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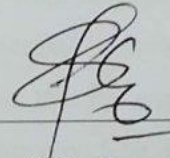
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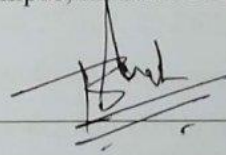
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The undersigned certify that they have read and recommended to the Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering for acceptance, a dissertation entitled “**Emission Assessment of Ground Support Equipment at Tribhuvan International Airport and Techno-Economic Comparison of ICE and Electric GSE**”, submitted by Rajesh Thapa in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

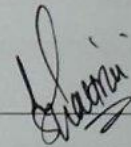


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## ABSTRACT

At Tribhuvan International Airport, Ground Support Equipment (GSE) currently operates on diesel fuel significantly contributing to greenhouse gas emissions due to the increased operations growth and consequently fuel consumption. The study assesses the emissions from the GSE operating at the international apron at TIA and conduct the comparative techno-economic study of internal combustion engine (ICE) and electric GSE. Emissions of the major pollutant's NO<sub>x</sub>+ HC, CO, PM and CO<sub>2</sub> were estimated using three different approaches: Primary Simple Approach, Secondary Simple Approach and Advanced Approach based on the aircraft movements, fuel consumption, equipment operational usage and characteristics. The estimated data from 2019-2024 were analyzed and future emissions up to 2030 were projected using two different forecasting methods: Linear Regression and Holt's Damped Trend Method. The results show that the emissions went down from 2020 to 2021 due to decrease in airport operations from covid-19 pandemic and sharply increased after 2022 with the CO<sub>2</sub> identified as dominant pollutant. Under business-as-usual conditions, by 2030 NO<sub>x</sub>+ HC, CO, PM and CO<sub>2</sub> could reach 20.693, 21.130, 1.442, 1512.538 metric tons under linear regression and 25.323, 25.865, 1.765, 1173.660 metric tons under Holt's Damped Trend methods respectively. Baggage tractors, airport shuttle buses, conveyor belts, tows trucks, passenger stairs and GPUs contribute almost 80% of total emissions, indicating where the electrification should be prioritized. And the scenario analysis with 10 % & 20% of electric GSE by 2026 show reduce in the emission trends though not sufficient for the absolute reduction. And the comparative study of technical specifications shows that the operational performance is comparable between ICE and electric GSE. Although the electric GSE has higher initial capital costs, government policy like tax subsidy on electric GSE significantly improve the economic viability of electric GSE. The study suggests the targeted emission control interventions with implementation of electric GSE and supportive government policies on electric GSE to ensure the economic viability.

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## LIST OF SYMBOLS

%	Percentage
$y_t$	Emission level at time 't' (Metric tons)
$\beta_0$	Intercept (Baseline Emission Level)
$\beta_1$	Slope Coefficient Representing the Rate of Change of Emissions
$\phi$	Damping parameter

## LIST OF ABBREVIATIONS

TIA	Tribhuvan International Airport
GSE	Ground Support Equipment
eGSE	Electric Ground Support Equipment
GPU	Ground Power Unit
ACU	Air Conditioning Unit
ASU	Air Starter Unit
ICAO	International Civil Aviation Authority
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
APU	Auxiliary Power Unit
ICE	Internal Combustion Engine
NO <sub>x</sub>	Nitrous Oxide
CO <sub>2</sub>	Carbon Dioxide
PM	Particulate Matter
LAX	Los Angeles International Airport
NAC	Nepal Airlines Corporation
CAAN	Civil Aviation Authority of Nepal

## CHAPTER ONE: INTRODUCTION

### 1.1 Background

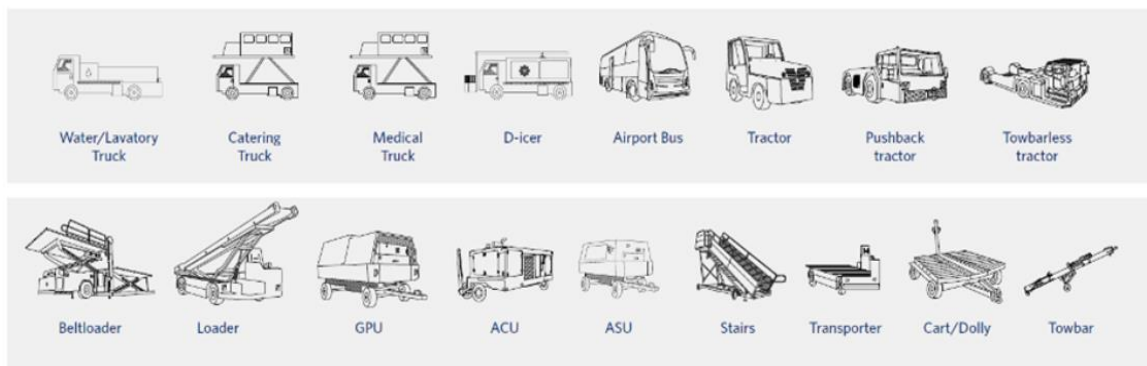
The aviation industry is a greatly interconnected and complex system that plays a important role in global transportation, economic growth and development and human mobility. It has become a important part of modern life making the world feel smaller and more connected. It helps people and goods move around the world quickly. This makes it easier for the people to involve in business, tourism, cultural exchange, education, communication etc. that would have been difficult or impossible to access in the past. It was expected to reach 9.5 billion passengers using air transport in 2024 marking 10% increase from 2023 and forecasted to exceed 12 billion by 2030. This is because of the strong growth in international markets (Annual World Airport Traffic Report, 2024) which shows that importance of the air transport in our daily lives.

On aviation industry, while much of the public's attention is typically focused on aircraft themselves that fly across the world, the less noticeable but equally essential components of airport operations take place on the ground. The effectiveness of aviation industry relies heavily on both the aircraft and the ground-based operations. Aircraft are the primary means of travel while the ground-based operations ensures that aircraft are properly maintained, loaded and ready for take-off. These ground-based operations include a wide range of services including aircraft maintenance, fuelling, passenger boarding and disembarking, catering, cargo and baggage handling, aircraft towing and taxing, lavatory servicing, potable water and many more. The equipment used to accomplish these functions is collectively known as ground support equipment and is the backbone of airport operations in modern days.

According to the definition of Wikipedia (The Free Encyclopaedia), Ground Support Equipment (GSE) is the support equipment found at an airport, usually on the apron, the servicing area by the terminal, used to service the aircraft between flights. As the name suggests, ground support equipment is there to support the operations of aircraft whilst on the ground and the role of this equipment generally involves ground power operations, aircraft mobility and cargo/passenger loading operations (Wikipedia contributors, n.d.).

Ground Support Equipment (GSE) refers to the various types of devices, vehicles, tools and machinery used at airports to service aircraft while they are on the ground and support aircraft operations between flights. The various types of ground support equipment's are as follows;

- a) Aircraft Pushback Tugs & Tractor
- b) Airport Passengers Bus
- c) Baggage Carts & Tractors, Conveyor Belt Loader/Unloader
- d) Step-Ladders/Stairs
- e) Water Service Trucks
- f) Lavatory Service Vehicles
- g) Catering Trucks
- h) Medical Trucks
- i) Aircraft Deicing Vehicles
- j) Ground Power Unit (GPU)
- k) Air Starter Unit (ASU)
- l) Air Conditioning Unit (ACU) etc.



**Figure 1.1:** Different Types of GSE

Ground support equipment (GSE) is essential for the efficiency, safety, and punctuality of air travel. When GSE operates properly, it enables rapid and safe turnaround of aircraft, reducing delays and ensuring both passenger comfort and safety. The reliability and availability of GSE are essential for an airport's overall operational efficiency. GSE's main roles at airports involve the efficient servicing, maintenance, and preparation of aircraft

while they are on the ground, which is vital for the safe and timely execution of flights. The key functions of GSE include:

- i. Aircraft mobility and Operations
- ii. Cargo and Passenger Handling
- iii. Aircraft servicing
- iv. Ground Power Service
- v. Safety and Emergency operations

These functions are essential for minimizing downtime so that GSE operator can ensure safety and keeping flights on schedule. Ground support equipment ensures that all necessary ground operations are completed on time and efficiently helping the aviation industry to operate smoothly. Without Ground Support Equipment (GSE), aircraft would be unable to depart, arrive or even remain on the ground safely and efficiently. As air transport and travel increase rapidly in volume and complexity, the demand for reliable and advanced GSE has increased directly in parallel.

The aviation industry helps the world economy a lot. It supports trade, tourism, communication, connectivity etc. and provides millions of jobs across the various sectors. However, alongside its economic and other various benefits, the industry also poses significant environmental challenges particularly in relation to climate change. Among the various sectors and sources within the aviation industry for climate change and environmental pollution, Ground support equipment (GSE) is one the prominent contributing factors but people often do not think about it and is a substantial contributor to the aviation related environmental effects. The majority of traditional GSE are powered by diesel or gasoline engines which are the major sources of local air pollution and carbon emissions. The combustion of fossil fuels in GSE releases harmful pollutants such as nitrogen oxides (NO<sub>x</sub>), particulate matter (PM) and carbon dioxide (CO<sub>2</sub>) which degrade global and local air quality and contribute to climate change. The density of these pollutants around airport environment causes serious health risks to the ground crew, airport staff and surrounding residential communities. The long term and continuous exposure can lead to respiratory diseases, cardiovascular problems and other health's issues, raising public health concerns and increasing the healthcare costs. Also, the GSE contributes to the

aviation sector's overall greenhouse gas emissions further increasing the overall impact on global climate. As the increase in the global awareness of environmental issues, the aviation industry is under a lot of pressure and critical observation to reduce its overall contribution to climate change. This pressure is driven by international climate commitments like the Paris Agreement which aims to limit the global warming to well below 2°C and by the regulatory frameworks like the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and ICAO Net Zero Carbon Emissions by 2050 for International Civil Aviation. These initiatives make airlines and airports adopt eco-friendly and use of the GSE type that is better for the environment, including reducing emissions from the ground operations.

In response to growing environmental issues and global warming from the greenhouses gases from the aviation industry, there is a growing global push towards sustainability and eco-friendly across all aspects of airport operations, particularly through the adoption of electric Ground Support Equipment (GSE). In the aviation industry, various sectors such as ground operations, aircraft operations, airport services etc. contribute to greenhouse gas emissions and as one of the quickest and most effective actions that we can take is to adopt electric equipment for ground operations or use fixed electrical power supplied from the grid. Electric Ground Support Equipment (GSE) refers to the various types of equipment used at airports to service and support aircraft, powered by rechargeable batteries whereas the conventional GSE rely on internal combustion engines. These batteries can be recharged using grid electricity or renewable energy sources such as solar, wind etc. making Electric GSE an eco-friendly alternative to traditional fuel-powered equipment. This fundamental and proper shift in energy use offers a more efficient and environmentally friendly solution to the operational and increased service demands of modern airports. The environmental advantages of electric Ground Support Equipment are significant and tangible. The first and foremost electric GSE produces zero tailpipe emissions, extensively reducing the release of the harmful pollutants such as carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO) and particulate matter (PM). This ultimately contributes to the improved and freshness of the air quality within the

airport's environment. And this is most important in areas with high volumes of ground traffic and close proximity to residential areas and urban populations. In addition to reducing emissions, electric GSE reduces noise pollution as it produces very small sounds in comparison to conventional Ground Support Equipment powered by internal combustion engines, creating a quieter and safer working environment for the ground crews and enhancing the overall passenger experiences at the airports. From an operational side, electric GSE also offers significant long-term benefits. These include lower operating costs as electricity is usually cheaper than the diesel or gasoline fuel and decreased in the maintenance due to less moving parts in electric GSE than internal combustion engine GSE. Over time these savings can cover the initial investment making an electric Ground Support Equipment an economically possible option for many airports. However, the transition to the electric Ground Support Equipment presents several logistical and financial challenges. Airports have to invest not only in the buying of new electric equipment but also in the development of adequate charging infrastructure. This includes the installation of more charging stations to keep operation smoothly and making the airport's electric grid better to handle the power needs. Even though there are some problems, the long-term benefits of using electric Ground Support Equipment are clear and significant. The adoption of it is an important step towards making airport operations more sustainable, efficient and environmentally friendly.

## **1.2 Problem Statement**

At Tribhuvan International Airport in Nepal the ground support equipment (GSE) is currently powered by fossil fuels. The use of these fossil fuel based GSE contributes a significant amount of greenhouse gases along with aircraft engines and Auxiliary Power Units (APU). This dependence on fossil fuels is degrading the air quality at the airport and is having a negative impact on the health of people living and working around it. Additionally, the noise generated by these GSE contribute to excessive noise pollution which poses risks to human health and disrupts local ecosystems. And the measurement of the emissions from the usage of existing ICE Ground Support Equipment (GSE) is one of the foremost initiations and easiest way to move ahead for the emissions control from aviation sector. Nepal's heavy reliance on imported fossil fuels mainly from India, is also

one of the weaknesses because any disruption in supply like economic blockade could affect airport operations and impact on the economy. Also, this dependence causes a lot of outflows of capital to buy these fuels. In contrast, Nepal has huge untapped renewable energy resources particularly in hydropower & solar that could be used to power electric GSE. The transitioning to electric GSE would not only reduce greenhouse gas emissions and noise pollution but also make Nepal's energy security better by reducing dependence on imported fossil fuels. This change would result in long-term economic benefits by lower operating and maintenance costs which would make the aviation industry more sustainable and stronger. Similarly, as the member states of ICAO and signatories state to the Paris agreement, it is our duty to take initiatives toward the adoption and promotion of clean energy and emissions controlling measures. Given these factors, the implementation of electric GSE at Tribhuvan International Airport is a long overdue but necessary step towards improving Nepal's environmental quality, public health and economic stability.

### **1.3 Significance of the Study**

The significance of the study includes several key aspects which are as follows;

#### **1.3.1 Environmental Impact and Sustainability**

**Reduction of Carbon Emissions:** Implementing electric ground support equipment (GSE) could significantly reduce greenhouse gas emissions at the airport, contributing to Nepal's environmental sustainability goals.

**Compliance with Global Standards:** Airports worldwide are transitioning to greener operations. The study could help Tribhuvan International Airport align with global environmental standards, possibly attracting more international airlines and passengers.

#### **1.3.2 Economic Feasibility**

**Capital Cost Analysis:** The study would assess the capital cost of both the ICE and electric GSE and cost ratio analysis between them to identify the economic viability of electric GSE in comparison to internal combustion engine GSE.

Operational Efficiency: Electric GSE may offer lower maintenance costs and improved efficiency compared to traditional equipment, leading to potential cost savings and increased operational efficiency.

### **1.3.3 Technical Feasibility**

Infrastructure Requirements: The study would explore the technical requirements for implementing electric GSE, such as the need for charging stations, power supply etc.

Equipment Performance: Comparative evaluation between the ICE and electric GSE on operational characteristics, performance and adaptability of electric GSE in the specific conditions of Tribhuvan International Airport is crucial for determining their feasibility.

### **1.3.4 Policy and Regulatory Implications**

Government Support: The study could influence government policies and regulations regarding the adoption of sustainable technologies in Nepal's aviation sector, potentially leading to incentives or subsidies.

Compliance with Aviation Regulations: Ensuring that the implementation of electric GSE complies with both national and international aviation regulations would be a critical aspect of the study.

### **1.3.5 Social and Health Benefits**

Improved Air Quality: Reducing the use of diesel-powered GSE can lead to improved air quality in and around the airport, benefiting airport workers and nearby communities.

Noise Reduction: Electric GSE typically produces less noise than traditional equipment, leading to a quieter airport environment.

### **1.3.6 Potential Challenges and Solutions**

Identifying Barriers: The study would identify potential challenges in implementing electric GSE, such as high upfront costs or technological limitations, and possible solutions to address these issues.

## **1.4 Objectives**

### **1.4.1 Main Objective**

The main objective of the study is to assess the emissions produced by Ground Support Equipment (GSE) at Tribhuvan International Airport (TIA) and perform a techno-economic comparative study between ICE & electric GSE.

### **1.4.2 Specific Objectives**

The specific objectives of the study are as follows:

- To estimate the emissions generated by GSE operating at TIA using different emission estimation approaches.
- To evaluate the technical specification and performance characteristics of ICE and electric GSE.
- To compare the capital cost and Policy impact of Tax subsidy and conduct economic analysis for the Charging station set up at TIA.
- To identify the benefits, challenges, and risks associated with eGSE implementation.

## **1.5 Limitations**

The following could be the study's potential limitations:

- a. Insufficient historical data on GSE usage or electricity consumption may affect the estimation and forecasting methods of the emissions.
- b. The study and analysis of the GSE of Nepal Airlines Corporation may not give whole figure of TIA though NAC provide the Ground handling support to all the international movement as this study didn't include the domestic movement and respective domestic operator GSE categories.
- c. Initial capital costs study and analysis of the GSE may not reflect the overall economic analysis for the implementation of the electric GSE instead of diesel-powered Ground Support Equipment.
- d. Lack of maintenance costs, fuel cost, operational cost, of electric and diesel powered GSE and electric GSE restricted the depth of the analysis and study.

## CHAPTER TWO: LITERATURE REVIEW

### 2.1 Previous Research

The report about “LAX Extremely Low Emission Technology Ground Support Equipment Feasibility Study” (Smith, 2015) looked at the possibility of using electric Ground Support Equipment at Los Angeles International Airport (LAX) to minimize emissions. The study identified that 37% of the existing GSE fleet is electric, while 16% operates on low emission fuels like LPG and CNG. Increasing electric GSE adoption could help LAX to achieve its goal of limiting fleet-wide emissions to 2.65 grams per brake-horsepower hour (gm/bhp-hr) for hydrocarbon (HC) and nitrogen oxides (NO<sub>x</sub>) but this transition requires significant investments on infrastructure, estimated at up to \$18.6 million for charging stations. Although electric GSE has higher initial costs (8-23% more than diesel) lowering operating expenses make it cost effective in long term run. The study recommends engaging stakeholders, implementing a performance-based GSE policy, expanding charging infrastructure, identifying alternative fuels and adopting a phased approach, prioritizing equipment that already has electric options. While electric GSE is not a complete solution, a good & strategic combination of electrification, alternative fuels and clean diesel technologies is necessary to meet LAX’s emissions reduction targets.

The Electrification of Baggage Tractor Fleet Report (Lammers , Gorke, & Khalil ) evaluates the feasibility of transitioning Delta Air Lines baggage tractor fleet at Hartsfield Jackson Atlanta International Airport (ATL) from internal combustion to electric powered. Delta operates 1028 baggage tractors at ATL with 831 still powered by internal combustion engines emitting approximately 27 million kg of CO<sub>2</sub> annually. Complete electrification would make a huge difference. It would reduce emissions to 1 million kg of CO<sub>2</sub> per year achieving a net reduction of 1.7 million kg. The project requires a high initial investment due to costs for buying electric chargers and change the vehicles to electric with an estimated payback period of 13 years. The transition of ICE to electric tractor would reduce the substantial fuel consumption reducing the annual fuel cost from \$7.5 million to \$0.47 million. In order to improve the feasibility, the report suggests prioritizing the 62 oldest, highest emitting tractors which contribute more to fleet emissions. Additionally, transition

of other IC ground support equipment such as belt loaders could optimize costs. The phased implementation strategy proper investment and maximized long term sustainability benefits aligning with Delta's border carbon reduction goals.

(Sari, Mohamed, & Jalil, 2022) In research study "The Optimization Using Electric Ground Support Equipment in Aviation Industry" carried out a cost-benefit analysis to compare the use of electric ground support equipment (eGSE) with traditional diesel-powered equipment. The analysis found that both electric and diesel-powered GSE are feasible investments with a Net Present Value (NPV) greater than zero which indicates the economical profitability. But when considering a 25 years lifespan the diesel-powered GSE was found to be more profitable than electric GSE. The paper concludes that electric GSE is a good possible option and aligns with environmental goals while the diesel GSE offers a higher financial return over a longer period. This finding concludes that the economic benefits of diesel GSE in long-term investments despite the environmental benefits and sustainability associated with electric alternatives.

(Morrow, Hochard, & Francfort, 2007) The study called "Cost Benefit Analysis Modeling Tool for Electric vs ICE Airport Ground Support Equipment-Development and Results" looked at the financial and environmental impacts of using electric ground support equipment (eGSE) in comparison to old internal combustion engine (ICE) powered GSE at airports. The study had focused on three main types of ground support equipment (GSE) Baggage Tractors, Belt Loaders and Pushback Tractors across the four US airports. The analysis carried out a detailed evaluation of the costs including capital cost, operating, maintenance and infrastructure expenses of both eGSE and ICE GSE. Additionally, the report consists an emissions module that estimates the reductions in emissions when replacing ICE GSE with eGSE. The results show that the financial benefits of eGSE largely depends on the rate of fuel escalation and the specific usage of the patterns of the equipment at different airports. Baggage Tractors and Belt Loaders generally have less payback period due to their higher fuel consumption whereas the Pushback Tractors have a longer payback period due to their higher initial costs and lower fuel consumption. However, if the cost of pushback tractors is shared or if they are converted to electric, they can be cost effective. The emissions analysis indicates that the significant reductions in pollutants like Carbon

Monoxide, hydrocarbons, nitrogen oxides and particulate matter with the adoption of eGSE. In general, the study provides depth information and tools for airlines and industry stake holders to assess the cost effectiveness and environmental benefits of transitioning to electric GSE.

A research article from Electric Power Research Institute EPRI, “Airport Electrification Strategy at the Los Angeles International Airport” (Institute, Rogers, Starcrest, & Bishop, 2008) found that Ground Support Equipment (GSE) provides many advantages including easier maintenance, greater reliability and significantly lower operating costs with electric baggage tractors costing less than \$9.00 per day compared to over \$20 for internal combustion GSE. Additionally, electric GSE operates quietly and produces no emissions and enhances safety. While battery limitations and charging downtime were problems earlier, fast charging technology has expanded their use in airports. LAX is a leader in GSE electrification with seven airlines already using electric equipment contributing to reduced emissions and cost savings. However, to achieve near-zero emissions renewable energy sources like solar, wind or wave power should be integrated into powering electric GSE at LAX.

The report “the Business Case for Electric GSE” (Sustainable Transport Solutions (STS), 2013) assesses the financial possibility of transforming from diesel to electric ground support equipment (GSE) at Heathrow Airport. The study focuses on four types of GSE Hi-Loaders, Mobile steps, Belt loaders and Aircraft tractors using whole life cost (WLC) methodology. The main cost components considered were capital expenses, operating costs, battery replacements and charging infrastructure. Two fuel price condition were evaluated to find cost effectiveness under different market conditions. The findings indicate that the electric GSE has the potential to make cost savings but the financial benefits vary depending on vehicle type and usage. The high consumption equipment like aircraft tractors and hi-loaders show a strong economic possibility for electrification. Electric aircraft tractors for instance, can achieve payback within 2 to 4 years with potential lifetime savings of up to £140,000. Similarly, electric hi-loaders become the cost effective after 8 years particularly when diesel prices are high. However smaller GSE such as mobile steps and belt loader face challenges due to their higher initial capital costs. The extra

expenses of chargers and battery replacements often exceed fuel savings making diesel a more economical viable unless the equipment operates at significantly high usage levels. The reports point that the financial viability of electric GSE is affected by factors such as operating hours, fuel costs and battery life. The Cost effectiveness could be improved with the extending battery life and utilizing shared infrastructure. Electric GSE can offer environmental benefits but the choice to invest should be based on the specific needs. The report indicates that the electrification of bigger and high usage GSE can give good capital returns. However, for the smaller equipment and expensive one, extra subsidies or further technological improvements could improve the economic conditions.

The Ground Support Equipment Emissions Policy (2019) at Los Angeles International Airport (LAX) setups a framework for reducing emissions from ground support Equipment (GSE) to meet stringent air quality goals. The policy sets a mission of reducing fleet wide GSE emissions to 1.8 grams per horsepower-hour of hydrocarbons (HC) and nitrogen oxides (NO<sub>x</sub>) by 2022 and further down to 1.0 g/hp-h by 2030. The GSE operators should provide annual reports on their emissions and develop action plan to achieve GSE emission reducing targets and develop action plans if interim targets are not met. Los Angeles World Airport (LAWA), in collaboration with GSE operators will oversee compliance through reporting mechanisms that is aligned with California Air Resources Board (CARB) regulations. Also, the policy encourages the adoption of alternative fuel technologies such as electric and hydrogen powered GSE by evaluating resources and infrastructure needs and facilitating the installation of charging station. In order to support these efforts, LAWA has initiated the LAX electric Ground Support Equipment incentive program which provides financial assistance to accelerate the transition to zero emission GSE. The policy focuses collaboration between LAWA and GSE operators recognizing that future air quality regulations may necessitate further emissions reductions. From this approach, LAX aims to significantly cut emissions and promote sustainable airport operations. (Ground Support Equipment Emissions Policy , 2019).

(Acharya & Bhattarai, 2021) The study examines greenhouse gas emissions from aircraft and Ground Support Equipment (GSE) at Tribhuvan International Airport (TIA) in Nepal. This study was done over three years from 2016 to 2018. The research was mainly focused

on emissions of carbon dioxide (CO<sub>2</sub>) indicating an increasing trend with emissions increasing from the 56.55 kilotons in 2016 to 71.86 kilotons in 2018. Emissions were calculated using the total movement of aircraft (landing and take-off (LTO) cycle) data and fuel consumption records for GSE with validation showing a minimum discrepancy of 2.59%. The study forecasts CO<sub>2</sub> emissions up to 2030 using time series analysis and regression analysis which predicted that the significant increases of greenhouse gases in future. Among various aircraft categories, Twin Medium Helicopter and Regional Jet aircrafts were the largest contributors to CO<sub>2</sub> emissions. Similarly, the international aircraft were identified as the highest emitters with the helicopters and emissions from GSE identified as least. GSE emissions particularly from Ramp buses and Baggage Tow Tractors showed significant contributions. The study recommended emission reduction scenarios such as replacing diesel powered GSE with electric ones and constructing an aerobridge predicting an 80% reduction in CO<sub>2</sub> emissions if these measures are implemented. Overall, the study presents the growing environmental impact of aviation at TIA and highlights the key strategies to mitigate the future emissions.

The transition to electric Ground Support Equipment was evaluated through the operational optimization, energy management, cost analysis and environmental assessment. (Timmerman, Rolin, Mouli, & Atasoy, 2024) developed a Mixed Integer Linear Programming (MILP) based task scheduling problem model to estimate the fleet size, charging demand, electricity consumption and scheduling of operational requirements for electric GSE at airports. The operations of KLM at Amsterdam Airport Schiphol were used and the study found that the many smaller and some larger types of GSE can operate for full day on a single charge if night charging is available at airports with night curfews. However, the GSE categories with higher demand such as water trucks, may require charging during day or big fleet sizes to maintain the operations. The study also focused that the operational practices such as parking equipment near aircraft stands between the operations can significantly reduce the energy uses and travel distance.

The implementation and adoption of the electric GSE is technically easy but requires careful planning. Airports must evaluate fleet size, charging requirements, power demand, operational schedules, parking locations and local grid capacity before the implementation.

The recent study indicates that the successful electrification depends on the proper charging infrastructure, smart charging schedules and sufficient electrical capacity within the airport premises. Studies also show that the integration of the renewable energy sources as the solar photovoltaic systems can further enhance the financial viability of the electric GSE operations (Yi He, 2026).

Although the high initial capital investment for the electric Ground Support Equipment (GSE) and charging stations the long-term operational benefits are significant. Electric GSE usually less costly to operate, has fewer moving parts that need to be serviced and lasts longer. The transition can be made even more economically viable by public incentives, government subsidies and airport sustainability programs. Hence the electric GSE is increasingly seen as a feasible and necessary way for the airports to reduce the emissions, develop and modernize the ground operations (European Alternative Fuels Observatory, n.d.).

## **2.2 Growing Global Momentum Toward Airport Electric GSE Transition**

Several leading airports and ground services provider have already begun and are accelerating the transition from the traditional internal combustion engines GSE to electric GSE. This showing a major shift in the aviation industry's approach for sustainability and operational efficiency. Mainly this is driven by the combination of environmental goals, long term financial advantages, regulatory pressure, the transition to electric GSE, setting an example for others in the industry. Electric GSE can reduce carbon dioxide emissions by approximately 35% - 52% and reduce the noise emissions by about 5.5 db(A) – 8.3db (A) per aircraft turnaround compared to traditional diesel Ground Support Equipment (International Air Transport Association (IATA), n.d.).

Swissport International, a leading global provider of aviation ground services is increasing the electrification of its Ground Support Equipment (GSE) fleet as part of its carbon reduction commitments and sustainable goals. It had committed that from the beginning in January 2025, would mandate that many categories of newly purchased GSE such as baggage tractors, conveyor belt loaders, passenger stairs, forklifts and service vehicles be ordered exclusively in electric variants with the goal of procuring only electric units by 2027 where feasible. This policy supports Swissport's target of achieving 55 % electric

GSE by 2032 and aligns with its planned investment of over one billion euros in electric GSE over the next decade. Approximately 14,300 units of fleet of GSE of Swissport have been providing the services around the various airports of Europe so it emphasizes the electrification of its fleet for operational reliability, safety, sustainability, reducing noise and emissions. It has already started several major airports like Zurich, Amsterdam Schiphol, Frankfurt etc. (Swissport International AG, 2024). As of mid-2025, the Swissport says that the roughly 25% of its global motorized GSE fleet is electric and having deployed over 1000 hybrid/electric units across dozens of countries (Swissport, 2025).

## **CHAPTER THREE: RESEARCH METHODOLOGY**

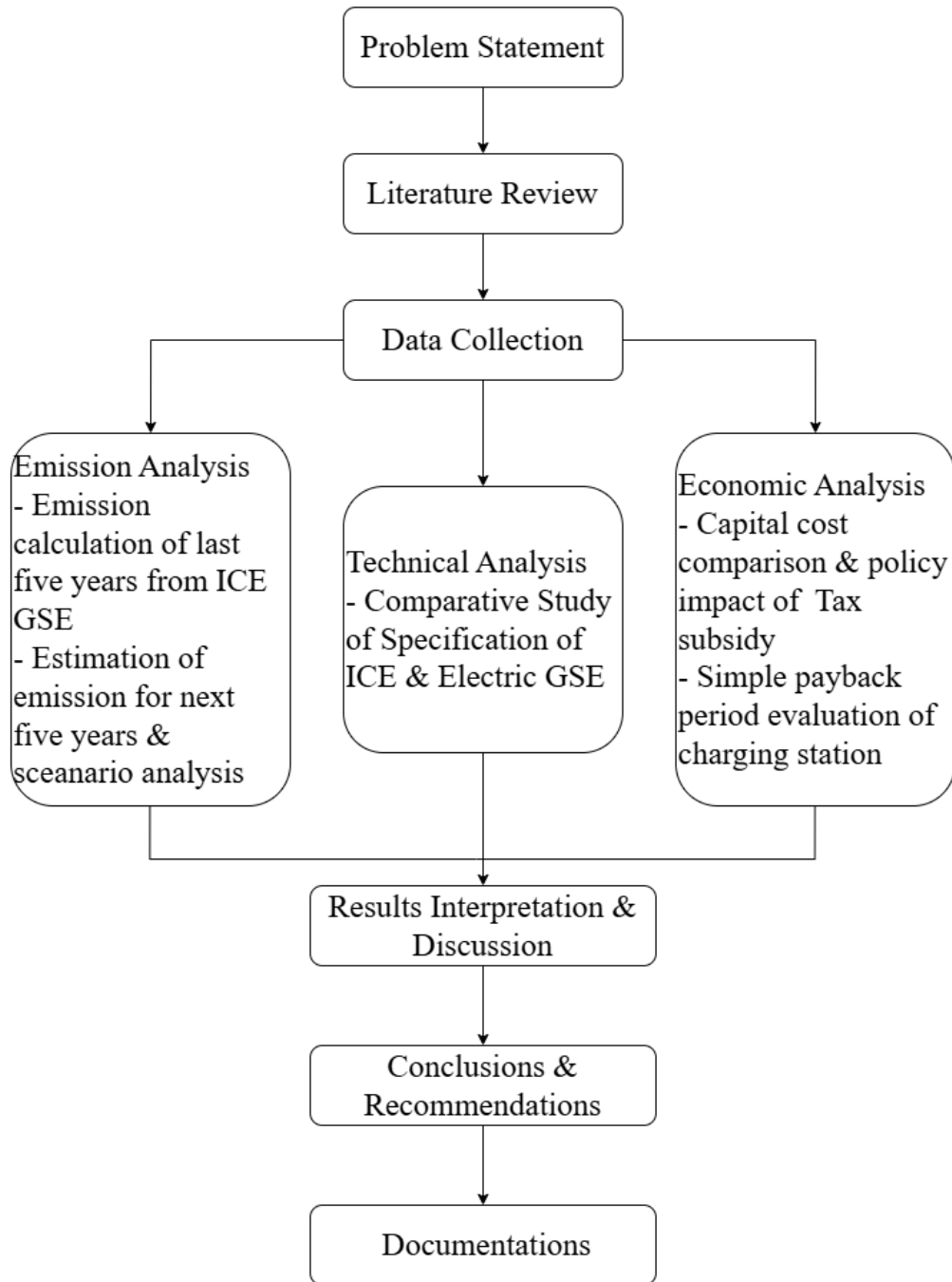
This chapter research methodology outlines the principles, techniques and procedures to assess, collect, analyze, and interpret data and provide the methodological framework for conducting emission analysis of existing ICE GSE at international apron of Tribhuvan International Airport (TIA) and the technical, economic comparative study of ICE & electric GSE. The methodology is adopted to systematically investigate the present use of GSE at TIA, comparative analysis of specification of ICE & electric GSE available in the market, cost evaluation and emission analysis of the existing ICE GSE and develop the evidence-based recommendations for potential implementation and actions. The research approach integrated the quantitative analysis, comparative assessment, forecasting modelling based on the past authentic and verifiable data sources.

### **3.1 Research Design**

This study adopts a quantitative, analytical and comparative research design to evaluate emissions from Ground Support Equipment (GSE) operating at the international ramp of Tribhuvan International Airport and to conduct a techno-economic comparative study of Internal Combustion Engine (ICE) and Electric GSE. A descriptive approach is used to document the existing GSE inventory, operational conditions, and fuel or energy consumption characteristics at the airport. An analytical and comparative approach is applied to examine the technical specifications of ICE and electric GSE and to perform an economic evaluation of both technologies. The study also includes the calculation of the simple payback period of operating charging stations in Nepal as a reference to support recommendations for establishing charging infrastructure at the airport. Also, forecasting methods are used to estimate future emissions based on calculated past emission data. The integration of these approaches enables a detailed assessment of environmental impacts and the techno-economic comparative study of transitioning from ICE-based GSE to electric alternatives.

### 3.2 Research Framework

The methodological framework for the study is illustrated below in the flowchart:



**Figure 3.1:** Flowchart for Methodology

### **3.3 Data Collection Methods**

The data for this study were collected using both primary and secondary sources to assure reliable technical, operational and economic information for the emission assessment of GSE used at TIA and techno-economic comparison of ICE and electric Ground Support Equipment (GSE).

#### **3.3.1 Primary Data**

The primary data for the study were collected and organized through field observations, stakeholder interviews and direct information requests related to Ground Support Equipment (GSE) operations and charging infrastructure.

Field observations were done at the Nepal Airlines Corporation (NAC) at Tribhuvan International Airport to identify the number, types, fuel categories and operational characteristics of Ground Support Equipment currently in use. Since the ground handling services at the airport are provided by the Ground Support Department of Nepal Airlines Corporation observations focused on obtaining and documenting the available GSE fleet, including their operational roles, fuel types (diesel or gasoline) and general usage patterns within the international ramp area. Interviews were held with staff from the Ground Support Department, maintenance personnel of Nepal Airlines Corporation to obtain detailed information regarding the existing GSE fleet. These interviews gave a detailed information on equipment availability, usage hours, fuel consumption patterns, maintenance practices, procedures and equipment utilization in daily airport ground operations.

In addition, charging station site visit and interviews were conducted with charging infrastructure stakeholders to obtain practical information regarding electric vehicle charging station installation and operation in Nepal. Discussions were carried out with officers from Nepal Electricity Authority and the owner of the Sital Basti Charging Station in Kathmandu. These interviews and discussions provided the information on the number and types of charging guns installed, transformer capacity requirements, installation costs, electricity tariff structures, and the selling price per unit of electricity. Similarly, information regarding latest cost of charger, converter and maintenance of charging station

were obtained from the EV Charger Nepal Pvt. Ltd. The collected information was used to estimate the capital and operational requirements for establishing charging infrastructure to support electric Ground Support Equipment at the airport.

### **3.3.2 Secondary Data**

Secondary data were collected from various sources to support this thesis study. For the evaluation and understanding of the existing Nepal Airlines Corporation (NAC) GSE fleet, the NAC GSE Daily Inspection Sheet was reviewed and checked to gather basic information on each of the equipment with the assessment and physical survey carried out on 26 March 2025. The NAC GSE Log Book provided additional details, including engine serial number, types and rated power. The total annual fuel consumption and operating hours of each GSE were obtained directly from NAC records for the study and which were the most prominent data for the study. And for the data on total international aircraft movements at TIA were obtained from the Civil Aviation Authority of Nepal (CAAN) Annual Reports 2024 and 2025. Standard emission factors of various pollutants and load factors were referenced from the ICAO Air Quality Manual (2020) and the Emission Estimation Techniques Manual and emission factors for EU IIIA and US T3 diesel engines were taken from dieselnets.com.

For the technical comparison between ICE and electric GSE, manufacturer catalogues were collected and analyzed from Nepalese air service operators. These catalogues were sourced from Weihai Guangtai Airport Equipment Co. Ltd., by the operator which provided the detailed specifications, including engine type, power ratings, battery capacity and operational features of six different types of ICE and electric GSE.

For the economic analysis of GSE, manufacturer costs were obtained from Nepalese air service operators which was obtained by them from the manufacturer on 2020 A.D. Tax calculations on the GSE categories were based on the Integrated Customs Tariff Rates (एकीकृत भन्सार महसुल दरबन्दी) for Fiscal Year 2081-82, and inflation data for China were referenced from World Bank reports to ensure accurate cost adjustments since the cost of GSE was from the quotation obtained in 2020. Operational expenses, including fuel and

maintenance costs for ICE GSE were provided by NAC Ground Support Department (GSD).

Similarly for the calculation and estimation of the simple payback period for the proposed charging station for electric GSE information on monthly electricity consumption, tentative operational and maintenance costs and initial investment costs were obtained from NEA Ratnapark office and Sital Basti Bidhutiya Sawari Charging Center, Kavrepalanchok.

### **3.4 Emission Analysis**

The emission analysis was conducted with the guidelines provided in the International Civil Aviation Organization (ICAO) Air Quality Manual (Doc 9889). Out of the four methods provided there, three different methods were used for emission analysis. They were:

- a. Primary Simple Approach
- b. Secondary Simple Approach
- c. Advanced Approach

And the pollutant Nitrogen oxides (NO<sub>x</sub>), Hydrocarbons (HC), Carbon monoxide (CO), Particulate matter (PM) and Carbon dioxide (CO<sub>2</sub>) were evaluated from the above three different approach.

#### **3.4.1 Primary Simple Approach**

In this approach, emissions are estimated by multiplying the number of aircraft arrivals and departures or total movement of aircraft by standard emission factors. For this study, the total international aircraft movements at TIA were multiplied by standard emission factors to estimate emissions. And this approach does not require a detailed assessment of the Ground Support Equipment (GSE) or its fleet operations. The emissions in this approach were calculated by the below equation (ICAO, 2020):

$$\text{Pollutant(X)} = \text{MOA (cycle)} \times \text{SEF (kg/cycle)} \quad \text{Equation 3.1}$$

where,

MOA = Total Movement of Aircraft (cycle)

SEF = Standard Emission Factor (kg/cycle)

### 3.4.2 Secondary Simple Approach

This method estimates the emission based on the total fuel consumed by the Ground Support Equipment (GSE). The actual fuel consumption or estimated fuel consumption were multiplied by average emission factors based on the type of fuel used in GSE i.e diesel or gasoline. In this study all the GSE were based on diesel fuel so the total diesel fuel consumed by the GSE was multiplied by the standard emission factors of diesel fuel. And this approach does not require the number, size or type of equipment used. The emissions equation for the calculation in this approach was given below (ICAO, 2020):

$$\text{Pollutant}(X) = \text{TFC (kg)} \times \text{SEF (g/kg)} \quad \text{Equation 3.2}$$

where,

TFC = Total Fuel Consumed (kg)

SEF = Standard Emission Factor (g/kg)

### 3.4.3 Advanced Approach

In the advanced method, emissions were calculated based on the average rated engine power of GSE, load factor used in facility operations for equipment type, emission factor for substance, time in service and deterioration factor. Deterioration factor should be based on the maintenance of GSE & reflecting age The equation for the emission calculation by advanced approach was (ICAO, 2020):

$$\text{Pollutant}(X) = \text{P(kW)} \times \text{L (\%)} \times \text{T(Hours)} \times \text{EF (g/kWh)} \times \text{DF} \quad \text{Equation 3.3}$$

where,

P = Average rated engine power (kW)

L = Load factor used in facility operations for equipment type

(Took reference for each type of GSE from manual)

T = Total time of operation (Hours)

EF = Emission Factors (kg/kWh)

(Based on the engine emission standard provided by Manufacturer)

DF = Deterioration factor (If required)

### **3.5 Technical Analysis**

Different types of ICE & electric Ground Support Equipment (GSE) are available on the market of different manufactures. In this study, six different ICE & electric GSE manufactured by Chinese company Weihai Gungatai were selected for comparison and analysis. These six types of GSE include GPU, Aircraft Towing Truck, Airport Passenger Bus, Passenger Stairs, Baggage towing tractor and Conveyor Belt. The technical specifications of both ICE and electric GSE of this company were obtained from the Nepalese Airlines operator for the reference and study purposes. A qualitative comparative technical study and analysis of the ICE & electric GSE on different parameter and aspects was conducted by organizing the specifications on tabular format.

### **3.6 Economic Analysis**

Economic analysis was just limited to the initial cost comparison between the diesel powered and electric Ground Support Equipment (GSE) due to unavailability of the operational cost, maintenance cost, fuel and energy cost etc. for evaluating the overall life cycle cost analysis between them. The initial cost comparison and cost ratio analysis between the major six categories (GPU, Aircraft Towing Truck (A320), Airport Shuttle Bus, Passenger Stairs, Baggage tractor and Conveyor Belt) were carried out but the initial cost didn't include the shipping/delivery cost as the cost for the ICE and electric GSE was same for each category. The comparative study was done in two different scenarios: taxed condition for both diesel and electric GSE and tax subsidy condition only to electric GSE. The total initial cost for each equipment category was used to determine the relative higher cost of electric GSE with respect to the ICE GSE. A cost ratio was calculated by dividing the total initial cost of electric GSE by the corresponding ICE GSE cost.

$$\text{Cost Ratio} = \text{Initial Cost of Electric GSE} / \text{Initial Cost of ICE GSE} \quad \text{Equation 3.4}$$

In addition, the percentage reduction in cost ratio due to tax subsidy on the electric GSE was calculated to evaluate the impact of tax subsidy on electric GSE. The reduction percentage was calculated by comparing the cost ration under taxed conditions with the cost ratio under tax subsidy condition on electric GSE. This method allows to evaluate how

policy interventions influence the economic feasibility of electric GSE implementation. The equation for the reduction percentage is given below:

$$\text{Percentage Reduction} = \frac{\text{CR(Tax)} - \text{CR(Subsidy)}}{\text{CR(Tax)}} \times 100 (\%) \quad \text{Equation 3.5}$$

where,

CR(Tax) = Cost Ratio under Taxed Conditions

CR(Subsidy) = Cost Ratio under Tax subsidy on electric GSE

Similarly, the economic analysis of the charging station was conducted using the simple payback period method based on the comparative data from two operating charging stations. The major parameters considered include initial installation cost, electricity cost price, selling price per unit for charging and charger type. The payback period was calculated by analyzing the annual revenue generated from the total unit of electricity consumed to the total investment, expected maintenance and operational cost. A comparative approach was used to assess along with the latest price for the different types of chargers and its setup. This methodology gives a practical basis for estimating the expected payback period of new charging station to be setup at TIA for electric GSE.

### **3.7 Forecasting**

The estimation of future emissions from the Ground Support Equipment (GSE) operations was done by the applying different forecasting techniques to calculated past annual emission data. It helps to project and study the trends of potential emission in the future. In this study, two forecasting methods were used: Linear Regression (Trend Projection Method) and Time Series Analysis using Exponential Smoothing (Holt's Damped Trend Method). These methods were used in this study due to their suitability for small data and their ability to capture the long-term emission trends.

#### **3.7.1 Linear Regression (Trend Projection Model)**

Linear Regression (the Trend Projection Method) is a classic statistical tool or the forecasting method that estimates future values by fitting a straight line or developing the linear relationship to the historical/observed data. It is a fundamental approach used for

predictive analysis and is good for spotting long-term patterns and predicting where the trend is directed.

The fundamental assumption in this model was that the emission levels follow a linear trend over a time and expressed as (Hyndman & Athanasopoulos, 2018):

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon \quad \text{Equation 3.6}$$

Where:

$y_t$  = Emission level at time 't' (Metric tons)

$\beta_0$  = Intercept (Baseline Emission Level)

$\beta_1$  = Slope Coefficient Representing the Rate of Change of Emissions

$x_t$  = Time (year)

$\varepsilon_t$  = Error term

It utilizes the Ordinary Least Squares (OLS) method to develop a linear relationship that minimizes the sum of squared errors between the actual and forecasted data by identifying the trend's direction and speed to estimate future values. The "LinearRegression" function from the scikit-learn library is used to fit the model using .fit() method and generate the future predictions based on the time variable using the .predict() method in python code. And the python code is trained the model by excluding the years 2020 & 2021, which were significantly impacted by the covid-19 pandemic.

### 3.7.2 Holt's Damped Trend Method

Holt's Damped Trend method is an expansion of simple exponential smoothing method that allows the projection of the future with the trend of historical data with damping factor in order to prevent the over forecast in the long run. The mathematical equation for this method consists of main three equations: Level equation, Trend equation and Forecast equation (Hyndman & Athanasopoulos, 2018):

Level Equation:

$$l_t = \alpha y_t + (1 - \alpha) (l_{t-1} + \phi b_{t-1}) \quad \text{Equation 3.7}$$

Trend Equation:

$$b_t = \beta(\ell_t - \ell_{t-1}) + (1-\beta) \phi b_{t-1} \quad \text{Equation 3.8}$$

Forecast Equation:

$$\hat{y}_{t+h} = \ell_t + (\phi + \phi^2 + \phi^3 + \dots + \phi^h) b_t \quad \text{Equation 3.9}$$

where,

$\ell_t$  = level component at time t

$b_t$  = trend component at time t

$\alpha$  = level smoothing parameter ( $0 < \alpha < 1$ )

$\beta$  = trend smoothing parameter ( $0 < \beta < 1$ )

$\phi$  = damping parameter ( $0 < \phi < 1$ )

h = forecast horizon

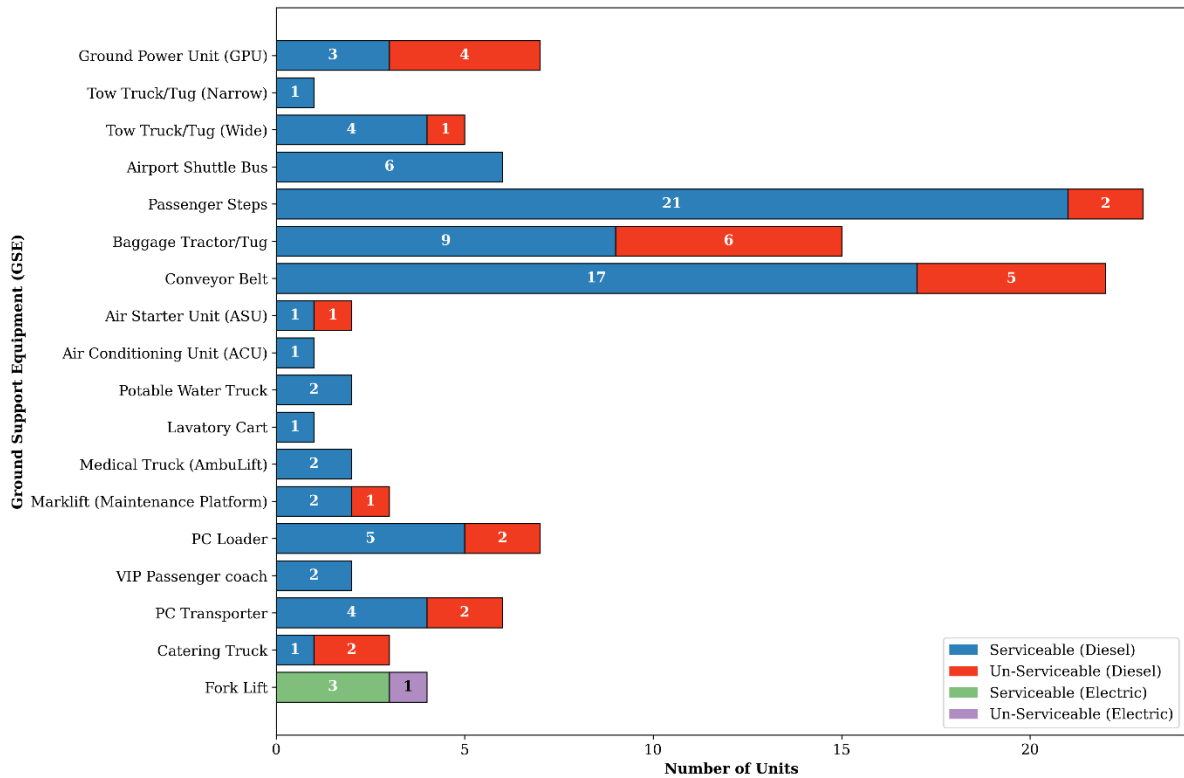
$\hat{y}_{t+h}$  = forecasted emission value

In this study, the exponential smoothing () function from the statsmodels library was used to implement Holt's Damped Trend Method in python programming. The function was used on the historical emission data that is in the y\_train. The argument trend 'add' was used to specify an additive trend which means that the emissions are expected to increase or decrease by about the same amount over time. The parameter damped\_trend=true enables the damping effect which reduces the magnitude of the trend in the future gradually and prevents from growing too quickly in the long term. The initialization\_method='estimated' option allowed the model to automatically estimates the initial level and trend values from the historical calculated emission data. The .fit()function is used to estimates the smoothing and trend the parameters. Then the .forecast(lem(forecast\_years)) function was used to generate the emission forecasts for the selected future years from 2025 to 2030.

## CHAPTER FOUR: RESULTS AND DISCUSSION

### 4.1 NAC GSE Assessment

The initial phase of this study involved a comprehensive physical and operational analysis of the Ground Support Equipment (GSE) operated by the Nepal Airlines Corporation (NAC) at Tribhuvan International Airport (TIA). From the physical inspections and review of the daily log sheets done on March 26, 2025 at TIA & NAC Ground Support Department (GSD), the foundational understanding of the current GSE was established particularly regarding the different types of GSE, their usage, availability, number etc. Based on the inspections and gathered collected data, the GSE fleet composition reflects a mix of essential air side service equipment including Ground Power Units (GPU), tow tractors (suitable for both the narrow body and wide body aircraft), airport shuttle buses, passenger stairs etc.



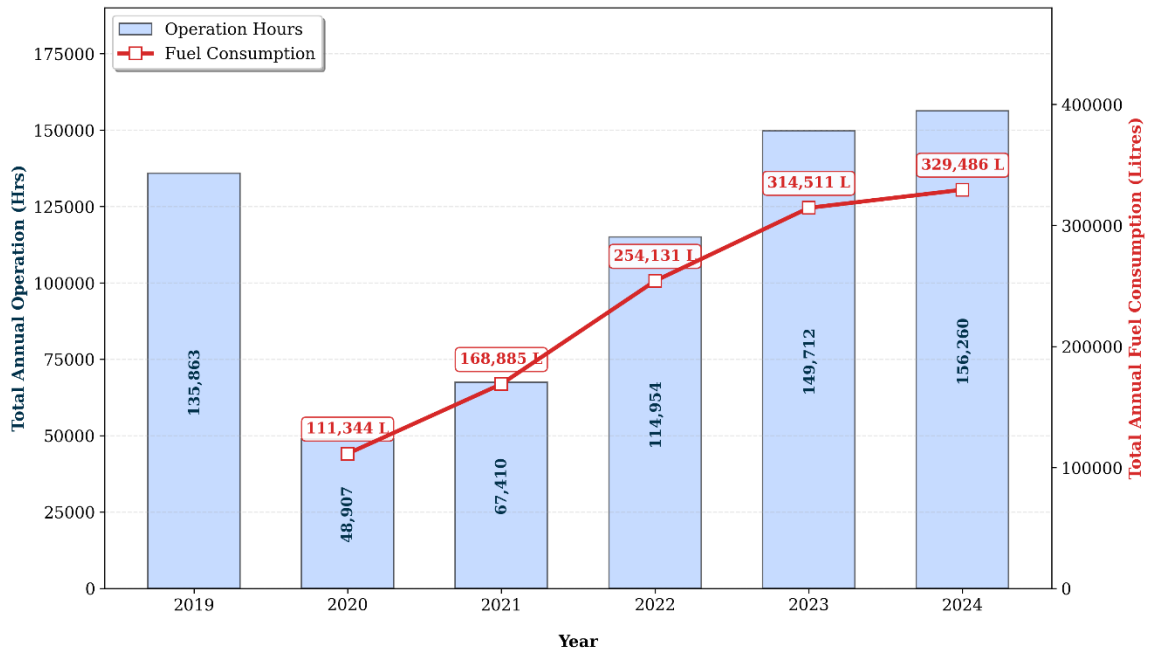
**Figure 4.1:** NAC Ground Support Equipment Assessment

Figure 4.1 illustrates the operational status and inventory of Ground Support Equipment (GSE) at Nepal Airlines Corporation (NAC) which provide the services at TIA. The horizontal bar chart categorizes the different types of GSE and distinguishes them based on the serviceability and fuel type, such as serviceable, unserviceable diesel units and serviceable, unserviceable electric units.

From the graph, it is observable that almost all the equipment in the fleet is diesel powered with only one equipment i.e., Forklift is electric, which is also introduced recently in service, with notable lack of diversity in the energy sources. The inventory reveals that the majority of the equipment supporting passenger services such as passenger steps, baggage tractors and conveyor belts constitutes the largest volume of the active fleet. For example, the data shows the 21 serviceable diesel passenger steps out of a total of 23, 17 serviceable diesel conveyor belts out of 22 and 9 serviceable baggage tractors out of 15. Ground Power Units (GPU) show a relatively uniform distribution between the serviceable and unserviceable units suggesting the dependability concerns in this category and the presence of the unserviceable units may impact in the operational efficiency since they are critical for supplying the power to the aircraft on ground during transit, maintenance etc. Similarly, the tow tractors/tugs and airport shuttle buses are lesser in number but are mostly in serviceable condition revealing their importance and possibly better maintenance practices. Smaller categories like the Air Starter Units (ASU), Air Conditioning Units (ACU), Lavatory carts, medical trucks, potable water cart, maintenance platform etc. have very limited units typically one or two and are mostly serviceable. This suggests their low utilization as well in comparison to other equipment available in the GSE fleet.

Overall, the graph highlights the heavily dependent of GSE fleet on conventional fuel-based equipment particularly diesel based, with just one type of equipment based on the electric sources, suggesting the significant potential for future electrification and emission reduction initiatives. Similarly, a considerable number of units across the multiple categories are unserviceable pointing to maintenance and operational challenges.

## 4.2 Operational Characteristics of GSE



**Figure 4.2:** Correlation of Total GSE Annual Operation (Hrs) and Fuel Consumption (Litres)

The operational data for the Ground Support Equipment (GSE) at TIA is illustrated in Figure 4.2. The graph is in a dual-axis format to present two distinct data sets over a six-year period. The horizontal axis (X-axis) represents the time progression from 2019 to 2024 in annual increments, vertical axis (Left Y-axis) measures the total annual operation (Hrs) or total annual GSE usage represented by the light blue bars and vertical axis (Right Y-axis) measures the total annual consumption (Litres) visualized through the red line with square markers.

### 4.2.1 Yearly Operation Hours Trend Analysis

The annual usage of the Ground Support Equipment (GSE) shows a fluctuating pattern with up and down over time. In pre-pandemic baseline year 2019, the airport maintained a high level of activity with the 135,863 operation hours. This period represents the normal operational state of TIA before the global covid pandemic which disrupted the global movement and travel. Then in 202 the hours dropped to 48, 907 hours due to covid

pandemic which is a drop of about 64 percent. It happened because of the less flights and activity on the ground during covid time. In 2021 the operation hours of GSE increased to 67,410 and 114,954 hours in 2022. From the 2022 onwards the graph shows a consistent and intense upwards trajectory and maximum on 2024 with annual usage 156,260 hrs , indicating the post pandemic effect and normal operation in global movement and travels which ultimately increased the usage of GSE.

#### **4.2.2 Yearly Fuel Consumption Trend Analysis**

The amount of fuel used by the Ground Support Equipment (GSE) follows the pattern as the hours it is used with little differences. In 2020 the fuel consumption of GSE recorded low which reflects the near-total shutdown of the international travel in Nepal due to COVID-19. Then the fuel consumption from 2021 to 2023 is very steep that the airport started busy again with increasing usage of Ground Support Equipment (GSE). By 2024, the fuel use was almost as high as it had ever been and the followed the same pattern as the increases in hours that the equipment was used.

#### **4.2.3 Correlation between Operating Hours and Fuel consumption**

The graph shows the strong direct linear relationship between the duration of usage of Ground Support Equipment (GSE) and the volume of the fuel consumed. When the GSE is used more it uses more fuel. But the connection between usage and fuel consumption is not a perfect straight line. The fact that the relationship between hours and fuel consumption is different from year to year means that there are factors that affect how much fuel is used. And these factors could include: Equipment age and maintenance conditions, operational efficiency and GSE operator's behavior, fuel quality and engine performance etc.

Although the higher operational activity reflects the recovery and growth of aviation services the simultaneous increase in the fuel consumption indicates that the airport's carbon emissions are likely to increase alongside the operational and economic growth. It emphasizes the importance of transitioning toward the sustainable and renewable energy source based GSE technologies in order to reduce the fossil fuel dependence and assist more sustainable airport operations.

### 4.3 Emission Estimation and Analysis

The detailed evaluation of the emission from the Ground Support Equipment at Tribhuvan International Airport was carried out using three different analytical approaches: Primary Simple Approach (PSA), Secondary Simple Approach (SSA) and Advanced Approach (AA). These three methods have been used to estimate the emissions of key pollutants such as Hydrocarbons (HC), Nitrogen Oxides (NO<sub>x</sub>), Carbon Monoxide (CO), Particulate Matter (PM) and Carbon dioxide (CO<sub>2</sub>) for a six-year period from 2019 to 2024.

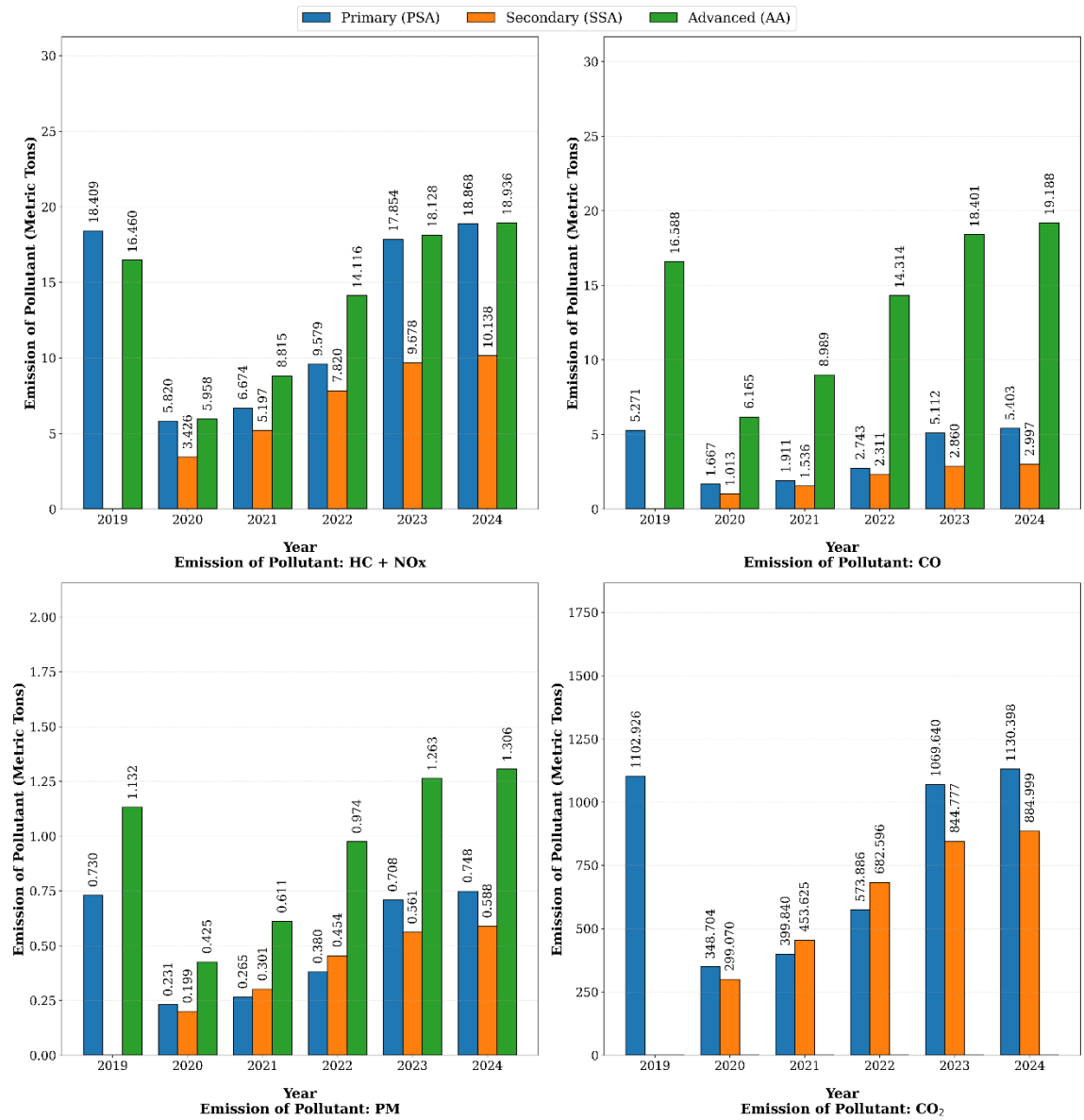


Figure 4.3: Comparative Presentation & Analysis of Emission of Pollutants

#### **4.3.1 Trend Analysis of HC+NO<sub>x</sub> Emissions**

The combined emissions of hydrocarbons (HC) and the nitrogen oxides (NO<sub>x</sub>) show the clear changes over time mainly due to variations in the airport activity. In 2019 emissions were relatively high reaching 18.409 metric tons using the Primary Simple Approach (PSA) and 16.460 metric tons with Advanced Approach (AA). And significant drop occurred in 2020 with emissions falling to 5.820 metric tons (PSA), 3.426 (Secondary Simple Approach) (SSA) and 5.928 metric tons (AA). In 2021 the value increased to 6.674 metric tons (PSA), 5.197 metric tons (SSA) and 8.815 metric tons (AA). These figures indicate the normal operational conditions in 2019 and sharp decrease in 2020 & 2021 due to less airport operational activities as the result of covid-19 pandemic. Then there was continuous rise in emissions as in 2022, 9.579 metric tons (PSA), 7.820 metric tons (SSA), 14.116 metric tons (AA) and 2023, 17.854 metric tons (PSA), 9.678 metric tons (SSA), 18.123 metric tons (AA). By 2024, the emissions reached to 18.868 metric tons (PSA), 10.138 metric tons (SSA) and 18.936 metric tons (AA) which indicates a full recovery in airport activity and possibly a rise in GSE usage in 2023 and 2024.

#### **4.3.2 Carbon Monoxide (CO) Emission characteristics**

The emissions of Carbon monoxide (CO) show the similar pattern over the time as hydrocarbon and nitrogen oxide but the numbers were different. In 2019 the emissions of hydrocarbon were 5.271 metric tons from PSA & 16.588 metric tons from advanced approach (AA). And in 2020 the emissions went down to value 1.667 from PSA, 1.013 from SSA and 6.165 metric tons from AA and 1.911 (PSA), 1.536 (SSA) and 8.989 metric tons (AA) in 2021. Then from 2022 the value of CO emissions kept going up to 2.743 from PSA, 2.311 from SSA & 14.314 metric tons from AA and in 2023 the value was 5.122 metric tons (PSA), 2.860 metric tons (SSA) and 18.401 metric tons (AA). In 2024 they reached their highest value over the period with 5.403 metric tons (PSA), 2.997 metric tons (SSA) and 19.188 (AA).

#### **4.3.3 Particulate Matter (PM) Emission Analysis**

The emission of Particulate matter (PM) was comparatively low in magnitude relative to gaseous pollutants but critically significant due to their direct implications on human health

and localized air quality. The estimation of Particulate matter reveals that a temporal trend closely aligned with the operational intensity characterized by the sharp decline in 2020 & 2021 and gradually increased with the reduction of pandemic covid-19 impact. In 2019 PM emission was estimated at 0.730 metric tons from PSA and 1.132 metric tons from AA. A major reduction is observed in 2020 with 0.231 (PSA), 0.199 (SSA) and 0.425 metric tons (AA) and rising to 0.265 (PSA), 0.301(SSA) and 0.611 metric tons (AA) in 2021. Further increasing to 0.380 (PSA), 0.454 (SSA) and 0.974 (AA) metric tons in 2022 and in 2023 it was 0.708 (PSA), 0.561 (SSA) and 1.263 metric tons (AA). And the upward trajectory was at highest value in 2024 with 0.784 (PSA), 0.588(SSA) and 1.306 metric tons (AA).

#### **4.3.4 Carbon dioxide (CO<sub>2</sub>) Emission Analysis**

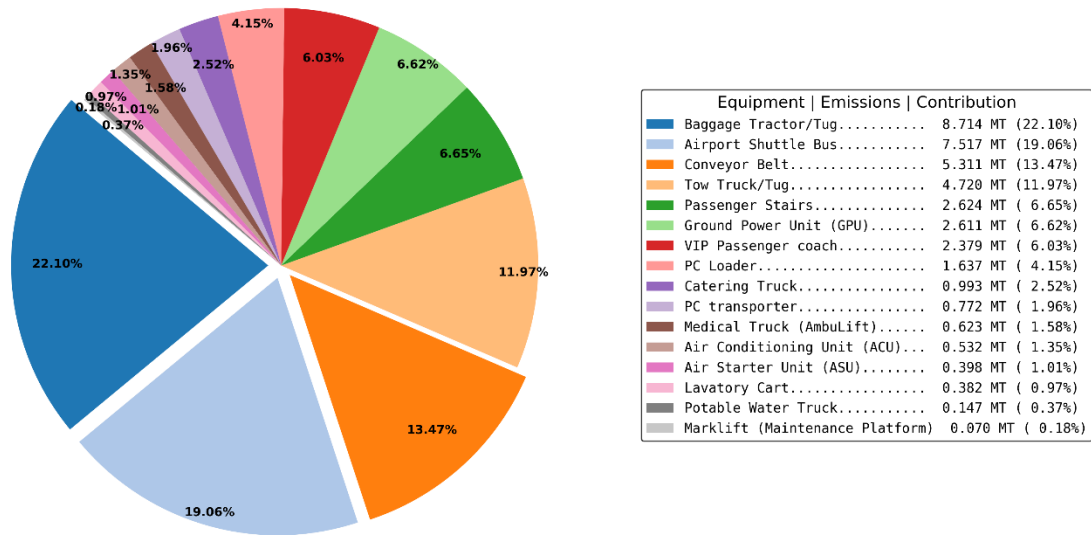
Carbon dioxide (CO<sub>2</sub>) emissions was calculated from two different approaches i.e., Primary Simple Approach (PSA) and Secondary Simple Approach (SSA). The value of the emissions of CO<sub>2</sub> is highest among all the pollutants representing the total fuel consumption and energy use. The temporal analysis indicates high baseline in 2019 with the emissions value recorded at 1102.926 metric tons under PSA followed by substantial reductions in 2020 to 348.704 (PSA) and 299.070 metric tons (SSA). In 2021 it is observed that the emission of CO<sub>2</sub> was recorded 399.840 (PSA) and 453.625 metric tons (SSA) and further increased to 573.886 (PSA) and 682.596 metric tons (SSA). A sharp escalation is observed in 2023 with the emissions reaching 1069.640 (PSA) and 844.777 metric tons (SSA) and peaking high in 2024 at 1130.938 (PSA) and 884.999 metric tons (SSA).

#### **4.3.5 Comparative Evaluation of Estimation Approaches**

Throughout the years the advanced approach (AA) consistently indicated the higher emission estimates than PSA and SSA of pollutants HC+NO<sub>x</sub>, CO and PM, which is due to detailed operational parameters which include equipment usage rates, load factors, engine performance etc. The difference between the PSA and SSA is not more and the higher estimation from advanced approach suggests that the simpler methods might underestimate the actual emission as they may not use the full complexity of the operations using GSE.

In case of CO<sub>2</sub> the emissions evaluated from the secondary simple approach (SSA) is considered more reliable than primary simple approach (PSA) due to its direct dependence on the total diesel fuel consumption and corresponding emission factors, which provide a more accurate representation of actual energy use. On the other hand, PSA estimates based on the total aircraft movements and generalized emission factors which may not fully capture the real scenario. So, the SSA is methodologically more robust for CO<sub>2</sub> emission estimation as it directly reflects the real diesel fuel burn rather than relying on activity based of the aircraft.

#### 4.4 Distribution of Emission by Equipment Type (Advanced Approach 2024)



**Figure 4.4:** Distribution of Total Emissions (HC+NO<sub>x</sub>+CO+PM): Advance Approach 2024

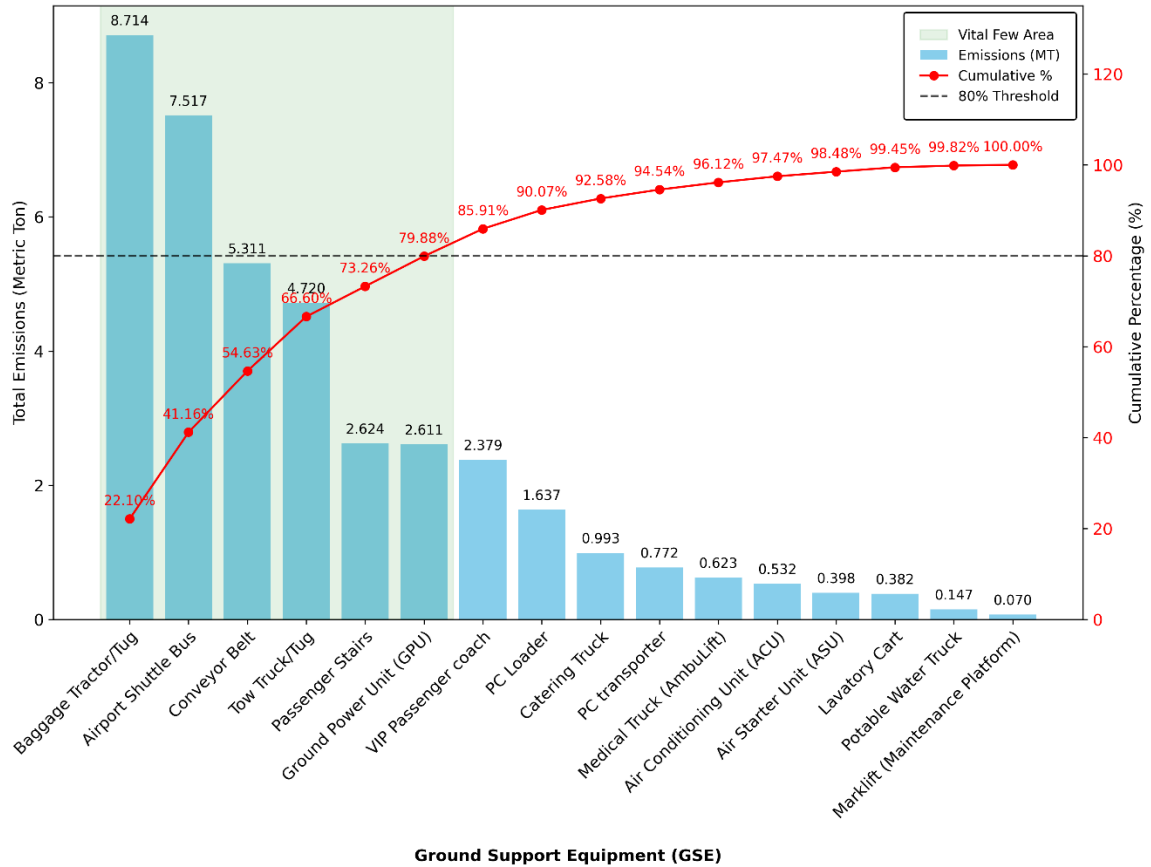
The emission from advance approach (AA), distribution analysis for 2024 shows that the Ground Support Equipment (GSE) categories contribute to emissions in a very non-uniform manner. Emissions include the pollutants like the Hydrocarbons (HC), Nitrogen Oxidex (NO<sub>x</sub>), Carbon Monoxide and the Particulate Matter (PM). The total emissions (HC+NO<sub>x</sub>+CO+PM) value for the Baggage Tractor/Tug shows that they are the major contributors to the emissions with the value of 8.714 metric tons which is 22.10 % of the

total emissions from the Ground Support Equipment. This is followed by the Airport Shuttle Buses with 7.517 metric tons of emissions which is 19.06 % and Conveyor Belts with 5.311 metric tons of emissions which is 13.47% of the total emissions from the GSE. These three types of the Ground Support Equipment (GSE) Baggage Tractors/Tugs, Airport Shuttle Buses and Conveyor Belts produce more than the half of the total emissions from other Ground Support Equipment (GSE) highlighting their dominant role in airport ground operations. So, these types of GSE are really important when it comes to reducing the emissions. Other significant contributors include the Tow Trucks (4.720 metric tons, 11.97%), Passenger Stairs (2.624 metric tons, 6.65%) and Ground Power Units (2.611 metric tons, 6.62%). These categories although individually smaller but collectively represent the significant share of emissions. On the other hand, equipment such as Lavatory Carts (0.382 metric tons, 0.970%), Potable Water Truck (0.147 metric tons, 0.37%) and Marklift (0.070 metric tons, 0.18%) contribute marginally each accounting for less than 1% of total emissions.

The distribution of total emissions Pie-Chart highlights that the targeted emission reduction measures should focus on high contributing Ground Support Equipment (GSE) categories would yield the most significant overall impact whereas the interventions on the minor contributors would have the limited effectiveness.

#### **4.5 Pareto Analysis of Emission Sources & Strategic Prioritization**

Pareto analysis is applied to identify the most dominant and influential emission equipment on the 80-20 principle which suggests that the most of the outcomes are often driven by a minority of causes. However, it is observed that that the only 20 % of Ground Support Equipment (GSE) did not contribute for the 80 % of emissions but it is close to it which makes it useful for making the strategic decisions and prioritization while taking the important actions for the emissions reduction and enabling the efficient allocation of mitigation effects.



**Figure 4.5:** Pareto Analysis of Total Emissions (NO<sub>x</sub>+ HC+ CO+PM): Advance Approach 2024

The Strategic focus of this study is summarized in Figure 4.5 and the chart sorts the Ground Support Equipment (GSE) by their total emission mass and plots a cumulative percentage curve. The figure clearly highlights that the emissions mainly come from the limited types of equipment. The analysis shows that the approximately 80% of the total emissions are generated by the limited number of GSE categories which is highlighted in the figure with the light green shaded region. Specifically, the cumulative contribution reaches around 80% with the inclusion of the top six to seven equipment types. They are:

1. Baggage Tractor/Tug
2. Airport Shuttle Bus
3. Conveyor Belt
4. Tow Truck

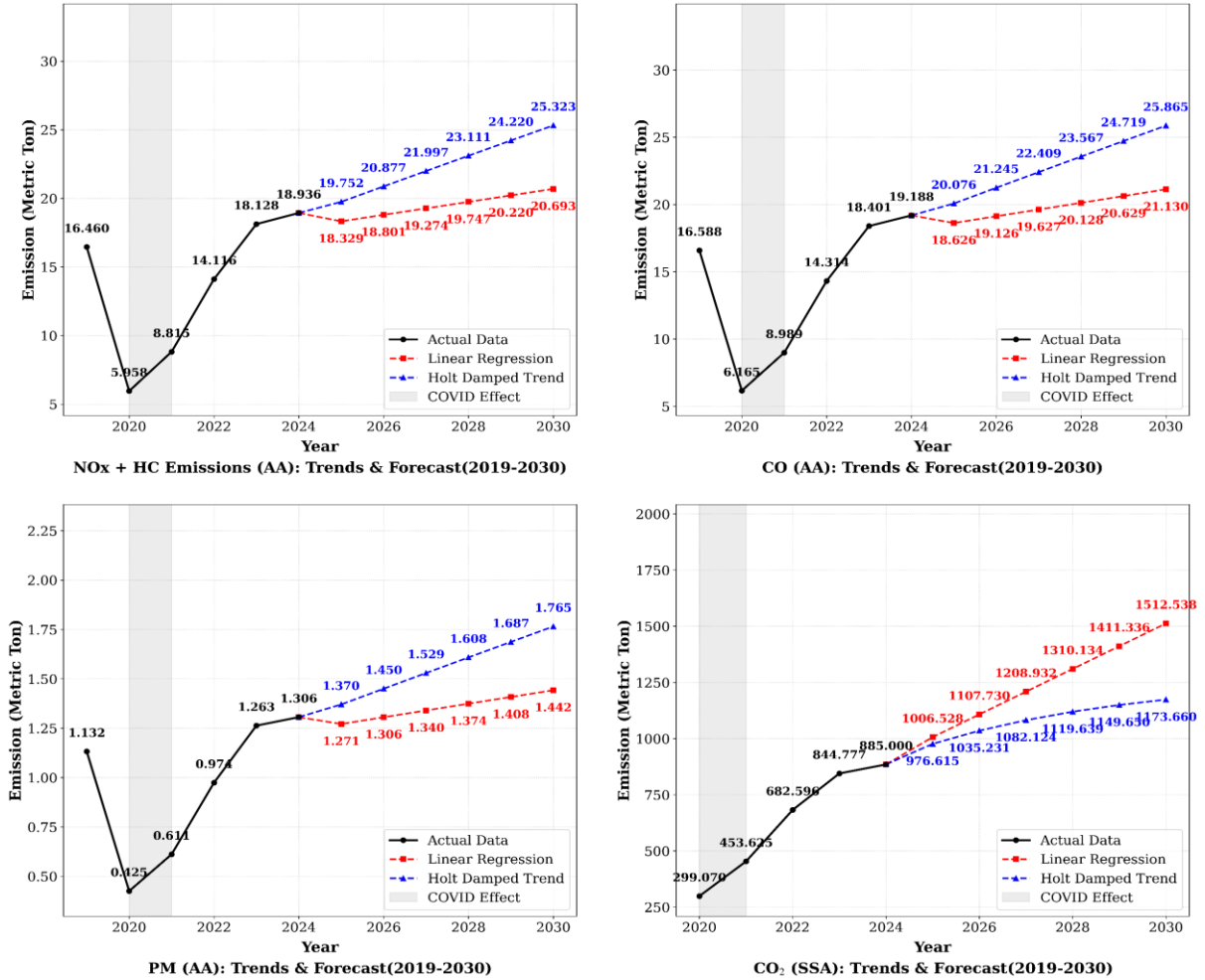
## 5. Passenger Stairs

## 6. Ground Power Unit (GPU)

This result is significant from a policy and planning perspective. It suggests that the precision and targeted interventions in a small subset of Ground Support Equipment (GSE) can result in substantial emission reductions. For example, electrification or hybridization of Baggage Tractors and Airport Shuttle Buses alone could significantly lower the overall emissions. Similarly, the implementation of Fixed Electric Ground Power (FEGP) or electric GPU instead of ICE GPU could reduce the emissions. The remaining equipment categories fall into the “insignificant or trivial many” group where the individual contributions in the total emission are very small and less impactful. At the initial phase of the targeted interventions, “trivial many” groups can be addressed in later phases while prioritizing the mentioned above six Ground Support Equipment (GSE).

### **4.6 Emission Forecasting Analysis**

The emission forecasting analysis was done to project the future emissions of key pollutants generated by the Ground Support Equipment (GSE) at Tribhuvan International Airport (TIA) in international ramp section up to the year 2030. Two forecasting methods were used: Linear Regression, representing a deterministic trend-based approach and Holt’s Damped Trend Method which accounts for the trend persistence with gradual stabilization over time. Forecasting was performed for four major pollutants HC+ NO<sub>x</sub>, CO, PM and CO<sub>2</sub> using Advanced Approach (AA) results for gaseous and particulate pollutants and Secondary Simple Approach (SSA) based estimates for CO<sub>2</sub>.



**Figure 4.6: Multi Pollutant Emissions Trends and Forecasting Analysis (2019-2030)**

#### 4.6.1 Multi-Pollutant Trend Projections

The multi-pollutant forecasting analysis gave a future oriented evaluation of emissions generated by the Ground Support Equipment (GSE) over the period 2019-2030. The forecasts were based on the historical emission data 2019-2024 which reflects a significant disruption in 2020 followed by a strong recovery that lasts until 2024. This recovery trend formed the basis for the future emission trajectories.

Across all the pollutants NO<sub>x</sub>+HC, CO, PM and CO<sub>2</sub> under the Business- As- Usual (BAU) conditions, there was a steady rise in all pollutants. HC+ NO<sub>x</sub> emissions increased from approximately 18.936 metric tons in 2024 to projected values of 20.693 metric tons under Linear Regression and 25.323 metric tons under Holt's Damped Trend method by 2030.

Similarly, the CO emissions escalated from 19.88 metric tons in 2024 to 21.130 metric tons (Linear) and 25.865 metric tons (Holt's). Also, the PM emissions showed a gradual rise from 1.306 metric tons in 2024 to 1.442 metric tons (Linear) and 1.765 metric tons (Holt's) by 2030. The emissions of CO<sub>2</sub> recorded the highest absolute increase, climbing from 884.999 metric tons in 2024 to 1512.538 metric tons under Linear Regression method and 1173.660 metric tons under Holt's Damped Trend method by 2030.

These projections reveal that the emissions levels are strongly dependent to operational growth and the fuel consumption patterns.

#### **4.6.2 Comparative Evaluation of Forecasting Models**

In Figure 4.6, the Linear Regression model was represented by the red dashed line whereas the Holt's Damped Trend Method was represented by the blue dashed line. From the figure, comparative analysis of Linear Regression method and Holt's Damped Trend method demonstrated the significant differences in forecasting behavior. This differences mainly arise from how each model interprets to ensure the Business -as -Usual projection, allowing the models to focus on the growth observed in 2019 and the post pandemic recovery phase i.e., 2022-2024 and the anomalous pandemic years 2020 were excluded.

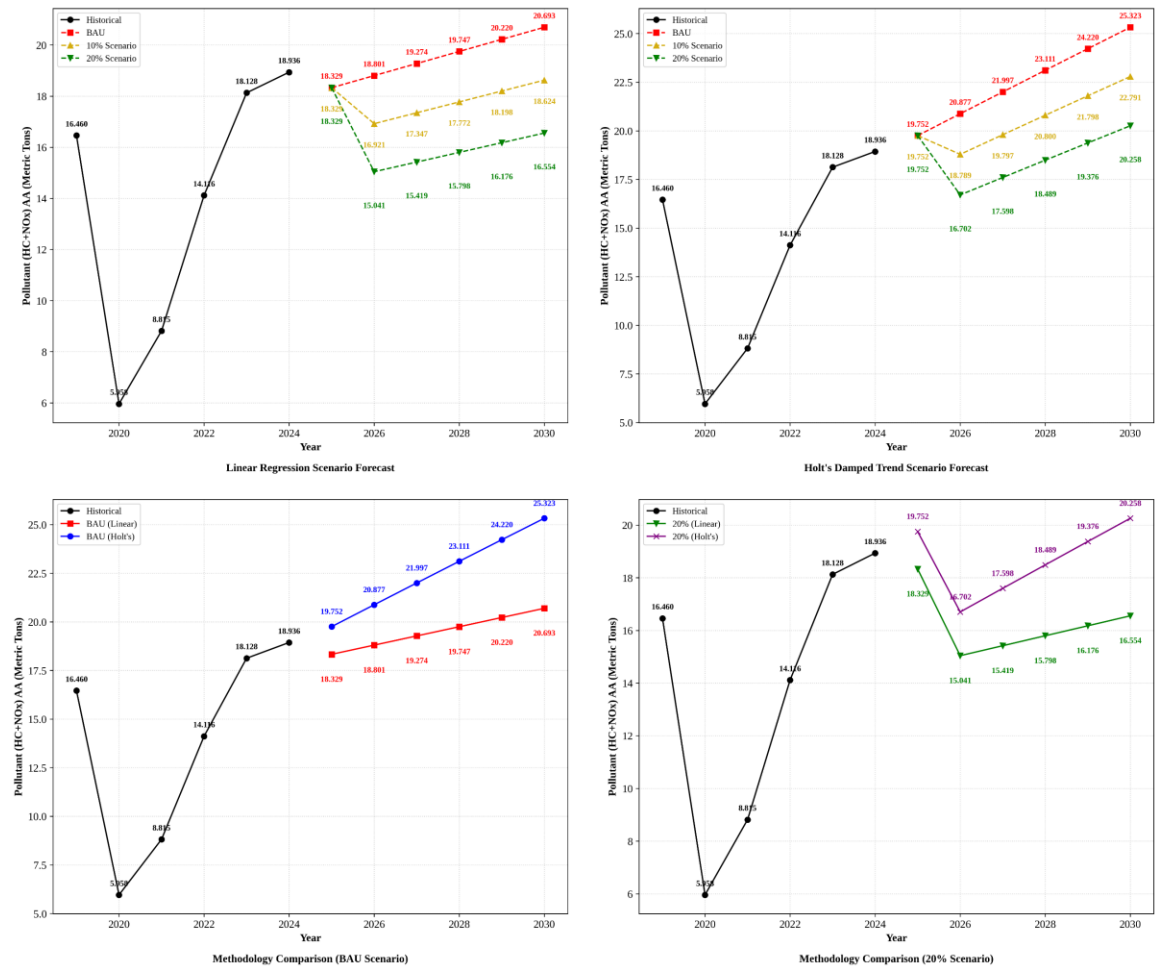
Linear Regression made smoother and more careful predictions as it assumed that the rate of the growth would stay the same over the time. However, for the pollutants such as HC+ NO<sub>x</sub>, CO and PM, the Holt's Damped Trend method results in a higher forecast by 2030 than the Linear Regression results which is because of the exponential smoothing it utilizes and is designed to be highly sensitive to the most recent rate of change which is seen high between 2022, 2023 & 2024. On the other hand, for CO<sub>2</sub> emissions Holt's method gave the lower values than the Linear Regression as the graph demonstrated that the growth was steadier and more consistent and allowed the damping feature of the Holt's Damped Trend method to work as intended. It identifies the upward trend but the mathematically bends the curve to reflect a future where growth start to level off due to better fuel efficiency or carbon reduction policies. And the Linear Regression however continues in a perfectly straight line forever.

The comparison reveals that the Linear Regression shows us a steady, average path based on the historical data while the Holt's Damped Trend method provides a current operational reality as it captures the recent high-speed recovery in local pollutants.

#### 4.7 Scenario Based Mitigation Analysis for eGSE Implementation

The shift from conventional Internal Combustion Engine (ICE) Ground Support Equipment (GSE) to eGSE was analyzed using two mitigation scenarios: Scenario 1 had a 10% electrification level and Scenario 2 had a 20% electrification level. Both scenarios were thought to start in the fiscal year 2026.

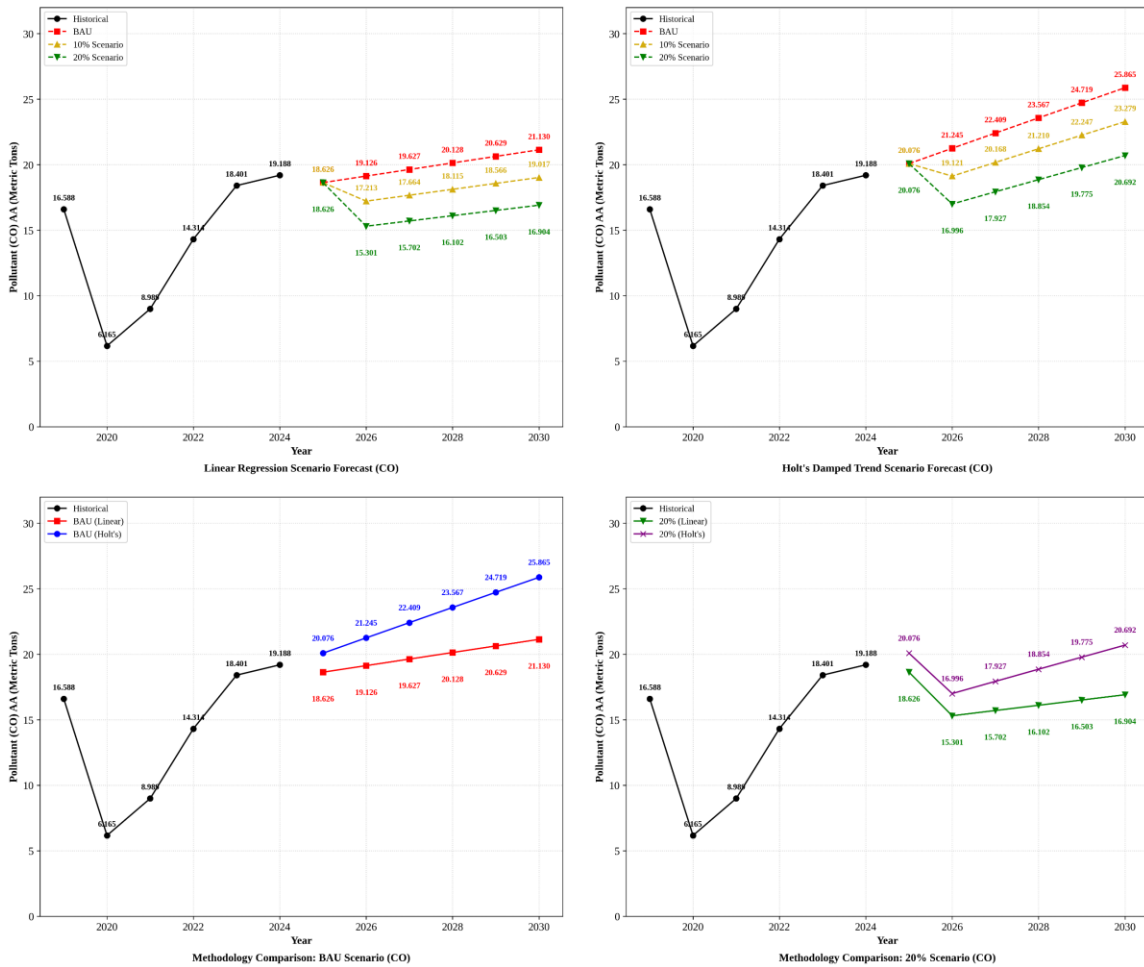
##### 4.7.1 Scenario Analysis of NO<sub>x</sub>+HC Emissions



**Figure 4.7:** Scenario Based Forecast of NO<sub>x</sub>+HC Emissions (2020-2030): BAU & eGSE Adoption Using Linear Regression & Holt's Damped Trend Models

Figure 4.7 illustrates a change in the emission curve starting in 2026. Under BAU, NO<sub>x</sub>+HC emissions are projected to reach 20.693 metric tons (Linear) and 25.323 metric tons (Holt's) by 2030. The 10% reduction scenario lowers emissions to approximately 18.624 metric tons (Linear) and 22.791 metric tons (Holt's) indicating a moderate reduction. A more significant mitigation impact is observed under 20% reduction scenario where emissions decrease to 16.554 metric tons (Linear) and 20.258 metric tons (Holt's) by 2030. This indicates the significant mitigation compared to BAU particularly in the early years following the implementation.

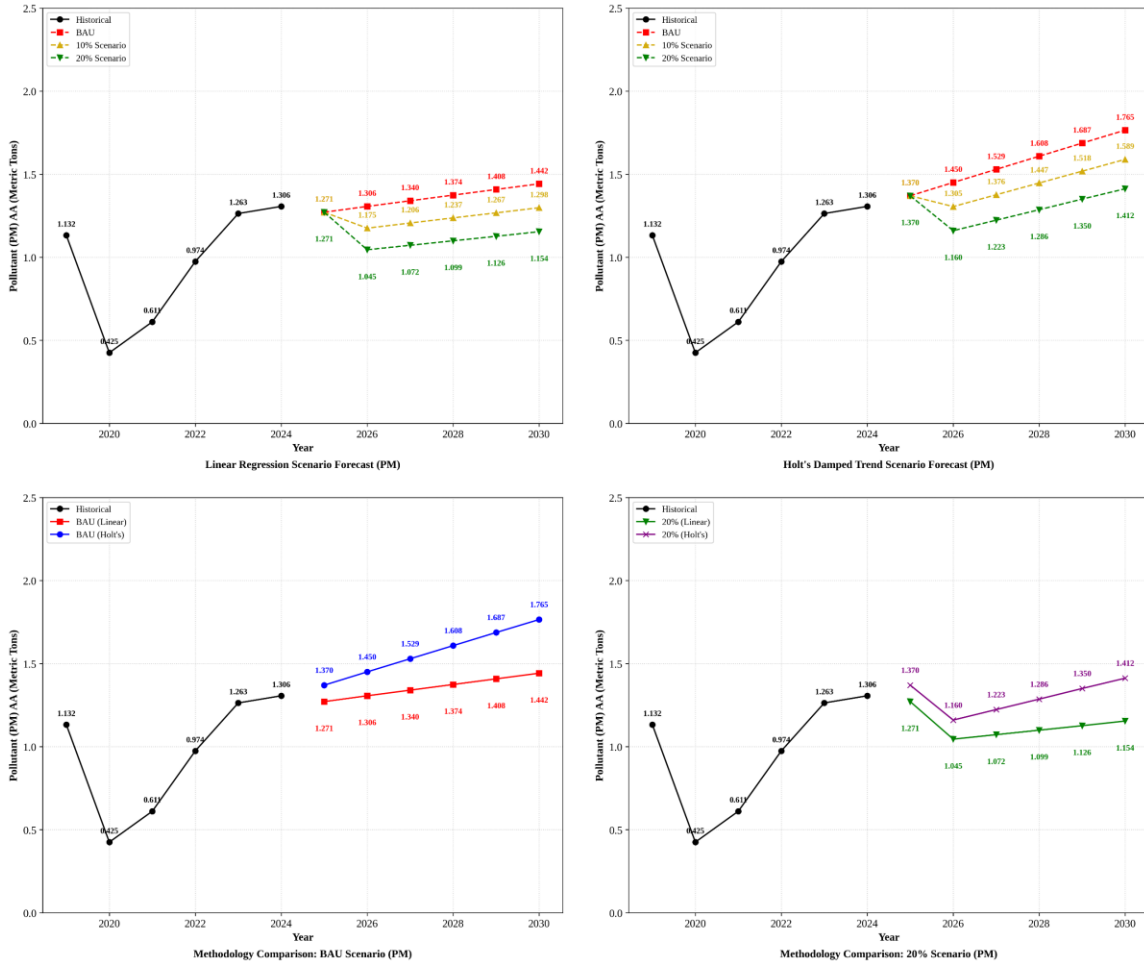
#### 4.7.2 Mitigation Potential for CO Emissions



**Figure 4.8:** Scenario Based Forecast of CO Emissions (2020-2030): BAU & eGSE Adoption Using Linear Regression & Holt's Damped Trend Models

Figure 4.8 reveals a similar mitigation response pattern comparable to that observed for NO<sub>x</sub>+HC, with electrification strategies producing measurable reductions relative to the business-as-usual (BAU) trajectory. Under BAU conditions, CO emissions are projected to increase to 21.130 metric tons (Linear Model) and 25.865 metric tons (Holt's Damped method) by 2030. The implementation of the 10% electrification scenario reduces emissions to 19.017 metric tons (Linear) and 23.279 metric tons (Holt's) indicating a moderate level of mitigation. A more significant impact is seen under the 20% electrification scenario, where emissions decline to 16.904 metric tons (Linear) and 20.692 metric tons (Holt's) by 2030 which indicate that the emission of over 4 metric tons annually reduced in comparison to the BAU projection. This decrease shows the how sensitive CO are to the electrification and are strongly linked to inefficient combustion and idling conditions. As more and more high idling GSE like baggage tractors, airport shuttle buses are electrified, the immediate reductions will be observed. The results also suggests that the partial electrification cuts emissions by a lot, full- and long-term mitigation or interventions would require more improvements and reductions of emissions.

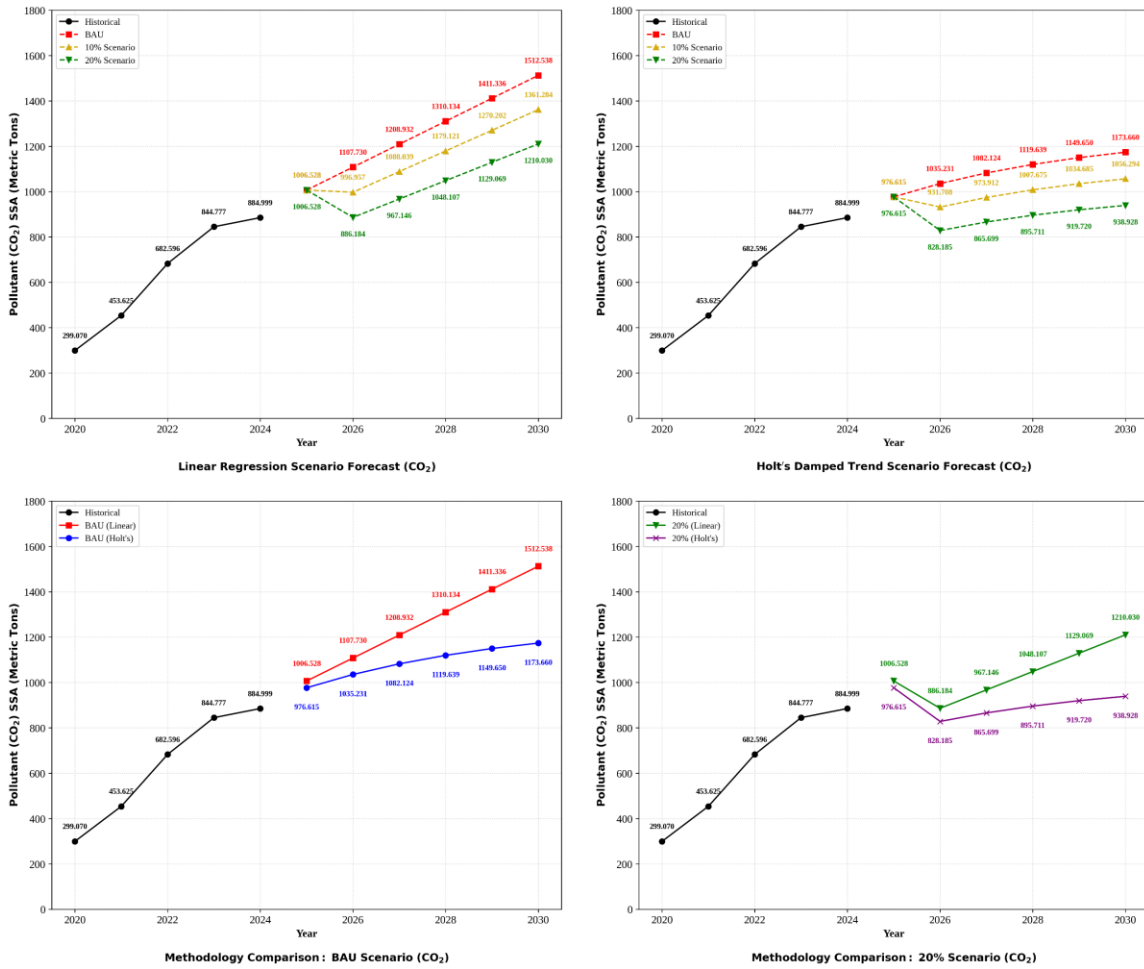
### 4.7.3 Scenario Analysis of PM Emissions



**Figure 4.9:** Scenario Based Forecast of PM Emissions (2020-2030): BAU & eGSE Adoption Using Linear Regression & Holt's Damped Trend Models

As presented in Figure 4.9, PM emissions show a strong response to electrification measures. Under business-as-usual (BAU) conditions, emissions are projected to reach 1.442 metric tons (Linear) and 1.765 metric tons (Holt's) by 2030, which reduce to 1.298 (Linear) and 1.589 metric tons (Holt's) under the 10 % electrification scenario of GSE and further to 1.154/1.412 metric tons under the 20% electrification scenario. The figure shows a clear downward shift in the emission trajectory path after 2026 confirming that PM is also highly responsive to the electrification of GSE. Despite the lower absolute values, the decrease is substantial due to the strong impact of PM on local air quality and public health.

### 4.7.4 Decarbonization Potential of CO<sub>2</sub> Emissions



**Figure 4.10:** Scenario Based Forecast of CO<sub>2</sub> Emissions (2020-2030): BAU & eGSE Adoption Using Linear Regression & Holt's Damped Trend Models

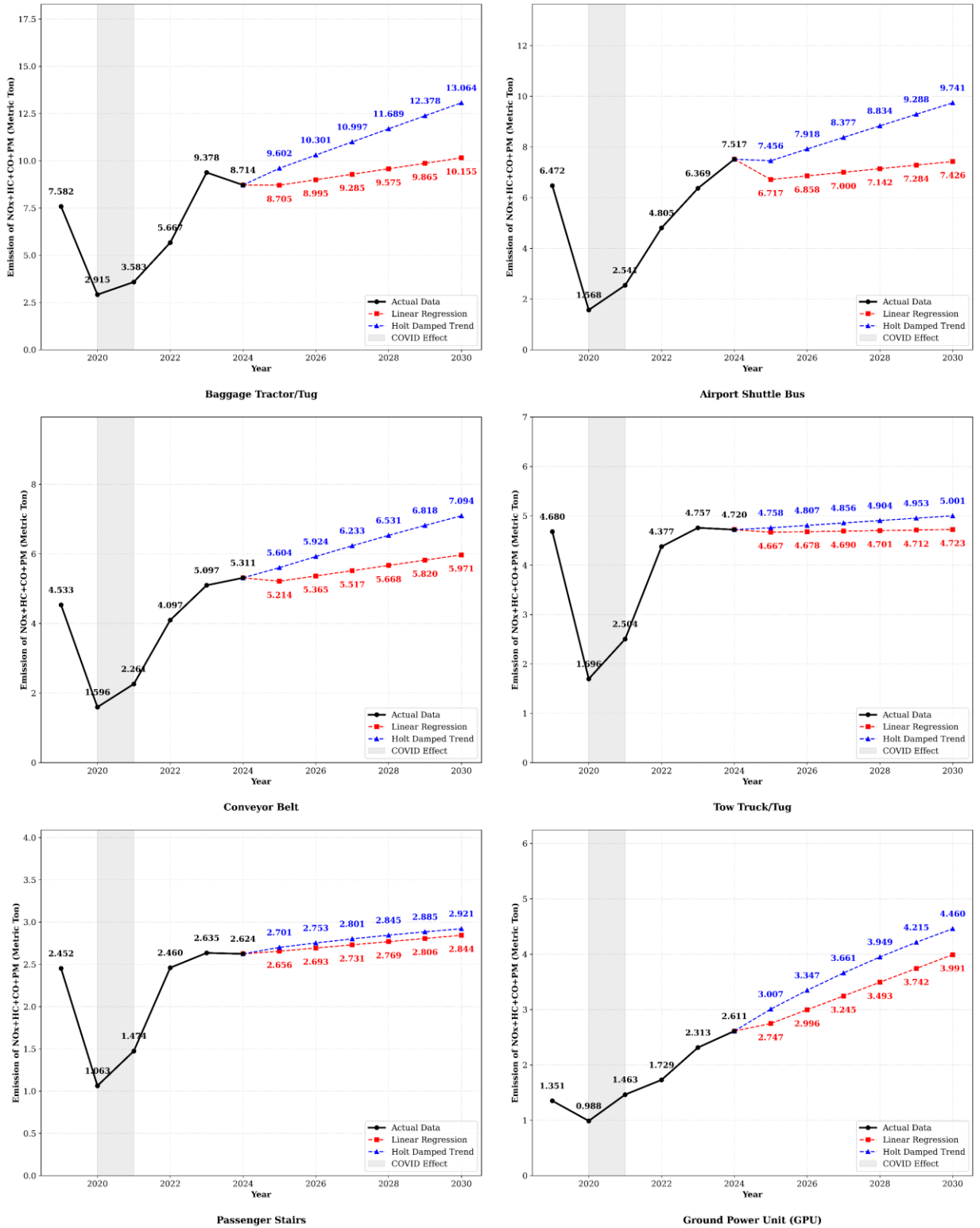
Figure 4.10 Shows the scenario-based forecast of CO<sub>2</sub> emissions under business-as-usual (BAU) and electrification condition on two different forecasting model: Linear Regression and Holt's Damped Trend Models. CO<sub>2</sub> emissions indicated that the highest reduction potential under targeted and mitigation scenarios due to their strong direct relationship with the fuel consumption. Under the BAU, emissions are estimated to reach 1512.538 metric tons (Linear) and 1173.660 metric tons (Holt's) by 2030. Then the 10% implementation of electric GSE could lower the emissions to 1361.281 metric tons (Linear) and 1056.291 metric tons (Holt's) and under the 20% reduction scenario, emissions are further reduced

to 1210.030 metric tons (Linear) and 938.928 metric tons (Holt's). This shows that the approximate annual CO<sub>2</sub> reduction is about the 150 metric tons and 300 metric tons with 10 % & 20% eGSE implementation respectively under Linear Regression model and 117 metric tons and 235 metric tons under Holt's Damped Trend method. This shows that the only the partial implementation of electric Ground Support Equipment (GSE) can significantly decarbonize airport ground operations and contribute importantly toward the long and sustainable climate and mitigation targets.

#### **4.7.5 Integrated Synthesis & Strategic Discussion**

The integrated results from the forecasting and scenario analysis gives a full visualization of how the emissions will change in the future at Tribhuvan International Airport (TIA) from the Ground Support Equipment (GSE). They indicate both the magnitude or extent of the problem and how effectively the targeted interventions or mitigation action work. If things remain same business as usual (BAU), the emissions of all pollutants are expected to keep increasing because of the growth in operations and continued dependence on the traditional GSE technologies. On the other hand, Scenario based results reveal a clear structural break starting in 2026 which reflects that the immediate implementations of electric GSE or actions of interventions on controlling emissions lead to the immediate and emission reductions. Although the 20% scenario always does better than the 10 % scenario, emissions don't go down in absolute terms, which indicates that the only the partial implementation is not enough for long term sustainability. Additionally, the differences between the forecasting models emphasize how important it is to use more than one analytical method when making the decisions to deal with the uncertainty and confirm that the targeted interventions is most require with reliable and sustainable strategy despite the uncertainties in traffic growth. Overall, for achieving the meaning fuel emission reductions at TIA from Ground Support Equipment (GSE), an integrated approach which includes the technological adoption and upgrade, operational optimization, policy driven interventions are must require.

## 4.8 Comparative Emission Assessment of key “Vital-Few” GSE Categories



**Figure 4.11: Historical Trends and Projected Emissions of Key GSE Categories**

Figure 4.11 presents precision assessment of emissions from the predominant Ground Support Equipment (GSE) categories identified through the prior Pareto Analysis as the “vital few”. The forecasting analysis was based on the emission estimates from the Advanced Approach (AA) (2019-2024) and forecasted emissions up to 2030 using Linear Regression and Holt’s Damped Trend methods. The results indicate that the baggage tractors remain the most substantial contributor among all the categories. From 2019 to 2023, emissions went up from 7.582 metric tons to 9.378 metric tons and slightly went down to 8.714 metric tons in 2024. And the forecasts indicates that the growth will continue predicting a total of about 10.155 metric tons of pollutants under Linear Regression and 13.064 metric tons under Holt’s Damped Trend method by 2030. Similarly, the airport shuttle bus category also makes a big difference with the emissions going up from 6.472 metric tons in 2019 to 7.517 metric tons in 2024. Then by 2030, the emission projection shows that the values will be 7.426 metric tons (Linear) and 9.741 metric tons (Holt’s) reflecting the increasing passenger’s movement.

For conveyor belt systems, emissions have been steadily rising from 4.533 metric tons in 2019 to 5.311 metric tons in 2024. Then they are expected to reach 5.971 metric tons (Linear) and 7.094 metric tons (Holt’s) by 2030. Similarly, the tow truck exhibits relatively stable rise with the emission of total pollutants from 4.680 metric tons in 2019 to 4.720 metric tons in 2024 and forecasted to reach 4.723 metric tons (Linear) and 5.001 metric tons (Holt’s) by 2030. On the other hand, passenger stairs emissions increased from 2.452 metric tons in 2019 to 2.624 metric tons in 2024 with the projection of 2.844 metric tons under Linear Regression and 2.921 under Holt’s Damped Trend method by 2030. And the Ground Power Unit (GPU) also show the substantial relative growth with the emissions going from 1.351 metric tons in 2019 to 2.611 metric tons in 2024. By 2030 they are expected to reach 3.991 metric tons (Linear) and 4.460 metric tons (Holt’s).

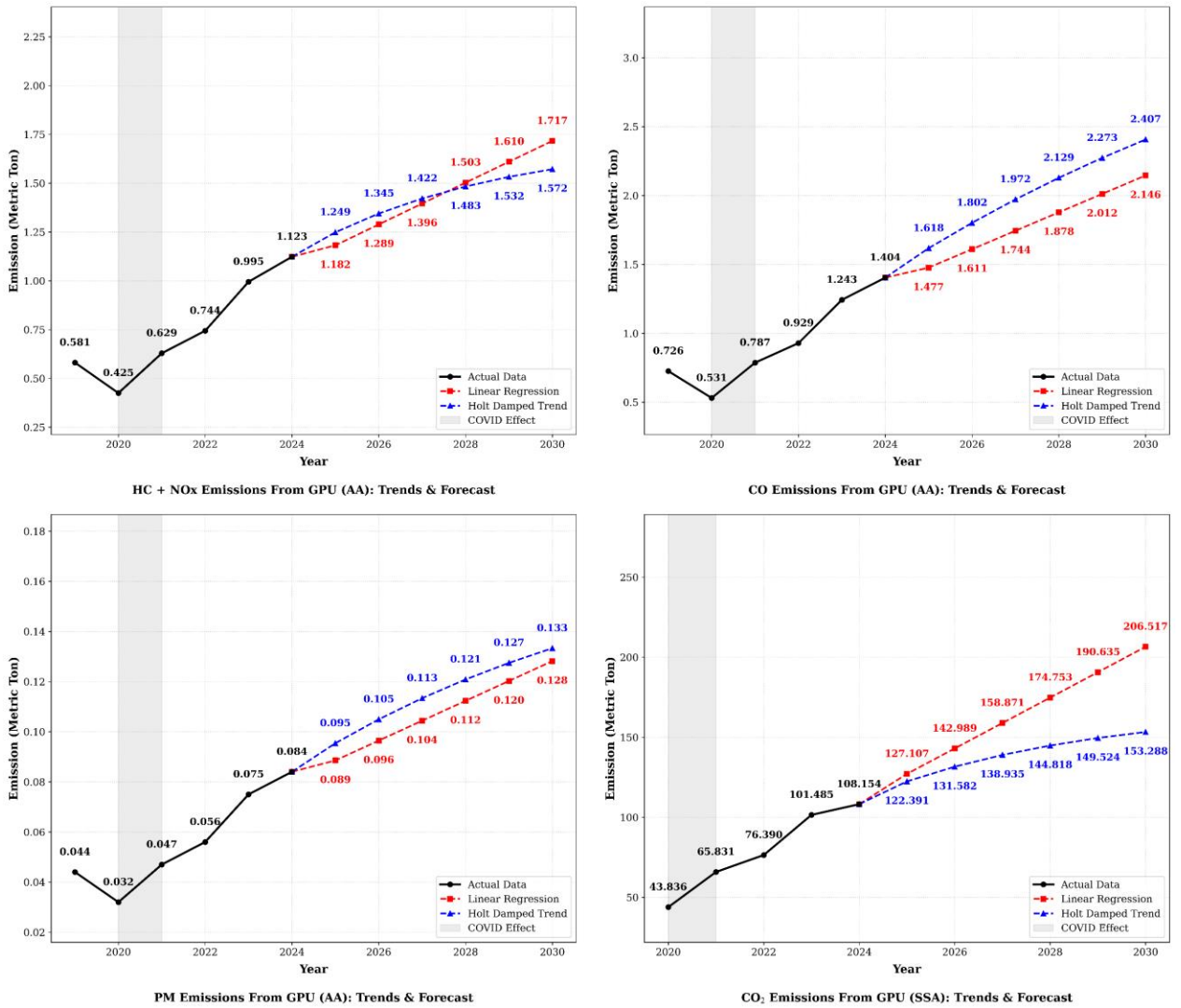
The comparative analysis suggests that the emissions are highly concentrated within a limited number of GSE categories, with the baggage tractors and shuttle buses dominating the overall contributions. From the strategic perspective, above results suggest that the targeted mitigation efforts focusing on these six majors contributing GSE categories would yield the most effective emission reductions. Electrification of baggage tractors, airport

shuttle buses and GPUs offer the substantial potential for improving and reductions of emissions of pollutants while maintaining the operational efficiency at the airport.

#### 4.9 Forecasting and Scenario-Based Analysis of GPU Emissions

The emissions of the pollutants  $\text{NO}_x+\text{HC}$ , CO and PM estimated from the Advanced Approach (AA) and  $\text{CO}_2$  from the Secondary Simple Approach (SSA) was forecasted.

##### 4.9.1 Trends and Projection Analysis of the Emission from the GPU



**Figure 4.12:** Trends and Projections of Pollutants Emissions from GPU

Figure 4.12 shows the trends and the projections value of pollutants from the operation of Ground Power Unit (GPU) under different scenarios. The emissions profile of the GPU indicates the steady rise of emissions. The emissions of NO<sub>x</sub>+HC went up from 0.581 metric tons in 2019 to 1.123 metric tons in 2024 and forecast results show that the emission of NO<sub>x</sub>+HC will be reaching approximately 1.717 metric tons under Linear Regression and 1.572 metric tons under Holt’s Damped Trend Method by 2030. Similarly, the CO emissions rose from 0.726 metric tons to 1.404 metric tons, PM from 0.044 metric tons to 0.084 over the same period 2019-2024 and CO<sub>2</sub> from 43.836 metric tons in 2020 to 108.154 metric tons in 2024. And the projection of the emission of PM under Linear Regression and Holt’s method shows that it will be reaching approximately 1.717 metric tons and 1.572 metric tons respectively and for CO 2.146 metric tons (Linear) & 2.407 metric tons (Holt’s), for PM 0.128 metric tons (Linear) & 0.133 metric tons (Holt’s) and for CO<sub>2</sub> 206.517 metric tons (Linear) and 153.288 (Holt’s) by 2030.

#### 4.9.2 Scenario Analysis of Emissions from the GPU

The implementation of Fixed Electric Ground Supply (FEGP) in 2028 on Linear Regression method results resulted in cumulative emission reductions of 4.830, 6.036, 0.358 & 571.923 metric tons for NO<sub>x</sub>+HC, CO, PM & CO<sub>2</sub> respectively and under delayed implementation scenario in 2030 the corresponding reductions were 1.717, 2.146, 0.126 & 206.517 metric tons which is also shown below in the Table 4.1.

**Table 4.1:** Total Emission Reductions (Metric Tons) under FEGP Implementation Scenarios on Linear Forecasting Results

FEGP Implementation	Year	NO <sub>x</sub> +HC	CO	PM	CO <sub>2</sub>
Scenario 1	2028	4.830	6.036	0.358	571.923
Scenario 2	2030	1.717	2.146	0.126	206.517

Similarly, based on the Holt’s Damped Trend method, the introduction of Fixed Electric Ground Supply (FEGP) from 2028 resulted in cumulative NO<sub>x</sub>+HC, CO, PM & CO<sub>2</sub> emission reductions of 4.587, 6.809, 0.381 & 447.630 metric tons respectively and 1.572,

2.407, 0.133 & 153.288 metric tons when delayed introduction in 2030 which is also shown below in the Table 4.2.

**Table 4.2:** Total Emission Reductions (Metric Tons) under FEGP Implementation  
Scenarios on Holt’s Forecasting Results

FEGP Implementation	Year	NOx+HC	CO	PM	CO2
Scenario 1	2028	4.587	6.809	0.381	447.630
Scenario 2	2030	1.572	2.407	0.133	153.288

#### 4.10 Technical Analysis

A technical comparison between the conventional Internal Combustion Engine (ICE) based Ground Support Equipment (GSE) and Electric Ground Support Equipment (eGSE) was carried out to identify and evaluate their operational characteristics, energy requirements and environmental performance. The comparative study considers the key parameters such as rated engine power, emission standards, towing or operational capacity for ICE equipment and battery capacity, motor power, charging time and operational duration for an electric equipment with a full charge. The comparative study was carried out on major six GSE categories which include Ground Power Unit (GPU), Aircraft Towing Tractor/Tug Airport Shuttle Buses, Passenger Stairs, Baggage Tractor and Conveyor Belt Loader. The detailed study of these GSE categories as given below in Table 4.3:

**Table 4.3:** Comparative Technical Specifications of ICE and Electric GSE

S.N	Ground Support Equipment (GSE)	ICE GSE	Electric GSE
1	Ground Power Unit (GPU)	<p>Engine: Cummins QSB4.5 diesel engine</p> <p>Rated power: 116 kW @ 2000 rpm</p> <p>Emission standard: Tier III</p> <p>Electrical output: 90 kVA</p> <p>Output supply: 115/200 V, 3-phase, 400 Hz</p> <p>Power factor: 0.8</p>	<p>Battery type: Lithium Iron Phosphate</p> <p>Battery capacity: 271 Ah (~160 kWh stored energy)</p> <p>Electrical output: 90 kVA</p> <p>Output supply: 3 × 115/200 V AC, 400 Hz</p> <p>Operational capability: Can supply B737-800 aircraft (~25 kVA average) continuously for ~6 hours</p>
2	Aircraft Towing Tractor (Tug)	<p>Engine: Cummins QSB4.5 diesel engine</p> <p>Rated power: 82 kW (110 hp) @ 2500 rpm</p> <p>Emission standard: Tier III</p> <p>Maximum drawbar pulls: 120 kN</p> <p>Maximum towing capacity: 150,000 kg</p> <p>Maximum driving speed: ~26 km/h</p>	<p>Motor type: Permanent Magnet Synchronous Motor (PMSM)</p> <p>Rated motor power: 60 kW</p> <p>Torque: 350 Nm</p> <p>Rated speed: 1637 rpm</p> <p>Battery capacity: 124.88 kWh</p> <p>Battery voltage: 618.24 V</p> <p>Charging time: 1–1.5 hours (120 kW charger)</p> <p>Operational range: ~115 km per full charge</p>

S.N	Ground Support Equipment (GSE)	ICE GSE	Electric GSE
3	Airport Passenger Bus	<p>Engine: Cummins ISDe210 diesel engine</p> <p>Rated power: 155 kW @ 2500 rpm</p> <p>Engine configuration: 6-cylinder electronically controlled</p> <p>Emission standard: Tier III</p> <p>Passenger capacity: 104 persons (14 seated)</p> <p>Gross vehicle weight: ~22,000 kg</p>	<p>Battery type: CATL Lithium Iron Phosphate battery</p> <p>Battery specification: 618 V / 404 Ah / 249 kWh</p> <p>Battery configuration: 8 battery packs</p> <p>Driving range: ~442 km (with 10% battery remaining)</p> <p>Charging time: 1.5–2 hours using 120 kW charger</p>
4	Passenger Stairs	<p>Engine: Cummins QSF2.8 diesel engine</p> <p>Rated power: 43 kW @ 2500 rpm</p> <p>Emission standard: Stage IIIA</p> <p>Aircraft door sill height range: 2400 mm – 5800 mm</p> <p>Compatible aircraft: A300, A320, A330, B737, B747, B757, B767, B777</p>	<p>Motor type: Permanent Magnet Synchronous Motor</p> <p>Motor power: 20 kW</p> <p>Torque: 95 Nm</p> <p>Battery type: CATL High Voltage Lithium Battery</p> <p>Battery capacity: 70.18 kWh</p> <p>Operational capability: ~55 flights per charge</p> <p>Charging time: &lt; 1 hour for full charging</p>

S.N	Ground Support Equipment (GSE)	ICE GSE	Electric GSE
5	Baggage Tractor	Engine: Cummins QSF2.8 diesel engine Rated power: 50 hp (36 kW) @ 2500 rpm Emission standard: Stage IIIA Rated traction capacity: 35 tons Fuel type: Diesel	Battery capacity: 64 kWh Operational range: ~180 km (unloaded) Charging time: 2–3 hours Rated traction capacity: 32.5 tons
6	Conveyor Belt Loader	Engine: ISUZU C240 diesel engine Rated power: 34.6 kW @ 2500 rpm Emission standard: Stage IIIA Load capacity: 1200 kg uniformly distributed Belt speed: 10–30 m/min Boom lift time: ~30 seconds Maximum inclination angle: 30°	Battery type: CATL Lithium Battery Battery capacity: 60.2 kWh Charging time: 20%–100% ≤ 1 hour Main motor: 20 kW, 95 Nm torque Auxiliary motor: 4 kW, 25.5 Nm torque Load capacity: 1000 kg uniformly distributed Boom lift time: 15–30 seconds Maximum inclination angle: 30° Operational capability: ~70 flights per charge

## 4.11 Economic Analysis

Under the economic analysis, the initial cost of GSE along with the cost ratio between electric and ICE GSE was analyzed and compared. And the economic analysis of the charging station was carried out separately.

### 4.11.1 Capital Cost Comparison of GSE and Policy Impact of Tax Subsidy

#### 4.11.1.1 Initial Cost Comparison with Tax

The initial cost analysis shows a big difference in cost between the diesel powered and electric Ground Support Equipment including the taxes as per the Integrated Customs Tariff Rates for Fiscal Year 2081-82. As demonstrated in the Table 4.4, electric GSE presents consistently higher buying costs across all types of Ground Support Equipment categories. The cost ratio ranges from 1.145 to 2.970 which indicates that the electric GSE need a more capital initially for buying particularly for the high-capacity equipment like Ground Power Units (GPU), Aircraft tow truck etc. On the other hand, the cost differences for the airport passenger buses are relatively lower which suggests that the economic viability of the different types of GSE categories can vary.

**Table 4.4:** Initial Cost & Cost Ratio of ICE & Electric under Taxed Conditions

Ground Support Equipment	Diesel Cost (USD)	Electric Cost (USD)	Cost Ratio
Ground Power Unit (GPU)	44,347	131,697	2.970
Aircraft Towing Truck (A320)	105,246	164,522	1.563
Airport Passenger Bus	209,282	239,525	1.145
Passenger Stairs	88,310	108,633	1.230
Baggage Tractor	42,340	72,583	1.714
Conveyor Belt	42,340	79,842	1.886

#### 4.11.1.2 Impact of Tax Subsidy on Electric GSE

The implementation of the tax subsidy on the electric Ground Support Equipment substantially decreases the capital cost differences between the electric and diesel powered

GSE as shown in the Table 4.5. The cost ratio goes down for all the types of GSE categories with the value ranging from 0.978 to 2.285. Due to the impact of tax subsidy on electric GSE, the cost ratio of airport passenger buses goes down below one (0.978) and all other equipment near about the one except GPU. This indicates that the electric GSE can be cheaper than diesel powered GSE when tax subsidies are implemented and improves the economic viability of the electric GSE over the ICE GSE.

**Table 4.5:** Initial Cost & Cost Ratio under Tax Subsidy on Electric GSE

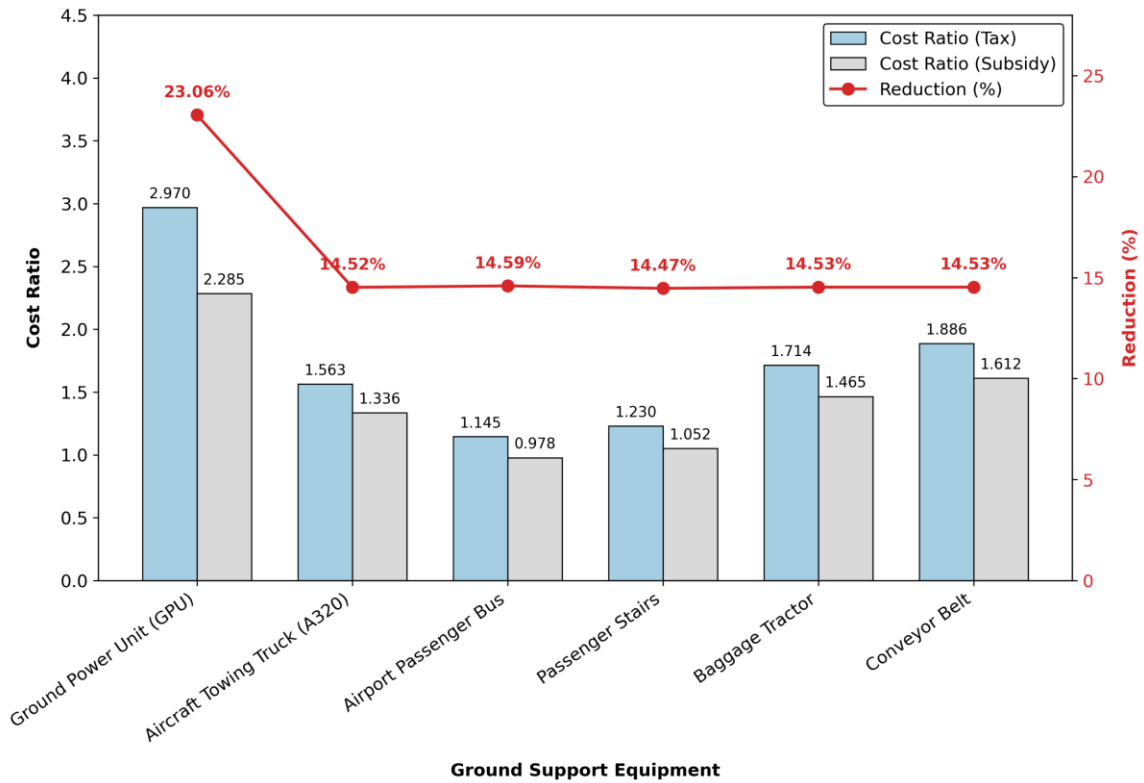
Ground Support Equipment	Diesel Cost (USD)	Electric Cost (USD)	Cost Ratio
Ground Power Unit (GPU)	44,347	101,344	2.285
Aircraft Towing Truck (A320)	105,246	140,641	1.336
Airport Passenger Bus	209,282	204,757	0.978
Passenger Stairs	88,310	92,864	1.052
Baggage Tractor	42,340	62,048	1.465
Conveyor Belt	42,340	68,252	1.612

#### 4.11.1.3 Cost Ratio Reduction Analysis

To measure the impact of the government tax subsidies, the percentage decrease in the cost ratio due to subsidy is calculated and analyzed. The reduction percentage in the Table 4.6 shows the real and actual impact that the subsidy could have in real scenario.

**Table 4.6:** Percentage Reduction in Cost Ratio due to Tax Subsidy

Ground Support Equipment	Cost Ratio (Tax)	Cost Ratio (Subsidy)	Reduction (%)
Ground Power Unit	2.970	2.285	23.06%
Aircraft Towing Truck (A320)	1.563	1.336	14.52%
Airport Passenger Bus	1.145	0.978	14.59%
Passenger Stairs	1.230	1.052	14.47%
Baggage Tractor	1.714	1.465	14.53%
Conveyor Belt	1.886	1.612	14.53%



**Figure 4.13:** Comparative Cost Ratio of ICE and Electric GSE under Tax and Subsidy Scenarios

Figure 4.13 shows the cost ratio comparison between the diesel powered and electric Ground Support Equipment (GSE) in taxed and tax subsidy in electric GSE conditions and percentage reduction in the cost. When the subsidies are applied the cost of GSE goes down for all the types of GSE categories. There is the biggest change in the capital cost of Ground Power Units (GPU), 23.06 % reduction in the cost of GPU and more than 14 % reduction in the cost of other GSE categories. This indicates that how important tax subsidies are in making electric GSE more affordable.

The analysis shows that the taxes make electric GSE more expensive which makes it difficult for electric GSE in comparison to traditional diesel based GSE without the government subsidies and electric friendly policies. When the targeted subsidies and

policies are introduced the capital cost gets much smaller for the electric which makes more economically viable and feasible.

From a strategic planning perspective, electrification efforts should prioritize equipment categories that demonstrate near or full cost parity under subsidy conditions and the equipment which are the contributor to the about 80% of the emissions of the total emission, such as airport passenger buses and passenger stairs. On the other hand, the expensive equipment like GPU may need more financial help or different alternative ways to save on operational costs to make them affordable.

#### **4.11.2 Economic Analysis for Charging Station**

The comparative assessment of the two working charging stations shows that it would be economically viable to setup an EV charging station for electric GSE at Tribhuvan International Airport (TIA). Table 4.7 shows that the charging station of NEA at Ratnapark has a simple payback period of approximately 3.95 years while the privately owned Sital Basti has a shorter payback period of approximately of 2.61 years. The difference is primarily due to the higher electricity selling price per unit at the Sita Basti Station and difference in initial cost due to different charging type and autonomous payment system through APP in NEA charging station despite both charging station having the same electricity purchase cost of NRs. 5.2 per unit. The selling tariff of NRs. 15 per unit compared to the average selling price of NRs. 9 per unit at NEA Ratnapark station leading to the faster cost recovery.

The NEA Ratnapark station has one high capacity “Stand Column DC EV Charger” with two 60kW DC charging guns and one 22kW AC charging socket, total output power of 142kW. In contrast, the Sital Basti Charging station has four “Wall Box DC Charger”, each with one 40kW DC charging guns, which may provide the greater operational flexibility and charger whereas NEA charging station may provide the faster charging rate of an EV.

Based on the comparison, it can be confirmed that the expected payback period for a new charging station at TIA would be likely fall between 2.61 and 3.95 years depending upon the type of charger, charging rate, charging tariff per unit, automatic payment system via APP etc. The recent drops in the costs of buying and installing charger, mobile app-based

payment systems at charging station, availability of different types of chargers make the charging station setup even more economically viable. According to the latest cost information from the EV Charger Nepal Pvt. Ltd., declining charger prices may reduce the payback period below the estimated range making the charging station investment increasingly attractive for airport electric GSE operations.

**Table 4.7:** Comparative Technical & Economic Characteristics of Reference EV Charging Stations

Parameter	NEA Head Office Charging Station, Ratnapark (Kathmandu)	Sital Basti Bidhutiya Sawari Charging Center, Kavrepalanchok
Charger Type	Stand Column DC EV Charger with AC (22 kW socket)	Wall box DC Commercial Charger
Number of Chargers	1	4
Total Charging Guns	3 (2 DC + 1 AC)	4 (1 per Charger)
Output Power	142 kW (2 × 60 kW DC + 22 kW AC)	40 kW per gun
Connection Type	CCS2	GB/T with 1 CCS2 Converter
Transformer Capacity	200 kVA	200 kVA
Electricity Cost (NRs/unit)	5.2	5.2
Demand Charge Price (NRs)	-	25,836
Selling Price (NRs/unit)	9 (Average)	15
Simple Payback Period (years)	3.95	2.61

## CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

- a. The Ground Support Equipment (GSE) fleet at Tribhuvan International Airport (TIA) under Nepal Airlines Corporation (NAC) still relies heavily on the diesel-powered internal combustion engines and the only one electric vehicle is forklift. And the notable portion of the GSE categories is unserviceable. The operational hours rising substantially from 48,907 hours in 2020 to 156,260 hours in 2024 which directly drives higher fuel consumption and emissions due to the long-term reliance on ICE equipment.
- b. The emissions analysis shows a strong relationship between the GSE operations and emissions of pollutants. Emissions of all the pollutants dropped significantly between 2020 and 2021 due to decrease in airport operations as the result of covid-19 pandemic but increased sharply after that reaching their highest levels in 2024. And the Advanced Approach (AA) estimated higher values and more accurate than other two methods as it uses real GSE usage, Power etc. CO<sub>2</sub> emissions were the highest of all the pollutants.
- c. The emissions are not distributed equally across the GSE fleet and highly concentrated among a few equipment categories. Baggage tractors, Airport Shuttle Buses, Conveyor belts, Tow Truck, Passenger Stairs and GPU approximately contributes to 80% of the total emissions and are the priority targets for the electrification to achieve maximum impact.
- d. Under the BAU scenario, all the pollutants indicate a steady upward rise toward 2030. Forecasting shows NO<sub>x</sub>+ HC, CO, PM and CO<sub>2</sub> could reach 20.693, 21.130, 1.442, 1512.538 metric tons under linear regression and 25.323, 25.865, 1.765, 1173.660 metric tons under Holt's Damped Trend methods respectively. And the scenario analysis with the implementation of 10% & 20 % electric GSE implementation in 2026 brings a structural break in emission trends though not sufficient for the absolute reduction.

- e. Ground Power Units (GPU) were one of the significant emission sources. Scenario based analysis indicates that the transition to Fixed Electrical Ground Power (FEGP) by 2028 or 2030 can drastically reduce the localized emissions with the 2028 implementation showing the more cumulative reduction impact.
- f. The comparative study of technical specifications between the ICE and electric GSE confirms that the operational performance of the electric GSE is comparable to ICE in almost all equipment, ICE GSE provide longer continuous operation due to easy and fast refueling and even electric GSE could provide the continuous operation with the proper management of battery charging system and also operate with high efficiency electric battery and motors with zero local emissions. The adoption of electric GSE can significantly reduce fuel consumption, emissions, noise in airport ground handling operations.
- g. Electric GSE needs a bigger initial investment for buying the equipment and building the charging station. But Supportive fiscal policies like government subsidies and tax policies make it even more feasible and less costly. Cost ratio analysis shows that the costs could be the same as diesel alternatives or near around.
- h. The study shows that the emissions are closely related and dependence to growth in operations and reliance on diesel. The partial electrification helps a lot but to make more sustainable, need full, phased and policy supported transition strategy and targeted interventions.

## **5.2 Recommendations**

- a. The present study is limited to the Ground Support Equipment (GSE) of Nepal Airlines Corporation (NAC) as it is the ground handling service provider at TIA international ramp and future work should include the domestic operations and GSE from the domestic operators, other airports in Nepal.
- b. Linear Regression and Holt's Damped Trend method were used in the forecasting due to less data frequency so incorporation of more sophisticated models such as machine learning, ARIMA or hybrid forecasting approached could improve prediction accuracy and better capture nonlinear operational trends in future study with more data frequency.

- c. This study analysis explores only on comparing initial costs and Cost ratio analysis between ICE and electric GSE and does not take into account operating expense such as fuel, maintenance and energy due to limited data availability. So, it should be taken as a preliminary assessment and a more detailed evaluation that includes full life cycle cost analysis would be needed to develop and gain a thorough understanding of the long-term economic benefits.
- d. Similarly, the further studies should conduct a detailed technical and economic analysis of Fixed Electric Ground Power (FEGP) utilizing Nepal's Grid Electricity at TIA, which would evaluate not only the reduction of emissions from the ICE GPU but also the emissions from the APU of the aircraft and the comparative study between electric GPU and FEGP is also recommended to explore the efficient option.
- e. Detailed study on electric GSE battery, battery performance and degradation, charging infrastructure analysis, optimal charging strategies, grid impact, integration with other renewable energy sources specific to Nepal's context and detailed economic analysis considering the dynamic factors such as fuel price, electricity price, inflation should be considered in the future research.

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## APPENDICES

### Appendix A: Tables

**Table A.1:** Default Emission Factors for Primary Simple Approach

Pollutant	GSE Technology 2000-2015		
	Narrow-Body Aircraft	Wide-Body Aircraft	Average
NO <sub>x</sub>	0.56	0.51	0.5350
HC	0.02	0.045	0.0325
CO	0.1	0.225	0.1625
PM	0.015	0.03	0.0225
CO <sub>2</sub>	20	48	34.000

**Table A.2:** Emissions Factors for Aircraft Handling for Secondary Simple Approach

Pollutant	Diesel (g/Kg)	Gasoline (g/Kg)
NO <sub>x</sub>	32.8	7.1
HC	3.4	17.6
CO	10.7	770.4
PM	2.1	0.1
CO <sub>2</sub>	3160	3197

**Table A.3:** EU IIIA Emissions Standards for Non-Road Diesel Engines

S.N	Net Power	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
	<i>kW</i>	<i>g/kWh</i>				
1	130 ≤ P ≤ 560	3.5	-	4	-	0.2
2	75 ≤ P < 130	5	-	4	-	0.3
3	37 ≤ P < 75	5	-	4.7	-	0.4
4	19 ≤ P < 37	5.5	-	7.5	-	0.6

## Appendix B: GSE Images



**Figure B.1:** Ground Power Unit (GPU)



**Figure B.2:** Aircraft Towing Truck



**Figure B.3:** Airport Passenger Bus



**Figure B.4:** Passenger Stairs



**Figure B.5:** Baggage Towing Tractor



**Figure B.6:** Conveyor Belt

## Appendix C: Forecasting Analysis Code

```
import pandas as pd

import numpy as np

import matplotlib.pyplot as plt

from sklearn.linear_model import LinearRegression

from statsmodels.tsa.holtwinters import ExponentialSmoothing

plt.rcParams['font.family'] = 'serif'

plt.rcParams['font.serif'] = ['Times New Roman'] + plt.rcParams['font.serif']

plt.rcParams['font.size'] = 12

plt.rcParams['mathtext.fontset'] = 'stix'

years_hist = np.array([2019, 2020, 2021, 2022, 2023, 2024])

forecast_years = np.array([2025, 2026, 2027, 2028, 2029, 2030])

plot_forecast_years = np.array([2024, 2025, 2026, 2027, 2028, 2029, 2030])

data = {

    'NOx + HC Emissions (AA): Trends & Forecast(2019-2030)': [16.460, 5.958, 8.815,

14.116, 18.128, 18.936],

    'CO (AA): Trends & Forecast(2019-2030)': [16.588, 6.165, 8.989, 14.314, 18.401,

19.188],

    'PM (AA): Trends & Forecast(2019-2030)': [1.132, 0.425, 0.611, 0.974, 1.263, 1.306],

    'rCO$_2$ (SSA): Trends & Forecast(2019-2030)': [0.000, 299.070, 453.625, 682.596,

844.777, 885.000]
```

```
}
```

```
def get_forecasts(years, values, model_indices, last_val):  
    y_train = np.array(values)[model_indices]  
    x_train = years[model_indices].reshape(-1, 1)  
    lr = LinearRegression().fit(x_train, y_train)  
    lr_pred = lr.predict(forecast_years.reshape(-1, 1))  
    hd_model = ExponentialSmoothing(y_train, trend='add', damped_trend=True,  
initialization_method="estimated").fit()  
    hd_pred = hd_model.forecast(len(forecast_years))  
    return np.concatenate([[last_val], lr_pred]), np.concatenate([[last_val], hd_pred])
```

```
idx_aa = [0, 3, 4, 5]
```

```
idx_co2 = [3, 4, 5]
```

```
fig, axes = plt.subplots(2, 2, figsize=(20, 17))
```

```
axes = axes.flatten()
```

```
color_actual, color_lr, color_hd = 'black', 'red', 'blue'
```

```
def add_labels(ax, x, y, color, pos='top', offset_pct=0.03):
```

```
    y_range = ax.get_ylim()[1] - ax.get_ylim()[0]
```

```
    offset = y_range * offset_pct
```

```
    for xi, yi in zip(x, y):
```

```
        va = 'bottom' if pos == 'top' else 'top'
```

```

y_text = yi + offset if pos == 'top' else yi - offset

ax.text(xi, y_text, f'{yi:.3f}', color=color, ha='center', va=va, fontsize=12,
fontweight='bold')

for i, name in enumerate(data.keys()):

    ax = axes[i]

    hist_vals = data[name]

    m_idx = idx_co2 if 'CO$_2$' in name else idx_aa

    lr_f, hd_f = get_forecasts(years_hist, hist_vals, m_idx, hist_vals[-1])

    disp_idx = slice(1, 6) if 'CO$_2$' in name else slice(0, 6)

    ax.plot(years_hist[disp_idx], np.array(hist_vals)[disp_idx], marker='o',
color=color_actual, label='Actual Data', zorder=10, linewidth=2.5)

    ax.plot(plot_forecast_years, lr_f, marker='s', linestyle='--', color=color_lr, label='Linear
Regression', zorder=5, linewidth=2)

    ax.plot(plot_forecast_years, hd_f, marker='^', linestyle='--', color=color_hd, label='Holt
Damped Trend', zorder=5, linewidth=2)

    ax.set_xlabel('Year', fontsize=14, fontweight='bold', labelpad=8)

    ax.set_ylabel('Emission (Metric Ton)', fontsize=14, fontweight='bold')

    y_max_val = max(np.array(hist_vals)[disp_idx].max(), lr_f.max(), hd_f.max())

    y_min_val = min(np.array(hist_vals)[disp_idx].min(), lr_f.min(), hd_f.min())

    ax.set_ylim(y_min_val * 0.7, y_max_val * 1.35)

```

```

add_labels(ax, years_hist[disp_idx], np.array(hist_vals)[disp_idx], COLOR_ACTUAL)

for yr_idx, yr in enumerate(forecast_years):

    v1, v2 = lr_f[yr_idx+1], hd_f[yr_idx+1]

    add_labels(ax, [yr], [v1], COLOR_LR, pos=('top' if v1 >= v2 else 'bottom'))

    add_labels(ax, [yr], [v2], COLOR_HD, pos=('top' if v2 > v1 else 'bottom'))

ax.axvspan(2020, 2021, color='gray', alpha=0.15, label='COVID Effect')

# y=-0.20 is the sweet spot to be close but avoid intersection
ax.set_title(f'{name}', y=-0.15, fontsize=14, fontweight='bold')

ax.legend(loc='lower right', frameon=True, fontsize=12)

ax.grid(True, linestyle=':', alpha=0.6)

ax.tick_params(axis='both', which='major', labelsize=12)

plt.tight_layout(h_pad=3, w_pad=3)


png_filename = 'Emission_Forecast_HighRes.png'
pdf_filename = 'Emission_Forecast_HighRes.pdf'

plt.savefig(png_filename, dpi=600, bbox_inches='tight')
plt.savefig(pdf_filename, bbox_inches='tight')
print(f'Files '{png_filename}' and '{pdf_filename}' generated.")

plt.show()

```

**Appendix D: Official Request and Approval Letters From GSD, NAC**



**TRIBHUVAN UNIVERSITY  
INSTITUTE OF ENGINEERING  
PULCHOWK CAMPUS**

**Department of Mechanical and Aerospace Engineering**

---

*Our Ref:*

To  
The Director,  
Ground Support Department  
Nepal Airlines Corporation  
Tribhuvan International Airport (TIA), Kathmandu Nepal.

Date: 2081/11/21

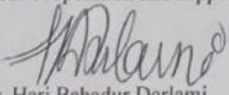
Nepal Airlines Corporation	1	2	3	4
Ground Support Department	File#			
Office of the Director	<small>I. Department/Year II. Department III. Dept. &amp; Region IV. Project</small>			
Repl. No. 491	Date: 2081/11/22			
Time: 15:00	ETK:			
Assigned to:				

**Subject: Requesting Essential Data for Thesis Completion**

**Dear Sir,**

With reference to the subject mentioned above, Mr. Rajesh Thapa, a graduate student from our campus, currently pursuing an M.Sc. in Renewable Energy, is working on his dissertation titled **"Technical and Economic Analysis for the Implementation of electric GSE at TIA & Emission analysis of Existing GSE"** under the department of Mechanical and Aerospace Engineering. For the successful completion of his thesis, he requires historical data (preferably of more than five years) including information on the nature, number, Power rating and fuel type of GSE currently operating at Tribhuvan International Airport (TIA). Additionally, he needs data related to maintenance and operational costs for the economic analysis, fuel consumption (diesel/petrol) and total annual operating hours of each GSE and any other pertinent data.

Therefore, I kindly request for your support in facilitating him on his thesis by providing permission to access the necessary data outlines above as it is intended for academic purposes. Your cooperation and support in this matter would be greatly appreciated.



Dr. Hari Bahadur Darlami  
Associate Professor (Renewable Energy and Alternative Fuel)  
Program Coordinator, M.Sc. Engineering in Renewable Energy  
Pulchowk Campus, Institute of Engineering  
Tribhuvan University

01. GrSD Admin

To coordinate with concerned sections for necessary facilitation, as per rule, as requested from the Dept. IOE.

DBH 123032025-

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Ananda Niketan, Pulchowk, Lalitpur, Nepal, G.P.O. Box 1175, Kathmandu  
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## Appendix E: Acceptance Page



**ADVANCED COLLEGE  
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### Journal of Advanced Journal of Advanced College of Engineering and Management

8<sup>th</sup> May, 2026

#### Letter of Acceptance

**Rajesh Thapa, Surya Prasad Adhikari**

The Editorial Board of Journal of Advanced College of Engineering and Management (jacem) (ISSN No: 2392-4853), is pleased to inform you that your manuscript "**EMISSION ASSESSMENT OF GROUND SUPPORT EQUIPMENT AT TIA AND TECHNO-ECONOMIC COMPARISON OF ICE AND ELECTRIC GSE**" has been reviewed by the referee and accepted for the publication. Your article will be published in the coming issue of Journal of Advanced College of Engineering and Management, Vol. 13.

We are delighted and thankful for considering this Journal as a venue of your valuable research work.


With Regards

Er. Ajaya Shrestha  
Editor-in-Chief, jacem  
Advanced College of Engineering and Management  
Email: [ajaya.shrestha@acem.edu.np](mailto:ajaya.shrestha@acem.edu.np)

# Appendix F: Plagiarism Check

## Rajesh Thapa

### Emission Assessment of Ground Support Equipment at Tribhuvan International Airport and Techno-Economic Compa...

 Tribhuvan University

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