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MBONIMPA JEAN DE LA PAIX

Reg No : 220020656

Email: mbonijean1@gmail.com

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The economic analysis of the adoption of electric vehicles in Rwanda. A forecast analysis from 2020-2050 using MAED-2

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Supervisor: Dr. Khan Jean de Dieu Hakizimana

Head of PhD programme and Research

ACE-ESD / CST/ University of Rwanda,

Kigali, March, 2025

DECLARATION

I, **MBONIMPA Jean de la Paix** do declare that this dissertation entitled “**The Economic analysis of the Adoption of Electric Vehicles in Rwanda. A forecast Analysis from 2020-2050 Using MAED-2**” is my original work. It has never been presented in any university or other institution for the award of degree or diploma or other testimonial. It is entirely my work and where people’s ideas are used, it has been indicated in the bibliography

Signature.....

MBONIMPA Jean de la Paix

Date..... /..... /.....

APPROVAL

This is to certify that this dissertation entitled “**The Economic analysis of the Adoption of Electric Vehicles in Rwanda. A forecast Analysis from 2020-2050 Using MAED-2**” is an original study conducted by *MBONIMPA Jean de la Paix* under my supervision.

Signature.....

Dr. Khan Jean de Dieu HAKIZIMANA

Date...../...../.....

DEDICATION

To:

My Lovely wife

My parents;

My Brothers and Sisters,

My Closest friends,

My classmates,

May God bless you all!!!!!!

ACKNOWLEDGEMENT

This dissertation represents the culmination of an enriching academic journey and the fulfillment of a milestone in my educational pursuit. I am profoundly grateful to the individuals and institutions that have supported and guided me throughout this endeavor.

First and foremost, my deepest gratitude goes to God Almighty for granting me the strength, wisdom, and perseverance to successfully undertake and complete this study. Glory and honor to Him for His abundant blessings throughout my academic journey.

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May the Almighty God bless everyone who contributed to the success of this work!

LIST OF ABBREVIATIONS

ACE-ESD: African Center of Excellence in Energy for Sustainable Development

BEV: Battery Electric Vehicle

CBA: Cost-Benefit Analysis

DOE: U.S. Department of Energy

EV: Electric Vehicle

FCEV: Fuel Cell Electric Vehicle

GDP: Gross Domestic Product

GoR: Government of Rwanda

HEV: Hybrid Electric Vehicle

IEA: International Energy Agency

IRENA: International Renewable Energy Agency

MAED-2: Model for Analysis of Energy Demand

MININFRA: Ministry of Infrastructure (Rwanda)

REMA: Rwanda Environment Management Authority

RURA: Rwanda Utilities Regulatory Authority

TAM: Technology Acceptance Model

TCO: Total Cost of Ownership

UNEP: United Nations Environment Programme

VISION 2050: Rwanda's National Development Strategy for 2050

IFC: International Finance Corporation

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ABSTRACT

The transportation sector in Rwanda remains heavily dependent on fossil fuels, contributing to high energy import costs and greenhouse-gas emissions. To align with the national goals of sustainable development and the Vision 2050 framework, this study analyzes the economic and environmental implications of adopting electric vehicles (EVs) in Rwanda's public transport sector. A quantitative, analytical research design was employed, integrating secondary data from national and international sources. The Model for Analysis of Energy Demand (MAED-2) was used to project energy demand and assess the economic outcomes of different EV-adoption scenarios for the period 2020–2050.

The results indicate that under the EV-adoption scenario, transport energy demand could decline by approximately **18%** compared to the baseline, while electricity demand is expected to increase by nearly 40 times. The findings further suggest potential annual savings of about USD 140 million in fuel imports by 2050, alongside a projected 18% reduction in CO₂ **emissions**. These outcomes highlight both economic and environmental benefits associated with the transition to e-mobility.

The study concludes that large-scale EV adoption is feasible and beneficial for Rwanda if supported by policies promoting renewable-energy generation, local EV assembly, and nationwide charging infrastructure. The findings provide evidence-based insights to guide policymakers in accelerating Rwanda's transition toward sustainable, low-carbon transport systems.

Keywords: Electric vehicles, MAED-2, energy demand, cost–benefit analysis, sustainable transport, Rwanda.

CHAPTER ONE: INTRODUCTION

1.0. Introduction

In this chapter, the researcher present the introduction and background to the study, problem statement, objectives of the study, research questions, Justification, scope of the research and the organization of thesis.

1.1. Background of the Study

The global automotive industry is undergoing a transformative shift towards electric vehicles (EVs) as a response to the urgent need for sustainable transportation solutions. The transportation sector is a significant contributor to global greenhouse gas emissions, accounting for nearly one-quarter of global CO₂ emissions, with road transport being the largest source within this sector (IEA, 2021). As countries worldwide intensify efforts to mitigate climate change, the adoption of EVs emerges as a critical strategy to reduce reliance on fossil fuels and lower carbon emissions.

While EVs offer substantial environmental benefits, including significant reductions in greenhouse gas emissions, they also present notable economic advantages. These include lower fuel costs, reduced maintenance expenses, and the potential to stimulate new industries within the green economy, which can contribute to job creation and economic growth (Buekers et al., 2014). The global EV market has experienced rapid growth, particularly in developed regions such as China, the United States, and Europe, driven by supportive government policies, technological advancements, and increasing consumer demand (IEA, 2022). However, the adoption of EVs in low- and middle-income countries, including Rwanda, has been slower due to several challenges, including high upfront costs and limited charging infrastructure (Briceño-Garmendia, 2022).

Rwanda, committed to achieving its Vision 2050 of transforming into a high-income, knowledge-based economy, recognizes the adoption of EVs as a pivotal step towards enhancing energy security, reducing environmental pollution, and promoting sustainable economic growth (GoR, 2020). The Rwandan government has implemented various initiatives, including tax incentives, infrastructure development, and public awareness campaigns, to support the uptake of EVs (MININFRA, 2021). Despite these efforts, significant challenges persist, including the high initial costs of EVs, the limited availability of charging infrastructure, and low levels of public awareness and acceptance.

Furthermore, the economic implications of widespread EV adoption in Rwanda, particularly concerning its impact on public transport, energy consumption, and overall economic growth,

have not been thoroughly analyzed. This gap in understanding presents a critical barrier to informed policymaking and effective implementation strategies. This study aims to address this gap by providing a comprehensive economic analysis of the adoption of electric vehicles in Rwanda, focusing on the public transport sector from 2020 to 2050.

Using the Model for Analysis of Energy Demand (MAED-2), a robust tool for projecting future energy demand based on socio-economic, technological, and demographic variables, this study analyzed various scenarios of EV adoption. The research considered key factors such as government policies, technological advancements, market trends, and consumer behavior to provide valuable insights into the potential economic benefits and challenges of EV adoption in Rwanda. By understanding these long-term impacts, the study aims to contribute to the development of more effective strategies to promote sustainable transportation in Rwanda, aligning with the country's broader development goals.

1.2. Problem Statement

Rwanda is pursuing a transition to electric vehicles (EVs) in its public transport sector to support its sustainable development goals. However, several challenges are hindering this effort. The high initial cost of EVs compared to traditional vehicles makes them financially inaccessible for many operators; worsen by limited financing options and inadequate incentives. Additionally, the country's charging infrastructure is underdeveloped, particularly for public transport fleets that require reliable networks in both urban and rural areas (Briceño-Garmendia, 2022). Public doubt further complicates the transition; transport operators and passengers often question the reliability and economic benefits of EVs due to insufficient information and exposure.

The lack of clear, evidence-based data on the long-term cost savings, operational efficiency, and environmental benefits of EVs contributes to hesitancy among key stakeholders. If these concerns are not effectively addressed, the adoption of EVs may be delayed, undermining Rwanda's Vision 2050 goal of becoming a high-income, sustainable economy (GoR, 2020). While the Rwandan government has introduced supportive policies, including tax incentives and infrastructure initiatives, comprehensive economic analyses assessing their effectiveness remain limited. There is a critical gap in understanding the economic implications of EV adoption, particularly in public transportation, where operational costs, energy demand and long-term financial sustainability need thorough evaluation.

This research seeks to fill this gap by conducting a detailed economic analysis of EV adoption in Rwanda's public transport sector. Using the Model for Analysis of Energy Demand (MAED-2), the study will forecast economic outcomes of various EV adoption scenarios

from 2020 to 2050. The findings will provide policymakers, transport operators, and investors with evidence-based insights into the economic feasibility, cost-effectiveness, and long-term impact of EV integration, facilitating informed decision-making and the development of more effective strategies for Rwanda's sustainable transport future.

1.3. Research Objectives

Objectives are the specified tasks researchers should undertake in response to the research hypothesis or question to accomplish the overall aim of the project. Kumar, R. (2014).

1.3.1. Main Objective

The main objective of this study is to conduct a comprehensive economic analysis of electric vehicle (EV) adoption in Rwanda's public transport sector, evaluating its impact on transportation costs, environmental sustainability, and economic growth while identifying the associated benefits, challenges, and policy implications.

1.3.2. Specific Objectives

The specific objectives of this research included but not limited to the following:

- i. Assess the current use of electric vehicle adoption in Rwanda's public transport sector.
- ii. To assess the economic benefits and challenges of EV adoption in Rwanda.
- iii. To assess the long-term economic effects of EV adoption from 2020 to 2050 using MAED-2.

1.4. Research Questions

The research questions included the following among others:

1. What is the current use of electric vehicle adoption in Rwanda's public transport sector?
2. What are the economic benefits and challenges associated with the adoption of electric vehicles in Rwanda?
3. What are the long-term economic effects of electric vehicle adoption in Rwanda from 2020 to 2050?

1.5. Significance of the Study

This study provides valuable insights into the economic implications of adopting electric vehicles (EVs) in Rwanda, offering several key benefits:

- i. **Policy Makers:** The findings will aid policymakers in understanding the economic and environmental impacts of EV adoption. This enables them to formulate more effective policies and incentives to promote the use of EVs, contributing to Rwanda's sustainable development goals and improving national transportation strategies.
- ii. **Public Transport Operators:** The study offers critical information on EVs' cost-effectiveness and benefits compared to traditional vehicles. This helps public transport operators make informed decisions about transitioning to electric fleets, potentially reducing operational costs and enhancing service efficiency.
- iii. **Environmental Advocates:** By evaluating EVs' environmental benefits, the study provides evidence to support environmental advocacy efforts. The data on emission reductions and air quality improvements help advocate for greater adoption of EVs as a strategy for mitigating climate change and improving public health.
- iv. **Investors and Businesses:** The research highlights economic opportunities associated with EV adoption, including potential areas for investment in EV infrastructure and technology. Businesses in the automotive and energy sectors gain insights into market trends and growth potential, which guide their strategic decisions and investments.
- v. **General Public:** The study raises awareness about the economic and environmental benefits of EVs among the general public. This increased understanding can drive public support for EV adoption and influence consumer choices, contributing to a broader acceptance and integration of electric vehicles in daily life.

1.6. Limitation of the study

The study's results faced limitations in generalizability due to factors beyond the researcher's control, including the availability and quality of data on electric vehicle (EV) adoption and performance in Rwanda, which affect the accuracy of the analysis. Additionally, the current state of EV infrastructure, such as charging stations and maintenance facilities, have not fully supported the findings, limiting their applicability to regions with varying levels of infrastructure development. Policy and regulatory changes can also influence the study's outcomes, as future revisions in government incentives or environmental standards may alter the relevance of the conclusions. Furthermore, market dynamics, such as fluctuations in fuel prices and technological advancements, as well as variability in public perception and adoption rates, impact the study's results and their applicability to different contexts.

1.7. Scope of the study

- i. **Conceptual Scope:** The study focuses on the economic analysis of electric vehicle (EV) adoption in Rwanda, particularly in the context of public transportation. It explores key economic concepts such as cost-effectiveness, environmental benefits, and the broader economic impact of EVs, including job creation and technology adoption.
- ii. **Content Scope:** The study covers several core areas: an evaluation of the cost-effectiveness of EVs compared to internal combustion engine vehicles, an assessment of the environmental impacts associated with EV adoption, and an analysis of the potential economic benefits and challenges of integrating EVs into Rwanda's public transport system. It also identifies the barriers and opportunities for scaling up EV adoption in the country.
- iii. **Geographical Scope:** The research was conducted within the context of Rwanda, with a particular focus on urban areas where public transport systems are most prevalent. The study considered data from various regions within Rwanda to understand the national implications of EV adoption.
- iv. **Time Scope:** The study analyzed data from the recent past, particularly the last five years, to assess the current state and trends in EV adoption in Rwanda. Additionally, it projects potential future outcomes based on current policies, infrastructure developments, and market trends, aiming to provide insights relevant to the next decade.

1.7. Dissertation Organization

This research is in five chapters, the first chapter presents the introduction and background to the study, the second presents the review of related literature while the third gives the research methodology. Chapter fourth presents, analyses and interprets the collected data while chapter five presents the conclusion and recommendations of the study.

CHAPTER TWO: LITERATURE REVIEW

2.0. Introduction

This chapter offers a detailed exploration of the literature concerning the economic analysis of electric vehicle (EV) adoption in Rwanda, with an emphasis on the public transportation sector. It is structured to cover both theoretical and empirical aspects, ensuring a comprehensive understanding of the relevant concepts, models, and research. Theoretical literature is discussed first, focusing on the foundational concepts and theories that inform EV adoption, including economic and environmental impacts and the application of the MAED-2 model for data analysis. The empirical literature then reviews global, regional, and local studies, highlighting the economic effects of EV adoption and the specific challenges in regions like Sub-Saharan Africa and Rwanda. A critical review follows, identifying research gaps and limitations in existing studies in relation to this research's objectives. Finally, the theoretical and conceptual frameworks are presented, explaining the relevant theories, models, and relationships between key study variables. The chapter concludes by summarizing the main issues discussed, paving the way for further analysis.

2.1. Theoretical Literature

2.1.1. Definition of Electric Vehicles

An electric vehicle (EV) is a type of vehicle that is powered entirely or partially by electric energy stored in batteries, rather than relying solely on an internal combustion engine (ICE) that uses fossil fuels like gasoline or diesel. According to the International Energy Agency (IEA), EVs are defined as vehicles that can be charged by connecting to an external source of electricity and can be driven without an auxiliary power source for a specified distance, depending on the vehicle type (IEA, 2020).

According to GIRISH.C et al (2021) "Electric vehicles (EVs) are a "hot item" in the auto world, with many auto manufacturers offering at least one model. Improved versions are on the horizon, too, for good reason. Electric vehicles require less maintenance than gas vehicles, and even though they may carry a higher price tag initially, the credits and lower operating costs often balance out the initial investment.

The world leaders are trying to reduce the carbon dioxide emission by half by 2030."By 2025, 20% of all new cars, bikes, and large trucks sold globally will be electric, according to the

latest forecast by the investment bank UBS. That will leap to 40% by 2030, and by 2040 virtually every new vehicle sold globally will be electric."

Electric vehicles are powered by electricity rather than any fuel which means that they do not produce any carbon emission.

2.1.2. Features of Electric Vehicles

Electric vehicles possess several distinctive features that set them apart from conventional internal combustion engine vehicles:

- i. **Energy and Energy Efficiency:** EVs are significantly more energy-efficient than traditional vehicles. According to the U.S. Department of Energy (DOE), electric motors convert over 85% of the electrical energy from the battery into mechanical energy, whereas ICE vehicles only convert about 20-30% of the energy stored in gasoline (DOE, 2021). This efficiency makes EVs more environmentally friendly and cost-effective in the long run.
- ii. **Zero Tailpipe Emissions:** One of the most significant environmental advantages of BEVs and PHEVs is their ability to operate with zero tailpipe emissions when running on electric power. This feature helps reduce urban air pollution and greenhouse gas emissions, contributing to cleaner air and a reduction in the overall carbon footprint (ICCT, 2018).
- iii. **Regenerative Braking:** EVs typically feature regenerative braking systems, which allow the vehicle to recover energy that would otherwise be lost during braking. This energy is converted back into electrical power and stored in the battery, extending the vehicle's range and improving overall efficiency (Gao & Jin, 2012).
- iv. **Quiet Operation:** EVs are much quieter than their ICE counterparts due to the absence of engine noise. The reduction in noise pollution is particularly beneficial in urban areas, improving the quality of life for residents and reducing stress levels associated with traffic noise (Orecchini, 2020).
- v. **Lower Operating Costs:** The operating costs of EVs are generally lower than those of conventional vehicles. This is due to lower fuel costs (electricity is cheaper than gasoline) and reduced maintenance requirements. EVs have fewer moving parts, no need for oil changes, and less wear on components such as brakes due to regenerative braking systems (IEA, 2020).
- vi. **Advanced Technology and Connectivity:** EVs often come equipped with advanced technology features such as over-the-air software updates, connected services, and

sophisticated driver-assistance systems. These features not only enhance the driving experience but also ensure that the vehicle's systems are up-to-date and optimized for performance (Sperling, 2018).

2.1.3. Types of Electric Vehicles

Electric vehicles (EVs) come in various types, each distinguished by the way they utilize electricity to power the vehicle. The most common types of electric vehicles are:

i. Battery Electric Vehicles (BEVs)

BEVs are fully electric vehicles that rely solely on electric power stored in batteries. They have no internal combustion engine (ICE) and produce zero tailpipe emissions. **Examples:** Tesla Model S, Nissan Leaf, Chevrolet Bolt. (IEA.2020).

ii. Plug-in Hybrid Electric Vehicles (PHEVs)

PHEVs combine an electric motor with a conventional internal combustion engine (ICE). They can operate on electric power alone for a certain range and switch to ICE when the battery is depleted. **Examples:** Toyota Prius Prime, Chevrolet Volt, BMW i3 REX. U.S. Department of Energy (2021).

iii. Hybrid Electric Vehicles (HEVs)

HEVs use both an electric motor and an ICE but cannot be plugged in to charge the battery. Instead, the battery is charged through regenerative braking and the ICE. **Examples:** Toyota Prius, Honda Civic Hybrid, Ford Fusion Hybrid. (EPA 2020).

iv. Fuel Cell Electric Vehicles (FCEVs)

FCEVs use hydrogen gas to power an electric motor. Unlike BEVs, they generate electricity through a chemical process in the fuel cell rather than relying on battery storage. **Examples:** Toyota Mirai, Hyundai Nexo, Honda Clarity Fuel Cell. (IEA.2019).

2.1.4. Why there is a pull for electric vehicles?

The increasing pull for electric vehicles (EVs) can be attributed to several factors these include:

Economic Factors: The cost dynamics of EVs have also been shifting in their favor. Battery prices, which are a significant component of the overall cost of EVs, have reportedly fallen by 73% since 2010. This reduction in battery costs is expected to make electric cars as affordable

as traditional fuel-powered vehicles in the near future. As a result, the total cost of ownership for EVs, including fuel and maintenance, is becoming increasingly competitive with that of conventional vehicles (BNEF, 2020).

Environmental Concerns: One of the primary drivers of EV adoption is the need to reduce greenhouse gas emissions. Currently, cars and trucks contribute to approximately 25% of global carbon dioxide emissions. As awareness of climate change grows, both consumers and governments are motivated to reduce these emissions by shifting from internal combustion engine vehicles to electric ones, which produce zero tailpipe emissions (IEA, 2020)

Energy Security: With the finite supply of petroleum and the volatility of global oil prices, many countries see EVs as a way to reduce their dependency on imported oil. This shift is especially crucial for countries with limited natural resources, as it enhances energy security and stabilizes fuel costs over the long term (IRENA, 2021).

Technological Advancements: The coming decade is expected to be dominated by advancements in EV technology, making them more accessible and practical for everyday use. Improvements in battery technology, charging infrastructure, and vehicle range are reducing the barriers to widespread adoption (IEA, 2021).

Government Policies and Incentives: Many governments are actively promoting EV adoption through subsidies, tax incentives, and the development of charging infrastructure. These policy measures are designed to accelerate the transition to electric mobility, aligning with broader goals of reducing carbon emissions and fostering green economic growth (UNEP, 2020).

Table 1: Comparison between electric vehicle and conventional Vehicle (Bakhsh, F. I., & Alam, M. S. (2011).

| Feature | Battery Electric Vehicles | I.C.Engine Vehicles |
|---------------------------|---------------------------------------|----------------------------|
| Prime mover | Electric Motor | I.C. engine |
| Powered by | Charged Battery, ultra-capacitors | Diesel, Petrol |
| Self-weight | High due to battery bank | Low as compared to EV |
| Power transmission | Both mechanical as well as electrical | Mechanical only |
| Braking system | Regenerative braking | Friction braking |
| Efficiency | High | low |
| Eco friendly | Yes | no |
| Initial cost | High | average |
| Running cost | Low | Very high |

2.1.5 Economic Impact of Electric Vehicles

The economic impact of electric vehicle (EV) adoption has been extensively studied by various researchers, each contributing unique insights into how EVs influence economic systems. Among the most notable researchers in this field is Dr. David Greene, who has made significant contributions to understanding the economic implications of transitioning from internal combustion engines to electric vehicles. (Greene, 2014)

Economic Impact of EV Adoption: Insights from Dr. David Greene

- a) *Reduction in Oil Dependency and Improved Energy Security:* Dr. David Greene, a leading researcher in the field of transportation energy and economics, has extensively studied the potential reduction in oil dependency through the adoption of electric vehicles. He argues that large-scale adoption of EVs could significantly decrease a nation's reliance on imported oil, leading to improved energy security. By reducing the demand for oil, countries can protect their economies from the volatility of global oil prices and mitigate the economic risks associated with oil supply disruptions.
- b) *Cost Savings for Consumers:* Greene has also highlighted the cost savings that consumers can experience through the adoption of EVs. Despite the higher upfront cost of EVs, their lower operating and maintenance costs can lead to significant savings over the vehicle's lifetime. According to Greene's research, the total cost of ownership for EVs is increasingly competitive with traditional vehicles, particularly as battery costs continue to decline and as more efficient charging infrastructure becomes available.
- c) *Job Creation and Economic Growth:* Another critical economic impact of EV adoption identified by Greene is the potential for job creation and economic growth. The EV industry encompasses a wide range of activities, including manufacturing, battery production, charging infrastructure development, and renewable energy integration. As the industry expands, it creates new job opportunities and stimulates economic growth, particularly in regions that invest in the necessary infrastructure and workforce training.
- d) *Environmental Benefits Leading to Economic Gains:* Greene also points out that the environmental benefits of EVs, such as reduced greenhouse gas emissions, can lead to long-term economic gains. By mitigating the effects of climate change and reducing pollution-related health costs, EV adoption contributes to a more sustainable economy.

This, in turn, can reduce the financial burden on public health systems and increase overall economic resilience.

- e) *Innovation and Technological Advancement*: Finally, Greene emphasizes that the adoption of EVs drives innovation and technological advancement, which can have a ripple effect across the economy. As companies invest in new technologies and develop more efficient and sustainable energy solutions, they contribute to broader economic transformation and competitiveness in the global market (Greene, 2014).

2.1.6. Electric Motorcycles in Rwanda

In Rwanda, more than half the vehicles on roads are "moto-taxis." Though they are the backbone of the country's transport system, they contribute to climate change. Thanks to a fast-growing electric motorbike start-up in Kigali, e-motorbikes are now cutting emissions and helping drivers, particularly young people, save money and fuel a greener future. Electric motorcycles (e-motos) are at the forefront of Rwanda's EV adoption. There are three key players who dominate this sector which are:

Ampersand: Ampersand Operates over 4,000 electric motorbikes in Kigali, has 32 battery swap stations in Kigali and Plans to manufacture 18,000 batteries for their fleet by 2025. (GIZ Rwanda 2024)

Safi Universal Link: Currently has 123 electric motorcycles in operation and operates 5 charging stations. Demonstrates plans for future expansion, with 280 additional e-motos expected to join the fleet soon. Twagirimana, J. (2023)

Rwanda Electric Motorcycle (REM): Runs a fleet of 280 electric motorcycles. Innovatively retrofits existing internal combustion engine (ICE) motorcycles into electric models, having converted 80 ICE bikes so far. Operates 5 charging stations and recently introduced 32 modern battery-electric vehicle (BEV) SUVs for its fleet. Twagirimana, J. (2023)

SPIRO

Spiro, an electric vehicle company, has deployed over 1,200 electric bikes in Rwanda. Spiro has expanded its automated swap stations across Rwanda, including in Kigali, Muhanga, Kayonza, Rwamagana, and Bugesera. Spiro's charging stations and battery swap systems are designed to use renewable energy sources(Equitane Group 2024)

2.1.7. Global Studies on the Economic Analysis of Electric Vehicle Adoption

i. Economic Impacts of EV Adoption Globally

Electric vehicles (EVs) have been studied extensively across the globe for their potential to reduce greenhouse gas emissions, decrease dependency on fossil fuels, and stimulate economic growth through the creation of new industries and jobs. For instance, a study by the International Energy Agency (IEA) (2020) found that EV adoption could lead to a reduction in global oil demand by approximately 2.5 million barrels per day by 2030. This shift not only impacts global energy markets but also has significant economic implications, including reduced transportation costs and increased investment in renewable energy sources.

ii. Public Transportation and EVs

In the context of public transportation, studies have highlighted the economic benefits of transitioning to electric buses and other forms of public EVs. A report by BloombergNEF (2020) indicated that electric buses are expected to achieve total cost of ownership (TCO) parity with diesel buses by 2025, primarily due to lower fuel and maintenance costs. The study also emphasized the role of government subsidies and incentives in accelerating the adoption of electric public transportation, which is critical for achieving long-term sustainability goals.

iii. MAED-2 Application in EV Analysis

The Model for Analysis of Energy Demand (MAED-2) has been applied in various studies to analyze the impact of EV adoption on energy demand and economic outcomes. For example, a study by the International Atomic Energy Agency (IAEA) (2019) utilized the MAED-2 model to project the future energy demand of EVs in developing countries, considering different adoption scenarios. The study highlighted the model's capability to simulate the economic impacts of varying levels of EV penetration, providing valuable insights for policymakers.

2.1.8. Regional Studies on the Economic Analysis of Electric Vehicle Adoption

a) EV Adoption in Sub-Saharan Africa

Sub-Saharan Africa presents unique challenges and opportunities for EV adoption, particularly in the public transportation sector. According to the International Renewable Energy Agency (IRENA) (2021), the economic benefits of EV adoption in this region include reduced oil imports, enhanced energy security, and job creation in the renewable energy

sector. However, the study also pointed out significant barriers such as the high initial cost of EVs, lack of charging infrastructure, and limited access to reliable electricity. These factors must be considered when analyzing the feasibility and economic impact of EV adoption in public transportation within this region.

b) Public Transportation and Electric Vehicles in Kenya

Kenya has made significant strides in exploring the potential of EVs in its public transportation system. A study by Kenya's Ministry of Transport (2020) assessed the economic viability of introducing electric buses in Nairobi. The findings indicated that while the upfront costs are higher, the long-term savings in fuel and maintenance, combined with reduced emissions, make EVs a financially sound investment. The study also recommended government intervention in the form of subsidies and incentives to overcome the initial cost barriers.

c) South Africa's Experience with EV Adoption

South Africa's approach to EV adoption has been influenced by its energy policies and economic conditions. Naidoo (2020) analyzed the potential economic impact of EV adoption in South Africa, particularly in the public transportation sector. The study found that the high costs of EVs and the limited charging infrastructure were major challenges. However, the study also noted that with the right policy interventions, such as tax incentives and infrastructure investments, EVs could play a crucial role in reducing South Africa's carbon footprint and improving energy efficiency in public transportation.

2.1.9. Local Studies on the Economic Analysis of Electric Vehicle Adoption in Rwanda

Electric vehicle (EV) adoption in Rwanda is gaining attention as part of the country's broader efforts to transition towards sustainable energy and reduce greenhouse gas emissions. Several studies have examined the economic implications of adopting EVs in Rwanda, focusing on factors such as cost-benefit analysis, infrastructure development, and the impact on public transportation.

a. Cost-Benefit Analysis of Electric Vehicles:

A study by Niyonsenga et al. (2021) explored the economic viability of adopting EVs in Rwanda, particularly focusing on the cost-benefit analysis for both consumers and the government. The study highlighted that, although the initial purchase cost of EVs is higher

than that of conventional vehicles, the long-term benefits, such as reduced fuel costs and lower maintenance expenses, could make EVs economically attractive. The study also noted potential savings in health-related costs due to reduced air pollution.

b. Infrastructure Development:

The adoption of EVs in Rwanda requires significant investment in infrastructure, particularly in charging stations. According to a report by the Rwanda Utilities Regulatory Authority (RURA) (2020), the government has initiated several projects to develop EV charging infrastructure across the country. These initiatives are essential to support the widespread use of EVs and ensure that the transition is economically feasible. The report emphasizes the need for public-private partnerships to finance and expand this infrastructure, which would, in turn, stimulate economic growth by creating jobs and fostering new business opportunities in the energy sector.

c. Impact on Public Transportation:

Rwanda's public transportation sector stands to benefit significantly from the adoption of electric buses and motorcycles. The Rwanda Environment Management Authority (REMA) (2022) conducted an analysis that projected significant reductions in operational costs for public transport operators using electric buses compared to diesel-powered ones. The study indicated that this shift could lead to lower transportation costs for consumers and contribute to the government's goals of reducing carbon emissions and dependence on imported fuels. Additionally, the study pointed out that the local assembly of electric motorcycles could drive industrial growth and create employment opportunities.

2.2. Empirical Literature

The adoption of electric vehicles (EVs) in public transportation has gained global attention as governments and stakeholders seek sustainable mobility solutions. Several empirical studies have examined the economic, environmental, and infrastructural aspects of EV adoption, particularly in developing economies like Rwanda. This section reviews key empirical findings related to government policies and incentives, economic viability, energy infrastructure, environmental and social impact, market adoption, and long-term economic implications of EVs.

2.2.1. Government Policies and Incentives

Governments worldwide have introduced various incentives to accelerate EV adoption, including tax exemptions, subsidies, and investment in charging infrastructure. A study by Mwaba (2021) assessed Rwanda's transition to a low-carbon economy and highlighted the importance of policy interventions in promoting EV adoption. The study found that fiscal incentives, such as import tax waivers on EVs and reduced electricity tariffs for charging stations, play a crucial role in influencing market adoption. Similarly, research in Kenya and South Africa shows that financial incentives and regulatory frameworks are significant determinants of EV market penetration (Bonsu, 2020). However, these studies emphasize the need for continuous policy evaluation to ensure long-term sustainability.

2.2.2. Economic Viability and Cost Comparison

Empirical evidence suggests that while the upfront cost of EVs remains high, their long-term operational benefits outweigh those of conventional internal combustion engine (ICE) vehicles. Mwaba (2021) found that EVs offer cost savings through reduced fuel expenses and lower maintenance costs, which can enhance profitability in the public transport sector. A comparative study conducted in Uganda found that electric motorcycles were 50% cheaper to operate compared to petrol-powered alternatives, leading to increased adoption in urban areas (Odhiambo, 2021). Additionally, studies in Europe and China indicate that total cost of ownership (TCO) models favor EVs when fuel price volatility and government incentives are factored in (IEA, 2021).

2.2.3. Energy Infrastructure and Grid Capacity

Infrastructure readiness is a critical determinant of EV adoption. Mwaba (2021) reported that Rwanda's energy sector has made progress in expanding electricity access, yet the country still faces challenges in developing a robust EV charging network. Similar findings were observed in Ghana, where inadequate charging infrastructure slowed EV penetration despite government incentives (Bower, 2020). Studies in Norway and the Netherlands indicate that extensive charging infrastructure directly correlates with higher EV adoption rates (Sikora, 2020). Therefore, investments in smart grid technology and renewable energy integration are essential for sustainable EV adoption in Rwanda.

2.2.4. Environmental and Social Impact

EV adoption contributes to reduced carbon emissions and improved air quality, leading to significant public health benefits. Mwaba (2021) found that increased EV penetration in Rwanda could lower transport-related emissions by up to 30% by 2050. Similar results were

reported in India, where EV fleets reduced urban air pollution levels by 25% (UNEP, 2020). Furthermore, studies in Kenya highlight how EVs can improve social welfare by lowering commuting costs and providing cleaner transport alternatives (Nalule, 2020). However, challenges such as battery disposal and recycling remain concerns that require policy intervention.

2.2.5. Market Adoption and Consumer Behavior

Consumer perception and market readiness play a crucial role in EV adoption. Mwaba (2021) highlighted that public skepticism due to limited awareness and concerns over reliability hinders EV uptake in Rwanda. A study in Ethiopia found that consumer trust significantly influences EV adoption, with early adopters driven by environmental consciousness and long-term cost savings (Makomere, 2020). Research in China suggests that aggressive marketing campaigns and consumer education programs can accelerate adoption rates (IEA, 2021).

2.2.6. Long-Term Economic Impact

Several empirical studies have modeled the long-term economic impact of EV adoption. Mwaba (2021) used a before-and-after analysis to assess Rwanda's energy transition, showing that investments in renewable energy and EVs can contribute to GDP growth and job creation. A study by the International Energy Agency (IEA) predicted that by 2050, EV adoption in developing countries could reduce fossil fuel imports by 40%, improving trade balances and energy security (IEA, 2021). Additionally, an assessment in South Korea found that EV integration into public transport systems generated employment opportunities in the manufacturing and service sectors (UNCTAD, 2020).

Empirical evidence from various studies confirms that EV adoption presents economic, environmental, and infrastructural benefits, particularly in emerging markets like Rwanda. While government incentives, cost-effectiveness, and environmental advantages support EV penetration, challenges such as high initial costs, inadequate infrastructure, and public skepticism must be addressed. Lessons from global case studies suggest that Rwanda can enhance EV adoption through targeted policies, investments in charging networks, and public awareness campaigns.

2.3. Critical Review and Research Gap Identification

a. Critical Review

The empirical literature on electric vehicle (EV) adoption highlights significant economic, environmental, and infrastructural implications for Rwanda's public transport sector. Several

studies, including Mwaba (2021), emphasize the role of government incentives in accelerating EV adoption. However, while tax waivers and financial subsidies have been effective in countries like Kenya and South Africa (Bonsu, 2020), their long-term economic sustainability remains unclear, particularly in low-income economies where government budgets are constrained. Moreover, the effectiveness of these policies in Rwanda requires further empirical validation, especially in terms of their impact on local transport operators and consumer behavior.

Cost-benefit analyses conducted in other African countries suggest that while EVs have lower operational costs compared to internal combustion engine (ICE) vehicles, their high initial costs continue to hinder widespread adoption (Odhiambo, 2021). Although global studies, such as those by the International Energy Agency (IEA, 2021), confirm that EVs are cost-effective in the long run, localized studies assessing their affordability in Rwanda's economic context are limited. The financial burden on small-scale transport operators remains underexplored, raising concerns about equity in the transition to electric mobility.

Another critical issue identified in existing literature is the inadequacy of charging infrastructure. While studies in developed economies like Norway (Sikora, 2020) establish a strong correlation between charging infrastructure availability and EV adoption, Rwanda's energy grid and charging infrastructure are still in their early stages. Mwaba (2021) highlights Rwanda's progress in electricity access but does not provide a detailed assessment of the capacity of the grid to support large-scale EV integration. Similarly, studies in Ghana (Bower, 2020) show that even with incentives, poor infrastructure can delay EV penetration, reinforcing the need for Rwanda-specific studies on grid capacity and investment strategies.

The environmental and social benefits of EVs, particularly in reducing greenhouse gas emissions and urban air pollution, are well-documented (UNEP, 2020). However, there is a lack of empirical research on the life-cycle environmental impact of EVs in Rwanda, including battery disposal and recycling challenges. While studies in India (UNEP, 2020) and China (IEA, 2021) highlight these concerns, Rwanda-specific data on the environmental trade-offs of EV adoption are scarce. Additionally, while market adoption studies in Ethiopia (Makomere, 2020) indicate that consumer perception plays a critical role in EV uptake, there is limited empirical evidence on Rwandan consumer attitudes, awareness, and willingness to transition to electric mobility.

Long-term economic impact studies predict positive outcomes, such as job creation and reduced fossil fuel dependency (UNCTAD, 2020). However, these projections are often based

on generalized models that may not fully capture Rwanda's unique economic structure. The extent to which EV adoption can contribute to local industrialization, such as battery manufacturing or EV assembly, remains underexplored. This raises questions about Rwanda's potential to develop a sustainable EV ecosystem beyond import-dependent adoption.

b. Research Gap Identification

Despite the extensive literature on EV adoption globally and regionally, several key gaps remain in the context of Rwanda:

Limited Localized Cost-Benefit Analysis: While studies confirm the long-term economic viability of EVs, there is insufficient Rwanda-specific research quantifying the financial feasibility of EV adoption for public transport operators, including total cost of ownership (TCO) assessments.

Charging Infrastructure and Grid Capacity: There is a lack of empirical studies evaluating Rwanda's energy infrastructure readiness for large-scale EV deployment, including grid resilience, charging station distribution, and potential impacts on electricity demand.

Consumer Behavior and Market Adoption: Research on Rwandan consumer perception, willingness to adopt EVs, and awareness of government incentives is minimal. Understanding behavioral barriers is crucial for designing effective policies.

Environmental Trade-Offs: While EVs reduce emissions, studies in Rwanda have not yet examined the full environmental life cycle of EV adoption, including battery disposal, recycling, and the sustainability of electricity sources.

Long-Term Economic Impact and Local Industry Development: Existing literature lacks insights into how EV adoption can stimulate Rwanda's local economy, such as opportunities for EV assembly, battery manufacturing, and job creation in the energy and transport sectors.

The existing literature provides valuable insights into the economic, infrastructural, and environmental aspects of EV adoption. However, critical research gaps remain in the Rwandan context, particularly in cost-benefit analysis, infrastructure readiness, consumer behavior, environmental sustainability, and long-term economic impact. Addressing these gaps will provide policymakers, investors, and stakeholders with evidence-based insights to develop sustainable and inclusive EV adoption strategies in Rwanda's public transport sector.

2.4 Theoretical Framework

The theoretical framework provides the conceptual foundation on which this study of the economic analysis of electric-vehicle (EV) adoption in Rwanda is built. It draws on established theories and models that explain the behavioral, economic, and environmental dynamics surrounding the diffusion of new technologies. By integrating perspectives from innovation, behavioral intention, economic evaluation, and sustainability, the framework offers a coherent structure for understanding the multiple factors influencing EV adoption, particularly within Rwanda's public-transport sector. It thus connects theoretical reasoning with the analytical approach later applied in the methodological chapter.

2.4.1 Applicable Theories and Models

A range of theories and modeling approaches provide insight into how and why societies transition toward cleaner transport systems. The following four are central to this study:

1. Diffusion of Innovations Theory (Everett M. Rogers, 1962)

This theory explains how new ideas and technologies spread within a social system through communication channels over time. Adoption is influenced by five key attributes—relative advantage, compatibility, complexity, trialability, and observability. In Rwanda, these dimensions help to explain the pace of EV uptake and identify barriers such as high initial cost and limited charging infrastructure. The theory guides the understanding of stakeholder behavior and policy interventions needed to accelerate adoption.

2. Cost–Benefit Analysis (CBA) (Jules Dupuit, 19th century)

CBA provides an economic lens for comparing alternative policy or investment options by quantifying costs and benefits. In the EV context, it evaluates whether long-term gains—fuel savings, reduced maintenance, and environmental improvements—outweigh high upfront and infrastructure costs. The framework informs decisions on the financial and social viability of e-mobility initiatives in Rwanda.

3. Technology Acceptance Model (TAM) (Fred Davis, 1989)

TAM posits that perceived usefulness and perceived ease of use determine an individual's intention to adopt a technology. Applied to Rwanda, it helps assess how transport operators and consumers perceive EVs in terms of efficiency, reliability, and convenience, offering behavioral insights into acceptance levels and awareness strategies.

4. Sustainable Development Theory (World Commission on Environment and Development, 1987)

This theory promotes development that meets present needs without compromising future generations. It underpins the environmental rationale for transitioning to e-mobility, aligning with Rwanda’s Vision 2050 and National Strategy for Transformation (NST1) objectives of a low-carbon, climate-resilient economy.

Together, these theories provide complementary perspectives—behavioral, economic, and environmental—offering a multidimensional explanation of the drivers and constraints shaping EV adoption in Rwanda.

2.4.2 Summary of Models Relevant to the Study

Globally, several models have been employed to project energy demand and assess electric-mobility impacts, including the **Model for Analysis of Energy Demand (MAED-2)**, the **Long-range Energy Alternatives Planning (LEAP)** model, and the **TIMES** optimization platform. While each facilitates energy-planning decisions, they differ in structure and data requirements.

MAED-2, developed by the International Atomic Energy Agency, estimates future energy needs from demographic, economic, and technological parameters and is data-efficient—making it suitable for developing contexts like Rwanda. **LEAP**, from the Stockholm Environment Institute, simulates full energy systems and emission trajectories, whereas **TIMES**, derived from the MARKAL family, applies optimization to identify least-cost technology pathways under policy or emission constraints.

For this study, **MAED-2** is adopted because it balances analytical rigor with modest data requirements and offers transparent relationships among socio-economic growth, transport expansion, and energy use. It enables scenario analysis of different levels of EV penetration and policy alternatives, thereby supporting evidence-based planning. Although **LEAP** and **TIMES** are powerful for integrated system optimization, **MAED-2** is more appropriate for forecasting sector-specific demand within Rwanda’s data environment and policy framework. This selection ensures that methodological decisions in Chapter Three rest on a sound theoretical and empirical foundation.

2.4.3 Application to Rwanda’s Electric-Vehicle Adoption

The integrated theoretical framework informs how the study evaluates Rwanda’s transition to electric mobility:

Behavioral Dimension: Diffusion of Innovations and TAM explain user and operator attitudes toward EV technologies.

Economic Dimension: CBA provides the rationale for comparing long-term benefits with short-term costs.

Environmental and Policy Dimension: Sustainable Development Theory situates EV adoption within Rwanda's green-growth agenda.

Analytical Dimension: MAED-2 operationalizes these insights by projecting future energy demand under various EV-adoption scenarios.

Through this combination, the framework establishes a holistic foundation for analyzing the economic and environmental impacts of EV adoption from 2024 to 2050 and for formulating policies that advance sustainable transport in Rwanda.

2.5. Conceptual Framework

Below is a conceptual framework diagram that visually represents the relationships between the key variables of this study on the economic analysis of electric vehicle adoption in Rwanda from 2024 to 2050.

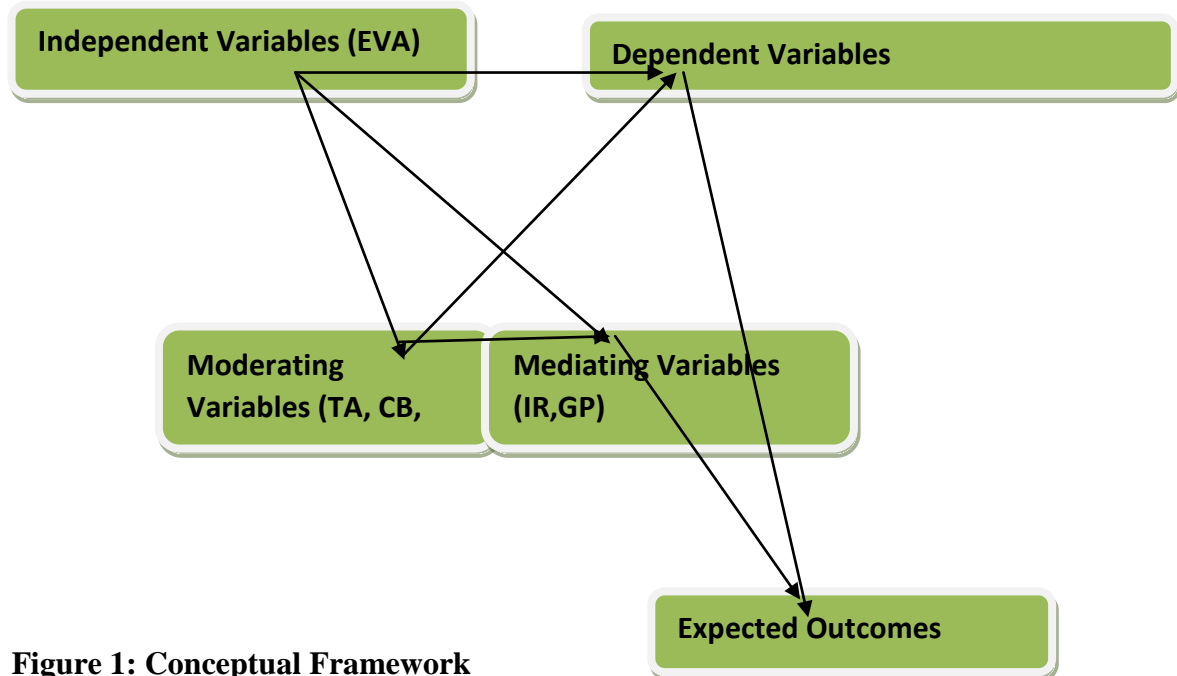


Figure 1: Conceptual Framework

Explanation of the Diagram

1. Independent Variables (EVA):

Electric Vehicle Adoption (EVA): This is the primary independent variable driving the study. It includes factors such as the number of EVs on the road, the annual growth rate of EV adoption, and market penetration rates. These factors directly influence the economic, environmental, infrastructural, and policy-related outcomes.

2. Dependent Variables

Economic Impact (EI): This encompasses the financial benefits of EV adoption, such as cost savings on fuel and maintenance, job creation within the EV supply chain, GDP contribution, and the reduction in fossil fuel imports. The study aims to quantify these economic benefits over the forecast period.

Environmental Impact (ENV): This includes the anticipated reduction in greenhouse gas emissions and other pollutants due to the transition from internal combustion engine vehicles

to EVs. It also considers the expected improvements in public health outcomes related to reduce air pollution.

Infrastructure Development (ID): This dependent variable focuses on the necessary infrastructure to support EV adoption, such as the density of charging networks, the integration of renewable energy sources, and the balance between electricity demand and supply.

Policy and Regulatory Framework (PRF): This dependent variable considers the effectiveness of government policies and regulations in promoting EV adoption. It includes incentives like subsidies and tax breaks, public awareness campaigns, and regulatory standards for EVs and related infrastructure.

3. **Moderating Variables:**

Technological advancements (TA), consumer behavior (CB), and economic factors (EF) are moderating variables that can influence the relationship between EV adoption and its impacts. For instance, improvements in battery technology and charging infrastructure can accelerate EV adoption, while economic factors such as fuel prices and disposable income levels can affect consumer willingness to switch to EVs.

4. **Mediating Variables:**

Infrastructure readiness (IR) and government policies (GP) are mediating variables that facilitate the expected outcomes. Effective policies and a well-developed charging infrastructure are essential for realizing the full economic and environmental benefits of EV adoption.

5. **Expected Outcomes:**

The study anticipates different outcomes over short-term (2020-2030), medium-term (2031-2040), and long-term (2041-2050) periods. These outcomes include initial adoption rates, significant economic and environmental impacts, and the establishment of a sustainable transportation system supported by robust infrastructure and policies.

The conceptual framework diagram above illustrates the relationships between the independent variable (Electric Vehicle Adoption) and the dependent variables (Economic Impact, Environmental Impact, Infrastructure Development, and Policy and Regulatory

Framework). Electric Vehicle Adoption directly influences these dependent variables, leading to economic benefits such as cost savings and job creation, environmental benefits through reduced emissions, and the development of necessary infrastructure and supportive policies. Technological advancements, consumer behavior, and economic factors act as moderating variables, shaping the strength and direction of these relationships. Infrastructure readiness and government policies serve as mediating variables, enabling the effective realization of the expected outcomes, which vary across short-term, medium-term, and long-term periods.

2.6. Chapter Summary

This chapter has presented a comprehensive review of the theoretical, empirical, and conceptual foundations that underpin the economic analysis of electric-vehicle (EV) adoption in Rwanda. It established that the transition to electric mobility is not merely a technological shift but a complex socio-economic and policy process influenced by innovation diffusion, user behavior, economic viability, and sustainability principles.

The theoretical literature provided a foundation for understanding the rationale behind EV adoption, focusing on the “why” rather than the “what.” Four main theories were explored to guide this study. The Diffusion of Innovations Theory explained how new technologies spread through social systems and the factors that influence their rate of adoption. The Technology Acceptance Model (TAM) offered insight into behavioral determinants such as perceived usefulness and ease of use. The Cost–Benefit Analysis (CBA) framework provided an economic lens to evaluate the long-term financial and societal impacts of adopting EVs. Finally, the Sustainable Development Theory grounded the research in the principles of environmental protection and intergenerational equity, aligning EV adoption with Rwanda’s Vision 2050 and National Strategy for Transformation (NST1). Together, these theories form a robust conceptual basis for assessing behavioral, economic, and environmental dimensions of e-mobility.

The empirical review further illustrated global and regional experiences with electric mobility, highlighting the technical, financial, and infrastructural challenges encountered in developing contexts. Studies from Sub-Saharan Africa reveal that while EV adoption can substantially reduce greenhouse-gas emissions and fuel import dependence, its success depends on supportive policies, reliable electricity supply, and public awareness. These findings provided valuable lessons and justified the selection of models appropriate for Rwanda’s context.

The discussion of applicable models summarized the strengths and limitations of global energy-demand forecasting tools—MAED-2, LEAP, and TIMES. Among them, MAED-2 was selected for this study due to its ability to link socio-economic development with sectoral energy demand using modest data inputs. This choice balances analytical rigor with practicality and allows scenario analysis of EV adoption levels, providing credible projections for policymaking.

Finally, the conceptual framework integrated insights from the reviewed theories and empirical studies, illustrating how variables such as policy support, technological readiness, cost factors, and environmental awareness interact to influence EV adoption in Rwanda. The framework guided the design of the research methodology and the interpretation of findings presented in subsequent chapters.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter outlines the methodological approach adopted for assessing the economic impact of electric vehicle (EV) adoption in Rwanda's public transportation sector. It explains the overall research design, setting, population, data collection, and analytical techniques used to address the study objectives. The chapter also describes the rationale for choosing the Model for Analysis of Energy Demand (MAED-2) as the principal simulation tool for projecting energy demand under various EV-adoption scenarios. In line with the theoretical frameworks discussed in Chapter Two, this methodology integrates economic analysis, diffusion theory, and sustainability principles to produce reliable and policy-relevant findings.

Methodology in applied research serves as the structured plan that links theoretical foundations to practical investigation (Creswell & Creswell, 2018). Accordingly, this chapter ensures that every analytical step from data sourcing to model simulation aligns with the research objectives, theoretical assumptions, and ethical standards of the University of Rwanda.

3.2 Research Design

This study employs a quantitative analytical and predictive research design, appropriate for exploring relationships among measurable variables such as cost, energy demand, and emission reduction. Quantitative designs allow for empirical validation through statistical and model-based analysis (Bryman, 2016). The research integrates secondary data analysis and scenario-based simulations to forecast the economic and environmental impacts of electric mobility adoption.

This design is particularly relevant because EV adoption is a systemic phenomenon involving quantifiable indicators such as electricity demand, vehicle operating costs, and greenhouse gas emissions. The study's analytical orientation enables objective evaluation of the magnitude of economic and policy outcomes under varying assumptions. The chosen design therefore ensures rigor, replicability, and comparability with global energy-modeling studies (Kothari, 2004).

3.3 Research Setting

The study focuses on Kigali City, the capital and most urbanized region of Rwanda, which serves as the main hub of national transport operations. Kigali hosts the majority of public transport companies, private operators, and EV pilot projects, including initiatives led by

Ampersand and Volkswagen Rwanda. Its high population density, organized bus routes, and expanding charging infrastructure make it an ideal microcosm for understanding national e-mobility dynamics (MININFRA, 2023).

Kigali's strategic importance in national transport policy is further highlighted by its inclusion in the Government of Rwanda's Green Mobility Policy (2021) and the Vision 2050 framework, which promote reduced fuel imports and sustainable transport solutions. The urban focus also facilitates access to reliable secondary data from national agencies and local industry partners.

3.4 Target Population

The target population consists of key actors and institutions directly or indirectly involved in Kigali's public transportation system. These include:

Public transport operators (bus companies, cooperative unions, and drivers);

Passengers and commuters who depend on public transport services;

Government agencies such as the Ministry of Infrastructure (MININFRA), the Rwanda Utilities Regulatory Authority (RURA), and the Rwanda Environment Management Authority (REMA); and Private sector stakeholders, notably electric-vehicle suppliers, charging-station companies, and maintenance service providers.

Because this research relies on secondary data, population data are extracted from official statistical and institutional records rather than direct surveys. Reports from the National Institute of Statistics of Rwanda (NISR) (2022), RURA Transport Sector Report (2023), and REMA Annual Environmental Report (2023) provide relevant indicators on energy consumption, vehicle registration, fuel imports, and passenger volume. This triangulation ensures that the data represent all major perspectives shaping Kigali's transport ecosystem.

3.5 Sample Size

Since the study is based exclusively on secondary data, a traditional sample size is not applicable. Instead, a comprehensive selection of validated datasets was used. Inclusion criteria were: (1) official or peer-reviewed source, (2) relevance to EV adoption or transport energy use, and (3) temporal coverage within the study's reference period (2020–2050). This approach follows recommendations by Saunders, Lewis, and Thornhill (2019) for analytical studies that use archival and documentary data to maximize reliability and external validity.

3.6 Data Collection Methods

The study draws entirely on secondary data, integrating both national and international sources:

Government agencies such as MININFRA, RURA, and the Rwanda Energy Group (REG) provide datasets on transport policies, vehicle registration, energy consumption, and electricity-grid capacity.

International organizations, including the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), supply comparative statistics and modeling parameters related to EV adoption and energy-system transformation.

Private-sector reports from firms like Ampersand, Volkswagen Rwanda, and Siemens e-Mobility offer cost, operational, and technical data for Rwanda's pilot projects.

Academic and research literature, drawn from peer-reviewed journals such as *Energy Policy*, *Renewable and Sustainable Energy Reviews*, and *Transportation Research Part D*, provides empirical findings and elasticity estimates relevant to transport-energy modeling.

Using multi-source secondary data enables cross-validation and ensures a comprehensive picture of the economic and environmental landscape influencing Rwanda's transition to e-mobility.

3.7. Data Collection Instruments

Data were gathered using structured document-analysis frameworks and data-extraction templates. These instruments facilitated systematic review and coding of quantitative indicators, such as fuel consumption, import values, and grid generation as well as qualitative insights on policy, technology, and market challenges.

Each dataset was reviewed for completeness, credibility, and temporal consistency. The frameworks followed the guidelines proposed by Bowen (2009), emphasizing authenticity, representativeness, and contextual meaning. Qualitative content was coded into thematic categories aligned with the study objectives: (1) economic impacts, (2) technological readiness, and (3) environmental benefits.

3.8. Procedures of Data Collection

Data were obtained through a systematic and iterative process:

Identification: Relevant publications and datasets were identified through database searches and government portals.

Retrieval: Documents were downloaded from institutional repositories such as the Rwanda Open Data Portal, IEA Data Library, and academic databases (ScienceDirect, ResearchGate).

Screening: Records were screened for time relevance, reliability, and methodological consistency.

Organization: Data were categorized under predefined themes corresponding to the study objectives.

Verification: Authenticity was validated through source triangulation and expert consultations.

Preparation: Cleaned data were entered into Excel for descriptive analysis and subsequently formatted for import into the MAED-2 model environment.

This procedure ensures transparency and replicability, in line with recommendations by O’Leary (2017) for documentary research.

3.9. Reliability and Validity of Instruments

Ensuring the trustworthiness of secondary data is critical for analytical accuracy. The study applies multiple techniques:

Triangulation: Cross-verification of findings from government, private, and international sources reduces bias and enhances validity (Patton, 2015).

Sensitivity Analysis: The robustness of MAED-2 projections was tested by altering key input parameters, GDP growth rate, vehicle-ownership elasticity, and energy intensity, to evaluate how outcomes respond to changes in assumptions.

Peer Review and Expert Consultation: Draft results and assumptions were reviewed by energy economists, engineers, and policymakers to validate methodological integrity.

Source Authentication: Only officially published, peer-reviewed, or institutionally validated documents were included in the analysis.

These measures collectively uphold the reliability and validity standards recommended by Mugenda (2003) for applied policy research.

3.10. Data Analysis Methods

The study applies a multi-layered analytical approach integrating descriptive, comparative, and model-based techniques:

Descriptive Statistical Analysis:

Used to examine historical trends in Rwanda's transport and energy sectors, including fuel imports, energy consumption, and CO₂ emissions (IEA, 2022).

Before-and-After Comparative Analysis:

Compares key economic indicators; fuel expenditure, transport costs, and emissions, before and after EV introduction to evaluate direct impacts (World Bank, 2023).

MAED-2 Model Simulation:

The MAED-2 model projects energy demand from 2020 to 2050 under baseline and EV-adoption scenarios. It disaggregates demand by sector (industry, transport, residential) and quantifies how transport electrification influences total national energy needs. This modeling approach has been validated in similar studies in Kenya, Egypt, and Morocco (IAEA, 2020).

Scenario Analysis:

Several scenarios were developed, Business-as-Usual (BAU), Moderate EV Adoption, and High EV Adoption to evaluate variations in energy demand, cost savings, and emission reduction.

Comparative Benchmarking:

Rwanda's e-mobility trends were compared with peer countries such as Kenya, Uganda, and Ethiopia to draw regional policy insights (Smit et al., 2023).

Quantitative results were analyzed using Microsoft Excel and visualized through graphs and tables, while qualitative insights were synthesized to interpret policy implications.

3.11. Ethical Considerations

This study adhered strictly to the University of Rwanda's Research Ethics Guidelines (2022). Although it primarily uses secondary data, ethical principles of transparency, acknowledgment, and data security were upheld:

Ethical Approval: Secured from the University of Rwanda's Ethics Committee prior to data collection.

Informed Consent: Ensured where any primary consultations or expert opinions were solicited.

Confidentiality: Institutional data and stakeholder communications were anonymized and stored securely.

Integrity and Acknowledgment: All secondary sources are properly cited and referenced to respect intellectual property rights.

Data Security: All digital materials were stored in encrypted files accessible only to the researcher.

These ethical standards ensure that the study aligns with both institutional policy and international norms for responsible research (Belmont Report, 1979).

3.12. Summary of Chapter Three

This chapter has detailed the methodological framework used to analyze the economic implications of electric-vehicle adoption in Rwanda. The research design was quantitative and predictive, relying on secondary data and model-based simulations. Data were systematically collected from credible national and international sources and analyzed using descriptive statistics and the MAED-2 modeling framework. Reliability was reinforced through triangulation and sensitivity testing, while ethical principles were strictly observed.

The chosen methodology ensures that the study's findings, presented in Chapter Four, are both scientifically credible and contextually relevant, providing robust evidence to support Rwanda's ongoing transition toward sustainable electric mobility.

CHAPTER FOUR: FINDINGS AND DISCUSSION

4.0 Introduction

This chapter presents the study's final findings, and seeks to respond to the research questions elaborated previously in the first chapter.

4.1 Presentation of findings

This section comes as a thorough presentation of the research findings, including the extensive data collected throughout the research and the careful statistical analyses, all of which are closely related to the predetermined study objectives. This section reveals the complex findings from the research through a thorough examination of the data gathered. The findings provide a comprehensive grasp of the study's main themes by combining both quantitative and qualitative observations. The talks that follow explore the significance and ramifications of these discoveries, establishing links between the noted trends and the main goals of the study.

4.1.1. The current Use of electric vehicle adoption in Rwanda's public transport sector

As of 3rd July 2020, the number of registered vehicles countrywide is 264,524 excluding security organs and Government vehicles. The transport sector is rapidly growing with an annual vehicle growth rate of 12%, therefore, if no action is taken, air pollution and resulting adverse health impacts will increase. Registered vehicles in **Rwanda** increased by 18% in two years, rising from 268,537 in 2021 to 330,166 in 2023, according to the 2024 Statistical Yearbook by NISR. Rwanda depends on imported fossil fuel for transportation services. In 2018, fuel products were among the largest single import product category into Rwanda. The overdependence on fossil fuel has a strong effect on the trade balance. (MININFRA 2021)

Table 2: Cumulative Number of vehicles registered by categories

| Category | Total Cumulative of Registered Vehicles up to 31 st December 2021 | Total Cumulative of Registered Vehicles up to 31st December 2022 | Total Cumulative of Registered Vehicles up to 31st December 2023 |
|----------------|--|--|--|
| Caterpillar | 177 | 196 | 218 |
| Bus | 2,084 | 2,287 | 2,892 |
| Trucks | 11,397 | 12,823 | 14,496 |
| Pick-up | 19,890 | 21,662 | 22,470 |
| Special Engine | 5,047 | 5,725 | 6,566 |
| Jeeps | 34,622 | 38,277 | 41,543 |
| Microbus | 2,414 | 2,829 | 3,061 |
| Minibus | 6,327 | 6,870 | 7,171 |

| | | | |
|----------------|----------------|----------------|----------------|
| Cars | 43,182 | 47,098 | 51,262 |
| Motors | 141,532 | 157,897 | 177,187 |
| Trailers | 1,234 | 1,341 | 1,636 |
| Semi- trailers | 555 | 652 | 875 |
| Tricycle | 73 | 224 | 648 |
| Unknown | 3 | 5 | 3 |
| Forklift | 0 | 101 | 138 |
| TOTAL | 268,537 | 297,987 | 330,166 |

Source: RRA 2024

Table 3: Number of registered Vehicles in Rwanda (NISR 2025)

| Vehicle Type | Number of Vehicles | Percentage of Total Vehicles |
|-------------------|--------------------|------------------------------|
| ICE Vehicles | 352,828 | 93.80% |
| Hybrid Vehicles | 6,660 | 1.80% |
| Electric Vehicles | 512 | 0.10% |
| Motorcycles | 177,187 | 47.90% |
| Total Vehicles | 372,187 | 100% |

Source: NISR 2025

Table 4: Trend in the number of licensed road transport operators per category

| Category | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|------|------|------|------|------|
| Public transport companies and cooperatives | 44 | 45 | 40 | 47 | 47 |
| Taxi cab companies and cooperatives | 50 | 49 | 48 | 48 | 52 |
| Rental car hires companies and cooperatives | 39 | 46 | 46 | 50 | 64 |
| Transport of goods companies and cooperatives | 27 | 30 | 22 | 27 | 35 |
| Driving Schools | 72 | 78 | 72 | 76 | 126 |

Source: RURA(2024)

Rwanda has been a pioneer in East Africa's electric transportation (e-mobility) market in recent years thanks to infrastructural projects, supportive regulations, and the commitment of numerous players. In order to discuss Rwanda's progress in e-mobility and the next steps required to ensure the sector's sustainable growth, key players from the government, private sector, academia, and development agencies convened at the recent Electric Mobility Forum Kigali, which was co-organized by GIZ Rwanda and MININFRA and took place on October 23–24 at the Four Season Hotel. With more than 70 attendees, the event outlined Rwanda's

accomplishments, pointed out obstacles, and gave interested parties a place to network, share ideas, and work together to create solutions. Here are some highlights from the event and some of the thoughts that were discussed.

Rwanda's commitment to sustainable transportation is underpinned by ambitious policies designed to encourage e-mobility. The Government of Rwanda has introduced zero VAT on EV imports, exemptions on import and excise duties for EV parts, and an industrial tariff for EV charging, making the sector more accessible. Additionally, the government provides rent-free land for charging stations, further incentivising infrastructure development. These measures are aligned with Rwanda's broader vision to become carbon neutral by 2050.

The impact of these policies is evident in the country's EV statistics. From a mere 19 EVs (both hybrid and fully electric) in 2020, Rwanda now has 512 fully electric cars and 6,660 hybrids registered in 2024. Rwanda also boasts over 4,000 electric motorbikes operated by Ampersand and an additional 1,200 bikes from Spiro. Ampersand, for instance, operates 32 battery swap stations around Kigali and expects to manufacture 18,000 batteries for their fleet by 2025. The potential savings for drivers are notable, with those switching to electric increasing their take-home pay by 45%, equating to around \$840 in annual savings on fuel and maintenance.

Electric Motorcycles

In Rwanda, more than half the vehicles on roads are "moto-taxis." Though they are the backbone of the country's transport system, they contribute to climate change. Thanks to a fast-growing electric motorbike start-up in Kigali, e-motorbikes are now cutting emissions and helping drivers, particularly young people, save money and fuel a greener future. Electric motorcycles (e-motos) are at the forefront of Rwanda's EV adoption. There are three key players who dominate this sector which are:

Ampersand Operates over 4,000 electric motorbikes in Kigali, has 32 battery swap stations in Kigali and Plans to manufacture 18,000 batteries for their fleet by 2025. (GIZ Rwanda 2024). **Safi Universal Link** Currently has 123 electric motorcycles in operation and operates 5 charging stations. Demonstrates plans for future expansion, with 280 additional e-motos expected to join the fleet soon. Twagirimana, J. (2023). **Rwanda Electric Motorcycle (REM)** Runs a fleet of 280 electric motorcycles. Innovatively retrofits existing internal combustion engine (ICE) motorcycles into electric models, having converted 80 ICE bikes so far. Operates 5 charging stations and recently introduced 32 modern battery-electric vehicle (BEV) SUVs for its fleet. Twagirimana, J. (2023)

Spiro, an electric vehicle company, has deployed over 1,200 electric bikes in Rwanda. Spiro has expanded its automated swap stations across Rwanda, including in Kigali, Muhanga, Kayonza, Rwamagana, and Bugesera. Spiro's charging stations and battery swap systems are designed to use renewable energy sources(Equitane Group 2024)

Electric Cars

The impact of these policies is evident in the country's EV statistics. From a mere 19 EVs (both hybrid and fully electric) in 2020, Rwanda now has 512 fully electric cars and 6,660 hybrids registered in 2024. Rwanda also boasts over 4,000 electric motorbikes operated by Ampersand and an additional 1,200 bikes from Spiro. Ampersand, for instance, operates 32 battery swap stations around Kigali and expects to manufacture 18,000 batteries for their fleet by 2025. The potential savings for drivers are notable, with those switching to electric increasing their take-home pay by 45%, equating to around \$840 in annual savings on fuel and maintenance. The adoption of electric cars in Rwanda is also gaining momentum, with contributions from two major players:

Victoria Autofast: Operates 124 plug-in hybrid electric vehicles (PHEVs), providing a transitional step toward full EV adoption. Has installed 130 domestic charging infrastructures and 10 public charging stations, creating a robust network to support electric cars.

Volkswagen Mobility: Introduced 20 electric cars (e-Golfs) into its fleet, primarily used for ride-hailing services in urban centers. Supports this operation with 2 public charging stations, ensuring the vehicles remain accessible and reliable for commuters.

The presence of Volkswagen and Victoria Autofast underscores Rwanda's ability to attract international automotive firms and demonstrates the viability of electric cars in a developing nation.

Companies like IZI Electric and Basigo are also driving electric bus adoption, each aiming to expand their fleets to 100 buses in the coming years. Both recently secured funding from the Rwanda Green Fund, helping them advance toward these ambitious targets. Currently IZI Electric operates 7 e-buses, and Basigo has 6 in service, both companies setting a foundation for Rwanda's cleaner public transport initiatives. Zirikana, F., & Kossakowski, P. (2024)

Companies like Kabisa and Meshpower play pivotal roles in expanding Rwanda's EV charging networks. Kabisa aims to have 38 EV charging stations by the end of 2024, ensuring a station every 100 km across the country. Meshpower is collaborating with Kabisa to install

high-standard stations and pilot solar-powered charging solutions, enhancing resilience and aligning with Rwanda’s carbon-neutral goals. Zirikana, F., & Kossakowski, P. (2024)

4.1.2. Economic assessment

Buses:

For Buses, the assessment revealed that capital cost (CAPEX) of an electric bus is almost 4 times the cost of an internal combustion engine (ICE) bus. The economic calculations showed that reducing by half the cost of battery and electricity would make electric buses have the same overall cost (CAPEX plus operating cost (OPEX)) as the ICE buses. (MININFRA.2021)

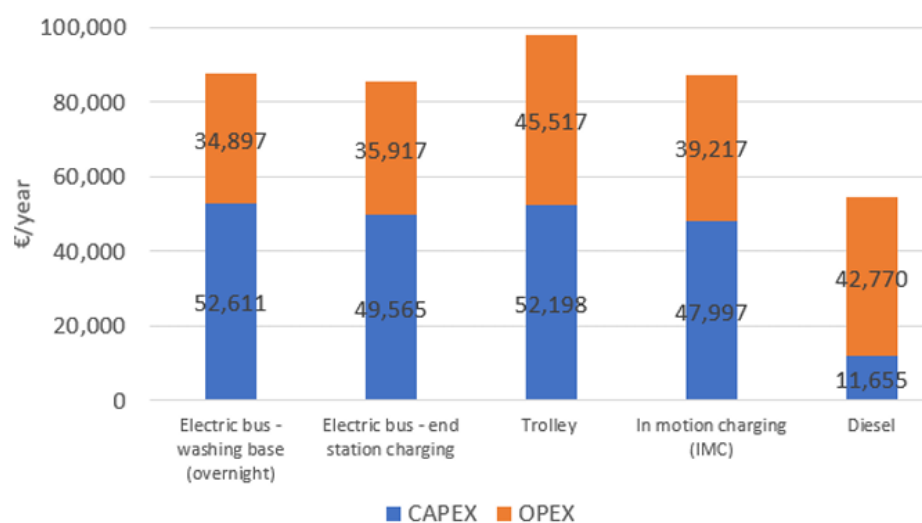


Figure 2 CAPEX and OPEX for bus cases. Single bus costs, including charging infrastructure

Taxi Cars

For taxi cars, the cost of electric car needs to decrease by approximately 15% to reach the same life cycle cost level as the fuel taxi, assuming they are charged fully overnight, or with fast charging. Figure 3 shows the cost split for taxi cases. (MININFRA.2021)

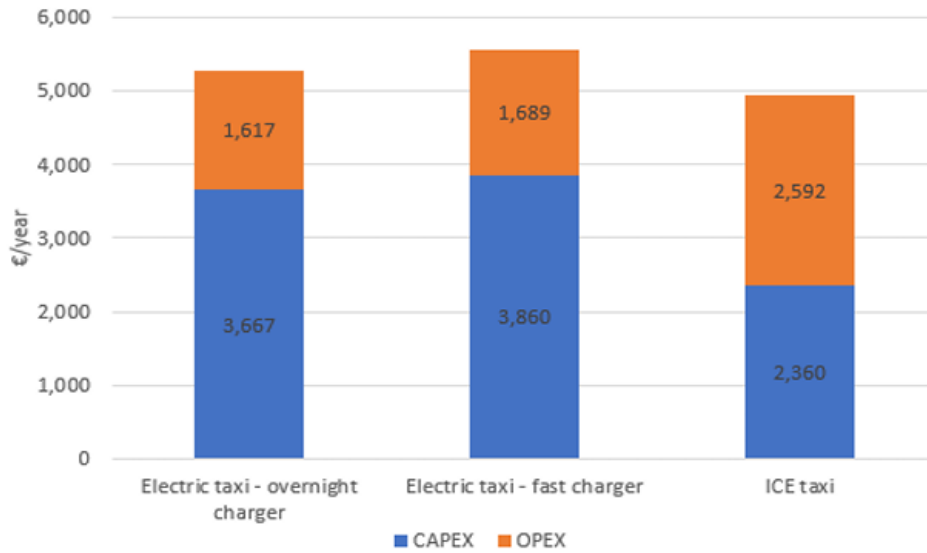


Figure 3: CAPEX and OPEX for taxi cases. Single vehicle costs.

Motorcycle taxi

For motorcycle taxi, the study indicated that the overall cost of electric motorcycle taxis is slightly higher than the fuel internal combustion engine motorcycle. Furthermore, the reduction of electricity tariff and any actions to reduce the upfront capital cost would result in a positive business case. As stipulated in the figure 4 below, the overall cost of electric motorcycle taxis is slightly higher than the fuel ICE motorcycle. (MININFRA.2021)

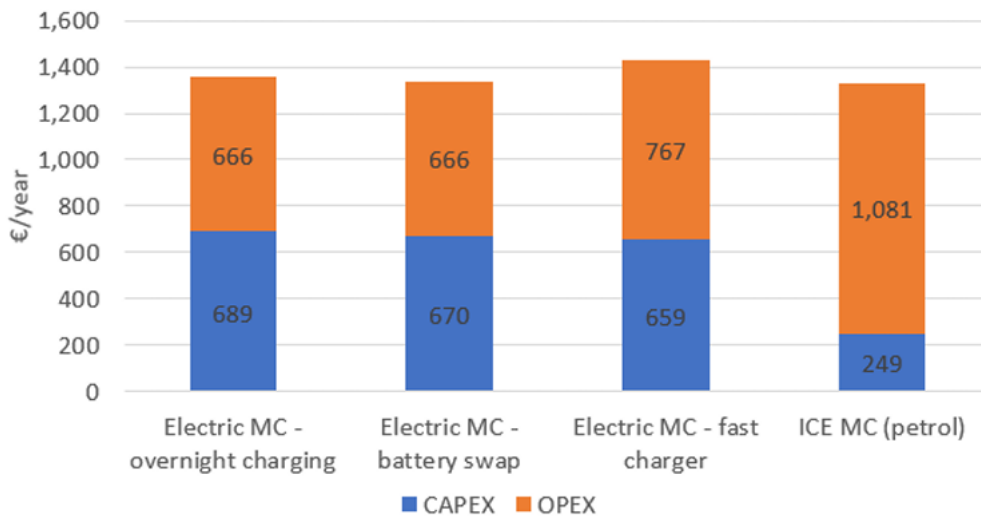


Figure 4: CAPEX and OPEX for MC. Single vehicle costs.

4.1.2. The economic benefits and challenges associated with the adoption of electric vehicles in Rwanda

4.1.2.1. The economic benefits of the adoption of electric vehicles in Rwanda

The following are the benefits of electric vehicles, as compared to corresponding petrol or diesel vehicles: (MININFRA 2021).

Low maintenance cost (almost half depending on vehicle category and use);

Electric vehicles have fewer moving parts than internal combustion engine (ICE) vehicles, reducing wear and tear. EVs do not require oil changes, fuel filters, or exhaust system repairs, lowering maintenance costs. Regenerative braking reduces brake pad wear, further minimizing expenses. Depending on vehicle category and usage, maintenance costs can be almost 50% lower than traditional vehicles. Over time, this translates into significant savings for both individuals and fleet operators.

Reduced environmental impacts related to climate change;

EVs produce no tailpipe emissions, reducing air pollution in urban areas and mitigating health issues like respiratory diseases. By shifting to renewable energy sources for electricity generation, overall emissions from transport can be further minimized. Unlike petrol or diesel vehicles, EVs do not contribute to oil spills, fuel extraction damage, or water contamination. Lower noise pollution also improves urban livability. These factors help combat climate change and protect ecosystems.

Reduced dependency on fossil products (oil imports);

Rwanda heavily depends on imported petroleum products, making fuel prices volatile due to global market fluctuations. EV adoption reduces reliance on oil imports, improving energy security and economic stability. Using locally generated electricity instead of imported fuel enhances national self-sufficiency. Over time, shifting to EVs and renewable energy integration supports sustainable economic growth. Reduced fossil fuel use also decreases the risks of geopolitical energy disruptions.

Decreased Greenhouse Gas (GHG) emissions by 17%;

Since transport is a major contributor to CO₂ emissions, shifting to EVs reduces greenhouse gas emissions significantly. EVs in Rwanda, powered by a cleaner electricity grid, produce lower lifetime emissions than petrol or diesel cars. The 17% reduction in GHG emissions helps Rwanda meet its Nationally Determined Contributions (NDCs) under the Paris

Agreement. This supports the country's climate action goals while reducing health-related costs from air pollution.

Reduced importation on oil products by 15% (gasoline 21% and diesel 9%) annually to stabilize balance of payment;

Rwanda spends a significant portion of its foreign exchange reserves on importing petroleum products. EV adoption can reduce annual oil imports by 15%, with gasoline imports declining by 21% and diesel by 9%. This helps stabilize the balance of payments by decreasing Rwanda's trade deficit. The money saved can be redirected towards critical sectors like infrastructure, healthcare, and education, promoting national economic growth.

Cost savings of 20 billion Rwandan francs on oil importation up to 2025;

The transition to EVs is projected to save 20 billion Rwandan francs (RWF) on fuel imports by 2025. These savings come from reduced fuel purchase costs, lower maintenance expenses, and enhanced energy efficiency. The government can use these savings for renewable energy investments, public transport expansion, or EV infrastructure development. Reducing fossil fuel imports also mitigates exposure to price fluctuations in global oil markets.

Increased electricity consumption by 132 GWh (15MW-installed capacity) to address the issues of anticipated generation surplus up to 2030.

Rwanda's anticipated electricity generation surplus can be efficiently utilized through EV adoption. By 2030, EVs are expected to consume 132 GWh of electricity, requiring an additional 15 MW of installed capacity. This increased electricity demand helps improve the economic viability of Rwanda's power sector, ensuring optimal use of existing infrastructure. A shift towards EVs powered by renewable energy further strengthens Rwanda's sustainable energy transition.

Job Creation in Emerging Industries

The shift to EVs offers opportunities for local job creation in manufacturing, assembly, maintenance, battery recycling, and charging infrastructure development. For example, Volkswagen Rwanda has already initiated EV assembly operations in the country. This development aligns with Rwanda's Vision 2050 to create a sustainable and innovation-driven economy (Rwanda Development Board, 2022).

Energy Security and Diversification

Adopting EVs allows Rwanda to leverage its growing renewable energy sector, including hydro, solar, and geothermal resources. This reduces dependency on fossil fuels and enhances energy security. The Rwanda Energy Group (REG) reports that 60% of the country's energy mix is renewable, making EVs a complementary solution for sustainable development.

Long-term Economic Growth

The adoption of EVs can foster long-term economic growth by:

Attracting Foreign Investment: Rwanda's commitment to green energy and EVs can attract international investments from companies like Tesla, BYD, and other clean technology firms.

Enhancing Trade Opportunities: Rwanda could position itself as a hub for EVs in East Africa, exporting assembled EVs to neighboring countries.

Improving Productivity: Reduced traffic pollution and health issues contribute to a more productive workforce.

Support for Sustainable Urban Development

EV adoption aligns with Rwanda's strategic urbanization goals. Kigali's city planning initiatives, such as eco-friendly zones and smart city concepts, are complemented by clean transportation solutions. This can improve property values and economic activity in urban centers.

4.1.3. Challenges and Gaps in Rwanda's E-Mobility Landscape

Despite Rwanda's remarkable progress, there are several key challenges that must be addressed to achieve full-scale EV adoption. According to Zirikana, F., & Kossakowski, P. (2024) some of these include:

Policy Awareness and Access: There is a need for a centralised platform to access EV-related policies. Many stakeholders are not fully aware of existing policies or struggle with policy implementation. Stake holders proposed creating a single online platform where they can access relevant policies, reports, and resources. Stakeholders also emphasized the need for regular forums that allow stakeholders from all sectors to contribute insights and feedback on existing policies, enhancing policy effectiveness and stakeholder engagement.

Financial Barriers: Access to financing remains a significant hurdle, particularly for new EV startups. While BRD (Rwanda Development Bank) supports the sector through the Green Fund and favorable financing terms (12% interest, 12-year terms), generally banks require substantial collateral, posing challenges for startups. There is a need for tailored financing

solutions and technical assistance to make EVs more accessible. To address these challenges, stakeholders suggested that BRD and the Central Bank of Rwanda work together to revise collateral requirements specifically for e-mobility ventures, potentially adopting guarantee schemes for higher accessibility.

After-Sales Support and Infrastructure: The need for maintenance support, access to spare parts, and testing tools was highlighted. Currently, tax exemptions are not extended to these crucial areas, creating challenges for servicing and the sustainability of the sector.

Lack of Skilled Workforce: Another key area identified was the shortage of skilled technicians and engineers trained in EV technology. Universities such as the University of Rwanda and Carnegie Mellon University Africa (CMU) are stepping up, with CMU introducing an “Electrical Systems for EV” course in its next semester. CMU also offered to lead a working group to address employment and capacity-building needs in the sector. The University of Rwanda’s second-life battery research program was also highlighted, focusing on strategies for reusing EV batteries and contributing to Rwanda’s circular economy goals in collaboration with private sector companies like Ampersand, Spiro, SLS Energy and EnviroSource.

Other Barriers to the Adoption of Electric Vehicles in Rwanda are:

1. High Initial Costs of EVs

One of the major barriers to EV adoption in Rwanda is the high upfront cost of purchasing electric vehicles. EVs are generally more expensive than internal combustion engine (ICE) vehicles, largely due to the cost of batteries, which account for 30–50% of the total vehicle cost. For a low-income country like Rwanda, where affordability is a concern, the high cost is a significant deterrent (African Development Bank, 2022).

2. Limited Charging Infrastructure

Rwanda lacks a comprehensive network of EV charging stations. As of now, only a few charging points exist in urban centers such as Kigali. The absence of adequate charging infrastructure discourages potential adopters due to "range anxiety" — the fear of running out of battery power without access to a charging station (Rwanda Utilities Regulatory Authority, 2023).

3. Dependency on Imported Technology

Rwanda relies heavily on importing EVs and related technologies, such as batteries and components. This dependency increases costs and limits local capacity for production,

maintenance, and repair. Furthermore, fluctuations in international trade policies and currency exchange rates can create uncertainties in EV supply (UNEP, 2021).

4. Limited Public Awareness and Acceptance

Public knowledge about EVs, their benefits, and their operation remains limited. Many Rwandans are unfamiliar with EVs and may be hesitant to transition from conventional vehicles. Cultural inertia and skepticism regarding EV performance and reliability, especially in rural areas, further slow adoption (IEA, 2023).

5. Inadequate Policy and Regulatory Framework

Although Rwanda has expressed interest in promoting EVs, the current policies and regulations lack clarity and comprehensive support. Incentives such as tax breaks, subsidies, or grants for EV buyers and manufacturers are still underdeveloped. The lack of a well-defined regulatory framework for EV operations hinders private-sector investment (Rwanda Development Board, 2022).

6. Energy Grid Capacity and Stability

Although Rwanda generates a significant portion of its electricity from renewable sources, its overall energy production is still relatively low. The adoption of EVs on a large scale would place additional demand on the national grid, potentially straining capacity. Addressing this challenge would require significant investments in grid expansion and stability (World Bank, 2022).

7. Limited Vehicle Options

The current market offers a limited variety of EV models suited to Rwandan conditions. For example, affordable EV options for motorcycles and small public transport vehicles, such as minibuses, are sparse. The lack of diversity in vehicle types constrains the ability of consumers and businesses to transition to EVs (Global EV Outlook, 2022).

8. Recycling and Disposal of Batteries

The adoption of EVs raises concerns about the recycling and disposal of lithium-ion batteries. Rwanda currently lacks the infrastructure for safe battery recycling or disposal, posing potential environmental and health risks. Establishing a circular economy for batteries is necessary but remains a significant challenge (UNEP, 2021).

9. Financing Barriers

Access to financing for EV purchases and infrastructure development is limited. Many individuals and small businesses, such as motorcycle taxi operators, lack access to affordable loans or leasing options for EV acquisition. Banks and financial institutions are hesitant to fund EV projects due to perceived risks and limited understanding of the technology (African Development Bank, 2022).

10. Rural Accessibility Issues

While urban centers like Kigali may see faster adoption of EVs, rural areas face greater challenges due to poor road networks, lack of electricity access, and insufficient charging infrastructure. This urban-rural divide could hinder equitable adoption of EVs across the country (Rwanda Development Board, 2022).

4.1.4. The evaluation of long-term economic effects of electric vehicle adoption in Rwanda from 2020 to 2050 Using MAED 2

Based on the MAED-2 model projections, the adoption of electric vehicles (EVs) in Rwanda's public transport sector will significantly impact the economy, energy consumption, and emissions. Below is a detailed analysis of the projected long-term economic effects.

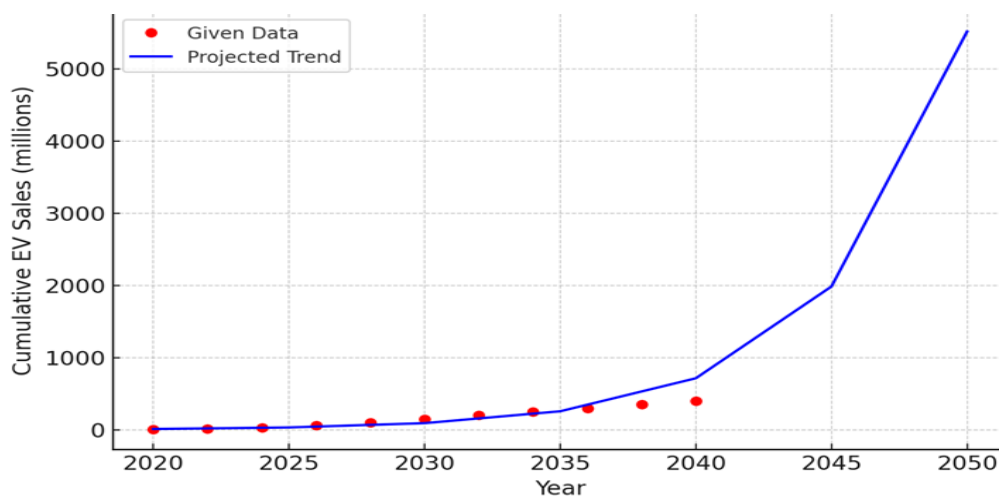


Figure 5: Projected Cumulative Sales of EVs 2020-2050(MAED-2)

4.1.4.1. Energy Demand Trends and Shift to Electricity

The transition to EVs will drive a substantial increase in electricity demand, while reducing reliance on motor fuels and fossil fuels:

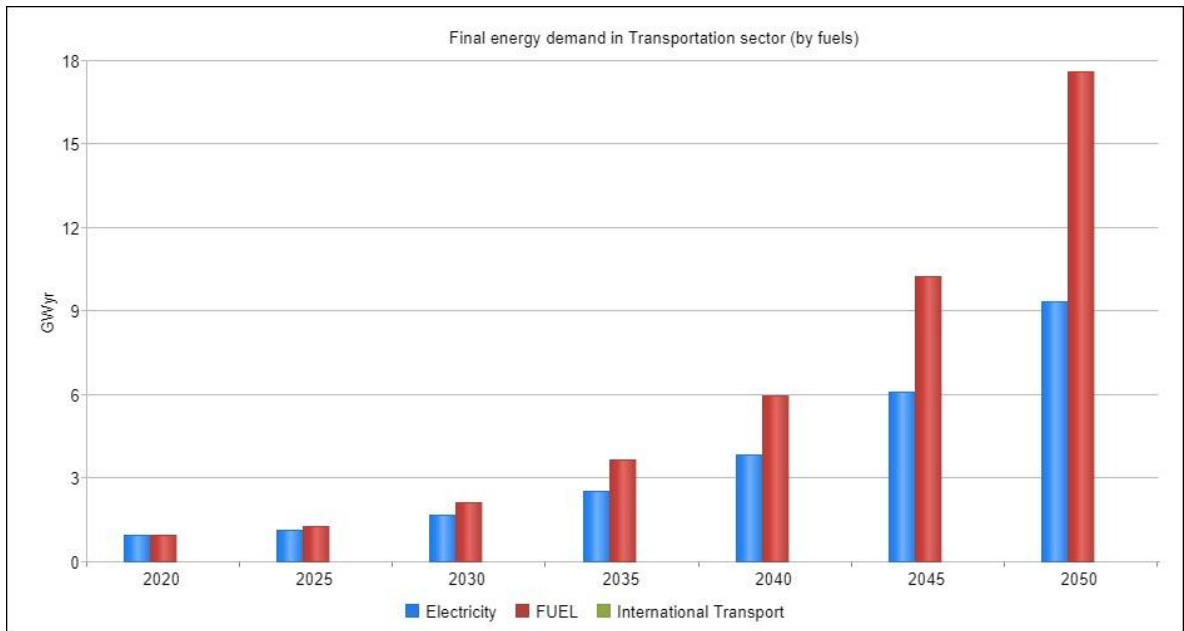


Figure 6: Final demand in transportation sector (by fuels)

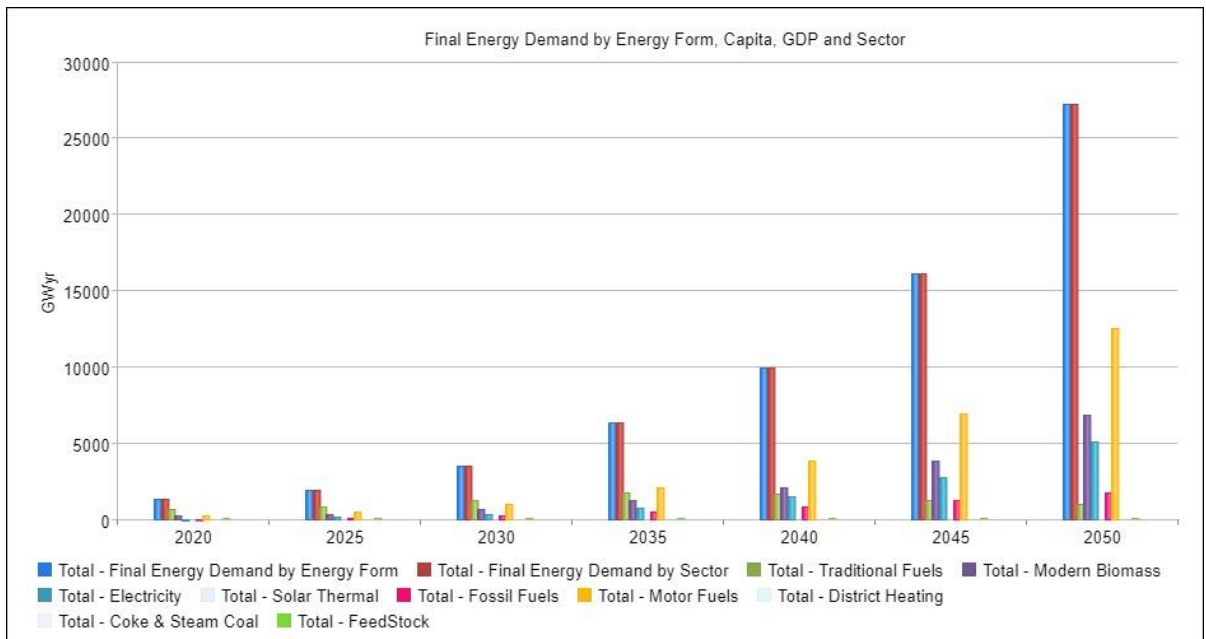


Figure 7: Final Energy Demand by Energy form, Capita, GDP and Sector

Electricity Demand Growth: In 2020, electricity demand was **83.02 GWyr**. By 2050, it is projected to increase to **4,813.48 GWyr**, a **57.9x increase**. The transport sector alone will contribute **9.31 GWyr** to electricity demand by 2050, indicating increased EV adoption.

Reduction in Motor Fuels Consumption: Motor fuels demand in 2020 was **278.22 GWyr**. It is projected to rise to **11,747.48 GWyr** in 2050, but this growth rate will slow down as EV adoption increases. Fossil fuels demand is also expected to slow, growing from **54.69 GWyr** in 2020 to **1,605.08 GWyr** in 2050.

Key Economic Impacts of Energy Transition

Cost Savings on Fuel Imports: Rwanda currently depends on imported petroleum products, which represent a significant cost burden. EV adoption will **reduce fuel import expenses**, improving the national trade balance. The shift to electricity (locally generated) will enhance energy security.

Increase in Electricity Generation & Investment in Infrastructure: To meet rising electricity demand, Rwanda will need significant investment in power generation, grid expansion, and charging infrastructure. This will drive economic activity in the energy sector and create jobs in renewable energy, power distribution, and EV servicing.

4.1.4.2. Transportation Sector Transformation

Public Transport Electrification: The transport sector's **electricity demand** will rise from **0.95 GWyr in 2020 to 9.31 GWyr in 2050**, suggesting an increasing number of electric buses and taxis. The decline in **motor fuel dependency** will enhance cost efficiency for public transport operators.

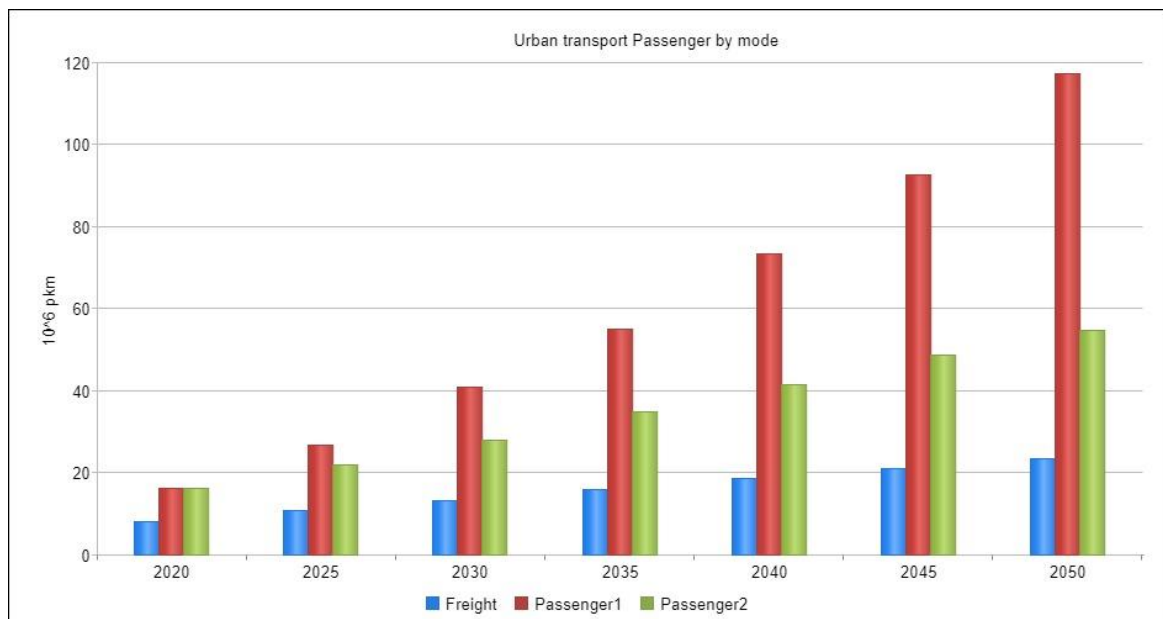


Figure 8: Urban transport Passenger by mode

Freight: Represents the transportation of goods, materials, and commodities. Includes trucks, trains, ships, and cargo planes. Energy demand is influenced by economic growth, trade, logistics infrastructure, and industrial activities.

Passenger 1: Represents public passenger transport modes. Includes buses, minibuses, trains, and possibly shared taxis. Energy consumption is based on population growth, urbanization, and policies promoting public transport.

Passenger 2: Represents private and individual passenger transport. Includes private cars, motorcycles, and other personal vehicles.

Demand is driven by income levels, urban sprawl, and preferences for private mobility. The rapid increase in energy demand for Passenger1 indicates a higher adoption of EV buses and taxis, which aligns with Rwanda's goal of electrifying public transport. This transition reduces fuel costs, improves air quality, and lowers operational expenses for transport operators.

Freight energy demand is increasing at a slower pace compared to passenger transport. While electric trucks are emerging globally, Rwanda's reliance on imports may delay widespread adoption. Policies such as tax exemptions for electric freight vehicles and investments in battery swapping infrastructure can accelerate this shift.

Economic Benefits:

Reduced Operational Costs for Transport Operators: Electric buses and taxis have **lower fueling and maintenance costs** compared to diesel or petrol vehicles. This translates into **lower fares** for passengers and improved affordability of public transport.

Job Creation and Industry Growth: New employment opportunities will emerge in **EV assembly, battery recycling, charging station management, and grid maintenance**. Growth in **local manufacturing** of EV components will stimulate industrial development.

Government Revenue and Investment Opportunities: The government can introduce **tax incentives and subsidies** to accelerate EV adoption while **generating revenue from electricity tariffs**. Foreign investments in Rwanda's EV sector are expected to increase, especially in battery technology and charging networks.

4.1.4.3. Environmental and Social Benefits

The shift to EVs will also contribute to environmental sustainability and public health:

Carbon Emission Reductions: EVs produce **zero tailpipe emissions**, significantly reducing CO₂ and particulate matter emissions. With increased electricity generation from **hydropower and solar**, Rwanda can cut its carbon footprint.

Improved Air Quality: Lower fossil fuel consumption in transport will **reduce urban air pollution**, leading to fewer respiratory diseases. This will decrease **healthcare costs** associated with pollution-related illnesses.

Energy Access and Rural Electrification: Increased electricity demand will drive investment in power generation, potentially improving **rural electrification rates**. EV charging stations could double as energy access points in remote areas.

4.1.4.4 Economic Growth and GDP Impact

As EV adoption scales up:

Productivity Gains: Lower transportation costs for businesses and individuals will **increase disposable income and economic productivity**.

EV Industry as a GDP Contributor: Manufacturing and maintenance of EVs will emerge as a new industrial sector, adding to GDP growth.

Long-Term Fiscal Benefits: While initial investments in EV infrastructure are high, **cost savings on fuel imports, health benefits, and job creation** will yield positive net economic gains.

The MAED-2 model projections highlight a strong **economic case for EV adoption in Rwanda**. The shift from fossil fuels to electricity will:

- Reduce energy import dependency.
- Enhance public transport efficiency.
- Boost job creation and industrialization.
- Improve environmental and public health outcomes.

By **2050**, Rwanda is expected to be a leader in sustainable mobility, leveraging its **hydropower and renewable energy capacity** to drive an electrified transport sector.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This chapter presents the conclusions drawn from the study findings and provides recommendations based on the economic analysis of electric vehicle (EV) adoption in Rwanda's public transport sector. The chapter also highlights policy implications and suggests areas for future research.

5.1 Summary of Key Findings

The study investigated the economic impact of adopting EVs in Rwanda's public transport sector, using the Model for Analysis of Energy Demand (MAED-2) to assess long-term projections from 2020 to 2050. The key findings are summarized as follows:

Current State of EV Adoption in Rwanda: Rwanda has made significant progress in EV adoption, with government incentives such as tax exemptions, infrastructure investment, and public-private partnerships driving growth. By 2024, Rwanda had **512 fully electric cars, 6,660 hybrid vehicles, and over 4,000 electric motorbikes** in operation. The government has also supported the sector through **rent-free land** for charging stations and a **50% reduction in electricity tariffs** for EV charging.

Economic Benefits of EV Adoption: The study found that EVs provide numerous economic benefits, including **lower operational costs (50% lower fuel and maintenance expenses compared to ICE vehicles), reduced dependency on imported fossil fuels**, and enhanced energy security. Rwanda spends approximately **\$500 million annually on fuel imports**, and widespread EV adoption could reduce this cost by **\$100 million per year by 2030**. The projected **fuel savings of 20 billion Rwandan francs (RWF) by 2025** and an estimated increase in electricity consumption by **132 GWh** will help optimize Rwanda's energy surplus utilization.

Challenges to EV Adoption: Despite the benefits, the study identified several barriers to EV adoption in Rwanda, including **high initial costs, limited charging infrastructure, inadequate financing options, and public skepticism**. The cost of an electric bus remains **50-70% higher** than that of an internal combustion engine (ICE) bus, with a typical electric bus priced at **RWF 200 million (\$170,000)** compared to **RWF 120 million (\$102,000)** for a diesel bus. To achieve cost parity, **battery prices need to decrease to below \$100 per kWh**, and electricity costs for charging should be reduced by an additional **30%**.

Long-Term Economic Impact: Using MAED-2 projections, the study estimated that widespread EV adoption would significantly **reduce Rwanda’s greenhouse gas emissions by 17%**, decrease fuel imports by **15%**, and create new employment opportunities in **vehicle manufacturing, maintenance, and charging infrastructure development**. By 2050, it is expected that **50% of public transport in Rwanda will be electrified**, leading to a **reduction of 1.2 million tons of CO2 emissions annually** and saving **\$200 million in fossil fuel imports**.

5.2 Policy Recommendations

Based on the findings, the study proposes the following policy recommendations to facilitate and accelerate EV adoption in Rwanda:

Enhancing Financial Incentives: The government should consider introducing more financial incentives, such as **subsidized loans with interest rates below 5%**, **tax credits covering 20-30% of EV purchase costs**, and **duty-free imports on EV components**. Establishing a **\$50 million green financing scheme** in collaboration with banks and development partners would make EVs more accessible to public transport operators.

Expanding Charging Infrastructure: Investments in widespread, strategically located charging stations are essential for ensuring EV viability. Rwanda currently has **fewer than 30 charging stations**, which must increase to **at least 150 stations by 2030** to support the projected EV growth. Partnerships with private sector entities should be strengthened to accelerate infrastructure expansion, targeting **at least one charging station every 10 km in urban areas**.

Reducing EV Acquisition Costs: Local manufacturing and assembly of EVs and their components should be encouraged to reduce import costs. Setting up **two EV assembly plants by 2030** could reduce the cost of electric motorcycles by **30%** and electric buses by **20%**. The government should support local businesses in developing **battery technology**, aiming for at least **40% local battery production** by 2040.

Public Awareness and Capacity Building: Educational campaigns should be conducted to inform transport operators and the general public about the economic benefits of EVs. A nationwide awareness program, backed by a **\$5 million budget**, should include **training programs for at least 1,000 mechanics and technicians** specializing in EV maintenance by 2030.

Integrating EV Policies with Energy Sector Planning: The projected increase in electricity demand due to EV adoption should be incorporated into Rwanda's national energy policy. The government should **expand renewable energy capacity by 500 MW by 2040**, ensuring that at least **80% of EV charging comes from renewable sources**.

Strengthening Policy and Regulatory Frameworks: Clear and enforceable policies on EV adoption, including **mandatory EV fleet conversion targets for public transport operators (e.g., 30% EV adoption by 2035)**, standardization of charging stations, battery disposal regulations, and incentives for research and development, should be put in place. Regular policy reviews should be conducted **every five years** to adapt to evolving technological advancements and market conditions.

5.3 Areas for Future Research

While this study has provided valuable insights into the economic implications of EV adoption in Rwanda, further research is needed in the following areas:

Comprehensive Cost-Benefit Analysis of EVs in Rwanda: Future studies should analyze the long-term financial implications of EV adoption, considering factors such as **total cost of ownership (TCO), infrastructure investments, and evolving battery costs**.

Consumer Behavior and Market Readiness: Research should be conducted to assess **public perception, willingness to adopt EVs, and key determinants influencing consumer choices in Rwanda**.

Environmental and Health Impact Assessments: Studies should focus on quantifying the **reduction in air pollution-related health issues** and associated healthcare cost savings from EV adoption.

Integration of EVs with Renewable Energy: Further research should explore the potential of **solar and hydroelectric-powered charging stations** and the feasibility of **vehicle-to-grid (V2G) technology** to enhance grid stability.

5.4 Conclusion

This study highlights the economic potential of EV adoption in Rwanda's public transport sector. While significant progress has been made, challenges remain in **affordability, infrastructure development, and policy implementation**. The study concludes that with the **right financial incentives, infrastructure investments, and policy frameworks**, Rwanda can achieve **sustainable and economically viable EV integration**. Implementing the proposed recommendations will not only promote green mobility but also contribute to the country's **Vision 2050 objectives of reducing carbon emissions, enhancing energy security, and creating new economic opportunities**.

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APPENDICES

6.1. Final Energy Demand by Energy Form, Capita, GDP and Sector(MAED-2)

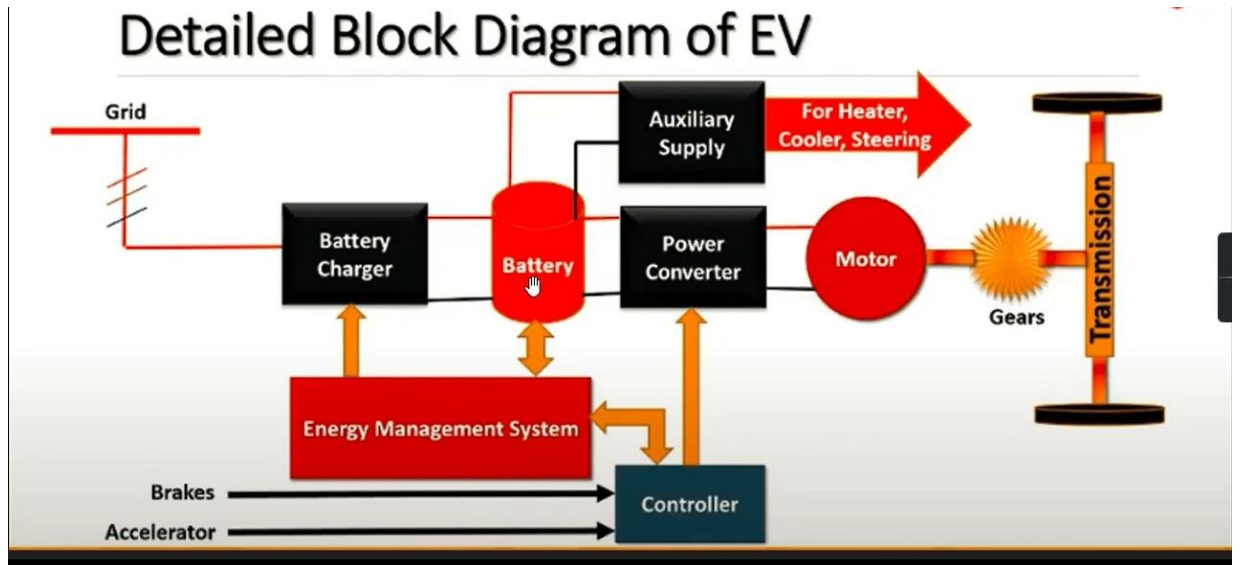
| GWyr | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|----------|----------|----------|----------|----------|-----------|-----------|
| Final Energy Demand by Energy Form | | | | | | | |
| Traditional Fuels | 683.30 | 811.28 | 1,259.96 | 1,752.69 | 1,688.91 | 1,270.94 | 975.33 |
| Modern Biomass | 260.68 | 366.80 | 647.80 | 1,226.62 | 2,110.06 | 3,808.13 | 6,813.79 |
| Electricity | 82.07 | 154.68 | 354.83 | 780.46 | 1,481.07 | 2,778.79 | 5,130.37 |
| Solar Thermal | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Fossil Fuels | 54.73 | 92.77 | 212.70 | 468.23 | 845.84 | 1,251.41 | 1,715.38 |
| Motor Fuels | 279.17 | 470.83 | 1,003.09 | 2,093.82 | 3,822.80 | 6,961.82 | 12,550.84 |
| District Heating | 0.00 | 0.03 | 0.11 | 0.58 | 1.69 | 3.81 | 8.18 |
| Coke & Steam Coal | 0.02 | 0.02 | 0.04 | 0.08 | 0.12 | 0.18 | 0.27 |
| FeedStock | 0.07 | 0.12 | 0.27 | 0.62 | 1.20 | 2.33 | 4.47 |
| Total - Final Energy Demand by Energy Form | 1,360.03 | 1,896.53 | 3,478.81 | 6,323.10 | 9,951.68 | 16,077.39 | 27,198.63 |
| Final Energy Demand per Capita & per GDP | | | | | | | |
| FE per Capita (MWh/cap) | 906.00 | 1,127.62 | 1,846.09 | 3,084.23 | 4,461.79 | 6,724.16 | 10,611.58 |
| FE per GDP (kWh/US\$) | 1,171.47 | 1,192.33 | 1,241.01 | 1,279.93 | 1,250.80 | 1,254.71 | 1,317.99 |
| Final Energy Demand by Sector | | | | | | | |
| Industry | 2.22 | 2.62 | 4.03 | 6.68 | 8.97 | 13.62 | 20.61 |
| Manufacturing | 0.74 | 0.95 | 1.67 | 3.45 | 4.98 | 8.48 | 13.96 |
| ACM | 1.48 | 1.67 | 2.35 | 3.23 | 4.00 | 5.13 | 6.65 |
| Transportation | 6.00 | 7.49 | 11.31 | 17.45 | 25.39 | 38.85 | 60.11 |
| Freig. transp. | 1.90 | 2.43 | 3.82 | 6.26 | 9.86 | 16.04 | 26.66 |
| Pass. transp | 4.10 | 5.06 | 7.49 | 11.19 | 15.53 | 22.80 | 33.46 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 1,351.81 | 1,886.43 | 3,463.47 | 6,298.97 | 9,917.31 | 16,024.93 | 27,117.91 |
| Total - Final Energy Demand by Sector | 1,360.03 | 1,896.53 | 3,478.81 | 6,323.10 | 9,951.68 | 16,077.39 | 27,198.63 |
| By Sector | | | | | | | |
| Traditional Fuels | | | | | | | |
| Industry | 1.23 | 1.26 | 1.63 | 2.00 | 2.18 | 2.39 | 2.47 |
| Manufacturing | 0.37 | 0.37 | 0.52 | 0.68 | 0.85 | 1.10 | 1.33 |
| ACM | 0.86 | 0.89 | 1.11 | 1.32 | 1.33 | 1.28 | 1.15 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 682.06 | 810.02 | 1,258.33 | 1,750.69 | 1,686.73 | 1,268.55 | 972.86 |
| Total - Traditional Fuels | 683.30 | 811.28 | 1,259.96 | 1,752.69 | 1,688.91 | 1,270.94 | 975.33 |
| Modern Biomass | | | | | | | |
| Industry | 0.25 | 0.37 | 0.66 | 1.14 | 1.66 | 2.48 | 3.75 |
| Manufacturing | 0.06 | 0.10 | 0.19 | 0.38 | 0.63 | 1.05 | 1.75 |

| | | | | | | | |
|------------------------|--------|--------|----------|----------|----------|----------|-----------|
| ACM | 0.19 | 0.27 | 0.47 | 0.76 | 1.03 | 1.43 | 2.01 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 260.42 | 366.44 | 647.14 | 1,225.48 | 2,108.41 | 3,805.65 | 6,810.03 |
| Total - Modern Biomass | 260.68 | 366.80 | 647.80 | 1,226.62 | 2,110.06 | 3,808.13 | 6,813.79 |
| Electricity | | | | | | | |
| Industry | 0.14 | 0.20 | 0.35 | 0.62 | 0.96 | 1.53 | 2.42 |
| Manufacturing | 0.05 | 0.08 | 0.16 | 0.31 | 0.50 | 0.85 | 1.42 |
| ACM | 0.09 | 0.12 | 0.20 | 0.32 | 0.46 | 0.68 | 1.00 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 81.93 | 154.48 | 354.47 | 779.83 | 1,480.10 | 2,777.26 | 5,127.96 |
| Total - Electricity | 82.07 | 154.68 | 354.83 | 780.46 | 1,481.07 | 2,778.79 | 5,130.37 |
| Solar Thermal | | | | | | | |
| Industry | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Manufacturing | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ACM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total - Solar Thermal | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Fossil Fuels | | | | | | | |
| Industry | 0.16 | 0.17 | 0.22 | 0.73 | 0.58 | 1.09 | 1.56 |
| Manufacturing | 0.04 | 0.07 | 0.12 | 0.66 | 0.49 | 0.96 | 1.39 |
| ACM | 0.12 | 0.11 | 0.10 | 0.07 | 0.09 | 0.13 | 0.17 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 54.57 | 92.60 | 212.48 | 467.50 | 845.26 | 1,250.32 | 1,713.82 |
| Total - Fossil Fuels | 54.73 | 92.77 | 212.70 | 468.23 | 845.84 | 1,251.41 | 1,715.38 |
| Motor Fuels | | | | | | | |
| Industry | 0.34 | 0.48 | 0.85 | 1.48 | 2.28 | 3.62 | 5.67 |
| Manufacturing | 0.13 | 0.19 | 0.37 | 0.73 | 1.19 | 2.01 | 3.34 |
| ACM | 0.22 | 0.29 | 0.48 | 0.76 | 1.08 | 1.61 | 2.32 |
| Transportation | 6.00 | 7.48 | 11.31 | 17.45 | 25.39 | 38.84 | 60.11 |
| Freig. transp. | 1.90 | 2.43 | 3.82 | 6.26 | 9.86 | 16.04 | 26.66 |
| Pass. transp | 4.10 | 5.06 | 7.49 | 11.19 | 15.53 | 22.80 | 33.45 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 272.83 | 462.87 | 990.93 | 2,074.89 | 3,795.13 | 6,919.36 | 12,485.06 |
| Total - Motor Fuels | 279.17 | 470.83 | 1,003.09 | 2,093.82 | 3,822.80 | 6,961.82 | 12,550.84 |
| District Heating | | | | | | | |

| | | | | | | | |
|---------------------------|------|------|------|------|------|------|------|
| Industry | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Manufacturing | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ACM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 0.00 | 0.03 | 0.11 | 0.58 | 1.69 | 3.81 | 8.17 |
| Total - District Heating | 0.00 | 0.03 | 0.11 | 0.58 | 1.69 | 3.81 | 8.18 |
| Coke & Steam Coal | | | | | | | |
| Industry | 0.02 | 0.02 | 0.04 | 0.08 | 0.12 | 0.18 | 0.27 |
| Manufacturing | 0.02 | 0.02 | 0.04 | 0.08 | 0.12 | 0.18 | 0.27 |
| ACM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total - Coke & Steam Coal | 0.02 | 0.02 | 0.04 | 0.08 | 0.12 | 0.18 | 0.27 |
| FeedStock | | | | | | | |
| Industry | 0.07 | 0.12 | 0.27 | 0.62 | 1.20 | 2.33 | 4.47 |
| Manufacturing | 0.07 | 0.12 | 0.27 | 0.62 | 1.20 | 2.33 | 4.47 |
| ACM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transportation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Freig. transp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pass. transp | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Household | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Service | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total – FeedStock | 0.07 | 0.12 | 0.27 | 0.62 | 1.20 | 2.33 | 4.47 |

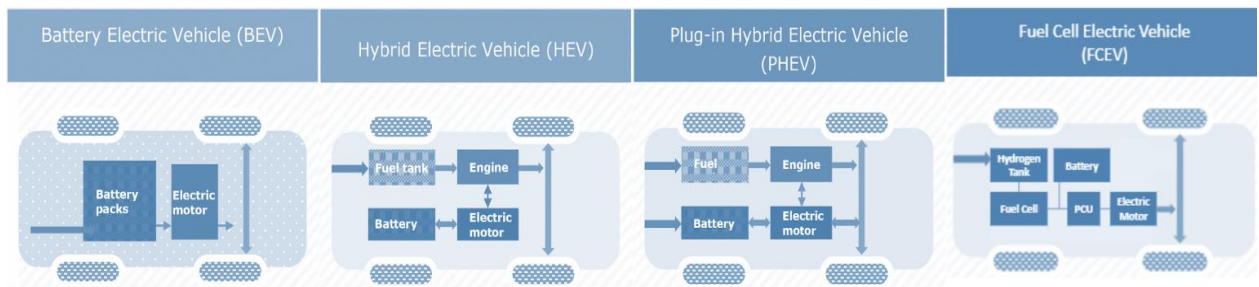
Figure 9: 6.1. Final Energy Demand by Energy Form, Capita, GDP and Sector

Figure 10 Detailed Block Diagram of Electric Vehicle



Source: Slides by GIRISH.C et al (2021)

Figure 11 Types of Electric Vehicles and their characteristics(NITI Aayog 2025)



Source: (NITI Aayog 2025)