between the final results are, however, not as high between the different scenarios compared to the difference between the low- and high-valuation estimates—see Section 2 of the report for more detailed explanations of why we indicate a low-value and a high-value estimate for several externalities. The two bottom lines of Table 17 present cumulative net values over a 20-year project period. These net results are indicated as undiscounted and discounted numbers. A discount factor of 6 per cent is assumed (Institute of Economic Growth, 2018). The discounted net value of the high-value estimate for the high-demand scenario amounts to more than INR 12.4 billion. The high-value estimate for the medium-demand scenario is around 19 per cent lower, and the respective net result for the low-demand scenario is more than 34 per cent lower. The low-value estimate for the high-demand scenario amounts to only slightly more than INR 5 billion, while the respective results are almost 24 per cent and almost 44 per cent lower for the medium- and low-demand scenarios respectively.

A 20-year project period is assumed since it is a typical lifetime for the bicycle lanes and other road infrastructure that are required for the functionality and uptake of the PBS system. Calculating results over the same time period allows the comparison of values as has been done for the integrated CBA in Section 4 of the report.

Table 17. Summary table of valued externalities: Added benefits and avoided costs per PBS demand scenario

Costs and benefits	Unit	PBS low demand		PBS medium demand		PBS high demand	
		Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate
Added benefits							
Benefits from physical activity	INR/day	38,550		54,744		78,104	
Value of time saved	INR/day	168,910		239,865		363,532	
Increases in retail revenues	INR/day	101,049		143,498		217,481	
Increase in property values	INR/day	487,397	1,457,123	487,397	1,457,123	487,397	1,457,123
Total added benefits	**INR/day**	**795,906**	**1,765,632**	**925,504**	**1,895,230**	**1,146,514**	**2,116,240**

Costs and benefits	Unit	PBS low demand		PBS medium demand		PBS high demand	
		Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate
Avoided and added costs							
Avoided cost of air pollution	INR/ day	33,415	339,093	47,452	481,538	71,917	729,805
Cost of increased exposure to air pollution	INR/ day	(54,181)		(76,941)		(116,610)	
Avoided social cost of carbon	INR/ day	2,003		2,845		4,311	
Avoided cost of accidents	INR/ day	1,891	16,784	2,685	23,834	4,070	36,122
Avoided cost of noise pollution	INR/ day	15,100		21,443		32,498	
Total avoided costs	**INR/ day**	**(1,772)**	**318,799**	**(2,516)**	**452,719**	**(3,814)**	**686,126**
Net results of valued externalities							
Total net value per day	**INR/ day**	**794,134**	**2,084,431**	**922,988**	**2,347,949**	**1,142,700**	**2,802,366**
Total net value per year	**INR million/ year**	**289.9**	**760.8**	**336.9**	**857.0**	**417.1**	**1,022.9**
Total net value over 20 years	**INR million**	**5,797.2**	**15,216.3**	**6,737.8**	**17,140.0**	**8,341.7**	**20,457.3**
Total net value over 20 years (discounted*)	**INR million**	**3,524.1**	**9,250.1**	**4,096.0**	**10,419.5**	**5,071.0**	**12,436.1**

Discount factor: 6 per cent (based on Institute of Economic Growth, 2018)

4.0 Integrated Cost–Benefit Analysis for the PBS System in Dwarka

This section presents an integrated cost–benefit analysis (CBA) of the PBS system in Dwarka. It is an integrated analysis because, in addition to conventional capital and operational expenditures for the PBS system (as well as its revenues from subscription and user fees), further cost and benefit factors are incorporated into the analysis. The added benefits and avoided costs of a successfully implemented PBS system, as calculated in the previous section, will be accounted for in the integrated CBA.

In the final part of this section, a project period of 20 years is considered to highlight the PBS system's net benefits and provide a reference point for the overall investments required for bicycle paths, lighting and safety infrastructure. This infrastructure is actually crucial to producing the high demand for the PBS system, but thus far is not accounted for in the CBA. The net benefits per PBS demand scenario calculated in this report indicate the maximum amount of investments that are viable for bicycle paths, lighting and safety infrastructure in order to consider the entire mobility project worthwhile from a societal point of view.

Table 18 displays the capital expenditures (Capex) and operational expenditures (Opex) as well as the revenues for the PBS system in Dwarka as daily values. These calculations are based on recent estimations by CGM (2019) that forecast the Opex and revenues over the course of the next five years and Capex expected to occur every seven years. Even though costs and revenues are expected to vary between the years, a simplified approach was used here to estimate daily average cost and revenues over the course of 20 years. User and subscription revenues vary between the three PBS demand scenarios, while costs are expected to be the same for all demand scenarios. Each scenario yields a net deficit, although this deficit is lowest for the high-demand scenario, amounting to a negative value of INR 56,401 per day. The net deficits of the medium- and low-demand scenarios are respectively higher as they generate less user and subscription fees to compensate for the Capex and Opex. Consequently, as long as only conventional cost and revenue factors are considered in the analysis, the PBS system is financially not attractive and does not appear to be a worthwhile investment.

Table 18. Conventional CBA, undiscounted daily values per PBS scenario (in INR) based on a project period of 20 years

Costs and benefits (in INR, undiscounted)	Unit	PBS low demand	PBS medium demand	PBS high demand
Costs				
Capital expenditures				
Bicycle cost	INR/day	23,055	23,055	23,055
Stations	INR/day	6,678	6,678	6,678
Call and operational control centre	INR/day	411	411	411

Costs and benefits (in INR, undiscounted)	Unit	PBS low demand	PBS medium demand	PBS high demand
Technology – website and mobile app	INR/day	411	411	411
Smart card and validation	INR/day	1,849	1,849	1,849
Redistribution vehicles	INR/day	1,233	1,233	1,233
Setting up of depot & workshop with spare parts	INR/day	616	616	616
Total Capex	**INR/day**	**34,253**	**34,253**	**34,253**
Operational expenditures				
Human resources	INR/day	33,416	33,416	33,416
Redistribution (electricity expenses)	INR/day	526	526	526
Repairs & maintenance	INR/day	21,699	21,699	21,699
Maintenance of premises including electricity	INR/day	1,644	1,644	1,644
Insurance	INR/day	3,616	3,616	3,616
Electricity expenses for workshop	INR/day	658	658	658
Mobile network charges	INR/day	7,233	7,233	7,233
Marketing	INR/day	822	822	822
Overhead + profit (25%)	INR/day	17,403	17,403	17,403
Total Opex	**INR/day**	**87,016**	**87,016**	**87,016**
Total cost: Average value per day	**INR/day**	**121,270**	**121,270**	**121,270**
Revenues				
User fees	INR/day	11,618	16,500	25,007
Subscription fees	INR/day	18,519	26,301	39,862
Total revenues: Average value per day	**INR/day**	**30,138**	**42,801**	**64,869**

Costs and benefits (in INR, undiscounted)	Unit	PBS low demand	PBS medium demand	PBS high demand
Net result (conventional): average value per day	**INR/day**	**(91,132)**	**(78,468)**	**(56,401)**

An additional revenue source that has not been considered in the analysis are parking fees. These fees could accrue hourly for users that park a borrowed bicycle outside of a bicycle station. If such fees are considered viable and are raised from bicycle users, they would represent a significant revenue stream. According to the following estimates indicated in the Detailed Project Report for Dwarka (CGM, 2015), the daily revenues from parking would be between 10 and 20 times higher than revenues from the daily user and subscription fees depending on the demand scenario. Revenues from parking fees, if tapped, can help finance the expansion of the PBS system and its long-term maintenance, without depending on CSR funding or any other government subsidy.

An integrated analysis provides a more holistic view for assessing whether the PBS system generates net benefits and can be considered a worthwhile investment. Table 19 displays the SAVi net results of an integrated CBA. Conventional costs and revenues per PBS demand scenario are supplemented by added benefits and avoided costs as calculated by the SAVi PBS model. The SAVi net results present the societal value of the PBS system and change the picture. The results of each demand scenario are more convincing than the conventional CBA results displayed in Table 18. The positive SAVi net results indicated in Table 19 as daily values and as overall values over the course of 20 years highlight that when integrating externalities into the assessment, the PBS system can be considered beneficial for the society and hence is a worthwhile investment. This holds true across the three demand scenarios while the higher the demand for the PBS system, the higher are the net benefits of the project. Likewise, Table 19 provides the net results per PBS demand scenario differentiated into low and high estimates in accordance with valuations conducted for the externalities (added benefits and avoided costs) in Section 3 of this report. The high estimate of the high-demand scenario yields daily net benefits of more than INR 2.7 million while the low estimate of this scenario only yields a net benefit of slightly more than INR 1 million. Discrepancies between the low and high estimates over a 20-year project period for this demand scenario are similarly high—the low estimate is associated with net benefits of INR 7.9 billion while the high estimate yields more than INR 20 billion. Results for the medium-demand scenario and the low-demand scenario are respectively lower but indeed, all scenarios yield significant positive net results. If, in addition, parking fees are raised, the net results of each scenario will be much higher.

The positive SAVi net results are naturally lower if a discount factor is applied to future costs and benefits. A discount factor of 8 per cent is used for discounting the conventional costs and revenues in the future while a discount factor of only 6 per cent is applied to the added benefits and avoided costs occurring over 20 years. The selection of these discount factors is based on a research report by the Institute of Economic Growth (2018) that proposes different discount factors for infrastructure projects in India. The institute recommends using a lower discount factor for long-term projects with environmental benefits. Because externalities calculated in this SAVi assessment represent primarily the environmental, economic and social benefits of the PBS system, it appears appropriate to use a lower discount factor for these as opposed to conventional cost and revenue streams. If these discount factors are applied, the low estimate of the high-demand scenario yields net benefits of INR 4.8 billion while the high estimate yields almost INR 12.2 billion.

Table 19. Integrated CBA, undiscounted daily values (in INR) per PBS scenario based on a project period of 20 years

Costs and benefits	Unit	PBS low demand		PBS medium demand		PBS high demand	
		Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate	Low-valuation estimate	High-valuation estimate
Conventional costs & revenues							
Total costs	INR/day	121,270		121,270		121,270	
Total revenues	INR/day	30,138		42,801		64,869	
Conventional net results	**INR/day**	**(91,132)**		**(78,468)**		**(56,401)**	
Valued externalities							
Total added benefits	INR/day	795,906	1,765,632	925,504	1,895,230	1,146,514	2,116,240
Total avoided costs	INR/day	(1,772)	318,799	(2,516)	452,719	(3,814)	686,126
Added benefits + avoided costs	**INR/day**	**794,134**	**2,084,431**	**922,988**	**2,347,949**	**1,142,700**	**2,802,366**
SAVi net results							
SAVi net results per day	**INR/day**	**703,002**	**1,993,299**	**844,520**	**2,269,481**	**1,086,299**	**2,745,965**
Total SAVi results over 20 years	**INR million**	**5,131.9**	**14,551.1**	**6,165.0**	**16,567.2**	**7,930.0**	**20,045.5**
Total SAVi results over 20 years (discounted*)	**INR million**	**3,143.6**	**8,869.6**	**3,764.5**	**10,088.0**	**4,824.9**	**12,190.0**

**Discount factors: 8 per cent for conventional costs and revenues, 6 per cent for added benefits and avoided costs (based on Institute of Economic Growth, 2018)*

It is important to analyze the SAVi net results in the context of sustainable transport infrastructure development in Dwarka. Deploying the PBS system successfully, achieving the demand figures estimated by CGM and realizing the added benefits and avoided costs as calculated in this SAVi assessment build on the premise that the required bicycle infrastructure will be provided by the municipality. This includes the construction of bicycle paths and adjustment of existing road infrastructure, new street lighting and traffic light systems to improve safety, street furniture, planting of trees to provide shade and better ambience for cyclists and pedestrians. Road and street lighting infrastructure are assumed to have a lifetime of approximately 20 years. Pavements might need to be refurbished every seven years, but major new capital expenditures for the bicycle infrastructure are only expected to occur after 20 years.

The calculated SAVi net results represent the societal value of sustainable transport infrastructure such as the PBS system in Dwarka. Therefore, the net results provide a reasonable starting point to estimate the maximum monetary amount additional bicycle and road safety infrastructure could cost over a course of 20 years (in addition to the implementation and operation of the PBS system). If overall costs for this infrastructure remain lower than the SAVi net results in respective demand scenarios, the investment can be considered worthwhile from a society and sustainable mobility point of view. The SAVi net results in Table 19 can be considered as benchmark values for public infrastructure planners responsible for deciding whether or not to invest into the provision of bicycle and road safety infrastructure.

If estimates for capital and operational expenditures for bicycle lanes and adjustment of road infrastructure, new street lighting, road safety components and planting of trees are lower than any of the calculated SAVi net results, infrastructure planners can rest assured that these investments are worthwhile from a societal point of view. More precisely, if lifecycle costs (discounted) for these infrastructure components are lower than INR 3,143 million, this would imply that even if the uptake of the PBS demand scenario is low (= low PBS demand scenario) and added benefits and avoided costs are estimated using conservative assumptions (low estimates) and are discounted over the period of 20 years, the overall benefits of a PBS system are still higher than additional expenditures for infrastructure provision. One also needs to recall the causal relation between infrastructure provision and demand: the better the provided infrastructure for cyclists, the higher the demand—and the higher the added benefits and avoided costs—will be. Therefore, it appears reasonable to define higher benchmark values for maximum infrastructure expenditures than the lower SAVi results of the low-demand scenario.

However, if infrastructure expenditures happen to be close to or higher than the low-value estimate of the high-demand scenario, infrastructure planners need to coordinate closely with the PBS system designer, the operator and other PBS experts to ensure that the uptake of the system reaches sufficient levels in Dwarka to achieve overall positive net results. In addition, we would like to point to the following: given that the low- and high-value estimates for the valuation of some externalities yield very distinct results, we recommend the review of the underlying assumptions and data sources used. The chosen valuation methodologies can indeed influence the overall investment rationale. This is particularly true for externality values of significant scale and hence large influence on the overall net results. These are "increase in property values" and "avoided cost of air pollution."

Finally, if additional investments (discounted) for the bicycle infrastructure over the course of 20 years exceed the SAVi net results of the high estimate for the high-demand scenario (INR 12,190 million), the investment under the given conditions cannot be considered worthwhile from a societal point of view. In that case, either investments for the bicycle infrastructure need to be reduced, higher demand numbers than the high-demand scenario need to be realized and/or the PBS system needs to generate additional revenue streams—such as revenues from advertisements on bicycles and bicycle stations.

5.0 Conclusions

The SAVi assessment of the PBS system in Dwarka provides a range of insightful results about the added benefits and avoided costs resulting from the successful implementation of this mobility project. If taking only conventional Capex, Opex and revenue stream into account, the PBS system—with the assumptions used—is not financially appealing and cannot be considered a worthwhile investment, even if the high-demand scenario materializes and high revenues are thereby generated. The PBS system could become financially viable only if parking fees are raised in addition to user and subscription fees. However, when assessing the value of transport projects, it is essential to assess further benefit and cost factors than traditional project finance factors. This SAVi assessment has accomplished this task by valuing environmental, social and economic externalities of the PBS system in Dwarka and integrating these into the cost–benefit analysis. This assessment hence goes beyond merely providing anecdotal evidence about the benefits of non-motorized transport projects. It is striking that the PBS system can only be considered beneficial and worthwhile from a societal and public policy point of view if the valued externalities are integrated into the cost–benefit analysis.

Indeed, the results of this SAVi assessment allow policy-makers and citizens to appreciate the PBS system. While the conventional net results (without integrating avoided costs and added benefits) yield negative daily values for all three demand scenarios, the picture completely changes if taking an integrated approach. Once the SAVi assessment results are incorporated into the calculations, Scenario 1 (low demand) yields positive daily net results between INR 0.70 million and INR 1.99 million, Scenario 2 (medium demand) yields positive daily net results between INR 0.84 million and INR 2.27 million, and Scenario 3 (high demand) yields positive daily net results between INR 1.09 million and INR 2.75 million. If summing up and discounting the daily net results over a 20-year project period, Scenario 1 yields positive results between INR 3.15 billion and INR 8.87 billion, Scenario 2 yields net results between 3.76 billion and INR 10.09 billion, and Scenario 3 yields net results between INR 4.82 billion and INR 12.19 billion. **Clearly, the SAVi assessment provides evidence that investing into the PBS system in Dwarka is worthwhile if the multiple environmental, social and economic benefits and avoided costs are taken into account.**

These cumulative net results also provide a benchmark for policy-makers to determine the scale of investment that could be earmarked for deploying public infrastructure components that are essential to make use of the PBS system. These include bicycle lanes, street lighting, further road safety infrastructure, street furniture and planting of trees. Even if conservative demand numbers and low estimates for the valuation of externalities are assumed, the discounted lifecycle cost for the additional infrastructure components can still be up to INR 3.143 billion. If these investment decisions are made, it will become more likely that high demand numbers for the PBS system can be achieved. This would again increase co-benefits resulting from increased use of the PBS system and the associated replacement of motorized transport.

Integrated assessments such as this one conducted by employing the Sustainable Asset Valuation (SAVi) methodology can help make a stronger case for bicycle sharing and other forms of sustainable mobility solutions. Altogether, this assessment has shown that the PBS system advances the realization of sustainable mobility targets in

Dwarka, improves the quality of life and therefore delivers the transport policy objectives defined in the Delhi Master Plan 2021:

- **Multi-modal, convenient, safe and affordable transport:** The PBS system will allow for more convenient and affordable access to public transport, including last-mile connectivity, and hence will facilitate multi-modal transport use. Moreover, the required bicycle infrastructure (bicycle path, traffic lights, street lighting) will improve safety in Dwarka.
- **Reduced emissions:** The SAVi results demonstrate that the shift from motorized transport to using the PBS system contributes to reduced vehicular emissions. The results of the low-demand scenario provide evidence that more than INR 2,000 in the social cost of carbon are reduced per day, almost INR 15,100 in the cost of noise pollution (health costs) are avoided per day and the air pollution costs avoided per day range between INR 33,415 and INR 339,093 depending on the assumed health costs of air pollutants.
- **Fewer fatality events:** The SAVi results on "avoided cost of accidents" demonstrate that the PBS system also contributes to a small extent to reducing the fatality rates in Dwarka, as promoted by the Master Plan.
- **Economic benefits:** Another objective is to allocate road space more equitably. The implementation of the PBS system contributes to this objective by providing more road space to cyclists. The SAVi assessment calculated economic effects resulting from this new allocation of road space. The low-demand scenario yields an increase in retail revenues of more than INR 101,000 per day as well as a one-time increase in property values in Dwarka ranging between INR 3,558 million and INR 10,637 million.
- **Enhanced transport efficiency:** The use of the PBS system will also enhance the efficiency of movement in Dwarka as evidenced by the value of time saved amounting to INR 168,910 per day in the low-demand scenario.
- **Health effects:** The valued health benefits associated with increased physical activity and reduced noise pollution are further indications of improved quality of life resulting from the availability and use of the PBS system in Dwarka. Only the increased cyclists' exposure to air pollution will have adverse health effects. This circumstance provides another good reason why the severe air pollution issues in Delhi and other cities in India need to be tackled.

The successful operation of this non-motorized transport infrastructure and intermodal mobility concept has the potential to transform Dwarka into a pilot area for sustainable mobility in Delhi. The CGM, concept developer of the PBS system and the commissioner of this SAVi assessment, is currently using the SAVi results in conversations with public authorities in India, including the Delhi Development Authority, to promote the implementation of this and other PBS systems in India. Progress is being made: the procurement of the project developer and operator for the Dwarka PBS system is proceeding, and public tenders for the construction of bicycle lanes and the installation of new street lighting are being prepared. IISD is pleased to support the progress of sustainable mobility and looks forward to providing advice and conducting further analyses on the sustainability value and the financial performance of infrastructure projects across India.

In this regard, we would like to highlight that the application of SAVi allows for a diversity of performance assessments beyond what has been applied for valuing the PBS system in Dwarka. A more in-depth project finance assessment is feasible if data is provided. Further transport infrastructure components such as roads and bus rapid transit systems can be assessed as well as other infrastructure assets, including energy generation, buildings, wastewater treatment, materials management and waste infrastructure, and nature-based infrastructure. Finally, it is possible to assess the financial performance of infrastructure projects under different risk scenarios, including the physical risks of climate change such as air temperature increases and changing precipitation patterns. SAVi assessments can be customized to the clients' needs and we look forward to conversations about how SAVi can support the deployment of sustainable infrastructure projects across India.

References

AirVisual. (2019). *World most polluted cities 2018 (PM2.5)*. Retrieved from https://www.airvisual.com/world-most-polluted-cities

Bora, B., Landge, V. & Dalai, B. (2018). Socio-economic costing of road traffic accidents: evidence from Nagpur city, Maharashtra, India. *Current Science, 114*(6), 1275–1283.

Buchanan, P. (2007). *Paved with gold. The real value of good street design.* Commission for Architecture and the Built Environment (CABE). Retrieved from https://www.designcouncil.org.uk/sites/default/files/asset/document/paved-with-gold_1.pdf

CE Delft, INFRAS and Fraunhofer ISI. (2011). *External costs of transport in Europe* (Update Study for 2008). Retrieved from http://ecocalc-test.ecotransit.org/CE_Delft_4215_External_Costs_of_Transport_in_Europe_def.pdf

Centre for Green Mobility (CGM). (2015). *Bicycle share system for Dwarka sub-city. Detailed Project report.* New Delhi: Delhi Development Authority and Centre for Green Mobility.

Delhi Development Authority (DDA). (2017). *Master Plan for Delhi-2021.* Draft incorporating modifications notified by Central Government up to 31 March, 2017 for reference only. Retrieved from: https://dda.org.in/tendernotices_docs/may1/MPD-2021_31.03.2017260417.pdf

Forrester, J. W. (1961). *Industrial dynamics.* Cambridge, MA: MIT Press.

Goel, R. & Guttikunda, S.K. (2015). Evolution of on-road vehicle exhaust emissions in Delhi. *Atmospheric Environment, 105,* 78–90.

Goel, R., Mohan, D., Guttikunda, S.K. & Tiwari, G. (2016). Assessment of motor vehicle use characteristics in three Indian cities. *Transportation Research Part D. Transport and Environment, 44,* 254–265.

Goodreturns. (2019). *Diesel price in New Delhi.* Retrieved from https://www.goodreturns.in/diesel-price-in-new-delhi.html

IBI Group. (2016). *Public bicycle sharing. Guidance document.* Prepared by Ministry of Urban Development. Government of India. Retrieved from http://www.sutpindia.com/skin/pdf/PC1B3_PBS_Guidance_Document.pdf

Institute of Economic Growth. (2018). *Reassessment of national parameters for project appraisal in India.* Delhi, 2018. Retrieved from https://niti.gov.in/sites/default/files/2019-06/Final%20Report%20of%20the%20Research%20Study%20on%20%20Reassessment%20of%20National%20Parameters%20for%20Project%20Appraisal%20in%20India%20conducted%20by%20Institute%20of%20Economic%20Growth%20(IEG)_Delhi.pdf

Ministry of Home Affairs (MHA). (2017). *Vital statistics of India based on the civil registration system 2015.* New Delhi: Office of the Registrar General, Vital Statistics Division. Retrieved from http://www.censusindia.gov.in/2011-Documents/CRS_Report/crs_report%202015_23062017.pdf

Narain, U. & Krupnick, A. (2007). *The impact of Delhi's CNG program on air quality* (RFF Discussion Paper No. 07-06). Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=969727

Nordhaus, W. (2017). Revisiting the social cost of carbon. PNAS, 11(7), 1518–1523.

Makaan. (2019). *Property rates & price trends in Dwarka, Delhi – 2019*. Retrieved from https://www.makaan.com/price-trends/property-rates-for-buy-in-dwarka-delhi-10212

Rabl, A. & Nazelle, A.D. (2012). Benefits of shift from car to active transport. *Transport Policy 19,* 121–131.

Ricardo AEA, DIW econ & University of Kiel (CAU). (2014). *Update of the handbook on external costs of transport. Final report.* Report for the European Commission: DG MOVE. Retrieved from https://ec.europa.eu/transport/sites/transport/files/handbook_on_external_costs_of_transport_2014_0.pdf

Roberts, N., Andersen, D.F., Deal, R.M., Garet, M.S., & Shaffer, W.A. (1983). *Introduction to computer simulation: The system dynamics approach.* Reading, Massachusetts: Addison-Wesley Publishing Company .

Sen, K.A., Tiwari, G. & Upadhyay, V. (2010). Estimating marginal external costs of transport in Delhi. *Transport Policy, 17,* 27–37. Retrieved from http://www.vref.se/download/18.6a462c7912efb9dc85f80004555/1377188299048/2010+Sen+-+Estimating+marginal+external+costs.pdf

Sengupta, R. & Mandal, S. (2005). *Health damage cost of automotive air pollution: Cost benefit analysis of fuel quality upgradation for Indian cities* (National Institute of Public Finance and Policy, Working Paper No. 37). Retrieved from http://www.nipfp.org.in/working_paper/wp05_nipfp_039.pdf

Sharma, N., Singh, A., Dhyani, R. & Gaur, S. (2014). Emission reduction from MRTS projects – A case study of Delhi metro. *Atmospheric Pollution Research, 5,* 721–728.

Song, Y. & Knaap, G. (2003). New urbanism and housing values: A disaggregate assessment. *Journal of Urban Economics, 54*(2), 218–238. Retrieved from https://www.sciencedirect.com/science/article/pii/S0094119003000597

Statista. (2015). *Value of per capita retail expenditure in major cities across India in 2015.* Retrieved from https://www.statista.com/statistics/658513/per-capita-retail-spending-india-major-cities/

The Energy and Resource Institute (TERI). (2018). *Benefits of cycling in India. An economic, environmental, and social assessment.* New Delhi: The Energy and Resource Institute. Retrieved from https://www.teriin.org/sites/default/files/2019-01/Benefits%20of%20Cycling%20in%20India%20-%20Report.pdf

The Times of India. (2019). *Delhi's per capita income three times the national average: Economic survey.* Retrieved from https://timesofindia.indiatimes.com/city/delhi/delhis-per-capita-income-three-times-the-national-average-economic-survey/articleshow/68128282.cms

UBS. (2018). *Cost of living in cities around the world. Prices and earnings 2018.* Retrieved from https://www.ubs.com/microsites/prices-earnings/en/explore/?category=Earnings&indicator=Earnings_Working%20hours%20and%20vacation%20days%20(average)_Work%20per%20year%20(hours)

United Nations Environment Programme (UNEP). (2014). *Using models for green economy policymaking.* Retrieved from https://www.un-page.org/files/public/content-page/unep_models_ge_for_web.pdf

Victoria Transport Policy Institute (VTPI). (2018). *Economic value of walkability.*

Wikimedia. (n.d.). *Location map India Delhi.* Retrieved from https://commons.wikimedia.org/wiki/File:Location_map_India_Delhi_EN.svg

World Health Organization (WHO). (2017). *Health economic assessment tool (HEAT) for walking and cycling. Methods and user guide on physical activity, air pollution, injuries and carbon impact assessments*. Copenhagen: WHO Regional Office for Europe. Retrieved from http://www.euro.who.int/en/publications/abstracts/health-economic-assessment-tool-heat-for-walking-and-for-cycling.-methods-and-user-guide-on-physical-activity,-air-pollution,-injuries-and-carbon-impact-assessments-2017

World Health Organization. (2018). *Ambient (outdoor) air quality and health.* Retrieved from https://www.who.int/mediacentre/factsheets/fs313/en/

Annex I: The SAVi Light Methodology for the PBS System

SAVi light originates from IISD's Sustainable Asset Valuation or SAVi methodology. This approved methodology for infrastructure valuation is based on multi-stakeholder engagement techniques, the use of systems thinking, system dynamics and project finance modelling to capture the lifecycle costs of environmental, social, economic and governance risks. Moreover, SAVi calculates the monetary value of environmental, social and economic externalities that results from deploying infrastructure projects. The SAVi light assessment for the PBS system in Dwarka focuses on this latter element.

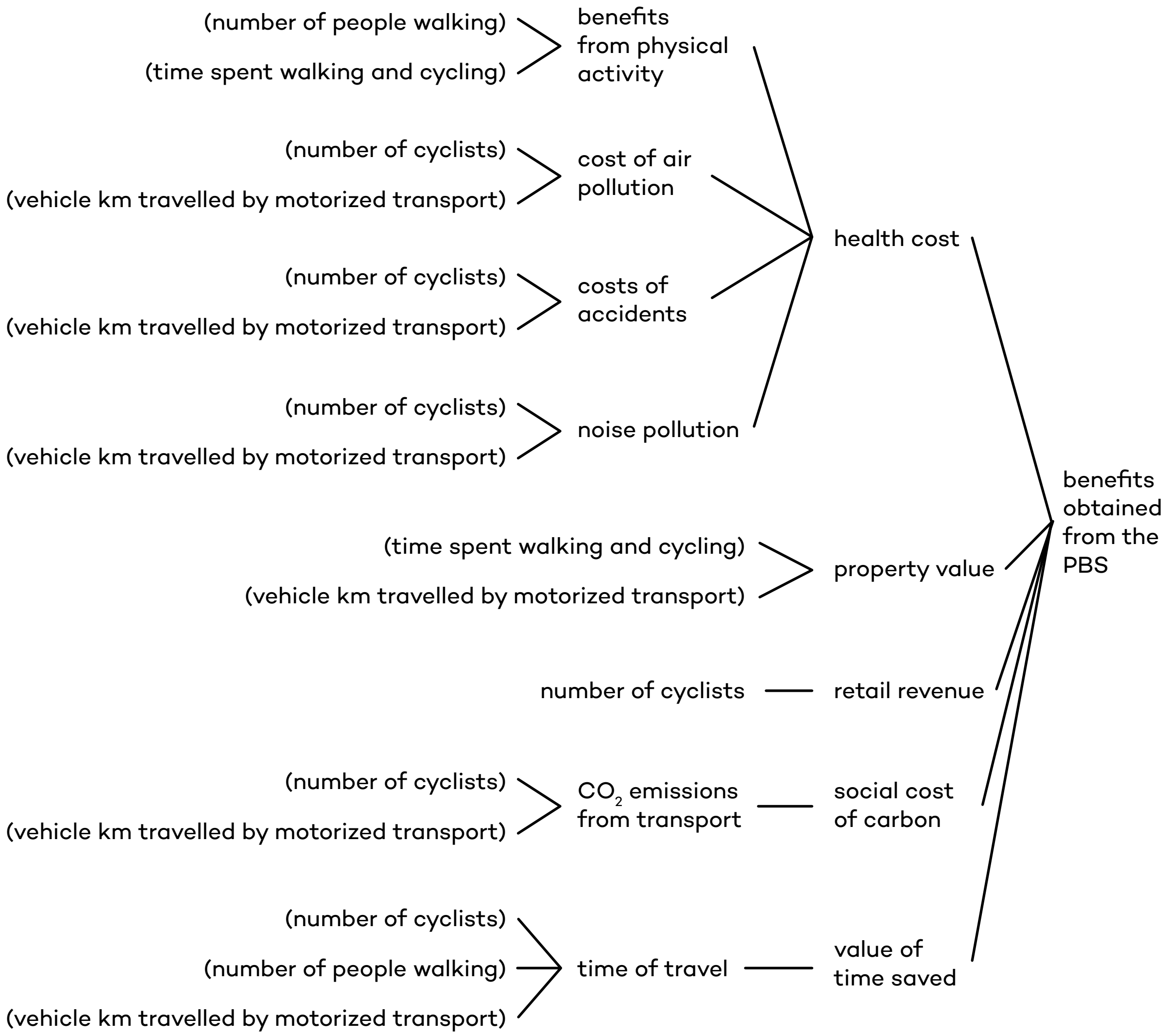
SAVi light uses a spreadsheet-based modelling approach that integrates data from project-specific documents and peer-reviewed research and scientific reports to estimate infrastructure performance and related externalities. Differently from the fully-fledged SAVi methodology, SAVi light does not include overarching systemic dynamics (i.e., factors that influence the operation of the asset analyzed). Being a less time-intensive modelling approach compared to an exhaustive SAVi assessment, SAVi light can be seen as a first step to generate awareness at the local level: it is in fact generally better suited (i) to perform an initial screening of an asset and its externalities, and (ii) to stimulate a local debate on the outcomes of infrastructure investments. A full SAVi assessment would be required to inform investment decisions in more depth, including support to policy formulation where complementary intervention options are required to offset the side effect (or unintended consequences) of infrastructure investments.

In the case of the Dwarka PBS system, data on demand for transport, vehicle mix and the expected reduction in vehicle-km and passenger-km, were obtained from project feasibility studies. The externalities analyzed were identified in collaboration with local stakeholders. Where required, in most cases due to the presence of strong causality but lack of location-specific data, additional data sources were used to quantify variables that served to measure and monetize externalities in Dwarka.

The SAVi light approach quantifies and monetizes the costs and benefits of the assessed infrastructure projects. The externalities assessed for this SAVi application are illustrated in the form of a *causes tree* in Figure A1. A causes tree highlights the causal chain of variables used for estimating the outcomes (positive and negative) of the PBS system. For example, the cost of air pollution is estimated based on the vehicle-km travelled and the emissions factors of air pollutants per km of various transport modes. The vehicle-km travelled with motorized vehicles are affected by the number of people that shift to using bicycles thanks to the PBS system, reducing system-wide air pollution, which leads to lower health cost in return. All valued externalities and the results are discussed in detail in Sections 2 and 3 of this report. Each externality is calculated and valued separately and contributes to estimating the net benefits of the PBS project.

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

Figure A1. Causes tree of the SAVi assessment for the PBS system in Dwarka



SAVi light estimates the net difference of biophysical parameters between a baseline scenario and an intervention scenario (e.g., kilogram of reduced NO_x emissions due to the use of the PBS 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 externality (e.g., a reduction of health costs due to lower air pollution and fewer health implications for citizens). The valuation of externalities 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 extent possible, using studies conducted in Delhi or India.

SAVi Sustainable Asset Valuation

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