SAVi Sustainable Asset Valuation

A Sustainable Asset Valuation of a Net-Zero Transport Strategy in Indonesia

TECHNICAL REPORT

IISD International Institute for Sustainable Development

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Acknowledgements

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

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

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Executive Summary

Purpose of This Assessment and the Sustainable Asset Valuation Methodology

The Sustainable Asset Valuation (SAVi) assessment of Indonesia's net-zero transport strategy is one of a series that focuses on quantifying the economic, social, and environmental outcomes of sustainable transport projects and strategies.

The series aims to enhance awareness of sustainable transport infrastructure investments and advise decision-makers on the importance of using a systemic approach when assessing mobility investments. All studies integrate the economic valuation of social and environmental impacts, such as health and CO_2 emissions, to underscore their significance in the transport investment decision-making process.

SAVi is a methodology that offers policy-makers and investors an all-encompassing and customized analysis of their infrastructure projects and portfolios, considering costs, benefits, risks, and externalities that are often disregarded in traditional valuations.

The following are the key components of a SAVi assessment:

- a combination of systems thinking and different modelling methodologies, such as spatial modelling, system dynamics modelling, and financial modelling.
- a customized approach to each individual infrastructure project, portfolio, or policy, tailored to their specific needs and requirements.
- a co-creation process that involves decision-makers and stakeholders, adopting a multistakeholder approach that allows for the identification of material risks and opportunities unique to each project or alternative. This fosters decision-makers' and stakeholders' ability to take a systemic approach to investments, thereby increasing the likelihood of the results' uptake, use, and impact.
- an analysis based on project-level data (where available), the SAVi database (derived from a literature review and data from previous SAVi applications), and best-in-class climate data from the EU Copernicus Climate Date Store (built into all SAVi models).

Net-Zero Transport Strategy in Indonesia

Indonesia is an emerging economy that has relied heavily on transportation to promote its economic development. As a consequence, transport (particularly road transport) is the most energy-intensive sector in the country—and one of the most polluting (G20 Insights, 2022). Transforming the transport sector in Indonesia is therefore crucial for reducing GHG emissions and improving energy efficiency (Ery Wijaya et al., 2021). To decarbonize the transport sector in Indonesia, it is necessary to adopt an approach that involves the electrification of transport, coupled with a significant share for renewable energy in electricity generation and a shift from individual, motorized transport modes to public and non-motorized modes (BAPPENAS, 2021). For the purposes of this assessment, air and marine transport infrastructure were not considered. This assessment consists of the following elements:

- four broad transport interventions: vehicle electrification, investment in public transport networks, teleworking, and decarbonization of the electricity supply.
- three main net-zero transport scenarios: one scenario consisting of investment in public transport systems, one scenario consisting of private vehicle electrification, and one mixed scenario combining both. These scenarios also include assumptions related to teleworking and decarbonization of the electricity supply for transport.
- two additional secondary scenarios representing a sensitivity analysis of private vehicle electrification and decarbonization of the electricity supply for transport.
- an integrated cost-benefit analysis (CBA) that includes the valuation of different indicators including three main investments and costs, four added benefits, and six avoided costs over a 30-year time horizon.

Findings

Table ES1 shows the results of the integrated CBA of the net-zero strategy in Indonesia for the three main scenarios that were assessed with the SAVi model.

Scenario 3, which combines all transport interventions, results in the highest positive outcomes across all indicators and a net benefit of IDR 6,926.03 trillion (USD 450.1 billion) until 2050. The second-most positive net-zero transport scenario is Scenario 2, which shows a cumulative net benefit of IDR 5,905.54 trillion USD 383.8 billion. Scenario 2 assumes a 100% rate of private vehicle electrification powered by 100% renewable energy. Scenario 1 assumes investment in electric public transport systems and teleworking only, and results in a cumulative net benefit of IDR 1,949.02 trillion (USD 126.7 billion).

Table ES1. Integrated cost-benefit analysis (discounted cumulative values for the three main net-zero transport scenarios), in IDR trillion

Integrated CBA (discounted at 11.33% and 3.5%)	Scenario 1. Investment in public transport system 2022–2050	Scenario 2. 100% Private vehicle electrification—100% renewable energy 2022–2050	Scenario 3. Mixed net-zero transport scenario—100% renewable energy 2022–2050
Investment and operation costs	**8,176.31**	**6,086.40**	**13,431.53**
Investment in power generation	40.59	1,400.98	1,392.17
Investment in renewable capacity	13.48	1,299.51	1,290.18
Operations and maintenance (O&M) costs of renewable capacity	3.95	316.17	314.57
Investment in non-renewable capacity	15.54	-139.24	-137.27
O&M costs of non-renewable capacity	7.62	-75.46	-75.31
Investment in non-motorized transport (NMT) infrastructure: *Avoid*	3,104.56	0.00	3,104.56
Investment in bus rapid transit (BRT) and mass rapid transit (MRT) infrastructure: *Shift*	5,031.17	0.00	5,031.17
Investment in BRT infrastructure	3,510.47	0.00	3,510.47
Investment in MRT infrastructure	1,520.70	0.00	1,520.70
Investment in electric vehicles: *Improve*	0.00	4,685.43	3,903.63
Investment in electric cars	0.00	4,309.84	3,591.33
O&M costs of electric cars	0.00	148.19	122.47
Investment in electric buses	0.00	61.94	51.67

Integrated CBA (discounted at 11.33% and 3.5%)	Scenario 1. Investment in public transport system 2022–2050	Scenario 2. 100% Private vehicle electrification—100% renewable energy 2022–2050	Scenario 3. Mixed net-zero transport scenario—100% renewable energy 2022–2050
O&M costs of electric buses	0.00	12.75	10.55
Investment in electric chargers	0.00	152.70	127.62
Added benefits	**470.48**	**1,407.75**	**1,792.33**
Real GDP	228.24	1,407.75	1,550.09
- Public revenue	34.24	211.16	232.51
- Disposable income	193.99	1,196.52	1,317.50
Revenues from BRT operation	222.82	0.00	222.82
Revenues from MRT operation	8.02	0.00	8.02
Benefits from physical activity	11.40	0.00	11.40
Avoided costs	**9,654.85**	**10,584.19**	**18,565.23**
Internal combustion engine (ICE) vehicles	0.00	4,226.68	3,527.21
Investment in ICE cars	0.00	4,000.77	3,339.99
O&M costs of ICE cars	0.00	164.43	135.96
Investment in ICE buses	0.00	51.92	43.36
O&M costs of ICE buses	0.00	9.56	7.91
Energy cost	229.12	859.09	970.30
Air pollution	788.33	2,140.80	2,395.51
Air pollution from energy consumption	824.10	1,746.56	1,999.38
Air pollution from power generation	-35.77	394.25	396.13

Integrated CBA (discounted at 11.33% and 3.5%)	Scenario 1. Investment in public transport system 2022–2050	Scenario 2. 100% Private vehicle electrification—100% renewable energy 2022–2050	Scenario 3. Mixed net-zero transport scenario—100% renewable energy 2022–2050
CO_2 emissions	545.19	3,263.15	3,500.80
Noise pollution	645.05	94.47	724.25
Accidents	7,447.16	0.00	7,447.16
Cumulative net benefits (undiscounted)	**2,609.32**	**23,622.33**	**23,225.01**
Cumulative net benefits (discounted)	**1,949.02**	**5,905.54**	**6,926.03**
Benefit-cost ratio	1.24	1.97	1.52

Source: Authors' calculations.

Despite the considerable investments aimed at reaching net-zero in the transport sector in Indonesia by 2050, there is a positive return for the country in all scenarios. For Scenarios 2 and 3, more than 35% of the societal benefits are connected to avoided accidents, reduced air and noise pollution, and lower CO_2 emissions. This illustrates the importance of including and valuing this benefit in CBAs of transport-related interventions.

The benefit-cost ratio (BCR) of the net-zero transport scenarios is also calculated. The BCR determines the overall value for money of a project. It illustrates the return for every unit (in IDR) invested by comparing the project's total benefits (including avoided costs) with the total costs. Scenario 2 provides the most attractive BCR, with 1.97 IDR for every 1 IDR invested. This is because the investment costs related to public transport interventions, which are included in the other two scenarios, are much higher. Some benefits of public transport, such as time savings and wider access to mobility options, could not be quantified for the purposes of this assessment but do provide additional societal benefits. The benefits of Scenarios 1 and 3 are, therefore, likely an underestimation.

While from a BCR perspective, Scenario 2 looks most attractive, the net benefits of Scenario 3 remain the largest for society. Private vehicle electrification alone will not address issues of congestion in urban areas in Indonesia. Congestion and the value of time lost have a negative impact on the economy.

Table ES2 shows the investment costs, added benefits, avoided costs, and BCRs of a sensitivity analysis of Scenario 2. In Scenario 2a, we consider a lower share of private vehicle electrification (20%), while in scenario 2b, we consider a 100% share of private vehicle electrification with no investments in the current energy mix.

Table ES2. Integrated CBA results and BCRs of the sensitivity analysis of Scenario 2 (secondary scenarios)

Integrated CBA (discounted; over a 30-year time horizon)	Scenario 2. 100% private vehicle electrification—100% renewable energy	Scenario 2a. 20% private vehicle electrification—100% renewable energy	Scenario 2b. 100% private vehicle electrification—current energy mix
Investment and costs (trillion IDR)	6,086.40	1,838.43	4,562.05
Added benefits (trillion IDR)	1,407.75	1,031.72	183.37
Avoided costs (trillion IDR)	10,584.19	4,572.07	6,597.62
Net benefits	**5,905.54**	**3,765.36**	**2,218.94**
BCR	**1.97**	**3.05**	**1.49**

Source: Authors' calculations.

The BCR for Scenario 2a amounts to 3.05, which is higher than the BCR of Scenarios 2 (1.97) or 2b (1.49). The results of Scenarios 2a and 2b are predominantly affected by the avoided costs generated by the shift toward renewable energy, not by the extent of uptake of private vehicle electrification. This underlines the importance of integrating net-zero transport strategies into efforts and policies aimed at decarbonizing the energy sector and vice versa. Net-zero ambitions in transport cannot be achieved without the decarbonization of the energy sector.

Overall, the analysis strongly suggests that a net-zero transport strategy combining an "avoid, shift, and improve" approach will be more successful in achieving net-zero by 2050 while delivering the largest benefits to society.

The SAVi assessment results can be considered benchmark values for policy-makers and public infrastructure planners. Integrated assessments, such as this one conducted using the SAVi methodology, can help make a stronger case for net-zero transport strategies at the national level. Table ES3 indicates how different stakeholders and decision-makers can use the results of this assessment to make more informed decisions.

Table ES3. How different stakeholders and decision-makers can use the results of the SAVi assessment of the net-zero transport strategy in Indonesia

Stakeholder	Role in the project	How the stakeholder can use the results of the assessment
Government	Design, implementation, and finance of the net-zero transport strategy in Indonesia	Regional and national governments can use the assessment results to raise awareness and justify investments and support for sustainable transport projects and strategies, as well as make these assessments a standard requirement for investment decisions.
Private sector/ industry	Project developers	Businesses and private sector entities can use the assessment results for additional advocacy for sustainable transport projects and net-zero transport strategies, as well as for identifying new opportunities for investment.
Donors and funders	Funding for sustainable transport projects and net-zero transport strategies	Donors can include the assessment results in their reporting processes to show the impacts of their investments. The assessment results can also be used for awareness raising of the benefits of net-zero transport strategies, with the ultimate aim of making these assessments a formal requirement.
Civil society organizations	Consultation with government on sustainable transport projects and net-zero transport strategies	Civil society organizations can use the assessment results to conduct more targeted advocacy for sustainable transport projects and to raise awareness of their value to society.

Source: Authors.

Abbreviations

BMZ	German Federal Ministry for Economic Cooperation and Development
BCR	benefit-cost ratio
BRT	bus rapid transit
CBA	cost-benefit analysis
CLD	causal loop diagram
CO_2	carbon dioxide
GHG	greenhouse gas emissions
ICE	internal combustion engine
IDR	Indonesian rupiah
MRT	mass rapid transit
NDC	nationally determined contributions
NMT	non-motorized transport
NOx	nitrogen oxides
O&M	operation and maintenance
$PM_{2.5}$	particulate matter with a diameter of less than 2.5 micrometres
RPJMN	National Medium-Term Development Plan
SAVi	Sustainable asset valuation tool
VSL	value of a statistical life

Glossary

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

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

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

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

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

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

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

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

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

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1.0 Introduction

1.1 Achieving Net-Zero in Indonesia

Indonesia is the world's fourth largest country, with a population of 273 million. The country is exposed to significant climate change risks, experiencing high air pollution levels and having much of its population living in low-lying areas that are prone to flooding. In addition, Indonesia's population and urbanization rates are expected to increase significantly in the coming decades, the former by about 20% until 2050 (World Bank, 2019). At the same time, the country has an area of 1,905 million km^2, including approximately 18,000 islands, and thus has a very strong potential for renewable energy, including 40% of the world's potential for geothermal energy (KPMG, 2021).

Although the Indonesian government has set a target of net-zero by 2060, it is expected that emissions will increase for many sectors over the next few years (KPMG, 2021). An increase in GHG emissions will have damaging effects on Indonesia's economy. One recent analysis shows that if the world is 2.0–2.6°C warmer by 2050, even if current pledges under the Paris Agreement are met, Indonesia's GDP could diminish by 16.7%–30.2% due to climate change impacts (Re Swiss Institute, 2021). Actions to achieve net-zero in Indonesia can end dependency on volatile fossil fuel markets, while at the same time protecting the extremely valuable natural capital of the country.

Importantly, in 2020 Indonesia officially adopted the National Medium-Term Development Plan (RPJMN) 2020–2024, a 5-year plan for a low-carbon, green, climate-resilient pathway to prosperity. Moreover, the National Long-Term Strategy for Low carbon and Climate Resilience 2050 (2021) highlights the need for balance between emissions reduction and economic development in Indonesia and states the importance of climate resilient development in the country. Lastly, Indonesia's Enhanced Nationally Determined Contributions (NDCs) (2002) also outline the importance of the country's transition to a low-carbon and climate-resilient future.

A recent scenario analysis developed by BAPPENAS (2021) aiming to inform the RPJMN 2020–2024 shows that a low-carbon growth path could deliver GDP growth of 6% annually on average for Indonesia until 2045 while also increasing employment growth and accelerating poverty reduction. Expanding on the low-carbon measures included in the RPJMN 2020–2024, the net-zero scenarios consist of actions that aim to fully replace fossil fuels with clean, renewable energy, improve energy efficiency, phase out fossil fuel subsidies by 2030, improve industry efficiency, protect and restore forests, peatlands and mangroves and adopt more sustainable practices in the agricultural sector, as well as in the forestry and fisheries sectors (BAPPENAS, 2021).

1.2 Achieving Net-Zero in the Transport Sector in Indonesia

Indonesia is an emerging economy that has relied heavily on transportation to promote its economic development. As a consequence, the transport sector, particularly road transport, is one of the most polluting sectors in the country and is a major contributor to air pollution and GHG emissions (G20 Insights, 2022). Since 2012, transport has become the most energy-intensive sector in Indonesia, accounting for one third of final energy consumption and 40% of CO_2 emissions today. From 2000 to 2019, energy consumption in the transport sector increased by 5.9% annually, with a 5.3% annual increase in GHG emissions. In addition, road transport is responsible for approximately 90% of total CO_2 emissions in the transport sector, 60% of which comes from passenger transport (International Energy Agency [IEA], 2022)—with the sector's emissions projected to grow by up to 50% in the next few decades (KPMG, 2021).

Transforming the transport sector in Indonesia is, therefore, crucial for reducing GHG emissions and improving energy efficiency, as the sector has the largest potential for energy savings (Ery Wijaya et al., 2021). The electrification of transport, coupled with a high share of renewable energy in electricity generation, could decarbonize Indonesia's transport sector (Climate Transparency, 2020). This would also have to be combined with a shift from motorized transport modes to public transport systems.

The following chapters explore the interventions identified within a large body of secondary sources that describe fundamental interventions in Indonesia's transport sector that would help the country meet a net-zero transport target by 2050. These secondary sources include, but are not limited to, government plans and strategies, country profiles, official reports, articles, and indexes:

- BAPPENAS. (2021). *A green economy for a net zero future: How Indonesia can build back better after COVID-19 with the Low Carbon Development Initiative* (LCDI).
- Climate Transparency. (2022). *Indonesia country profile*.
- Coalition for Urban Transitions. (2021). *Seizing Indonesia's urban opportunity: compact, connected, clean and resilient cities as drivers of sustainable development*.
- G20 Insights. (2022). *A path to zero-emissions vehicles and greener infrastructure development in Indonesia*.
- Institute for Essential Services Reform. (2021). *Indonesia energy transition outlook 2022—Tracking progress of energy transition in Indonesia: Aiming for net-zero emissions by 2050.*
- Institute for Transportation and Development Policy Indonesia. (2021). *Indonesia: Racing to net zero.*
- International Energy Agency. (2022). *An energy sector roadmap to net zero emissions in Indonesia*.
- Laan, T., & McCulloch, N. (2019). *Energy transition in support of the Low-Carbon Development Initiative in Indonesia: Transport sector*.
- Republic of Indonesia. (2020). *The National Medium-Term Development Plan for 2020–2024*.

- Republic of Indonesia. (2021). *Long-Term Strategy for Low Carbon and Climate Resilience 2050*.
- Republic of Indonesia. (2022). *Enhanced nationally determined contributions*.
- Sutiyono, G., & Giwangkara, J. (2021). *Raising Indonesia's net zero ambition: the pivotal role of energy systems in setting and reaching a net zero target*.
- United Nations Framework Convention on Climate Change. (2021). *Indonesia third biennial update*.
- KPMG (2021), Net Zero readiness index, 2021

The next chapters will introduce the four main interventions that are required for Indonesia to achieve net-zero in its transport sector. While the interventions have considerable benefits, they cannot reach net-zero if implemented in isolation. A combined approach—that includes electrification of private transport, investment in public transport, and decarbonization of the electricity supply—is, therefore, recommended.

1.2.1 Electrification of Private Transport

Electrification of the transport sector is paramount to meeting net-zero targets by 2050 and achieving full decarbonization of Indonesia's energy system. The electrification of road transport, in particular, would address the single largest source of fossil fuel demand today and would boost energy efficiency, reducing the need for Indonesia to import oil or use biofuels as a replacement.

According to Indonesia's RPJMN, clean energy utilization in the transport sector is largely underdeveloped, although there is considerable potential for the electrification of private vehicles and public transport systems (Republic of Indonesia, 2020). However, electrification targets in the BAPPENAS scenario analysis (2021) show targets of 100% electrification of Indonesia's transport fleet in three scenarios: by 2040, 2045, and 2060.

In addition, Indonesia already introduced nationwide targets for electric vehicles set under the National Energy Plan in 2017. These targets are for 2.1 million e-bikes, 2,200 e-cars, and 10% of public e-bus fleets on the road by 2025. More recently, an inclusive roadmap was also developed that compiles electric vehicle adoption commitments and targets from state-owned enterprises and businesses. According to this more inclusive roadmap, Indonesia aims to have a total of 715,694 e-bikes, 27,408 e-cars, and 8,264 e-buses on the road by 2025 (Sutiyono & Giwangkara, 2021).

Despite the above, market penetration of electric vehicles in Indonesia remains low. By the third quarter of 2021, electric vehicle sales accounted for less than 1% of total car sales. Hence, it will be challenging to meet the government target of reaching 2 million electric cars by 2030. At the same time, the development of supporting infrastructure, such as public charging stations and battery swap stations, is also moving at a slow pace (Institute for Essential Services Reform, 2021).

1.2.2 Investment in Public Transport Systems and Non-Motorized Transport

Transport infrastructure in Indonesia has predominantly focused on motorized transport systems, with motorcycles accounting for a transport modal share of 84% (Institute for Transportation and Development Policy [ITDP], 2021). However, it is necessary that a large percentage of Indonesia's population shift to the use of public transport systems in the future and that public investments stimulate the use and rollout of non-motorized transport (NMT) networks. This shift could potentially address traffic congestion challenges while significantly reducing air pollution levels and GHG emissions (Republic of Indonesia, 2021). Currently, the share of public transportation in Indonesian cities such as Jakarta, Bandung, and Surabaya is below 20%, while major cities in Asia, such as Tokyo, Singapore, and Hong Kong are well above 50% (Republic of Indonesia, 2020).

A study by the Coalition for Urban Transitions (2021) found that about a quarter of Indonesia's urban GHG abatement potential was in transport, highlighting the benefits of investing in sustainable urban mobility systems, including public transport systems and NMT networks such as walking and cycling infrastructure (Coalition for Urban Transitions, 2021). In addition, according to Indonesia's RPJMN), the main strategic issue with urban transportation in Indonesia is the inadequate availability of public transport systems.

According to the United Nations Framework Convention on Climate Change's *Third Biennial Update Report on Indonesia* (2021), the technology needs of the energy sector for achieving NDC targets can be partly met by the improvement of public transport networks, by the development of intelligent transport systems and by the development of mass rapid transit (MRT) systems and technology, among other options. For example, the first phase of the MRT project that opened in Jakarta in 2019 has already exceeded its target of serving 65,000 passengers daily while creating jobs and reducing both travel time and cost, all of which indicate how successful such public transport systems can be (Centre for Public Impact, 2019).

In addition, public transportation can also act as a starting point for electrification in Indonesia. For instance, the TransJakarta BRT system in Jakarta runs approximately 237 kilometres daily and has roughly 4,000 buses. Electrification of public transport fleets such as this one can help meet electric vehicle targets and achieve economies of scale while also reducing GHG emissions (ITDP, 2021).

1.2.3 Teleworking

Teleworking has the potential to significantly reduce transport use and, therefore, diminish air pollution and GHG emissions, accelerating the transition toward net-zero. According to projections for energy sector development in Indonesia's Long-Term Strategy for Low Carbon and Climate Resilience 2050 (2021), in the future, a considerable fraction of the workforce in Indonesia will be working from home, including home offices or businesses such as small shops, maintenance and repair services, and restaurants. This trend will be exacerbated with advancements in information and communication technologies. The net-zero scenarios highlighted in IEA (2022) also emphasize behavioural changes, such as teleworking, that could reduce the need to commute by private motorized vehicles.

1.2.4 Decarbonization of the Electricity Supply

While it is critical to encourage public transport use and switch to electric vehicles, it is also crucial to decarbonize the electricity supply in order to fully realize the climate benefits of electrification. Indonesia's energy sector is currently dominated by fossil fuels, predominantly coal, which accounts for 63% of the country's electricity generation. The public sector in Indonesia has a central role in providing the right incentives for the gradual phasing out of coal and other fossil fuels while at the same time increasing renewable energy capacities to meet net-zero targets by mid-century (Climate Transparency, 2020).

One of the main policy directions in the context of economic resource management in the RPJMN is to meet energy and electricity generation demand by prioritizing new and renewable energy. Also, the energy strategy underpinning the net-zero scenarios developed by BAPPENAS (2021) has three key elements: improving energy efficiency, decarbonizing the energy supply through renewable energy (combined with electrification and clean alternatives), and realigning incentives by ending fossil fuel subsidies by 2030.

Indonesia is already planning to achieve 23% of renewable energy in its energy mix by 2025. However, the current status of renewable energy in Indonesia is still around 15%. Indonesia's economy is still heavily dominated by coal, oil, and gas as primary energy sources, but plans show aspirations to minimize coal to a maximum of 30% (and oil to a maximum of 25%) of the energy mix by 2025 (Republic of Indonesia, 2022).

1.3 Purpose of a Sustainable Asset Valuation of the Net-Zero Transport Strategy in Indonesia

This report aims to provide a comprehensive assessment of the environmental, social, and economic costs and benefits associated with transport interventions aiming to meet net-zero targets. The Sustainable Asset Valuation (SAVi) of this set of interventions is based on a customized system dynamics model that runs different scenarios and incorporates a wide range of valued economic, social, and environmental added benefits and avoided costs.

Section 2 of the report presents the methodology, including an overview of system dynamics and the causal loop diagram (CLD) that was created for this assessment. This section also includes a summary of the economic, social, and environmental indicators. Section 3 provides an overview of scenarios, assumptions, the valuation methods for each indicator, and the data sources. Section 4 presents the results: the integrated cost-benefit analysis (CBA) tables that demonstrate the total cumulative monetary values for the net-zero transport scenarios, followed by a detailed discussion of each added benefit and avoided cost. Section 5 concludes the discussion and presents the main takeaways.

2.0 Methodology

This section introduces the system dynamics methodology used for the SAVi assessment of the net-zero transport strategy in Indonesia. It provides an overview of the CLD, as well as a summary of the transport impacts related to the net-zero transport strategy from a systemic perspective. The second part of this section summarizes the investment and costs, added benefits, and avoided costs used in the assessment.

2.1 System Mapping

We use system maps as a first qualitative step to understand the relationships within which interventions take place. This will serve as a blueprint for the subsequent quantitative model. System maps are a tool to get a more comprehensive understanding of causal relationships and dynamics.

2.1.1 Systems Thinking and System Dynamics

The underlying dynamics of the net-zero transport strategy in Indonesia, including driving forces and key indicators, are summarized in the CLD displayed in Figure 2. The CLD includes the main indicators analyzed during this SAVi assessment, their interconnections with other relevant variables, and the feedback loops they form. The CLD illustrates the interconnections of the economy with a wide range of social and environmental parameters while highlighting key dynamics and potential trade-offs emerging from different development strategies. The CLD is the starting point for the development of the mathematical stock and flow model.

2.1.2 Reading a Causal Loop Diagram

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

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

Table 1. Causal relations and causality

Variable A	Variable B	Sign
⬆	⬆	+
⬇	⬇	+
⬆	⬇	–
⬇	⬆	–

Source: Authors.

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

2.1.3 Causal Loop Diagram for the Net-Zero Transport Strategy in Indonesia

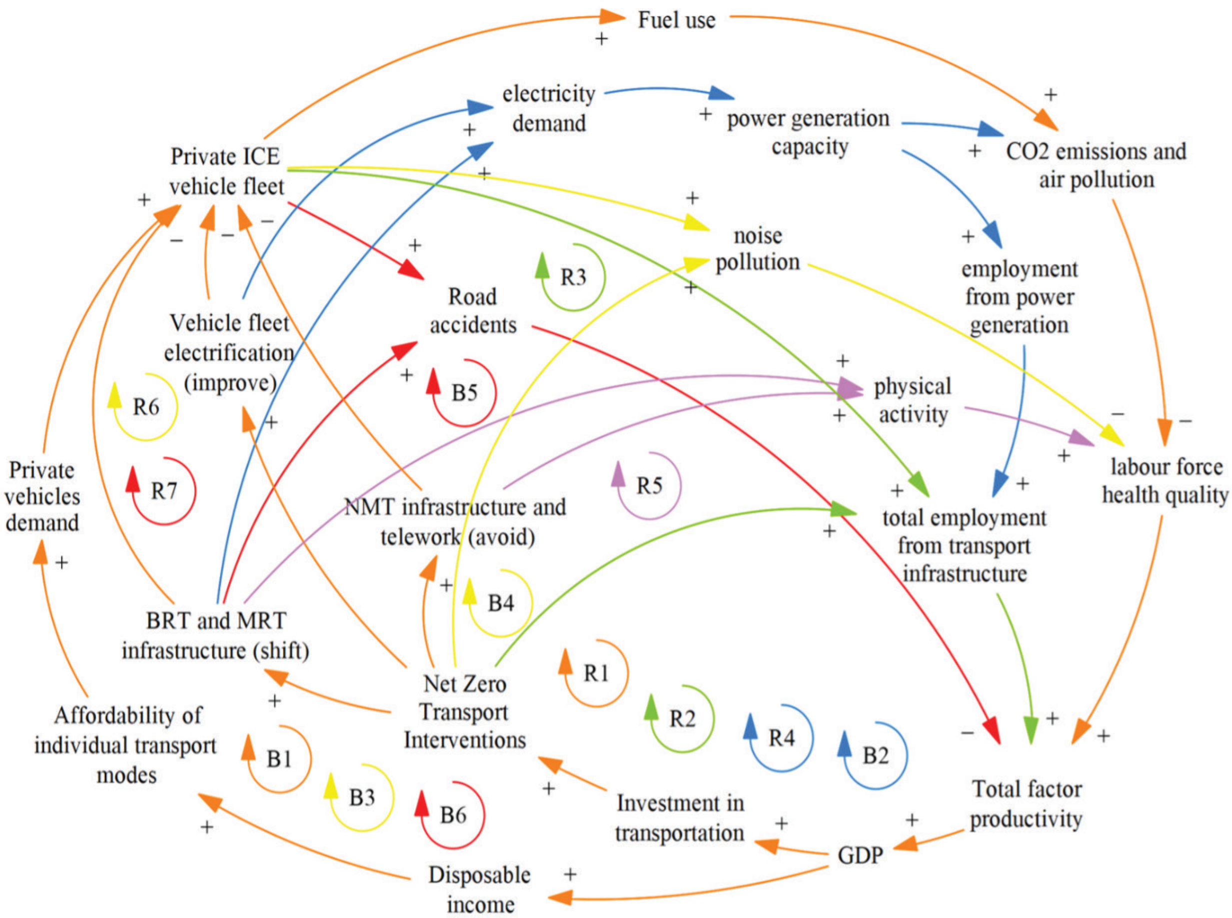
The CLD was developed based on literature review and the Green Economy Model (GEM) for Indonesia. The material indicators and dynamics were validated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Indonesia in discussion of the preliminary results.

The impacts of the net-zero transport strategy in Indonesia are manifold and diverse. These impacts are presented in a CLD or, more simply, a systems map, shown in Figure 1.

The CLD represents actions framed in the "avoid-shift-improve" approach that seeks to bring transport emissions toward net-zero by 2050. There are several dynamics that strengthen the use of net-zero transport (reinforcing loops) and other dynamics that shorten the impacts of net-zero transport (balancing loops). R1 is one of the main loops reinforcing the implementation of NMT infrastructure and telework ("avoid"), BRT and MRT infrastructure ("shift") and vehicle fleet electrification ("improve"). This is because of the reduced fuel use from the private ICE vehicle fleet, which stimulates economic growth and the demand for mobility. The employment generated from net-zero transport (R2) and the potential reduction from private ICE vehicle use (R3) also contribute to income creation and economic growth, as well as changes in demand for mobility. In addition, "shift" and "improve" interventions require electricity generation and further stimulate employment creation (R4). "Avoid" and "shift" interventions instead trigger more physical activity due to the use of active transport modes (R5). Finally, noise pollution (R6) and road accidents (R7) from private ICE vehicles come into play, being the result of several net-zero transport interventions simultaneously.

The balancing loops that can counteract the impact of the net-zero transport interventions are represented by the impact of CO_2 emissions and air pollution from power generation on "shift" and "improve" interventions (B2) (if thermal power generation is used to generate electricity for transport), the effect of noise pollution (B4) and effect of road accidents resulting from higher volume of travel (B5). Other balancing loops can reduce the effects of private ICE vehicles use and hence play an enabling role for net-zero transport modes, such as the impact of CO_2 emissions and air pollution on private vehicle demand (B1), the effect of noise pollution on the private ICE vehicle fleet (B3), and the effect of road accidents on private vehicle demand (B6).

Figure 1. Causal loop diagram for the net-zero transport strategy in Indonesia



Source: Authors' diagram.

2.2 Summary of Indicators Valued by the SAVi Assessment

Table 2 provides an overview of the indicators included in the assessment, the stakeholders for whom they are of primary importance and the extent to which these have economic, social or environmental impacts.

Table 2. Investments, costs, added benefits and avoided costs

Indicators: Main categories	Indicators: Subcategories	Stakeholders of relevance (government, households, private sector)	Social, environmental, economic
Investments and costs			
Investment in power generation	Investment and O&M costs of both renewable and non-renewable capacity	Government, private sector	Economic, environmental
Investment in public transportation (avoid and shift)	Investment in NMT, BRT, and MRT infrastructure	Government, private sector	Economic, social
Investment in electric vehicles (improve)	Investment and O&M costs of electric cars and buses and electric chargers	Households, private sector, government	Economic, environmental
Added benefits			
Real GDP	Including public revenue and disposable income	Government, private sector, households	Economic
Revenues from public transportation	Revenues from BRT and MRT infrastructure	Government	Economic
Benefits from physical activity		Households	Social
Avoided costs			
ICE vehicles	Investment and O&M costs of conventional cars and buses	Households, government, private sector	Economic
Energy cost		Government, private sector, households	Economic

Indicators: Main categories	Indicators: Subcategories	Stakeholders of relevance (government, households, private sector)	Social, environmental, economic
Air pollution	Air pollution from energy consumption and power generation	Households	Environmental
CO_2 emissions		Government	Environmental
Noise pollution		Households	Social
Accidents		Government, households	Social

Source: Authors.

All of the above indicators are considered in the calculation of the BCR for this assessment. To understand the impact and share of wider added benefits and avoided costs—which are traditionally overlooked in project analysis—and take the perspective of different stakeholders and what "their" BCR may look like, we provide a mix of different BCR calculations in addition to a BCR that takes all into account. Table 3 provides an overview of the mix of indicators taken into account the other BCR calculations.

Table 3. Benefit-cost ratios considered in the SAVi assessment of the net-zero transport strategy in Indonesia

BCR	Indicators considered
BCR – Government	**Investment and costs:** Power generation, investment in NMT, BRT, and MRT systems, investment and O&M costs of electric buses and electric chargers **Added benefits:** Public revenues from GDP, revenue from BRT and MRT operation **Avoided costs:** Investment and O&M of conventional buses, CO_2 emissions
BCR – Households/ society	**Investment and costs:** Investment and O&M costs of electric cars **Added benefits:** Disposable income from GDP, benefits from physical activity **Avoided costs:** Investment and O&M of conventional cars, energy cost, air pollution, CO_2 emissions, noise pollution, accidents
BCR – Tangible impacts only	**Investment and costs:** All **Added benefits:** GDP, revenues from BRT and MRT operation **Avoided costs:** Investment and O&M of conventional cars and buses, energy cost
BCR – Intangible impacts only	**Added benefits:** Benefits from physical activity **Avoided costs:** Air pollution, CO_2 emissions, noise pollution, accidents

Source: Authors.

2.3 Discount Rates

A discount rate is applied to all of the above indicators. Two different discount rates are used in the first integrated CBA, shown in Table 16. Primarily, a discount rate of 11.33% is applied for all investments and costs, including the broad indicators of power generation, investment in public transport systems and investment in electric vehicles. The same discount rate is also applied for tangible added benefits and avoided costs such as GDP contribution, revenues from public transport systems, investments in conventional ICE vehicles, and energy costs. The discount rate is based on current government 30-year bond yields in Indonesia plus a 4% risk premium (World Government Bonds, 2022). The latter is used to compensate for country risk specificities associated with investing in Indonesia.

For the social and environmental indicators of the assessment, in other words, the intangible added benefits and avoided costs, such as added benefits from increased physical activity and avoided costs of air pollution, noise pollution, CO_2 emissions, and number of accidents, the lower discount rate of 3.5% is applied, as per the Green Book guidance (UK Government, 2022). These intangible added benefits and avoided costs represent primarily the environmental and social parameters of the net-zero transport scenarios; therefore, it appears appropriate to use a lower discount rate for these as opposed to the tangible added benefits and avoided costs as well as the conventional investment costs and revenues. The second integrated CBA, shown in Table 16, uses the 3.5% discount rate for all tangible and intangible indicators considered in the SAVi model. By using a lower discount rate across all indicators in the SAVi analysis and assigning a higher value to the benefits that the net-zero transport strategy in Indonesia can have, this analysis emphasizes the importance of addressing climate change impacts that are likely going to worsen in the coming decades.

2.4 Limitations

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

3.0 Scenarios and Assumptions

Tables 4 and 5 provide an overview of the scenarios and the interventions simulated in the SAVi assessment. These interventions are used to create the net-zero transport scenarios. Some of the scenarios that we modelled do not achieve net-zero but are presented in the analysis to help provide a comparison between the costs and benefits of the different sustainable transport interventions being considered in Indonesia. Table 6 clarifies the scenarios that achieve net-zero and those that don't.

Scenario 1 combines the "avoid and shift" approach and includes mainly public interventions in large NMT, BRT, and MRT transport systems. Scenario 2 combines the "avoid and improve" approach and focuses heavily on private vehicle electrification in combination with a reform of the energy sector toward renewable energy. Scenario 3 combines the "avoid, shift and improve" approach and is a mix of interventions in Scenarios 1 and 2. Finally, we also include different sensitivity analyses (secondary Scenarios 2a and 2b) which represent a lower private vehicle electrification rate and a lower renewable energy percentage that is based on the current energy mix in Indonesia, respectively.

Table 4. Description of the scenarios simulated in the net-zero transport strategy SAVi assessment

Net-zero transport scenarios	Assumptions	Achieving net-zero by 2050
Main scenarios		
Scenario 1	This scenario includes investments in public transportation systems, such as BRT and MRT transport networks that are 100% electric, and a drop in demand for mobility due to teleworking. It also introduces an NMT system.	Not achieving net-zero by 2050
Scenario 2	This scenario includes 100% private vehicle electrification that is powered by 100% renewable energy and teleworking.	Achieving net-zero by 2050
Scenario 3	This scenario combines all of the above interventions with 100% renewable energy.	Achieving net-zero by 2050
Secondary scenarios		
Scenario 2a	This scenario includes 20% private vehicle electrification that is powered by 100% renewable energy and teleworking.	Not achieving net-zero by 2050
Scenario 2b	This scenario includes 100% private vehicle electrification that is powered by 17.6% renewable energy, based on the current energy mix in Indonesia, and teleworking.	Not achieving net-zero by 2050

Source: Authors.

Table 5. Summary of the scenarios simulated in the net-zero transport strategy SAVi assessment.

Net-zero transport scenarios	**Teleworking** (by 2050)	**NMT** (2022–2030)	**BRT** (2022–2030)	**MRT** (2022–2030)	**Vehicle electrification** (by 2050)	**Renewable energy** (by 2050)
Primary scenarios						
Scenario 1: Investment in public transport systems	15% of consumption avoided	kms of NMT infrastructure built/year: 50,000	kms of BRT infrastructure built/year: 10,000[1]	kms of MRT infrastructure built/year: 150		
Scenario 2: Private vehicle electrification	15% of consumption avoided				100%	100%
Scenario 3: Mixed	15% of consumption avoided	kms of NMT infrastructure built/year: 50,000	kms of BRT infrastructure built/year: 10,000	kms of MRT infrastructure built/year: 150	100%	100%
Secondary scenarios						
Scenario 2a: Private vehicle electrification –20%	15% of consumption avoided				20%	100%
Scenario 2b: Private vehicle electrification – current energy mix	15% of consumption avoided				100%	No change in energy mix – 17.6% energy from renewable energy

Source: Authors.

[1] Net-zero scenarios for transport require ambitious and effective strategies. We acknowledge that this is an ambitious assumption that considers a long-term horizon for successful implementation of BRT systems across the country. The assessment aims to show the outcomes across a range of scenarios, including high-ambition ones.

Tables 7, 8, and 9 represent each main net-zero transport scenario individually and the interventions used, as well as their assumptions. Teleworking has been included in all scenarios in the form of a 15% reduction in transport-related energy consumption. Teleworking is a relatively recent working trend that was partly spurred on by the COVID-19 pandemic. This results in a lack of data on how to calculate its wider impacts. In addition, teleworking is indirectly related to savings in a lot of different variables as well as some added benefits and avoided costs, such as GDP, energy costs, air pollution, and CO2 emissions, that result partly from avoided fuel demand. This is why the integrated costs and benefits are calculated based on an estimation that teleworking reduces 15% of transport-related energy demand.

Table 6. Net-zero transport scenario 1: Investment in public transport systems

Intervention	Intervention input parameter	Units	Assumption
Avoid			
Public transport system: NMT	NMT infrastructure construction rate Persons impacted by the NMT infrastructure	km/year	kms of NMT infrastructure built per year from 2022 to 2030: 50,000
Teleworking	Share of avoided transport use from teleworking	%	15% of energy consumption from transport avoided by 2050
Shift			
Public transport system: BRT	BRT infrastructure construction rate	km/year	kms of BRT infrastructure built per year from 2022 to 2030: 10,000
Public transport system: MRT	MRT infrastructure construction rate	km/year	kms of MRT infrastructure built per year from 2022 to 2030: 150

Source: Authors.

Table 7. Net-zero transport Scenario 2: Private vehicle electrification, including sensitivity analyses 2a and 2b

Intervention	Intervention input parameter	Units	Assumption		
			Scenario 2	Scenario 2a	Scenario 2b
Avoid					
Teleworking	Share of avoided transport use from teleworking	%	15% of energy consumption from transport avoided by 2050		
Improve					
Vehicle electrification	Desired share of transport electrified	%	Share of the petroleum demand from transport: 30% by 2030 and 100% by 2050	Share of the petroleum demand from transport: 20% by 2050	Share of the petroleum demand from transport: 30% by 2030 and 100% by 2050
Decarbonization of the electricity supply	Share of electricity generation from renewable energy sources	%	Share of the electricity generation capacity that is renewable: 100% by 2050		Share of the electricity generation capacity that is renewable: 17.6%, based on current energy mix

Source: Authors.

Table 8. Net-zero transport Scenario 3: Mixed

Intervention	Intervention input parameter	Units	Assumption
Avoid			
Teleworking	Share of avoided transport use from teleworking	%	15% of energy consumption from transport avoided by 2050 (IEA, 2022)
Public transport system: NMT	NMT infrastructure construction rate	km/year	km of NMT infrastructure built per year from 2022 to 2030: 50,000

Intervention	Intervention input parameter	Units	Assumption
Shift			
Public transport system: BRT	BRT infrastructure construction rate	km/year	km of BRT infrastructure built per year from 2022 to 2030: 10,000
Public transport system: MRT	MRT infrastructure construction rate	km/year	km of MRT infrastructure built per year from 2022 to 2030: 150
Improve			
Vehicle electrification	Desired share of transport electrified	%	Share of petroleum demand electrified in transport: 30% by 2030 and 100% by 2050
Decarbonization of the electricity supply	Share of electricity generation from renewable energy sources	%	Share of the electricity generation capacity that is renewable: 100% by 2050

Source: Authors.

3.1 Valuation Methodologies for the Investment and Costs, Added Benefits and Avoided Costs

3.1.1 INVESTMENT AND COSTS

3.1.1.1 Power Generation

The power generation category includes investment in renewable capacity and O&M costs of renewable capacity, as well as investment and O&M costs of non-renewable capacity. To calculate the total capital investment in power generation, the capital cost per megawatt of power generation capacity was multiplied by the power generation capacity for both renewable and non-renewable categories.

The same calculation approach was applied for O&M costs for both power generation categories. A cost per megawatt of power generation capacity was multiplied by the electricity generation rate. Data on the cost per megawatt of different power generation technologies are shown in Table 9.

Table 9. Power generation technologies and their cost per megawatt by 2030

Power generation technologies	Capital cost (USD/MW)	O&M cost (USD/MW per year)
Steam coal	950,000	40,000
Diesel	1,810,000	35,160
Marine fuel oil	650,000	11,000
Natural gas	375,000	20,000
Nuclear	2,775,000	130,000
Biomass	1,850,000	65,000
Hydropower	2,262,000	48,750
Geothermal	2,850,000	57,500
Solar	460,000	11,000
Ocean	4,375,000	130,000
Syngas	2,000,000	75,000
Wind	1,545,000	39,750

Source: Inter-American Development Bank, 2012; IEA, 2022.

3.1.1.2 Investment in NMT, BRT, and MRT

This category includes the investment costs of the three different types of public transport systems under discussion. Investment in NMT, which includes active transport modes such as walking and cycling, is associated with the "avoid" approach. This is because the development and expansion of NMT networks will lead to a shift from private motorized transport to active transport; therefore, unnecessary transport will be partly avoided. Similarly, investment in BRT and MRT public transport systems is linked to the "shift" approach, as in both cases, there is a shift from polluting motorized transport modes to cleaner and more energy-efficient public transport systems.

In the absence of Indonesia-specific values on NMT values per km (capital costs) we used proxy investment values from the NMT network in India, according to which capital costs are IDR 12,003,917,146 per NMT km, and O&M costs are IDR 84,691,883 per NMT km per year. For the capital costs of the BRT system, an average of three different sources of data based on Jakarta BRT lines (ITDP, 2017) was calculated, resulting in IDR 53,186,195,332 per BRT km. For the BRT O&M costs, a share of the capital investment of 4.5% per year was assumed based on UN Development Programme (UNDP) (2015), resulting in a cost of IDR 2,398,236,451 per BRT km yearly. Lastly, values for capital investment in MRT are based on the projected investment of the MRT system in Jakarta, calculated as IDR 1,098,913,305,442 per MRT km (Indonesia Investments, 2022). The O&M cost is IDR 126,695,804,768 per MRT km per year based on an MRT Jakarta study (Nurcahyo et al., 2020). The length of the three infrastructure types is presented in Table 10. The NMT network will reach 355,468 km by 2031, with a construction rate of 50,000 km/year from 2023 to 2030. The BRT network extends for 71,094 km by 2031 with a construction rate of 10,000 km/year from 2023 and 2030, and the MRT network reaches 1,066 km by 2031 with a construction rate of 150 km/year during the same period as the NMT and BRT networks.

Table 10. Length of public transport networks

	Unit	2023	2025	2028	2031	2050
NMT	km	1,171	101,171	251,171	355,468	355,468
BRT	km	234	20,234	50,234	71,094	71,094
MRT	km	4	154	754	1,066	1,066

Source: Authors.

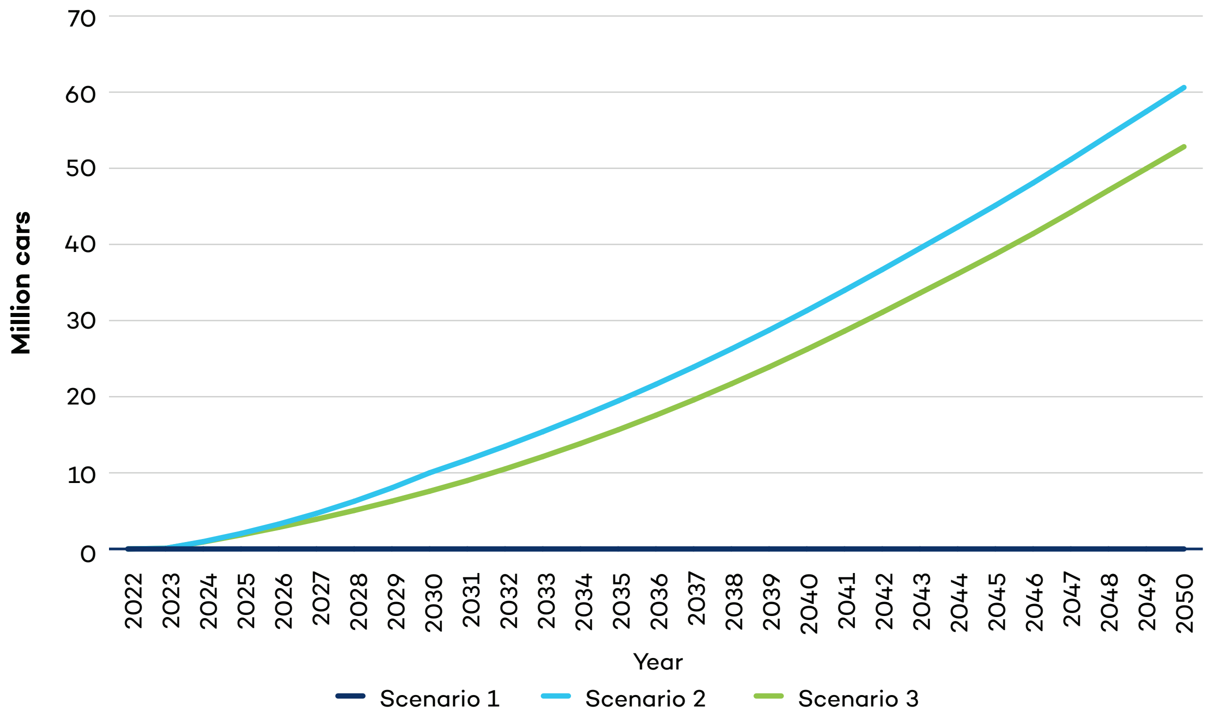
3.1.1.3 Electric Vehicles

The electric vehicles category includes investment and O&M costs of electric cars, investment and O&M costs of electric buses, and investment in electric chargers. This category is linked to the “improve” approach, as the introduction of electric vehicles would improve the transport system overall.

To estimate the total investment in electric vehicles, the number of electric cars and buses that are implemented (or otherwise the purchase rate of electric cars and buses) was multiplied by the cost per vehicle. The capital cost per electric car is projected to decrease from IDR 452,369,727 per car by 2020 to IDR 331,759,256 per car by 2040 (BAPPENAS, 2021), and the capital cost per electric bus is projected to decrease from IDR 1,583,093,867 per bus by 2020 to IDR 1,130,781,333 per bus by 2040 (Economic Research Institute for ASEAN and East Asia [ERIA], 2017). For the O&M costs of electric vehicles, the average number of electric cars and buses per year (or the vehicle stock of electric cars and buses) was multiplied by O&M costs per electric car and bus per year. The O&M value for electric cars is projected to decrease from IDR 1,914,641 per car per year by 2020 to IDR 1,447,287 per car per year by 2040 (ERIA, 2017) and the O&M cost for electric buses is estimated as IDR 30,151,370 per bus per year (BAPPENAS, 2021).

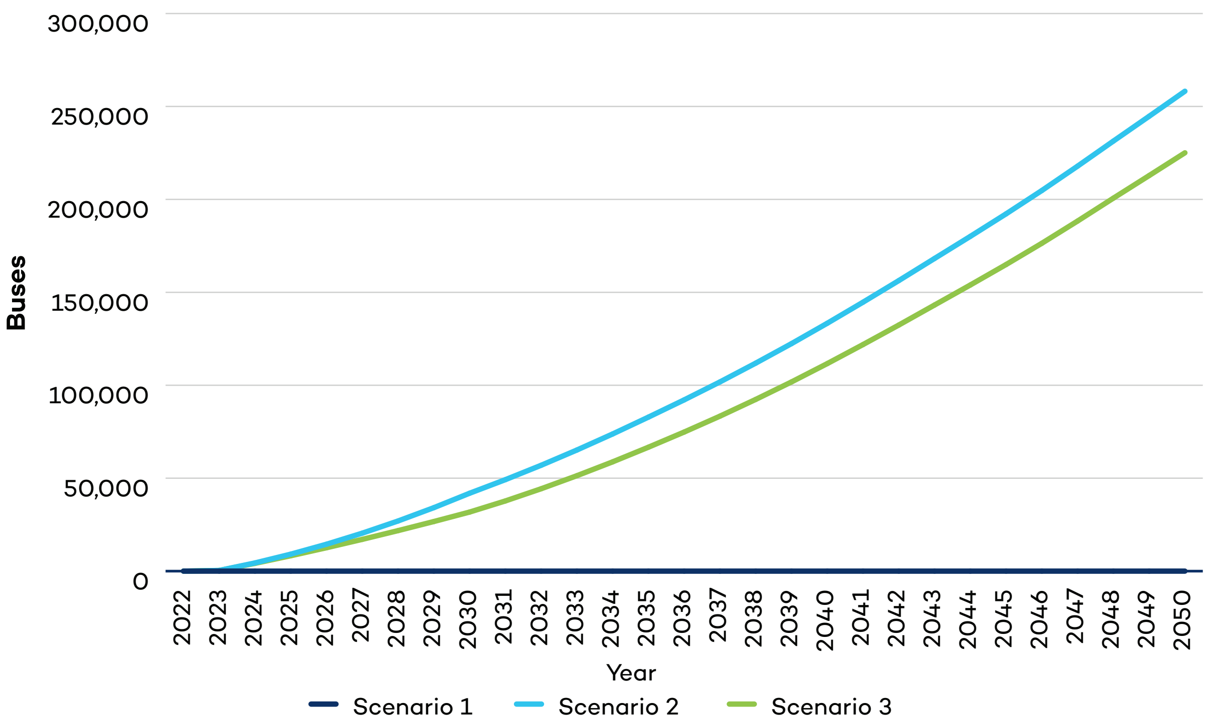
The number of electric vehicles considered in this SAVi assessment, including cars and buses, is shown in figures 2 and 3. As they show, by 2050, the stock of electric vehicles amounts to 61 million cars and approximately 258,000 thousand buses in net-zero Scenario 2, and to 53 million cars and 225,000 buses in net-zero Scenario 3.

Figure 2. Number of electric cars per net-zero scenario



Source: Authors' diagram.

Figure 3. Number of electric buses per net-zero scenario



Source: Authors' diagram.

3.1.2 ADDED BENEFITS

3.1.2.1 Real GDP

The shift from motorized transport modes to less-carbon-intensive and more energy-efficient alternatives, such as electric vehicles, is expected to have positive effects on GDP in Indonesia, especially in the medium to long term, as a result of reduced energy spending combined with lower emissions and air pollution. In addition to presenting results for real GDP, the analysis offers details on the economic contribution of each investment and scenario for public revenue and disposable income, in order to show the extent to which the government and citizens benefit from increases in economic activity. The estimation of the real GDP is based on the GEM and is calculated endogenously based on three components that make up a country's economy: industry, services and agriculture. Capital, employment, and total factor productivity are considered part of the services and industry production functions. For the agriculture component, the value added per ton of production was considered and multiplied by the total production of agriculture in Indonesia and is more marginally impacted by transport investments.

When considering the structure of the national accounts at the macroeconomic level, GDP offers a complete estimate of the impact of the investments analyzed. Further, results for (i) taxation (i.e., a transfer from producers to the government) and (ii) household revenues (i.e., GDP minus taxation) are provided. As a result, the benefits created for the economy should consider either GDP or public revenues and income, depending on the analysis performed. Summing up all three indicators would result in the overestimation of the economic impacts (i.e., double-counting). The extra detail allows for the estimation of the BCR from the perspectives of different economic actors. To estimate the above, it is important to compare the investment of a given economic actor (e.g., government) with the economic actor's tangible revenues (e.g., in public revenues) and subsequently add the relevant added benefits and avoided costs.

3.1.2.2 Revenues From BRT and MRT Operation

Revenues from BRT and MRT operation for the net-zero transport strategy in Indonesia are estimated based on data on the public transport systems in Indonesia's capital city, Jakarta. Revenues from both public transport systems represent the total revenues from the purchase of tickets by BRT and MRT passengers. For the BRT system, the ticket price used for this assessment is IDR 3,500/trip, based on the 2020 flat-rate fare of the TransJakarta system, a BRT system operated by the metropolitan government in Jakarta (Jauregui-Fung, 2022). For the MRT system, the average ticket price is IDR 7,000/trip, corresponding to the ticket price of the Jakarta MRT system for a four-station journey. The ticket price of the MRT system in Jakarta is considered to be IDR 3,000/trip when entering a station and an additional IDR 1,000 per every additional station the commuter passes through during each journey (Jakarta travel guide, 2022). To calculate the annual total revenues, revenues from both BRT and MRT systems are summed up. For the BRT revenues, the BRT ticket price is multiplied by the trips per year of BRT users; for the MRT revenues, the average price per MRT trip is multiplied by the total trips made using the MRT system. The number of trips per year for each public transport system was calculated by using the demand projections of the SAVi model (persons per year) and the number of yearly trips per person. The latter is assumed to be 1.5 daily trips multiplied, with an average of 220 working days per year.

3.1.2.3 Health Benefits From Increased Physical Activity

The shift from motorized transport modes to NMT systems is estimated to have significant positive health impacts by increasing the physical activity levels of NMT users. 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). HEAT's methodology makes it possible to estimate the reduced risk of all-cause mortality due to increased physical activity. The reduction in relative risk of mortality is valued using the value of a statistical life (VSL). The methodology is also applied in this SAVi assessment to value the benefits for people in Indonesia switching from motorized transport modes to walking through the provision of public transport networks such as NMT, BRT, and MRT. A crude death rate of 3.6 people per 1,000 was used, based on values from Delhi (Ministry of Home Affairs, 2017), and a VSL of INR 28 million (IDR 5.29 billion) was obtained from a report of The Energy and Resources Institute (TERI) (2018).

To calculate the benefits of increased physical activity, it is essential to quantify the net change in mortality rate before and after the implementation of the public transport systems. The SAVi assessment of the NMT network in Coimbatore, India (Kapetanakis et al., 2022) was used to estimate the changes in the crude death rate before and after its implementation. Based on this assessment, the crude death rate is 3.597 people per 1,000. The net change in mortality rate is then multiplied by the VSL to find the monetary benefit that is delivered as a result of increased physical activity.

3.1.3 AVOIDED COSTS

3.1.3.1 ICE Vehicles

ICE vehicles are vehicles powered by fossil fuels, such as petrol and diesel. The majority of vehicles on the road today are ICE vehicles. The ICE vehicles category of the CBA produced includes investment costs and O&M costs of ICE cars and investment costs and O&M costs of ICE buses. The category of ICE vehicles is associated with the "improve" approach since it assumes that ICE vehicles and buses will be gradually replaced by electric vehicles, therefore improving energy efficiency in order to achieve net-zero by 2050 in Indonesia.

To estimate the total avoided investment costs of ICE vehicles, the number of ICE cars and buses that are replaced by electric cars and buses was multiplied by the cost of each ICE car or bus. The capital cost per ICE car is IDR 331,674,964, and the capital cost per ICE bus is IDR 1,010,435,774 based on ERIA (2017). In addition, for the total avoided O&M costs of ICE vehicles, the average number of ICE cars and buses every year (the vehicle stock of ICE cars and buses) was multiplied by O&M costs per ICE car and bus per year. The O&M cost for ICE cars is IDR 1,658,924 per car per year (ERIA, 2017) and the O&M cost for ICE buses is IDR 22,624,162 per bus per year (BAPPENAS, 2021).

3.1.3.2 Energy Cost

The net-zero transport strategy total energy cost, which is the total cost paid by energy consumers in Indonesia, is based on the energy demand and supply forecasts generated by GEM. The energy cost modelled is based on the sum of the costs arising from four different types of energy sources: electricity, coal, crude oil, and natural gas.

It is assumed that renewable energy is gradually added to the power generation mix, and transport is electrified until it reaches net-zero by 2050. The more that renewable energy sources are used for generating energy for transport in Indonesia, the bigger the reduction in the cost of electricity for energy consumers. In addition, as renewable energy sources gradually replace coal, crude oil, and natural gas in the transport sector, the costs of these energy sources decrease.

Overall, energy cost is considered an avoided cost in this assessment because as the share of renewable energy sources gradually increases in the transport energy mix in Indonesia, total electricity cost decreases, even though more electricity is consumed by Indonesia's population. This is based on the assumption that renewable energy will become cheaper and more energy efficient than fossil fuels in the future.

3.1.3.3 Air Pollution

The shift from motorized, fuel-based transport modes to the use of public transport systems, including NMT, BRT, and MRT, will reduce air pollution levels generated by Indonesia's transport sector. In addition, the SAVi model uses assumptions regarding the number of people impacted by this shift as a share of Indonesia's national population. The share of people impacted is 32% in 2030 and 28% in 2050, and it is primarily located in urban areas where air pollution is a concern. It is estimated that following the end of the construction period of the NMT, BRT, and MRT systems in 2030, air pollution levels stay the same instead of increasing.

In the model, the cost of air pollution is calculated for both energy consumption (demand side) and power generation (supply side) in relation to the amount of air pollutants generated by fossil fuel use. The valuation of $PM_{2.5}$, NO_x, and SO_2 emissions is included. For air pollution from energy consumption, emissions are calculated by multiplying the demand of energy per source (natural gas, coal, petroleum, and biomass) in the transport sector by the corresponding air pollution factor. For the power generation sector, air emissions are calculated by multiplying the electricity generation rate per technology by the corresponding emission factor of each pollutant per technology. Transport-related air pollution is likely to decrease over time as fossil fuel-powered vehicles will become more energy efficient and will be gradually replaced by electric vehicles. More details on both calculations can be found in the GEM that was customized for the Indonesia IV2045 model (BAPPENAS, 2021).

The health cost of air pollution for both sectors is calculated by multiplying the total emissions per type of pollutant ($PM_{2.5}$, NO_x and SO_2) with the health cost per ton of each respective pollutant. Table 11 shows the cost factors used per type of pollutant.

Table 11. Health cost of air pollution

Cost of air pollution factors	Unit	
Total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$	USD/ton $PM_{2.5}$	6,300
Total dollar value (mortality and morbidity) per ton of directly emitted NO_x	USD/ton NO_x	2,400
Total dollar value (mortality and morbidity) per ton of directly emitted SO_2	USD/ton SO_2	4,000

Source: Pirmana et al., 2021.

3.1.3.4 CO_2 Emissions

The social cost of carbon represents the economic cost of an additional ton of carbon dioxide or its equivalent (tCO_2e) into the atmosphere. It can be regarded as the discounted value of economic welfare from an additional unit of carbon dioxide emissions (Nordhaus, 2017).[2] In the model, a life-cycle approach that considers the carbon emissions from both transport energy use and power generation is applied. Changes in energy demand, and therefore in CO_2 emissions, are considered both from the shift from individual motorized transport modes to public transport systems and the gradual transition from polluting energy sources to electricity generated with renewable energy. The social cost of carbon per kg of CO_2 is based on Nordhaus (2017) and amounts to USD 0.031.

To calculate the avoided costs of CO_2 emissions, the demand per energy source is multiplied by the emissions factor per energy source. The CO_2 emissions factor (ton/terajoule [TJ]) of each energy source considered in the SAVi assessment is shown in Table 12. It is important to note that the CO_2 emission factors for electricity change over time as more electricity is generated from renewable sources in the net-zero transport scenarios.

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

Table 12. CO_2 emission factor per energy source

Energy source	CO_2 emission factors (ton/TJ)		
Year	**2022**	**2030**	**2050**
Petroleum	70.02	70.02	70.02
Natural gas	56.1	56.1	56.1
Biofuels and waste	30.81	30.81	30.81
Coal	94.6	94.6	94.6
Electricity	239.3	192.3	0

Source: Gómez et al., 2006.

3.1.3.5 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 infarctions (heart attacks) (Ricardo-AEA et al., 2014). The calculation of the cost of noise pollution follows a bottom-up approach that considers the number of people exposed to noise and the total cost of noise pollution, calculated by multiplying the cost of noise per person exposed by the total amount of people exposed. Finally, weighting factors are applied to account for differences in noise characteristics between different modes of transportation (van Essen et al., 2011).

In the SAVi assessment of the net-zero transport strategy in Indonesia, the avoided cost of noise pollution is estimated based on the replacement of individual transport modes with public transport systems such as NMT, BRT, and MRT, which are characterized by less noise. The total value is estimated based on the reduced noise emissions per v-km per transport mode being replaced by the public transport networks. The SAVi assessment generates noise costs for different transport modes, as shown in Table 13.

Table 13. Noise cost per v-km by transport mode

Noise cost per v-km	Unit	in EUR	in IDR
Bus	value/v-km	0.0016	26.71
4-wheeler (car)	value/v-km	0.0017	28.38
2-wheeler (motorcycle)	value/v-km	0.0144	240.37
Metro	value/v-km	0.0012	20.03

Source: van Essen et al., 2011.

3.1.3.6 Accidents

The valuation of traffic accidents for the net-zero transport strategy in Indonesia is calculated using several factors. Firstly, it is assumed that the shift from individual motorized transport modes to public transport systems, including BRT and MRT systems, will considerably reduce the number of traffic accidents. Accidents from NMT modes, such as cycling and walking, are not considered in the valuation due to the lack of data.

The kilometres travelled by each transport mode, including car, motorcycle, bus and railway, are calculated by the SAVi model. The total avoided kms travelled are based on the sum of avoided kms travelled by the BRT and MRT systems. This is calculated by multiplying the passengers that are impacted or the occupancy rate of the BRT and MRT modes by the avoided km per user for each of the two public transport modes. The indicators considered for the cost valuation are human capital cost (consumption loss) and resource cost (damages, administrative costs, medical costs) considered as public cost, and human suffering cost, considered as private cost. The total avoided kms travelled is then multiplied by the accident cost per km travelled, shown in more detail in Table 14.

Table 14. Cost of accident per transport mode

Transport mode	Unit	Cost of accident per passenger km
Bus	EUR/passenger-km	0.0016
4-wheeler (car)	EUR/passenger-km	0.0017
2-wheeler (motorcycle)	EUR/passenger-km	0.0144
Metro	EUR/passenger-km	0.0012

Source: van Essen et al., 2011.

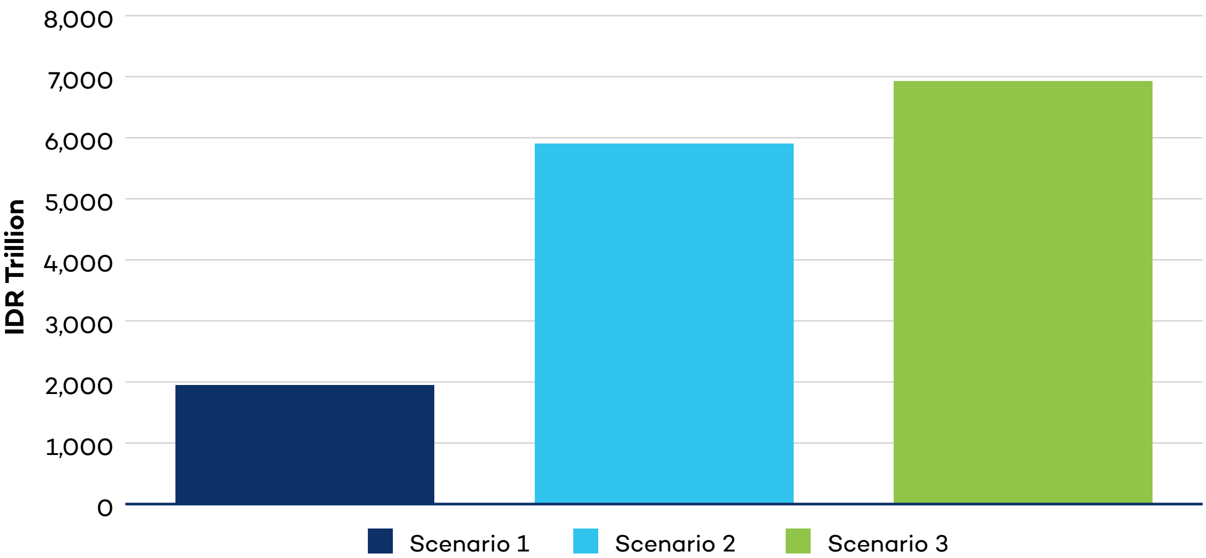
4.0 Results

4.1 Integrated Cost-Benefit Analysis

Tables 16 and 17 show the results of the integrated CBA, with different discount rates. The undiscounted results of the integrated CBA are provided in Appendix B. Once the discount rates (11.33% and 3.5%) are applied to future costs and benefits, the net results for the different net-zero transport scenarios are naturally lower. This is because a discount rate acts as a rate of interest that is applied to future costs and benefits in order to discount them to their present value.

Figure 4 compares the net benefits of each scenario. Scenario 1 yields cumulative discounted net benefits of IDR 1,949.02 trillion, Scenario 2 yields IDR 5,905.54 trillion and Scenario 3, which combines all interventions leads to IDR 6,926.03 trillion.

Figure 4. Net benefits of the three scenarios (discounted at 11.3% and 3.5%)



Source: Authors' diagram.

The most beneficial net-zero transport scenario for Indonesia is Scenario 3 (mixed), which shows the highest positive outcomes across economic, social, and environmental indicators, compared to all other main and secondary scenarios. Scenario 3 achieves net-zero but also considers a wide range of societal benefits that are critical for a just transition to net-zero by 2050. Not surprisingly, a mixed approach that combines investment in public transport systems ("avoid & shift") with private vehicle electrification ("improve"), teleworking (avoid), and decarbonization of the electricity supply of the transport sector, shows the highest values. In addition, the benefits generated from a mixed approach are better distributed among Indonesia's population, evidenced by the high values of Scenario 3 across the different economic, social, and environmental indicators used in the analysis. For instance, impacts such as the avoided costs of energy cost, avoided CO_2 emissions, and avoided air pollution costs will affect a large share of Indonesia's population at both city and country levels. On the other hand, because of combining all interventions, the investments and costs of Scenario 3 are also the highest among all scenarios modelled in the SAVi assessment, as this requires many new infrastructure developments that have high initial costs. Despite their high costs, these interventions that combine the use of public transport systems have significant societal benefits in the long term.

Table 15. Integrated CBA (discounted values at 11.33% and 3.5% for the net-zero transport scenarios), IDR trillion

Integrated CBA (discounted at 11.33% and 3.5%)	**Scenario 1. Investment in public transport system**	**Scenario 2. 100% private vehicle electrification – 100% RE**	**Scenario 3. Mixed net-zero transport scenario – 100% RE**
	2022–2050	**2022–2050**	**2022–2050**
Investment and operation costs	**8,176.31**	**6,086.40**	**13,431.53**
Investment in power generation	*40.59*	*1,400.98*	*1,392.17*
Investment in renewable capacity	13.48	1,299.51	1,290.18
O&M costs of renewable capacity	3.95	316.17	314.57
Investment in non-renewable capacity	15.54	-139.24	-137.27
O&M costs of non-renewable capacity	7.62	-75.46	-75.31
NMT infrastructure: *Avoid*	*3,104.56*	*0.00*	*3,104.56*
BRT and MRT infrastructure: *Shift*	*5,031.17*	*0.00*	*5,031.17*
Investment in BRT infrastructure	3,510.47	0.00	3,510.47
Investment in MRT infrastructure	1,520.70	0.00	1,520.70
Investment in electric vehicles: *Improve*	*0.00*	*4,685.43*	*3,903.63*
Investment in electric cars	0.00	4,309.84	3,591.33
O&M costs of electric cars	0.00	148.19	122.47

Integrated CBA (discounted at 11.33% and 3.5%)	**Scenario 1. Investment in public transport system**	**Scenario 2. 100% private vehicle electrification – 100% RE**	**Scenario 3. Mixed net-zero transport scenario – 100% RE**
	2022–2050	**2022–2050**	**2022–2050**
Investment in electric buses	0.00	61.94	51.67
O&M costs of electric buses	0.00	12.75	10.55
Investment in electric chargers	0.00	152.70	127.62
Added benefits	**470.48**	**1,407.75**	**1,792.33**
Real GDP	228.24	1,407.75	1,550.09
- Public revenue	34.24	211.16	232.51
- Disposable income	193.99	1,196.52	1,317.50
Revenues from BRT operation	222.82	0.00	222.82
Revenues from MRT operation	8.02	0.00	8.02
Benefits from physical activity	11.40	0.00	11.40
Avoided costs	**9,654.85**	**10,584.19**	**18,565.23**
ICE vehicles	0.00	4,226.68	3,527.21
Investment in ICE cars	0.00	4,000.77	3,339.99
O&M costs of ICE cars	0.00	164.43	135.96
Investment in ICE buses	0.00	51.92	43.36
O&M costs of ICE buses	0.00	9.56	7.91
Energy cost	229.12	859.09	970.30
Air pollution	788.33	2,140.80	2,395.51

Integrated CBA (discounted at 11.33% and 3.5%)	Scenario 1. Investment in public transport system	Scenario 2. 100% private vehicle electrification – 100% RE	Scenario 3. Mixed net-zero transport scenario – 100% RE
	2022–2050	2022–2050	2022–2050
Air pollution from energy consumption	824.10	1,746.56	1,999.38
Air pollution from power generation	-35.77	394.25	396.13
CO_2 emissions	545.19	3,263.15	3,500.80
Noise pollution	645.05	94.47	724.25
Accidents	7,447.16	0.00	7,447.16
Cumulative net benefits (undiscounted)	**2,609.32**	**23,622.33**	**23,225.01**
Cumulative net benefits (discounted)	**1,949.02**	**5,905.54**	**6,926.03**
BCR	1.24	1.97	1.52

Source: Authors' calculations.

Integrated CBAs analyze investments and costs, including power generation from both renewable and non-renewable sources, along with associated O&M expenses. Power generation plays a crucial role in determining the shift toward sustainable energy sources. Investments are categorized as "avoid" (e.g., NMT infrastructure to reduce unnecessary travel), "shift" (e.g., BRT and MRT systems to promote public transport), or "improve" (e.g., electric vehicles to replace polluting vehicles). Additionally, the CBA assesses the benefits of interventions, including government revenues, GDP growth, and enhanced physical activity around public transport stations. It also values the cost savings related to the gradual replacement of ICE vehicles with electric ones, the transition to cleaner energy sources, and reductions in air pollution, CO_2 emissions, noise pollution, and traffic accidents.

Table 16. Integrated CBA (discounted values at 3.5% for the net-zero transport scenarios), IDR trillion

Integrated CBA (discounted at 3.5%)	Scenario 1. Investment in public transport system	Scenario 2. Private vehicle electrification	Scenario 3. Mixed net-zero transport scenario
	2022–2050	**2022–2050**	**2022–2050**
Investment and costs	**13,260.00**	**16,778.02**	**28,093.19**
Investment in power generation	93.46	4,416.56	4,351.00
Investment in renewable capacity	25.52	3,804.04	3,748.35
O&M costs of renewable capacity	13.17	1,254.43	1,242.24
Investment in non-renewable capacity	29.13	-350.46	-347.71
O&M costs of non-renewable capacity	25.64	-291.45	-291.87
Investment in NMT infrastructure: *Avoid*	4,389.85	0.00	4,389.85
Investment in BRT and MRT infrastructure: *Shift*	8,776.69	0.00	8,776.69
Investment in BRT infrastructure	5,845.38	0.00	5,845.38
Investment in MRT infrastructure	2,931.32	0.00	2,931.32
Investment in electric vehicles: *Improve*	0.00	12,361.46	10,575.65
Investment in electric cars	0.00	11,249.74	9,633.50
O&M costs of electric cars	0.00	515.96	432.32
Investment in electric buses	0.00	161.95	138.78
O&M costs of electric buses	0.00	45.02	37.75
Investment in electric chargers	0.00	388.78	333.29

Integrated CBA (discounted at 3.5%)	Scenario 1. Investment in public transport system 2022–2050	Scenario 2. Private vehicle electrification 2022–2050	Scenario 3. Mixed net-zero transport scenario 2022–2050
Added benefits	**1,591.08**	**7,026.11**	**8,183.57**
Real GDP	983.12	7,026.11	7,575.61
- Public revenue	147.47	1,053.92	1,136.34
- Disposable income	835.58	5,971.86	6,438.89
Revenues from BRT operation	575.84	0.00	575.84
Revenues from MRT operation	20.73	0.00	20.73
Benefits from physical activity	11.40	0.00	11.40
Avoided costs	**10,109.52**	**20,317.41**	**27,495.19**
ICE vehicles	0.00	11,500.10	9,860.92
Investment in ICE cars	0.00	10,745.74	9,225.64
O&M costs of ICE cars	0.00	581.23	487.30
Investment in ICE buses	0.00	139.37	119.66
O&M costs of ICE buses	0.00	33.76	28.31
Energy cost	683.78	3,318.89	3,566.54
Air pollution	788.33	2,140.80	2,395.51
Air pollution from energy consumption	824.10	1,746.56	1,999.38
Air pollution from power generation	-35.77	394.25	396.13
CO_2 emissions	545.19	3,263.15	3,500.80
Noise pollution	645.05	94.47	724.25
Accidents	7,447.16	0.00	7,447.16

Integrated CBA (discounted at 3.5%)	Scenario 1. Investment in public transport system	Scenario 2. Private vehicle electrification	Scenario 3. Mixed net-zero transport scenario
	2022–2050	2022–2050	2022–2050
Cumulative net benefits (discounted)	**-1,559.40**	**10,565.50**	**7,585.57**
BCR	**0.88**	**1.63**	**1.27**

Source: Authors' calculations.

Table 17 provides the results of a sensitivity analysis of Scenario 2. Scenario 2a yields a IDR 3,765.36 trillion net benefit over 30 years, while Scenario 2b amounts to a cumulative net benefit of IDR 2,218.94 trillion. Both secondary scenarios can be compared to Scenario 2 which, as shown earlier, yields cumulative discounted benefits of IDR 5,905.54 trillion. The sensitivity analysis of Scenario 2 and the results of the secondary Scenarios 2a and 2b highlight the importance of changing the current energy mix of the transport sector in Indonesia by replacing carbon-intensive and highly polluting fossil fuel-based energy sources with electricity generated from renewable energy. While a mixed approach that combines interventions such as investment in public transport systems and electrification of private vehicles is crucial in achieving net-zero in the transport sector in Indonesia by 2050, it needs to be complemented by the gradual decarbonization of the electricity supply. The net results and the BCRs of both secondary scenarios are naturally high compared to the main scenarios because investment costs are minimal.

Table 17. Integrated CBA (discounted values for the net-zero transport Scenario 2, including sensitivity analysis of Scenarios 2a and 2b), IDR trillion

Integrated CBA (discounted)	Scenario 2. 100% Private vehicle electrification – 100% RE	Scenario 2a. 20% Private vehicle electrification – 100% RE	Scenario 2b. 100% Private vehicle electrification – current energy mix
	2022–2050	2022–2050	2022–2050
Investment and costs	**6,086.40**	**1,838.43**	**4,562.05**
Investment in power generation	*1,400.98*	*972.10*	*234.75*
Investment in renewable capacity	1,299.51	987.55	80.19
O&M costs of renewable capacity	316.17	244.50	21.91
Investment in non-renewable capacity	-139.24	-168.16	90.22

Integrated CBA (discounted)	Scenario 2. 100% Private vehicle electrification – 100% RE	Scenario 2a. 20% Private vehicle electrification – 100% RE	Scenario 2b. 100% Private vehicle electrification – current energy mix
	2022–2050	2022–2050	2022–2050
O&M costs of non-renewable capacity	-75.46	-91.79	42.42
Investment in NMT infrastructure: *Avoid*	0.00	0.00	0.00
Investment in BRT and MRT infrastructure: *Shift*	0.00	0.00	0.00
Investment in BRT infrastructure	0.00	0.00	0.00
Investment in MRT infrastructure	0.00	0.00	0.00
Investment in electric vehicles: *Improve*	4,685.43	866.33	4,327.31
Investment in electric cars	4,309.84	796.94	3,976.65
O&M costs of electric cars	148.19	27.45	140.10
Investment in electric buses	61.94	11.45	57.12
O&M costs of electric buses	12.75	2.36	12.04
Investment in electric chargers	152.70	28.13	141.39
Added benefits	**1,407.75**	**1,031.72**	**183.37**
Real GDP	1,407.75	1,031.72	183.37
- Public revenue	211.16	154.76	27.51
- Disposable income	1,196.52	876.90	155.86
Revenues from BRT operation	0.00	0.00	0.00
Revenues from MRT operation	0.00	0.00	0.00
Benefits from physical activity	0.00	0.00	0.00

Integrated CBA (discounted)	**Scenario 2. 100% Private vehicle electrification – 100% RE**	**Scenario 2a. 20% Private vehicle electrification – 100% RE**	**Scenario 2b. 100% Private vehicle electrification – current energy mix**
	2022–2050	**2022–2050**	**2022–2050**
Avoided costs	**10,584.19**	**4,572.07**	**6,597.62**
ICE vehicles	4,226.68	783.23	3,883.31
Investment in ICE cars	4,000.77	741.35	3,671.42
O&M costs of ICE cars	164.43	30.49	155.21
Investment in ICE buses	51.92	9.62	47.65
O&M costs of ICE buses	9.56	1.77	9.03
Energy cost	859.09	556.97	299.45
Air pollution	2,140.80	786.37	1,747.02
Air pollution from energy consumption	1,746.56	310.03	1,988.99
Air pollution from power generation	394.25	476.34	-241.98
CO_2 emissions	3,263.15	2,427.81	581.21
Noise pollution	94.47	17.69	86.65
Accidents	0.00	0.00	0.00
Annual cumulative net benefits (discounted)	**5,905.54**	**3,765.36**	**2,218.94**
BCR	**1.97**	**3.05**	**1.49**

Source: Authors' calculations.

4.2 Benefit-to-Cost Ratios From Different Perspectives

The SAVi assessment of the net-zero strategy in Indonesia also compares the BCRs of the different net-zero transport scenarios. The BCR of Scenario 1 is 1.24, the BCR of Scenario 2 is 1.97, and the mixed scenario shows a BCR of 1.52. The 2a and 2b secondary scenarios that represent sensitivity analyses of Scenario 2, show BCRs of 3.05 and 1.49, respectively. The results show that the potential economic value generation for society from investments in sustainable transport is significant enough that the inclusion of sustainable transport investments should be considered for all future provincial and national development plans in Indonesia.

In addition, the SAVi model calculates four additional BCRs across the net-zero transport scenarios for comparison. Each additional BCR considers a different mix of relevant indicators, as explained in Chapter 2.2. A more detailed overview of which indicators are considered in the calculation of the different BCRs can be found in Table 3.

Two of the additional BCRs aim to demonstrate the value for money of the net-zero transport strategy from the perspectives of the government and from households/society. Considering the main scenarios, the highest BCR from the government perspective is found in Scenario 2 (1.31), and by far the highest BCR from the perspective of households/society is found in Scenario 3 (4.93). The BCR for the households/society category cannot be calculated for Scenario 1, as households do not contribute to the investment costs of public transport systems. If the secondary scenarios are considered, Scenario 2a shows the highest BCRs from both the government and households/society perspectives, with 1.54 and 5.34, respectively. The overall results show that the government has a lower BCR than households/society across all main and secondary net-zero scenarios, demonstrating that most added benefits and avoided costs of the net-zero transport strategy will be accrued by the Indonesian population.

The two remaining BCRs differentiate between tangible and intangible impacts of the net-zero transport scenarios. The former is based on estimations of only tangible economic indicators, and the latter considers the project from a societal point of view, including intangible indicators such as social and environmental added benefits and avoided costs. The BCR that considers tangible impacts leads to significantly lower values than the BCR that considers intangible impacts across all main and secondary scenarios. From the main scenarios, the highest BCR that considers tangible impacts is found in Scenario 2, with 1.07. The highest BCR that considers intangible impacts is found in Scenario 1, with 1.15. Considering the secondary scenarios, Scenario 2a shows the highest BCR values for both tangible and intangible BCRs, with 1.29 and 1.76, respectively. These results show that the BCR that considers intangible impacts is significantly higher than the BCR that considers tangible impacts across all net-zero scenarios, signifying the importance of quantifying and integrating intangible social and environmental parameters in transport infrastructure assessments.

Table 18 shows the BCRs from all perspectives and across all scenarios modelled.

Table 18. BCRs from different perspectives and across all net-zero transport scenarios (discounted at 11.33% and 3.5%)

	Main scenarios			Secondary scenarios	
BCRs (based on discounted values)	**Scenario 1. Investment in public transport systems**	**Scenario 2. Private vehicle electrification**	**Scenario 3. Mixed net-zero transport scenario**	**Scenario 2a. Private vehicle electrification – 20%**	**Scenario 2b. Private vehicle electrification – current energy mix**
BCR	1.24	1.97	1.52	3.05	1.49
BCR - Government	0.07	1.31	0.25	1.54	1.08
BCR - Households/ society	N/A	2.31	4.93	5.34	1.58
BCR - Tangible impacts only	0.08	1.07	0.47	1.29	0.96
BCR - Intangible impacts only	1.15	0.90	1.05	1.76	0.53

Source: Authors' calculations.

4.3 Detailed Discussion of Added Costs and Avoided Benefits

This chapter discusses in further detail the added benefits and avoided costs, showing the performance of a few key economic, social, and environmental indicators across the three main net-zero transport scenarios.

In terms of added benefits, Scenario 3 shows the highest values, with IDR 1,792.33 trillion followed by Scenario 2, with IDR 1,407.75 trillion. Within the added benefits, the values of GDP benefits and income creation are as follows:

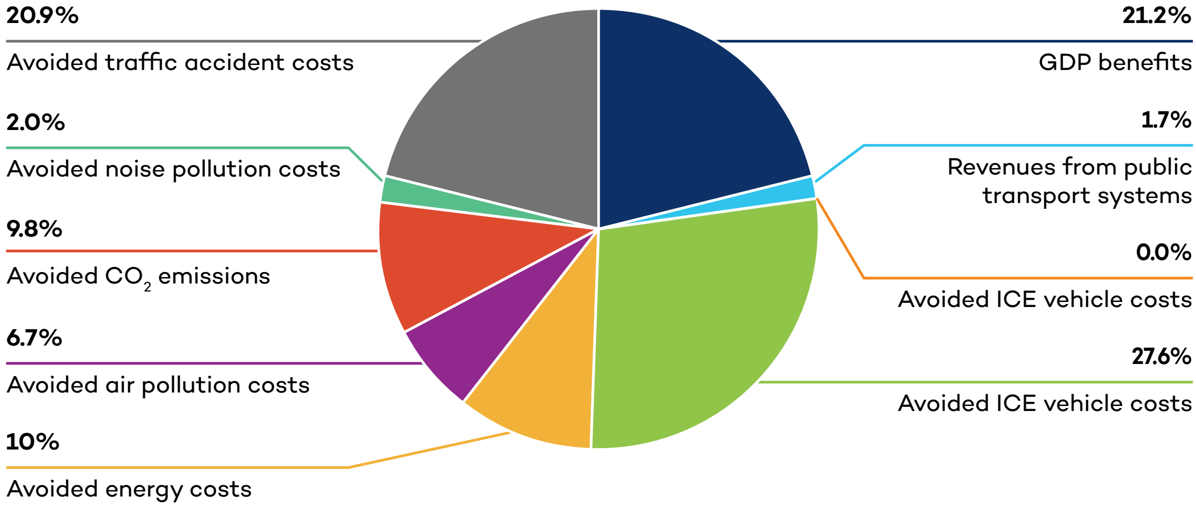
- **GDP benefits and income creation:** The real GDP benefits are highest in Scenario 3 and Scenario 2 with IDR 1,550.09 trillion (representing 21.2% of all added benefits and avoided costs) and IDR 1,407.75 trillion (representing 25.7%), respectively. Similarly, to the real GDP benefits above, Scenario 3 has the highest cumulative disposable income benefits with IDR 1,317.50 trillion (5,458,319 jobs created until 2050), followed by Scenario 2, which shows values of IDR 1,196.52 trillion (3,045,602 jobs created until 2050).

Lastly, Scenario 3 shows total avoided costs of IDR 36,132.31 trillion. Scenario 2 and Scenario 1 follow with IDR 26,283.42 trillion and IDR 15,435.96 trillion respectively. Within the avoided costs, the following outcomes stand out:

- Avoided CO_2 emissions: The cumulative avoided CO_2 emissions amount to IDR 3,500.80 trillion in Scenario 3 (9.8%) or 15,255 million tons of CO_2 emissions avoided by 2050 and IDR 3,263.15 trillion in Scenario 2 (11.9%) or 14,466 million tons of CO_2 emissions avoided. Due to current high motorization rates in Indonesia, electrifying 100% of private vehicles rather than only investing in public transport systems generates the biggest reductions in CO_2 emissions.
- Avoided energy cost: Avoided energy costs are the highest in Scenario 3, with IDR 970.30 trillion and in Scenario 2, with IDR 859.09 trillion (both representing 12.1%). Similar to the indicator above, electrifying 100% of private vehicles rather than only investing in public transport brings about the highest avoided energy costs in Indonesia.
- Avoided air pollution: Avoided air pollution costs from both energy consumption and power generation amount to IDR 2,395.51 trillion in Scenario 3 (6.7%) and IDR 2,140.80 trillion in Scenario 2 (7.8%)
- Avoided accidents: Avoided costs of accidents for Scenarios 3 and 1 are the same, showing values of IDR 7,447.16 trillion (representing 20.9% in the former). Scenario 2 does not have any avoided costs of accidents, as the number of vehicles on the road does not change.

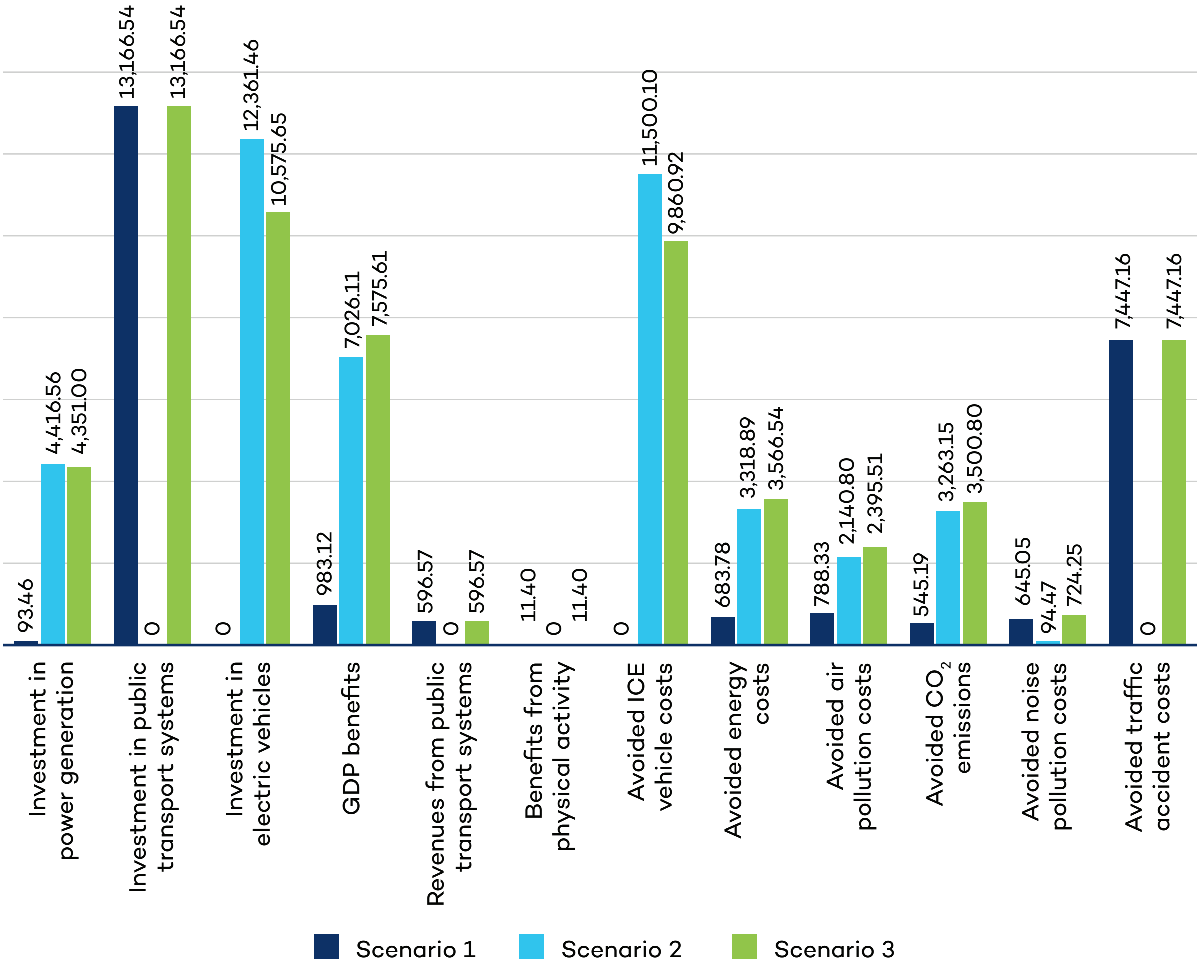
Figure 5 illustrates the share of added benefits and avoided costs under Scenario 3, while Figure 6 provides the comparison of the indicators across the three scenarios.

Figure 5. Added benefits and avoided costs of Scenario 3



Source: Authors' diagram.

Figure 6. Investment costs, revenues, added benefits, and avoided costs across the three main scenarios



Source: Authors' diagram.

4.3.1 GDP BENEFITS

The shift from motorized transport modes to cleaner and more energy-efficient public transport systems, along with the introduction of electric vehicles, will have a positive impact on Indonesia's GDP. The real GDP indicator is divided into public revenue and disposable income, showing the extent to which the government or society benefits from GDP increases. Table 22 shows the cumulative discounted values of real GDP benefits, including public revenue and disposable income, across the main net-zero transport scenarios.

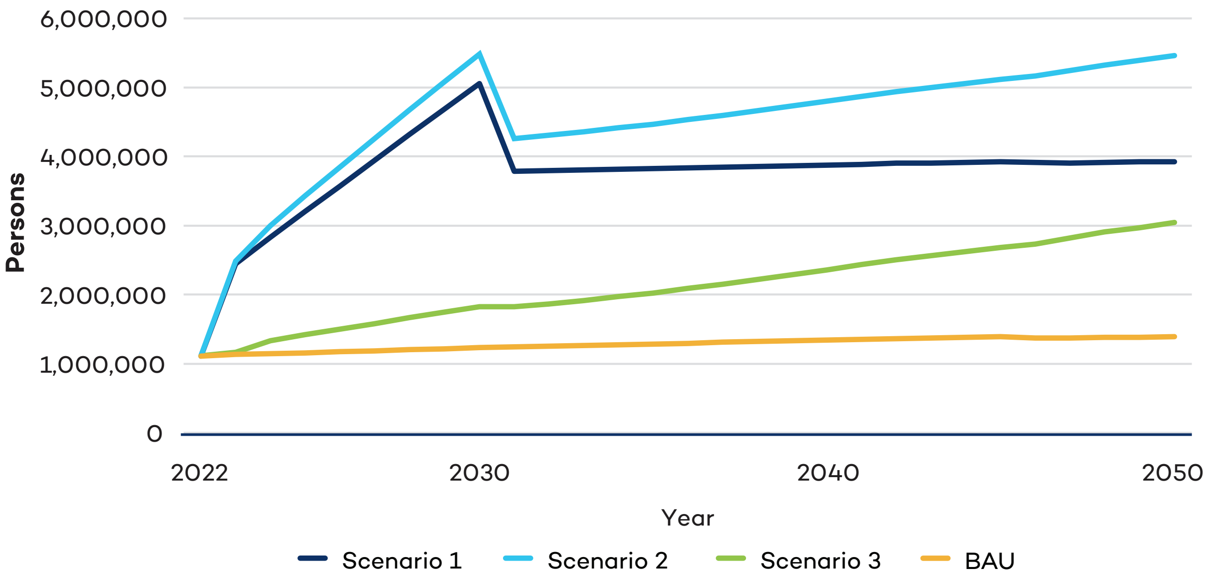
Table 19. Cumulative values of real GDP benefits across main net-zero transport scenarios (discounted at 11.33%), IDR trillion

Scenarios (2022-2050)	Scenario 1	Scenario 2	Scenario 3
Real GDP	228.24	1,407.75	1,550.09
Public revenue	34.24	211.16	232.51
Disposable income	193.99	1,196.52	1,317.50

Source: Authors' calculations.

Figure 7 shows the number of green jobs created as a result of the different net-zero scenarios: public transport (construction and O&M jobs), vehicle electrification (manufacturing of vehicles, installation of chargers and O&M jobs for vehicles) or both. The peak in jobs created is because of the construction of public transport infrastructure and vehicle production.

Figure 7. Total green jobs created



Source: Authors' diagram.

4.3.2 REVENUES FROM BRT AND MRT OPERATION

The introduction of the BRT and MRT systems will lead to increased revenues through the purchase of tickets by BRT and MRT users. As mentioned in Section 3.1.2, the average BRT ticket price of a trip is IDR 3,500, and the average MRT ticket price is IDR 7,000.

For both BRT and MRT systems, the average ticket price is multiplied by the BRT and MRT demand projections, respectively based on the total yearly trips made using both public transport systems. The latter is calculated based on the assumption that there are 1.5 daily trips multiplied by an average of 220 working days per year. The resulting cumulative discounted revenues of the BRT system until 2050 amount to IDR 222.82 trillion. The resulting cumulative discounted revenues of the MRT system to 2050 amount to IDR 8.02 trillion. These values are summarized in Table 21. Scenario 2 does not show any values because these revenues are related only to public transport systems.

Table 20. Cumulative values of BRT and MRT revenues across main net-zero transport scenarios (discounted at 11.33%), IDR trillion

Scenarios (2022–2050)	Scenario 1	Scenario 2	Scenario 3
Revenues from BRT operation	222.82	0.00	222.82
Revenues from MRT operation	8.02	0.00	8.02

Source: Authors' calculations.

4.3.3 HEALTH BENEFITS FROM INCREASED PHYSICAL ACTIVITY

The shift from private, motorized transport modes to public transport systems such as NMT, BRT, and MRT will have significant positive health impacts, for example, resulting from increased physical activity. These health benefits are delivered due to the additional time people spend walking to and from NMT, BRT, and MRT stations. In the case of NMT, the health benefits are higher, as users spend more time walking or cycling to reach their destination. Table 24 shows the cumulative discounted health benefits across the three net-zero transport scenarios. As shown in the table, Scenario 2 does not show any values because these benefits are only delivered from the implementation of public transport systems.

Table 21. Cumulative values of health benefits from increased physical activity across main net-zero transport scenarios (discounted at 3.5%), IDR trillion

Scenarios (2022–2050)	Scenario 1	Scenario 2	Scenario 3
Benefits from physical activity	11.40	0.00	11.40

Source: Authors' calculations.

4.3.4 AVOIDED COSTS OF ICE VEHICLES

This category includes investment costs and O&M costs of ICE vehicles, both cars and buses. This category is linked to the "improve" approach because it is assumed that ICE vehicles will be gradually replaced by electric vehicles in order to achieve net-zero by 2050 in Indonesia. Table 25 shows the cumulative values of avoided costs of ICE vehicles across all three main net-zero transport scenarios. As demonstrated in the table, investment in ICE cars is the most costly, followed by O&M costs of ICE cars and investment in ICE buses, for all four scenarios.

Table 22. Cumulative values of avoided costs of conventional vehicles across main net-zero transport scenarios (discounted at 11.33%), IDR trillion

Scenarios (2022–2050)	Scenario 1	Scenario 2	Scenario 3
ICE vehicles	*0.00*	*4,226.68*	*3,527.21*
Investment in ICE cars	0.00	4,000.77	3,339.99
O&M costs of ICE cars	0.00	164.43	135.96
Investment in ICE buses	0.00	51.92	43.36
O&M costs of ICE buses	0.00	9.56	7.91

Source: Authors' calculations.

4.3.5 AVOIDED ENERGY COST

The total energy cost is evaluated in this SAVi assessment as the cost paid by energy consumers in Indonesia. The energy cost is based on the sum of costs from four different energy sources, including the electricity, coal, crude oil, and natural gas. It is assumed that renewable energy sources are gradually introduced to the total transport energy mix in Indonesia until 2050 and that the more renewable sources are used, the bigger the reduction in the cost of the other energy sources. Table 23 indicates the cumulative discounted values of avoided energy costs across the net-zero transport scenarios modelled in the SAVi model.

Table 23. Cumulative values of avoided energy costs across main net-zero transport scenarios (discounted at 11.33%), IDR trillion

Scenarios (2022–2050)	Scenario 1	Scenario 2	Scenario 3
Energy costs	229.12	859.09	970.30

Source: Authors' calculations.

4.3.6 AVOIDED COST OF AIR POLLUTION

In the SAVi assessment, it is assumed that the shift from motorized, fuel-based transport modes to public transport systems such as NMT, BRT, and MRT will reduce the air pollution levels generated by Indonesia's transport sector. The avoided cost of air pollution is estimated based on each transport mode's air pollutants and the health costs associated with emitting 1 kg of a specific air pollutant. In addition, two sources of air pollution are included in this SAVi assessment: air pollution from energy consumption and air pollution from power generation. Table 24 demonstrates these values across the three main net-zero transport scenarios modelled.

Table 24. Cumulative values of avoided costs of air pollution real across main net-zero transport scenarios (discounted at 3.5%), IDR trillion

Scenarios (2022–2050)	Scenario 1	Scenario 2	Scenario 3
Air pollution	*788.33*	*2,140.80*	*2,395.51*
Air pollution from energy consumption	824.10	1,746.56	1,999.38
Air pollution from power generation	-35.77	394.25	396.13

Source: Authors' calculations.

4.3.7 AVOIDED COSTS OF CO_2 EMISSIONS

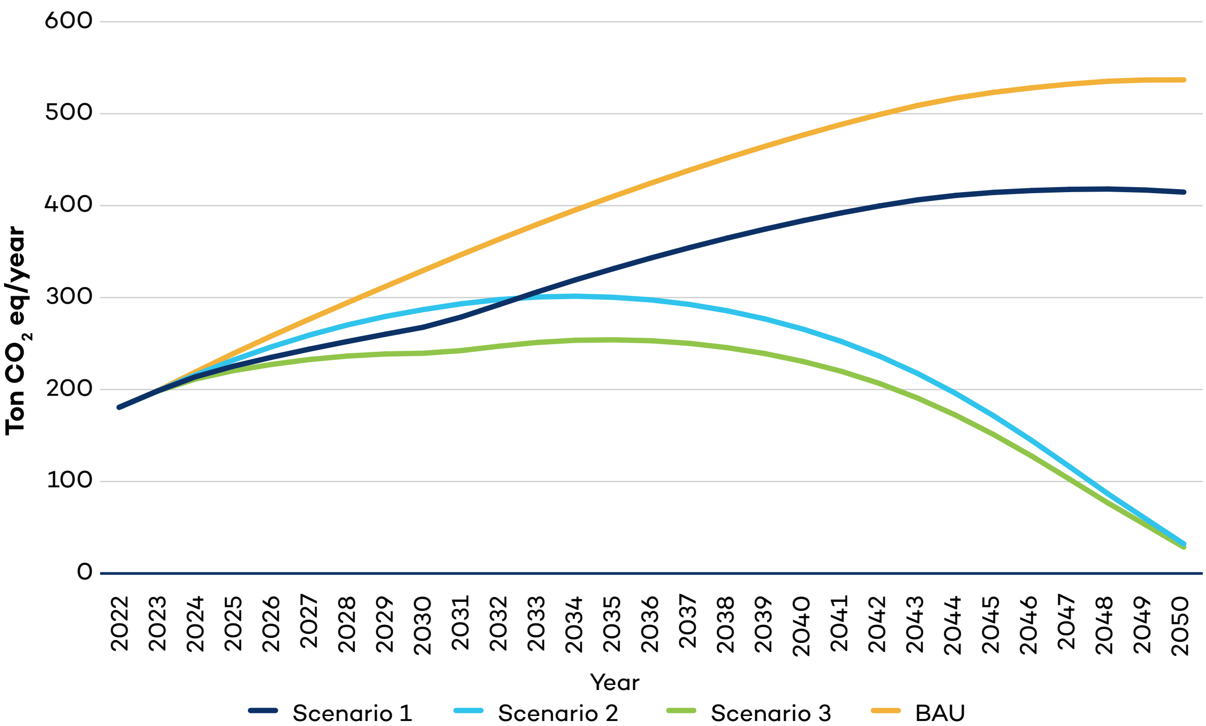
Changes in energy demand are considered from two transitions: the shift from individual motorized transport modes to public transport systems and the shift from polluting energy sources to cleaner ones powered by renewable energy. Both shifts will lead to considerable reduction in CO_2 emissions levels. These reductions or avoided costs of CO_2 emissions, are demonstrated in Table 25, for the main net-zero transport scenarios included in the SAVi model. The CO_2 emission reductions over time are shown in Figure 8.

Table 25. Cumulative values of avoided costs of CO_2 emissions across main net-zero transport scenarios (discounted at 3.5%), IDR trillion

CO_2 emissions	545.19	3,263.15	3,500.80

Source: Authors' calculations.

Figure 8. Transport-related CO_2 emissions



Source: Authors' diagram.

4.3.8 AVOIDED COST OF NOISE POLLUTION

Some transport modes cause significant noise emissions that can lead to negative health effects for humans exposed to the noise. For example, noise from individual, motorized transport modes can lead to stress-related health effects, such as hypertension. In this SAVi assessment, the avoided cost of noise pollution is estimated based on the replacement of individual transport modes with public transport systems such as NMT, BRT, and MRT, which are considerably less noisy. Table 26 shows the cumulative discounted values of avoided noise pollution costs across the net-zero transport scenarios modelled.

Table 26. Cumulative values of avoided noise pollution costs across main net-zero transport scenarios (discounted at 3.5%), IDR trillion

Scenarios (2022–2050)	Scenario 1	Scenario 2	Scenario 3
Noise pollution	645.05	94.47	724.25

Source: Authors' calculations.

4.3.9 AVOIDED COST OF ACCIDENTS

In the SAVi assessment of the net-zero transport strategy in Indonesia, it is assumed the shift from individual, motorized transport modes to public transport systems, such as BRT and MRT systems, will lead to a reduced number of traffic accidents. Due to the lack of data, accidents from NMT modes such as cycling and walking are not considered in the valuation. The cumulative avoided costs of accidents in the three main net-zero transport scenarios modelled are demonstrated in Table 27. As shown in the table, Scenario 2 does not show any values because in private vehicle electrification, the number of cars on the road remains the same.

Table 27. Cumulative values of avoided costs of accidents across main net-zero transport scenarios (discounted at 3.5%), IDR trillion

Scenarios (2022–2050)	Scenario 1	Scenario 2	Scenario 3
Accidents	7,447.16	0.00	7,447.16

Source: Authors' calculations.

5.0 Discussion and Conclusion

All interventions analyzed in this report, which include investment in public transport systems ("avoid & shift"), private vehicle electrification ("improve"), teleworking ("avoid") and decarbonization of the electricity supply for transport, are economically viable, in both the long and medium terms. They can make important contributions to decarbonizing the transport sector in Indonesia.

The BCRs are positive, and the value of avoided costs and added benefits is significant. In fact, certain scenarios are not economically viable when these externalities are not considered (e.g., Scenario 3). Using a conventional approach that considers only tangible benefits would, therefore, be misleading and discourage investments in sustainable transport.

The results also show that the benefits of sustainable transport are shared across several economic areas. For instance, households and citizens benefit from reduced air pollution, lower energy costs, and fewer accidents; businesses benefit from reduced time of travel and employment creation; the government benefits from increased tax revenues and from avoided investments in conventional transport infrastructure.

In order to maximize societal benefits, a mix of public and private investment and efforts will be required to generate the IDR 6,926.03 trillion in benefits over 30 years (Scenario 3). Scenario 3 combines all interventions across the "avoid-shift-improve" strategy. It requires the highest investment but at the same time, it delivers the most positive outcomes across economic, social, and environmental indicators for both avoided costs and added benefits.

These results also illustrate that governments need to take a systemic approach to addressing transport and mobility projects and embrace strategies that also include interventions in the energy sector. Calculating the future benefits of sustainable transport investments and decarbonizing the energy sector will be critical to making the case for investing in sustainable infrastructure.

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Appendix A. SAVi assessment and the IV2045 Model

The Low Carbon Development Initiative (LCDI), a national priority program of the Government of Indonesia, led the production of a report based on the IV2045 model results. The goal of the report was to inform the advancement of low-carbon, green recovery and green economic transformation in the wake of the COVID-19 pandemic (BAPPENAS, 2021). The IV2045 model is built using systems thinking principles and system dynamics modelling techniques to assess, coherently and comprehensively, low-carbon development policies considering the interactions of social, economic, and environmental dimensions. Due to the methodology used, the model contains feedback relationships within and across key model structures, including the stocks (state variables) and flows that represent the system, non-linear relationships, and material/information delays.

The model includes feedback relationships for three dimensions: the economy dimension, which includes government sectors and trade; the social dimension, which includes demographics, labour force participation and labour supply; and the environmental dimension, which includes land use, biodiversity, energy, water, fisheries, carbon emissions, and climate impacts (BAPPENAS, 2021). It also includes COVID-19 dynamics, cost of individual interventions, and valuation of externalities, complemented by additional externalities in the current SAVi assessment.

The SAVi assessment for net-zero transport in Indonesia was built on top of the IV2045 model. This synergy allows (for example) the measurement of the impact of transport interventions on GDP, which is modelled endogenously in IV2045. Transport-related policies were implemented particularly in the energy demand and supply sectors of IV2045.

Appendix B. Undiscounted Integrated Cost-Benefit Analysis

Table B1. Integrated cost-benefit analysis (CBA) (undiscounted values for the net-zero transport scenarios), IDR trillion

Integrated CBA (undiscounted)	Scenario 1. Investment in public transport system 2022–2050	Scenario 2. Private vehicle electrification 2022–2050	Scenario 3. Mixed net-zero transport scenario 2022–2050
Investment and costs	**20,509.70**	**29,961.91**	**46,865.28**
Investment in power generation	*150.01*	*8,436.23*	*8,286.69*
Investment in renewable capacity	35.94	7,053.38	6,931.89
O&M costs of renewable capacity	24.74	2,583.29	2,553.61
Investment in non-renewable capacity	41.02	-603.85	-600.72
O&M costs of non-renewable capacity	48.32	-596.58	-598.09
Investment in NMT infrastructure: *Avoid*	*5,331.03*	*0.00*	*5,331.03*
Investment in BRT and MRT infrastructure: *Shift*	12,473.06	0.00	12,473.06
Investment in BRT infrastructure	8,060.81	0.00	8,060.81
Investment in MRT infrastructure	4,412.26	0.00	4,412.26
Investment in electric vehicles: *Improve*	*0.00*	*21,638.86*	*18,761.70*
Investment in electric cars	0.00	19,586.83	17,006.72
O&M costs of electric cars	0.00	1,008.86	850.84

Integrated CBA (undiscounted)	Scenario 1. Investment in public transport system 2022–2050	Scenario 2. Private vehicle electrification 2022–2050	Scenario 3. Mixed net-zero transport scenario 2022–2050
Investment in electric buses	0.00	282.43	245.36
O&M costs of electric buses	0.00	88.46	74.65
Investment in electric chargers	0.00	672.27	584.13
Added benefits	**3,110.29**	**15,641.23**	**17,783.78**
Real GDP	2,071.48	15,641.23	16,744.97
- Public revenue	310.72	2,346.18	2,511.74
- Disposable income	1,760.60	13,294.32	14,232.40
Revenues from BRT operation	983.91	0.00	983.91
Revenues from MRT operation	35.42	0.00	35.42
Benefits from physical activity	19.48	0.00	19.48
Avoided costs	**17,453.13**	**38,056.19**	**50,293.72**
ICE vehicles	0.00	20,389.53	17,713.19
Investment in ICE cars	0.00	18,935.32	16,479.59
O&M costs of ICE cars	0.00	1,142.26	963.86
Investment in ICE buses	0.00	245.60	213.76
O&M costs of ICE buses	0.00	66.35	55.99
Energy cost	1,257.28	6,762.53	7,146.96
Air pollution	1,413.93	4,193.58	4,569.34
Air pollution from energy consumption	1,480.83	3,383.47	3,755.49
Air pollution from power generation	-66.89	810.12	813.85

Integrated CBA (undiscounted)	Scenario 1. Investment in public transport system	Scenario 2. Private vehicle electrification	Scenario 3. Mixed net-zero transport scenario
	2022–2050	2022–2050	2022–2050
CO_2 emissions	954.98	6,524.89	6,880.63
Noise pollution	1,102.18	185.66	1,258.84
Accidents	12,724.75	0.00	12,724.75
Cumulative net benefits (undiscounted)	**2,609.32**	**23,622.33**	**23,225.01**
BCR	**1.15**	**1.79**	**1.52**

Source: Authors' calculations.

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

Table C1. Overview of key assumptions used in the SAVi assessment of the net-zero transport strategy in Indonesia

Parameters for calculating added benefits and avoided costs				Level of data collection		
Investment and cost, added benefit, or avoided cost	**Indicator**	**Value**	**Data source**	**Urban/ regional**	**National**	**International**
Power generation	Cost per megawatt of different power generation technologies	Steam coal: capital cost USD 950,000, O&M cost USD 40,000; diesel: capital cost USD 1,810,000, O&M cost USD 35,160 etc.	IEA, 2022		X	
Investment in NMT infrastructure	Capital costs per NMT km	USD 796,330/IDR 12,003,917,146	Kapetanakis et al., 2022			X
	O&M costs per NMT km	USD 5,618/IDR 84,691,883	Kapetanakis et al., 2022			X
Investment in BRT infrastructure	Capital costs per BRT km	USD 3.53 million/IDR 53,186,195,332	ITDP Indonesia, 2017		X	
	O&M costs per BRT km	USD 159,128/IDR 2,398,236,451	UNDP, 2015	X		
Investment in MRT infrastructure	Capital costs per MRT km	USD 72.9 million/IDR 1,098,913,305,442	Indonesia Investments, 2022	X		
	O&M costs per MRT km	USD 8.4 million /IDR 126,695,804,768	Rahmat et al., 2020			X

Parameters for calculating added benefits and avoided costs				**Level of data collection**		
Investment and cost, added benefit, or avoided cost	**Indicator**	**Value**	**Data source**	**Urban/ regional**	**National**	**International**
Investment in electric vehicles: *Improve*	Capital cost per electric car (2020–2040)	USD 30,000–22,000/IDR 452,369,727	BAPPENAS, 2021		X	
	O&M cost electric car (2020–2040) per year	USD 127–96/IDR 1,914,641 - 1,447,287	ERIA, 2017		X	
	Capital cost per electric bus (2020-2040)	USD 105,000–75,000/ IDR 1,583,093,867–1,130,781,333	ERIA, 2017		X	
	O&M cost electric bus per year	USD 2,000/IDR 30,151,370	BAPPENAS, 2021		X	
Real GDP	Real GDP based on capital services, employment and productivity		GEM			X
Revenues from BRT use	Average BRT ticket price	3,500 IDR/trip	Jauregui-Fung, 2022		X	
Revenues from MRT operation	Average MRT ticket price	3,000 IDR/trip when entering an MRT station, 1,000 IDR per every additional MRT station	Jakarta Travel Guide, 2022	X		

Parameters for calculating added benefits and avoided costs				**Level of data collection**		
Investment and cost, added benefit, or avoided cost	**Indicator**	**Value**	**Data source**	**Urban/ regional**	**National**	**International**
Benefits from physical activity	Crude death rate per 1,000 people	3.6	Ministry of Road Transport and Highways, 2017			X
	Value of statistical life	IDR 5.29 billion	TERI, 2018			X
	Reduction of the crude death rate as a result of the implementation of the NMT network	0.003	Kapetanakis et al., 2022			X
ICE vehicles	Capital cost per ICE car	USD 22,000/ IDR 331,674,964	ERIA, 2017			X
	O&M cost electric car per year	USD 110/IDR 1,658,924	ERIA, 2017		X	
	Capital cost per ICE bus	USD 67,000/IDR 1,010,435,774	ERIA, 2017		X	
	O&M cost electric bus per year	USD 1,500/IDR 22,624,162	BAPPENAS, 2021			X
Energy cost	Energy cost based on sum of four energy sources		GEM			X

Parameters for calculating added benefits and avoided costs				**Level of data collection**		
Investment and cost, added benefit, or avoided cost	**Indicator**	**Value**	**Data source**	**Urban/ regional**	**National**	**International**
Air pollution	Total dollar value per ton of directly emitted $PM_{2.5}$ (2020–2050)	USD 6,300–160,000 per ton $PM_{2.5}$	Pirmana et al., 2021		X	
	Total dollar value per ton of directly emitted NO_x (2020–2050)	USD 2,400–7,000 per ton NO_x			X	
	Total dollar value per ton of directly emitted SO_2 (2020–2050)	USD 4,000 – 51,000 per ton SO_2			X	
CO_2 emissions	Social cost of carbon	0.031 USD/kg	Nordhaus, 2017			X
	CO_2 emission factors per energy source	E.g., petroleum (70.02 ton/ TJ), natural gas (56.1 ton/ TJ) etc.	Gómez et al., 2006			X
Noise pollution	Noise cost per v-km		van Essen et al., 2011			X
Accidents	Cost of accidents per transport mode		van Essen et al., 2011			X

Source: Authors' calculations.

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