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INSTITUTE OF ENGINEERING
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**Augmentation of Incinerator Performance for Waste-to-Energy (WtE) Conversion:
A Case Study of Tribhuvan International Airport (TIA), Kathmandu, Nepal**

**by
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**A THESIS
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THE DEGREE OF
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**DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
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ABSTRACT

This thesis aims to optimize the incineration system installed in TIA so as to improve the waste-to-energy (WtE system) conversion system by resolving its environmental and operational challenges. The near about 350 tons of waste generation per month at TIA, where around 57% of the waste is combustible, including paper (39%) and plastics (18%). Traditional incinerators employ high diesel consumption and incomplete combustion, hence inadequate energy recovery of indicated emissions (high PM, CO, and NO_x).

The waste characterization, calorific value, emission analysis were performed to study and optimize incinerator performance. The key findings showed that the highest gross calorific value (4,143 kcal/kg) was produced from sun-dried aggregate waste, which is suitable for energy recovery. Emission tests showed compliance with Nepal's standards but needed advanced controls to comply with international standards prescribed by the International Civil Aviation Organization (ICAO).

To achieve meaningful improvements, the study's author proposed more sophisticated technology, such as selective catalytic reduction (SCR) system, organic Rankine cycle (ORC) technology that would increase energy recovery efficiency up to around 65% and PM emissions reduced below 10 mg/Nm³. A techno-economic analysis identified some financial constraints for upgrades. The payback period while using seven days' sun dry mixed combustible waste i.e. Sample 3 was 2.61 years.

The study finds that TIA can reduce landfill dependence significantly, produce renewable energy (up to 3,311.3 MWh annually) which means 259.9 kW capacity of standby power house was available during the operation of installed incinerator plant at full load capacity and comply with global sustainability goals through the modernization of its incineration system. The recommendations focus on the adoption of ORC, SCR and Pre-treatment of waste.

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LIST OF ABBREVIATIONS

C&D	Construction and Demolition Debris
CAPEX	Capital Expenditure
CEMS	Continuous Emission Monitoring Systems
CFD	Computational Fluid Dynamics
CFM	Cubic Feet per Minute
CO₂	Carbon Dioxide
DO	Discrete Ordinate
FD Fan	Forced Draft Fan
GCV	Gross Calorific Value
GHG	Greenhouse Gas
HCl	Hydrochloric Acid
HF	Hydrogen Fluoride
HP	Horsepower
HSD	High-Speed Diesel
ICAO	International Civil Aviation Organization
ID Fan	Induced Draft Fan
IRR	Internal Rate of Return
KTM	TIA (IATA code)
kW	Kilowatt
LCA	Life-Cycle Assessment
LCoE	Levelized Cost of Electricity
MCB	Miniature Circuit Breaker
Mmwg	Millimeters Water Gauge
MOC	Material of Construction
MSW	Municipal Solid Waste
NAST	National Academy of Science and Technology
NO_x	Nitrogen Oxides
OPEX	Operational Expenditure
ORC	Organic Rankine Cycle
PID	Proportional-Integral-Derivative
PLC	Programmable Logic Controller
PM	Particulate Matter
PVC	Polyvinyl Chloride
RETS	Renewable Energy Test Station
SCR	Selective Catalytic Reduction

SNCR	Selective Non-Catalytic Reduction
SO_x	Sulfur Oxides
SPM	Suspended Particulate Matter
TIA	Tribhuvan International Airport
TOC	Total Organic Carbon
VNKT	TIA (ICAO code)
VOCs	Volatile Organic Compounds
WtE	Waste-to-Energy

CHAPTER ONE: INTRODUCTION

1.1 Background

Airports are integral to global transportation, acting as hubs for passengers, cargo, and aircraft operations. The steady growth in passenger numbers and flight frequencies has led to a proportional increase in waste generation, adding pressure on airport waste management systems and emphasizing the need for sustainable practices. As critical infrastructures, they support economic growth, international connectivity, and cultural exchange. However, airports also present significant environmental challenges due to their complex operations and high resource consumption. The growing number of passengers and flights worldwide has amplified the environmental footprint of airports, necessitating the adoption of sustainable practices. In response, the International Civil Aviation Organization (ICAO) has emerged as a pivotal body, guiding global aviation toward environmentally responsible operations. ICAO's initiatives emphasize integrating sustainable practices into airport planning, design, and operations [1], [2].

One major environmental concern at airports is waste generation and management. Airports produce diverse waste streams, including municipal solid waste, hazardous materials, and confidential documents. The complexity of airport activities, such as retail, dining, and maintenance, contributes to significant waste generation. Effective waste management is critical for environmental protection, operational efficiency, and compliance with international regulations. Inadequate waste disposal can lead to pollution, wildlife hazards, and greenhouse gas emissions. To mitigate these impacts, many airports are transitioning toward circular economy models and WtE systems [3], [4].

Energy recovery and efficiency play a vital role in modern waste management systems at airports. Technologies such as cogeneration, which simultaneously produces electricity and heat from waste, and thermal recovery systems, which capture and repurpose heat energy, are increasingly being integrated into airport operations to enhance sustainability. By integrating energy recovery systems into incinerators, airports can convert waste heat into electricity or other usable forms of energy. This not only reduces reliance on conventional energy sources but also contributes to emission reductions. Emission monitoring is equally critical; comprehensive data on pollutants such as dioxins, furans, and particulate matter ensures compliance with environmental standards and guides improvements in operational efficiency [5], [6].

Daily waste collection at TIA includes a variety of waste streams, ranging from organic and recyclable materials to hazardous substances. The waste characteristics highlight the need for tailored management strategies, as improper segregation or disposal can exacerbate environmental risks. Historical utilization of incinerators at TIA has revealed gaps in operational efficiency and energy recovery. The incinerators, primarily installed over one decades ago, rely on outdated combustion technology that consumes excessive amounts of diesel fuel. This inefficiency contributes to higher operational costs and significant emissions of pollutants, including carbon dioxide and fine particulate matter, underscoring the urgent need for modernization. Emissions data have shown elevated levels of harmful substances, underscoring the need for modernization and optimization of waste management processes [3], [7].

TIA (IATA: KTM, ICAO: VNKT), Nepal's primary international gateway, connects Nepal to over 40 destinations in 17 countries. With Approximately 350 tons of waste generated monthly due to passenger and operational activities, managing this waste effectively is critical for both operational efficiency and environmental compliance. Serving over 2,000 passengers per hour across its domestic and international terminals, TIA generates substantial waste daily. The airport's reliance on incinerators for waste disposal has proven essential for handling sensitive materials such as confidential documents, but challenges remain in ensuring complete combustion, minimizing emissions, and recovering energy. Modernizing TIA's waste management systems through advanced incineration technologies and robust monitoring mechanisms can align its practices with ICAO's environmental standards and Nepal's sustainability goals [1], [2], [8].

Leveraging successful examples from global airports, such as Changi Airport's energy recovery initiatives, TIA can enhance its operational efficiency while contributing to broader environmental goals. By addressing existing gaps in waste management and focusing on energy recovery and emissions reduction, TIA has the potential to serve as a model for sustainable airport operations [6], [7].

1.2 Statement of problem

TIA, the maingateway of Nepal, is struggling with huge waste management related problems. With more than 2,000 passengers processed every hour, theairport produces a wide range of waste streams, including municipal waste, hazardous materials and confidential paperwork. Existing incineration technology and operationalconditions lead to inefficient combustion and emissions of toxic pollutants such as dioxins and particulate matters. Air and solid waste emissions potentially jeopardizing public health, degrading

air quality, and creating additional landfill dependence that contributing to environmental degradation and high operational cost [1], [3]. TIA's incinerators are also very fuel-hungry, running mostly on diesel, contributing to greenhouse gas emissions. Not having energy recovery systems means wasted potential energy, leading to operational inefficiencies. Insufficient data monitoring further hinders process optimization, making it difficult to address inefficiencies or comply with ICAO's environmental standards [5]

Optimizing incineration, integrating energy recovery, and improving data monitoring are critical for sustainable operations. Successful examples, like Changi Airport's energy recovery systems, demonstrate the feasibility of these measures, offering TIA a path to reduce emissions, enhance efficiency, and align with ICAO guidelines while serving as a model for sustainable aviation waste management [7].

1.3 Research Questions

- What are the key characteristics of waste generated at TIA, and how can improved waste segregation and pre-processing enhance incineration efficiency?
- How can the current incineration system at TIA be optimized to improve combustion efficiency and reduce harmful emissions such as dioxins, furans, and particulate matter?
- What is the energy recovery potential of the incineration process at TIA, and how can waste heat be effectively converted into usable energy forms, such as electricity or thermal energy?
- What are the baseline emissions from the existing incinerators, and what advanced technologies (e.g., scrubbers, catalytic converters) can be implemented to ensure compliance with ICAO and local environmental standards?

1.4 Objectives

Main objective

- To develop a comprehensive approach for augmenting the performance of the incineration system at TIA for sustainable waste management.

Specific objectives

- To analyze waste characteristics and identify pre-processing needs to enhance incinerator's efficiency.
- To analyze the incineration performance of TIA to reduce emissions and improve sustainable waste management.
- To evaluate Potential Energy Recovery from the Incinerator.
- To analyze emissions from Incinerator.

1.5 Limitations

The limitations of implementing energy from airport waste initiatives at TIA may include:

- Access to detailed data on the current incineration system at TIA may be limited.
- The research may not explore all potential WtE conversion technologies due to resource constraints.
- Implementation of proposed improvements was requiring cooperation from TIA authorities.
- The experiment is conducted outsource due to lack of instrument facilities available at site.

CHAPTER TWO: LITERATURE REVIEW

2.1 Airport Waste: A Global Outlook

Airports are major ecosystems because they carry out multiple operations pursuing they generate various streams of waste such as services to passengers, retail shop, aircraft maintenance, construction, etc. The efficient handling of these waste products is important in minimizing their effect on the atmosphere and aligning with our objectives for environmental sustainability worldwide.

The waste generated at airports can be classified as municipal solid waste (MSW), construction and demolition debris (C&D), hazardous materials, and deplaned waste from aircraft [9]. Airports are like little cities, generating tons of waste that need to be handled properly. Key to sustainable waste management are reduction, reuse, recycling and energy recovery (milliontons) as highlighted in the ICAO waste hierarchy [9].

A systematic review of waste management practices at airports worldwide found all of the airport studies highlighted a need for sustainable waste diversion strategies to reduce landfill dependence [10]. The authors noted the challenges posed by the COVID-19 pandemic to waste composition and the rise of hazardous waste streams leading to the need for innovative waste management solutions [10].

This paper studied the characteristic nature of MSW and assessed the possible waste management strategies through a case study at Astana International Airport based on MSW generation and greenhouse gas emissions (GHG). Sarbassov et al. (2020) showed that integrated recycling and WtE systems can reduce emissions significantly and improve operational efficiencies [11]. Likewise, Istanbul Airport adopted a waste zero plan and can recycle up to 49% of their waste, and significantly reduces waste that goes to landfills, as per the findings of [7]. This demonstrates the possibility of adopting circular economy principles at airports [7].

However, one of the examples of sustainable waste management practices is Kansai International Airport. A study by Baxter et al (2018) described how the airport utilized highly sophisticated waste sorting and recycling systems to reduce landfill waste in compliance with strict environmental regulations [12].

At TIA, Nepal, The multi-dimensional problems of waste management in Nepal at TIA include poor segregation systems, old-age incineration technology and absence of data monitoring. There were no education-based systematic waste management strategies

and there were no regulated Solid waste management workshops or collaboration from stakeholder as described by Manandhar (2024) [13].

On a broader perspective, Ferrulli (2016) has recently proposed the Green Airport Design Evaluation (GrADE) framework, which allows for a similar assessment regarding the sustainability level of airport infrastructure [14]. As a reference, Ferrulli (2016) proposed a new sustainability framework for airports that incorporates environmental, operational, and regulatory parameters to help improve sustainable airport design and operations [14].

Overall, these studies highlight the necessity of implementing concrete waste management practices. Airports worldwide are embarking on a multi-faceted transition towards zero-waste and WtE systems, utilizing innovative methods and policy frameworks to minimize their environmental impacts. This not only alleviates waste management issues, but when practiced, can lead to the generation of renewable energy and conservation of resources.

2.2 Characterization of Airport Waste

Airports are a major source of waste due to the multitude of activities that take place landside and airside. Landside functions, like retail, food and beverage, and administrative activities, add significantly to municipal solid waste (MSW); while airside operations, like aircraft maintenance, aircraft ground handling, and cargo operations, reuse with specialized waste streams, including hazardous waste and lavatory waste. Food waste, paper, and plastics are typically the largest contributors to airport waste (MSW). Food waste is one of the most prominent types of waste generated in terminals and on planes, due to catering operations, and airport waste management represents a complex challenge [3], [5].

One interesting aspect of airports is the heterogeneity of waste streams. For example, deplaned waste varies as a function of two key factors, length of flight as well as the type of service (i.e., full-service airlines generate more waste than low-cost carriers, although "waste" on a low-cost carrier flight may be less food portions and more drinks through extra purchases) – with long-haul flights generating much more compared to short-haul flights because of flights providing meals and drinks. Maintenance activities can generate various hazardous wastes (e.g., chemicals and oils) that must be handled properly for regulatory compliance. Lavatory waste is a very complex waste stream to manage as it is an intermediate waste that first needs to be treated to eliminate the health and environmental hazards [7], [12].

Waste characterization enables improved waste management practices, as shown by insights of global case studies. Kansai International Airport, for example, performed detailed audits showing that a large percentage of waste was recyclable or compostable, allowing for specific interventions to reduce landfill use. Istanbul Airport found organic waste to be the major component, which was successfully directed to composting facilities. These results highlight the need for detailed waste characterization to improve recovery of resources and decrease environmental effects [4], [12]

Automated sorting systems and audits can enable airports to categorize waste streams and find opportunities for recycling and energy recovery. Ultimately, lessons on successful implementations at San Francisco International Airport and Oslo Gardermoen Airport have shown that ambitious recycling streams complemented by composting and waste-to-energy (WtE) systems contribute to reduced landfilling and both economic and environmental benefits. A complete characterization and continuous monitoring of waste generated at the airport are paramount to align waste management strategies by airports with overall sustainability indicators worldwide [4], [6].

2.3 Energy Recovery and Efficiency

Energy recovery is a key component of modern waste management systems, and notably in WtE incinerators. These systems are solving critical energy problems globally by turning waste into usable power, cutting down the reliance on fossil fuels, and helping meet renewable energy goals. These advanced systems enable the conversion of heat energy produced through waste incineration into electric power and thermal energy, thus considerably curbing landfill reliance and facilitating eco-friendly energy generation. It has been demonstrated in studies that the combination of both cogeneration and Organic Rankine Cycle (ORC) technologies can increase the energy recovery efficiency by as much as 30% over traditional systems. For example, the thermal and electrical efficiencies of a WtE plant located in Denmark were studied by [4], [6] who show significant improvements by optimizing the combustion process and waste feed composition.

Municipal waste treatment in Europe, more than 90 million tons municipal waste are treated each year, producing about 40 TWh of electricity and 90 TWh of heat with highly efficient energy recovery systems [4]. Innovations in thermal modeling have facilitated the precise regulation of heat transfer phenomena, thereby optimizing energy extraction and minimizing operational expenses [5]. The operation of furnaces needs to be stable because fluctuations in the input of waste and combustion temperature can negatively influence

the energy output. Advanced control systems optimize combustion dynamics and ensure linear energy recovery rates [3], ensuring a minimum possible residue.

More of the energy recovery systems construct and integrate WtE with district heating, seen in Sweden and Denmark, which allows for the utilization of surplus heat from incinerated materials to heat neighboring residential sectors and lessen reliances on fossil fuels [1]. Although this system has been highly successful in those areas, in new territories scalability faces barriers of infrastructure costs, climate conditions, and regulations. For example, the high upfront cost of district heating networks can deter investment in developing economies, while the efficiency of the heat transfer may be compromised in warmer regions where heating demand is lower. It needs nuanced solutions like public-private partnership, innovative financing models and localized deployment of the technology. Comparative studies on the sustainability potential of WtE plants have corroborated the emissions associated with fossil fuels [15], [16], similar to research on alternative fuels and auxiliary energy sources, e.g., biomass co-firing, which have a considerable potential for further improving the sustainability of WtE plants [4], [12].

Also, (2011) showed that disposal of certain waste types especially PVC and impregnated wood are critical as they strongly influence energy recovery and emission. Their analysis showed that controlling the feed of waste could optimize combustion efficiency while minimizing pollutant formation. The findings from this study can provide effective guides for the pre-treatment of MSW at TIA to maximize the calorific value and minimize the operational disruption.

The study by Kwon et al. (2024) provides additional insights by analyzing the operational data for 44 incineration facilities in South Korea [17]. They found that average energy recovery efficiency was 71%, and that using waste heat boilers integrated with incinerators was advantageous. These boilers recovered thermal and electric energy, resulting in a reduction of greenhouse gas emissions. These methodologies are useful in informing strategies to enhance the energy recovery performance of your case study's incinerator.

2.4 Emissions Measurement, Monitoring and Environment Input

Air emissions are closely connected to the environmental impact caused by waste incineration, which illustrates the importance of real-time monitoring and mitigation strategies. When waste gets burned, emissions of particulate matter (PM), nitrogen oxides (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOCs) and heavy metals are released. To comply with strict regulatory emission limits and reduce the release of

pollutants, a number of advanced flue gas cleaning technologies have been implemented, including selective catalytic reduction (SCR), activated carbon filters, and wet scrubbers [4].

Well-kept journals on waste incineration, such as the Journal of the Air Pollution Control Association and Atmospheric Environment, record studies of municipal waste incinerators in Japan and Germany confirming the success of advanced emission controls. Systems such as selective catalytic redactors (SCR) have reduced NO_x emissions by over 85%, and wet scrubbers have been instrumental in removing acid gases such as HCl in order to meet stringent environmental standards [7], [12]. Emissions profiling has further revealed a correlation between the composition of waste and the concentration of specific pollutants, proving that the prevention of dioxins at the source also requires the pretreatment of specific materials of high chlorine content, such as PVC [5].

Real-time monitoring technologies such as infrared spectrometers and mass spectrometry allow for accurate emissions tracking. A WtE facility in Copenhagen installed continuously emissions monitoring systems and reduced nitrogen oxide levels by 25% over three years. Using these advanced techniques, they were able to fine-tune certain parameters at runtime based on actual conditions in the environment, thus obtaining maximum efficiency and at the same time adhering to environmental law. These technologies offer real-time data on pollutant concentrations that allow continuous tuning of incineration conditions to optimize combustion and minimize emissions [12]. The reviewed studies demonstrate the simultaneous relevance of strict emission limits and energy recovery in waste incineration. The ammonia-based SNCR process achieved not only lower NO_x emissions than were regulated, but also with lower ammonia slip, contributing to both environmentally sound emissions management and sustainability. PRF production not only drives down the reliance on landfilling and greenhouse gaseous emissions through optimized combustion and energy recovery but facilitates a myriad of other advantages in improving global sustainability objectives [5].

The new incinerators with advanced emission controls in Denmark and other countries remove up to 99 percent of harmful pollutants, making the decision to incinerate socially acceptable among environmentally-conscious citizens. Lastly, the usage of WtE technologies have mitigated greenhouse gas emissions by not only replacing the use of fossil fuels through offset worth roughly 1 million tons per year [18]. Significant power generation for local energy grids[6] indicates that existing municipal incinerators with upgraded emission controls in South Korea, for example, reduce total particulate matter emissions to 40% of their previous output.

2.5 Incinerator Utilization History and Optimization

The use of incinerators at TIA dates back to a time when waste generation was significantly lower than today's level, making it difficult to keep pace with current waste volumes using outdated technology. The incinerators were originally designed to handle small amounts of waste, and they are now facing inefficiencies that include poor combustion, excessive fuel use, and high emissions. For example, incineration emissions data collected by TIA showed that dioxin concentrations exceeded recommended levels 20%, necessitating urgent upgrades of TIA's incinerators [18].

Improving the performance of incinerators involves a range of both technological innovations and operational adjustments. Studies of municipal incinerators have demonstrated that combustion efficiency can be improved by 15-20% through tuning operation parameters such as air supply and furnace temperature. By implementing real time monitoring systems on site in Switzerland, operators were capable of addressing inefficiencies in the operation of the waste to energy plant as they arose, achieving the benefits of reducing emissions by 25% and increasing energy recovery rates [6].

High-efficiency incinerator technology, including modular configuration and plasma arc gasification, are good technologies to be used. But these technologies also have challenges, including high up-front capital costs and complex operational requirements. This, for instance, requires high-end infrastructure and energy input to be effective, which may not always be viable in resource-poor region. Moreover, the needed maintenance and operational skills for such systems can become another challenge for large-scale adoption. Targeted subsidies, operator training programs, and scaled pilot projects could alleviate these shortcomings and make them more practical and less costly to implement. Such systems offer advantages in combustion temperature and WtE conversion control, leading to cleaner emissions and improved energy yields [19].

2.6 Techno-Economic Assessment of WtE Incineration

The study by Zeng et al. : A techno-economic analysis of waste-to-energy incineration in the context of Java Island in Indonesia [18]. Key findings include:

- **Cost Effectiveness:** The LCoE of WtE incineration was estimated as 0.044 USD/kWh (more competitive than this region's average electricity price of 0.069 USD/kWh).

- **Electricity Generation Opportunity:** The incineration of municipal solid waste in Java Island can contribute to 3.72% of Indonesia's renewable energy target with a total estimated electricity generation of 2,316,523 MWh/year (by 2025).
- **Environmental benefits:** Transitioning from landfilling to WtE incineration practices can help to lower carbon emissions by 41% and realize higher benefits in mitigating the impacts of global warming potential, acidification and eutrophication.
- **Economic Aspect:** Each of the observed cities of Java Island is calculated to have a positive net present value (NPV), indicating economic potential for WtE. Internal rates of return (IRR) values spanned 29% to 56%, greatly higher than the discount rate of 3%

This evaluation highlights the feasibility of WtE incineration on an extensive scale in urban areas with considerable waste generation. These results are directly relevant to the case of TIA, whose implementation of WtE technologies on the state level can yield similar economic and environmental benefits.

CHAPTER THREE: METHODOLOGY

This chapter establishes an approach to airport waste management systems, focusing on energy recovery and emissions measurement, and on incineration of secret papers. Using document and technology reviews, primary data collection, incinerators performance enhancement, emissions testing, and a techno-economic-environmental analysis, this approach provides data for sustainable and efficient waste management practices in Nepal's aviation. The conceptual framework is as follows: Figure 3: 1

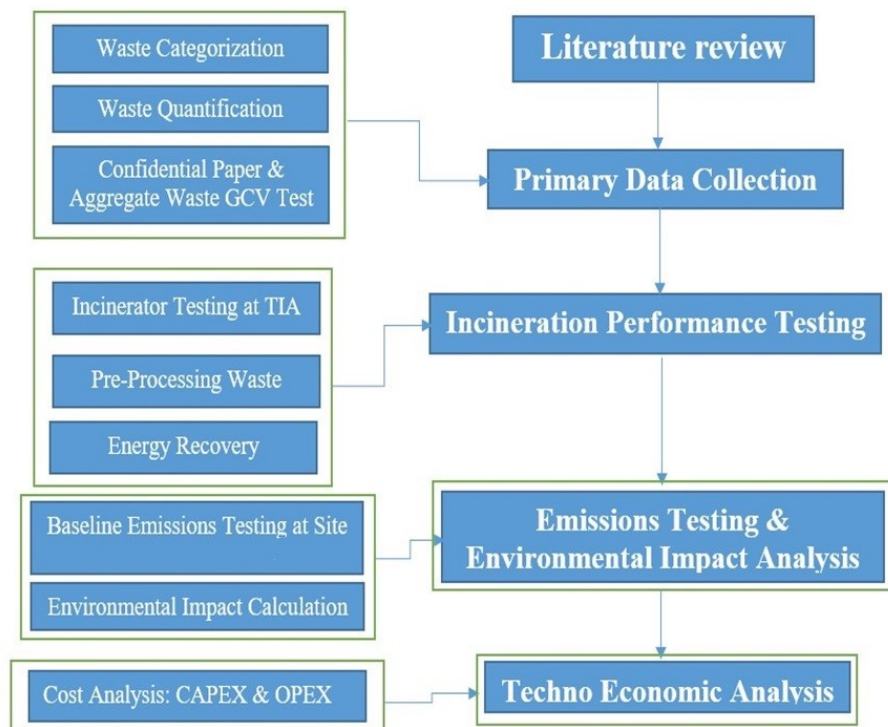


Figure 3.1: Conceptual Framework

The research methodology is divided into 5 phases, with each segment built to ensure systematic approaches to solving the challenge of optimizing the incineration system in TIA for sustainable waste management.

It starts with the literature study for setting up an overview of important aspects linked with the research. It also examines available and prospective approaches to tapping waste heat and turning it into useable forms of energy like electricity or thermal energy. The cost for different potential emission control technologies, suitable for incineration systems, are also analyzed and this serves as a reference for possible upgrades to incineration systems in the future in Nepal.

3.1 Primary Data Collection and Analysis

The second stage is to quantify and characterize the waste being produced at TIA. Waste is modelled as paper and paper products waste, plastic and plastic products waste, glass, metal, rubber & textiles, organic waste, deplaned and confidential paper streams for a clearer understanding of its composition and possibilities of recovering energy. Proximate and ultimate analysis of paper waste is carried out to determine moisture content, calorific value, and elemental composition. The existing emissions data, including dioxins, furans, particulate matter (PM) and greenhouse gases (GHGs) and operational parameters (temperature, residence time, and excess air) are analyzed. By collecting and account for such data, the current conditions of the incineration system can be assessed and also deductions on possible improvements in the design or inputs that can be made for an efficient outcome.

3.1.1 Sampling Strategy

The sampling process at TIA was designed to characterize waste streams and optimize incinerator feed composition for maximum energy recovery, following ASTM D5231 (Standard Guide for Composite Sampling of Municipal Solid Waste) for municipal solid waste (MSW) composite sampling. Three waste samples were collected from TIA to assess calorific value, composition, and combustion efficiency:

- Sample 1: Official paper waste (confidential documents).
- Sample 2: Aggregate waste (mixed airport combustible waste).
- Sample 3: Aggregate waste (mixed airport combustible waste with 7 days Sun dry).

3.1.2 Methodology

The sampling method is representative sampling.

- Sample 1 (Paper Waste): Collected from Store Section of TIA (5 kg, homogenized).
- Sample 2 (Aggregate Waste): Gathered from daily airport waste collection site (10 kg, quartering method to reduce bias. The quartering method, also known as coning and quartering, is a technique used to reduce the size of a sample while maintaining representativeness, by dividing the sample into quarters and discarding two diagonally opposite quarters).

- **Sample 2 (Aggregate Waste):** Gathered from daily airport waste collection site (10 kg, quartering method to reduce bias. The quartering method, also known as coning and quartering, is a technique used to reduce the size of a sample while maintaining representativeness, by dividing the sample into quarters and discarding two diagonally opposite quarters).
- **Sample 3 (mixed airport combustible waste with 7 days Sun dry):** The aggregate waste sample, representing TIA's mixed combustible waste stream (paper, plastics, textiles, and organic residues), was collected from airport waste collection site, sun-dried for 7 days to simulate typical pre-processing conditions, and homogenized per ASTM D5231.

3.1.3 Calorific Value Testing

Instrument: Microprocessor Bomb Calorimeter (Toshniwal CC01/M3). Standard: ASTM D5865 (Gross Calorific Value).

Microprocessor-Based Bomb Calorimeter

A microprocessor-based bomb calorimeter is an advanced device used to measure the Gross Calorific Value (GCV) of solid and liquid fuels, including waste materials like paper and aggregate waste. It operates on the principle of constant-volume combustion (oxygen bomb method) and uses microprocessor-based controls for precise temperature measurements and calculations.

Process of Finding the Gross Calorific Value (GCV) of Waste (Fuel)

- **Sample Preparation** A small, dried, and finely powdered sample (typically 0.5–1.0 g) of the waste material (e.g., paper or aggregate waste) is weighed accurately. The sample is compressed into a pellet to ensure complete combustion.
- **Loading the Bomb Calorimeter** The pellet is placed in a crucible inside a stainless steel bomb. A fuse wire (usually made of nickel-chromium) is connected to the electrodes and placed in contact with the sample. The bomb is filled with high-purity oxygen (25–30 atm) to ensure complete combustion.
- **Immersion in Water & Temperature Measurement** An electric current is passed through the fuse wire, igniting the sample. The waste combusts completely, releasing heat, which raises the temperature of the surrounding water.

- Temperature Rise Measurement The microprocessor records the temperature change (dT) with high precision. The system accounts for heat losses and corrections (e.g., fuse wire contribution, nitric acid formation).
- Calculation of GCV

The GCV is calculated using the formula: $GCV = (W \cdot dT - E_{corr})/m$ Where: W = Water equivalent of the calorimeter (heat capacity, in kcal/°C) dT = Temperature rise (°C) E_{corr} = Corrections (fuse wire heat, acid formation, etc.) m = Mass of the sample (kg)

Assumptions & Boundary Conditions

- Complete Combustion: The sample fully burns in the oxygen-rich environment. Any unburnt residue is considered negligible.
- Adiabatic Conditions: The calorimeter is assumed to be perfectly insulated (no heat loss to surroundings). In reality, corrections are applied for minor heat exchange.
- No Side Reactions: The combustion produces only CO₂, H₂O, and negligible SO₂/NO_x (though corrections may apply). Sulphur and nitrogen in the waste may form H₂SO₄ and HNO₃, contributing slightly to heat release.
- Standard Conditions The test follows ASTM D5865 or ISO 1928 standards for solid fuels. The reference temperature is typically 25°C.

3.2 Incineration Performance Testing

The third phase addresses performance testing of the incineration system at TIA, such as, but not limited to, outdated combustion technology, high fuel consumption, and poor emissions control. The practical tests were carried out, i.e. "burning" aggregate waste, seven days sun dry mixed waste and "confidential" paper waste, all generated at the TIA. Moreover, energy recovery systems, including Organic Rankine Cycle (ORC) systems and heat exchangers, are adopted for the conversion of waste heat to useful arising of electricity and heating.

3.3 Emissions Testing & Environmental Impact Analysis

Phase four includes baseline emissions testing to measure the four major pollutants from existing, currently-operating incinerators carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter.

Emission Data Logging and Testing Process

The emission test data from the 200 kg/hr incinerator at TIA was logged using standardized methods to assess compliance with Nepal’s National Emission Standards. Below is a detailed breakdown of the process, boundary conditions, and assumptions.

3.4 Emission Testing Process

- Pre-Test Preparations: Selection of Sampling Points: Sampling ports were installed at the stack outlet (30m height) to ensure representative gas collection. The IS 11255 (Part 1)–1985 guidelines were followed for particulate matter (PM) sampling.
- Calibration of Instruments:
 - Flue Gas Analyzer: Calibrated for CO, NO_x, SO_x, and O₂.
 - Gravimetric Setup: Calibrated for Suspended Particulate Matter (SPM).
 - Gravimetric Setup: Calibrated for Suspended Particulate Matter (SPM).
 - Fyrite Kit: Used for O₂ measurement.
 - Fuel and Operational Conditions
 - Fuel: High-Speed Diesel (HSD) was used.
 - Steady-State Operation: The incinerator was run at full capacity (200 kg/hr) for 30 minutes before testing to stabilize emissions.

3.4.1 Measurement Method and Instrument Used for the Analysis

Table 3.1: Pollutant Measurement Methods and Instruments

S.N.	Pollutant	Measurement Method	Instrument/Technique
1	Suspended Particulate Matter (SPM)	Gravimetric (Filter-based)	Cyclone + Bag Filter
2	Carbon Monoxide (CO)	Electrochemical Sensor	Flue Gas Analyzer
3	Oxides of Nitrogen (NO _x)	Jacobs-Hochheiser (Chemiluminescence)	NO _x Analyzer
4	Oxides of Sulphur (SO _x)	SO ₂ Absorber Method	SO ₂ Absorber + Spectrophotometer

The methods used for emissions measurement correspond to recognized environmental monitoring protocols thus the data are reliable SPM is sampled gravimetrically (filter based) through cyclone and bag filter setup, which is one of the internationally accepted methods for particulate sampling. CO detection utilizes an electrochemical sensor within a flue gas analyzer that yields real-time and accurate values. The detection of Oxides of

Nitrogen (NO_x), is based on the Jacobs-Hochheiser method + chemiluminescence detector, which is very sensitive and causes less interferences, whereas Oxides of Sulphur (SO_x) are usually studied through a SO₂ absorber attached to a spectrophotometer, giving it great robustness for the quantification of sulfur compounds. Air emission monitoring used at TIA's WtE plant are based on scientific methods meeting the global air quality standards. By employing gravimetric, electrochemical, chemiluminescence, and titration methodologies, accurate measurement of pollutants can be achieved, facilitating the facility's adherence to national regulations. While this transparency is beneficial, it could be even more powerful with the integration of Continuous Emission Monitoring Systems (CEMS), which provide real-time emissions data and reduce the burden on regulators.

Boundary Conditions

- Stack Height & Dispersion: The 30m stack height ensures proper dispersion, reducing ground-level pollution (Nepal's standard: $\geq 11\text{m}$). The stack velocity (2.7 m/s) was verified to ensure adequate draft.
- Reference Oxygen (O₂) Correction: The emissions were normalized to 11% O₂ (standard reference) to compare with regulatory limits fairly.

Formula:

$$C_{\text{corrected}} = C_{\text{measured}} \times \frac{21 - O_{2,\text{ref}}}{21 - O_{2,\text{measured}}} \quad (3.1)$$

Where O₂ (ref) = 11%

Standard Assumptions

- Complete Combustion: All the organic carbon converts to CO₂, and nitrogen to NO_x. The unburnt hydrocarbons (TOC) were minimal (2.1 mg/Nm³ vs. limit: 20 mg/Nm³).
- Negligible Interference: The Cross-sensitivity between gases (e.g., SO₂ affecting NO_x readings) was minimized via calibrated sensors.
- No External Contamination: The ambient air ingress into the stack was assumed negligible (verified via O₂ levels (14.6%).

- **Representative Sampling:** Three samples were taken to ensure repeatability (though the report shows one test cycle).

The emission test followed IS/ISO standards with assumptions (steady-state, complete combustion) and corrections (O₂ normalization). The data confirms the incinerator's compliance but highlights NO_x reduction as a potential upgrade area for your thesis's optimization goals.

3.5 Techno-Economic Analysis

Finally, a techno-economic analysis in the last phase, as to the economic and operational results of the proposed system upgrades. Economies of scale: Execution costs, capex (CAPital EXpenditure) and opex (OPERational EXpenditure) are assessed to find out whether the project is economical. The study also looks at possibilities for energy recovery and volume reduction, giving a more complete picture of the system's performance and sustainability. By doing so, it ensures that the suggestions made are economically viable as well as eco-friendly ones.

By following this structured methodology, the study aims to develop a comprehensive approach to augmenting the performance of the incineration system at TIA, aligning it with global sustainability goals and best practices in WtE conversion.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 TIA Waste Characteristics

Across all the months, paper and paper products consistently make up the largest portion of the waste. Plastic waste is also a significant concern, consistently representing a large chunk of the total waste. This highlights the ongoing challenges of managing plastic. Another notable component is organic waste. Since it makes up a considerable portion of the daily waste, composting programs could significantly reduce the amount of waste going to landfills. Other Categories like Glass, Metal, Rubber & Textiles, and Others contribute smaller but still significant amounts.

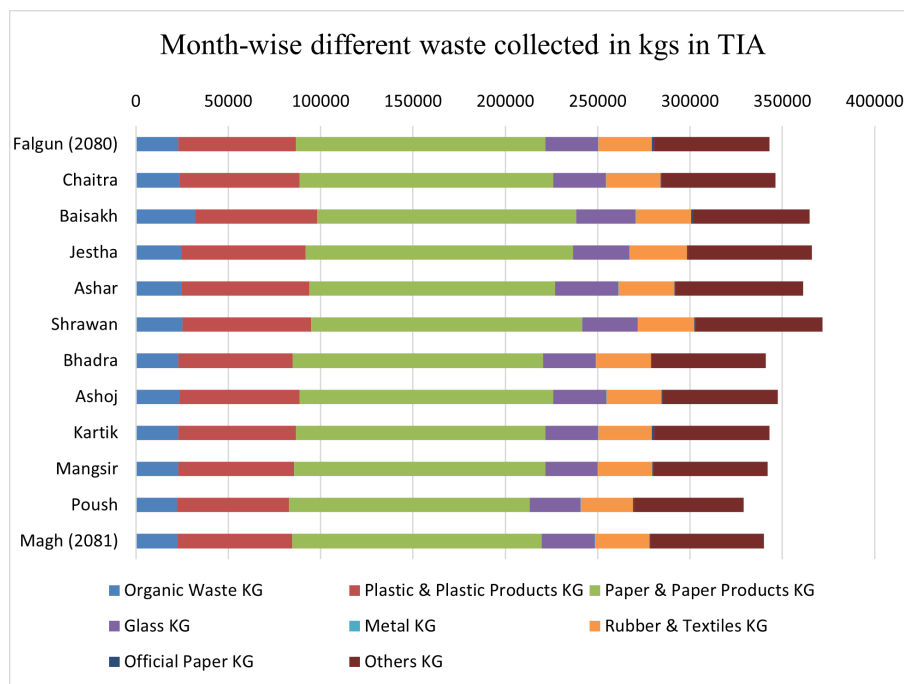


Figure 4.1: Monthly Waste Collection by Type (Stacked)- Full Year Data

The waste collection data from Falgun 2080 to Magh 2081 reveals consistent waste generation patterns with some monthly variations. Paper and plastic are the dominant waste categories, highlighting the need for targeted recycling efforts. Effective waste management strategies, including waste reduction, reuse, recycling, and organic waste management, are crucial to address the environmental challenges posed by this waste stream. Further investigation into the specific factors driving waste generation in Ashoj could provide valuable insights for optimizing waste management practices. Consistent data collection and monitoring are essential for informed decision-making and continuous improvement in waste management.

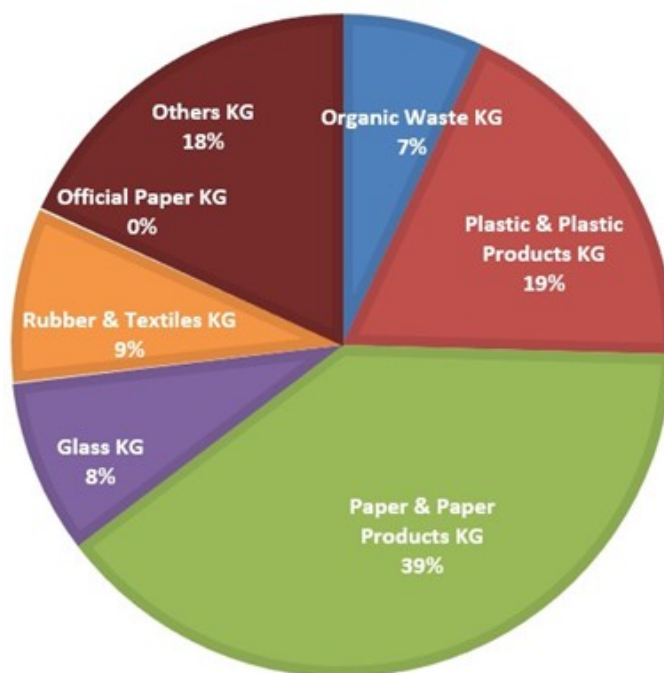


Figure 4.2: Total Waste Collected by Type

The waste composition data from TIA shows a diverse waste stream with a dominant presence of paper and paper products (39%), followed by plastics and plastic products 19%, Organic waste contributes about 7%, with the remaining types (glass, rubber & textiles, metals, and official paper) forming a smaller portion of the total 350 tons of waste generated monthly. From a waste-to-energy perspective, this composition makes a strong case for incineration, particularly because most of the waste (about 58%) is dry, combustible material like paper and plastics that have high calorific values and are ideal for energy recovery through thermal treatment. The relatively small percentage of organic waste (7%) suggests that while biological treatment technologies such as anaerobic digestion or composting could be added; their potential would be limited in extent at TIA. Anaerobic digestion is best suited to wet, organic-laden waste such as food waste or sludge, which is not the prevalent component of the TIA waste stream. Similarly, composting is possible for biodegradable waste, but the low organic content at TIA reduces the viability of this process as a key approach. Additionally, both processes require strict source separation and high consistency of operation, which may be difficult to maintain at a high passenger traffic airport with multiple sources of waste generation.

Incineration, however, appears to be a highly suitable option for TIA due to several reasons. To begin with, the combustible fraction is high, meaning that a high proportion of the waste can be converted to thermal energy. Secondly, incineration achieves a significant

volume reduction of waste (up to 90%), thus easing pressures on landfill space. This is especially pertinent in the context of Kathmandu’s growing waste management issues.

Based on the waste composition and quantity at TIA, incineration is still a suitable and effective waste-to-energy method. It is well suited to the nature of the waste generated, particularly the high quantities of paper and plastic. While alternatives like anaerobic digestion and composting are ecologically feasible, they are less effective and convenient at TIA due to the low proportion of organic waste. With proper segregation, emission control, and pre-treatment, an incinerator can significantly reduce landfill dependency while generating utilizable energy providing a sustainable airport waste management method.

Table 4.1: Descriptive Statistics of Monthly Waste Collection at TIA (Magh 2081 to Falgun 2082)

Waste Category	Mean (kg)	Std. Dev. (kg)	Min (kg)	25th Percentile (kg)	Count
Organic Waste	1541.35	4146.91	700.00	720.00	378
Plastic & Plastic Products	2381.66	10713.66	5.00	8.13	378
Paper & Paper Products	1812.14	7966.31	5.00	10.00	378
Glass	1162.50	3998.29	5.00	60.00	261
Metal	2687.90	8661.45	5.00	900.00	286
Others	3341.26	9633.18	60.00	1150.00	171
Total Daily Waste	21937.81	59037.45	10778.00	11067.00	31

The analysis of monthly waste collection at Tribhuvan International Airport (TIA) from Magh 2081 to Falgun 2082 reveals significant variation in the volume and composition of waste generated. Organic waste had a mean of approximately 1541.35 kg, while plastic and plastic products accounted for a slightly higher average of 2381.66 kg, indicating their dominance in the waste stream. Paper waste followed closely with a mean of 1812.14 kg. However, the standard deviations for plastic, paper, metal, and others were notably high, suggesting considerable day-to-day variability and the presence of outliers, possibly due to peak traffic days or special events. Glass and metal were collected in relatively lower but variable quantities, with median values indicating sporadic but sizable disposals. The category labeled "Others" also showed high dispersion with a mean of 3341.26 kg, implying mixed or unclassified waste types. Total daily waste weight, available for only 31 days, averaged around 21.9 metric tons, reflecting the scale of operations at TIA. These findings underscore the need for targeted waste reduction strategies, particularly in

managing plastic and composite waste, and improving the consistency of waste logging practices.

4.2 Gross Calorific Value of Airport Waste

Gross calorific value (GCV) is an important element in assessing the energy potential of waste materials. It tells how much heat energy is released from a complete combustion of the fuel of the unit mass. Fuel with a high calorific value can produce more energy when burnt (as with incineration) than fuel that has a low calorific value.

Waste material (Samples) calorific value testing was performed at Renewable Energy Test Station (RETS), of National Academy of Science and Technology (NAST) on official paper waste, aggregate waste and mixed 7 days sun dry waste from TIA due to unavailable equipment's and lab set at site.

The sampling process at TIA was completed to characterize waste streams and optimize incinerator feed composition for maximum energy recovery, The ASTM D5231 (Standard Guide for Composite Sampling of Municipal Solid Waste) method was followed for sampling. Three waste samples were collected from TIA to assess calorific value, composition, and combustion efficiency:

- Sample 1: Official paper waste (confidential documents).
- Sample 2: Aggregate waste (mixed airport combustible waste).
- Sample 3: Aggregate waste (mixed airport combustible waste with 7 days Sun dry).



Figure 4.3: Sample Prepared for GCV Testing at RETS (NAST)

Figure 4.4: Gross Calorific Value of all Three Samples

Sample 1:	
Type of Fuel:	Official paper waste of TIA
Average Gross Calorific Value:	3126.375 kcal/kg
Sample 2:	
Type of Fuel:	Aggregate waste of TIA
Average Gross Calorific Value:	2664.412 kcal/kg
Sample 3:	
Type of Fuel:	Mixed airport combustible waste with 7 days Sun dry
Average Gross Calorific Value:	4,143.121 kcal/kg

(Source: Experimental Data of TIA Waste Tested at RETS)

About 15 grams of each three prepared sample was handover to RETS (NAST) for the Gross Calorific Value (GCV) testing.

4.2.1 Official Paper Waste (Sample 1)

The gross calorific value of 3126.375 kcal/kg is fairly high as paper waste consists of a considerable energy content. This is expected, as most of paper is cellulose, a good source of energy that burns.

4.2.2 Aggregate Waste (Sample 2)

The gross calorific value is 2664.412 kcal/kg which is lower than that of sample 1 official paper waste due to mixed waste with lower calorific value of organic waste and moisture contents in it. And the fact that aggregate waste is often an heterogeneous amalgamation of different materials, some of them with low energy content (such as plastics or organic matter, resulting in a lower overall calorific value).

4.2.3 Mixed Waste with 7 days Sun Dry (Sample 3)

The gross calorific value is 4,143.121 kcal/kg which is the highest of all three samples. And the fact that mixed combustible airport waste with seven days' sun removed the moisture content in the waste hence increased the gross calorific value Table 4: 1 shows the Gross Calorific Value Test Data Analysis of all three samples.

The results suggested that seven days' sun dry mixed waste were more suitable for energy recovery through incineration compared to aggregate waste. This was because seven days' sun dry mixed waste has a higher energy yield per unit mass. However, aggregate waste

Table 4.2: TIA Emission Data Comparison with ICAO Standards and Nepals Standard

S.N.	Pollutant	ICAO Standard (@ 11% O ₂ in mg/Nm ³)	Compliance Status	Nepal's Standard	TIA's Current Performance Status	Compliance Status
1.	Particulate Matter (PM)	≤ 10 (for modern WtE plants)	✗ Non-compliant	50 mg/Nm ³	37.5	✗ Non-compliant
2.	Carbon Monoxide (CO)	≤ 50	✓ Compliant	≤ 50	≤ 12.5	✓ Compliant
3.	Nitrogen Oxides (NO _x)	≤ 200 ppm	✓ Compliant	≤ 200 ppm	120 ppm	✓ Compliant
4.	Sulphur Oxides (SO _x)	≤ 50 ppm	✓ Compliant	≤ 200 ppm	< 5 ppm	✓ Compliant

may still be viable for incineration, especially if it contains a significant proportion of combustible materials. Further segregation and analysis of the waste composition could help optimize its use as a fuel source.

Using waste materials with high calorific values for energy recovery can reduce the reliance on fossil fuels and contribute to sustainable waste management practices. This makes them a viable alternative for energy generation in WtE plants.

4.3 TIA Emission Data Analysis

The TIA currently relies on outdated incineration technology, due to its reliance on basic combustion technology without advanced flue gas cleaning systems, leading to inefficient waste destruction and high emissions of pollutants like dioxins, particulate matter (PM), and nitrogen oxides (NO_x). Manual operation and lack of real-time monitoring resulted in inconsistent performance, while the absence of energy recovery mechanisms wasted potential electricity and heat generation.

By adopting advanced incineration technologies, TIA can align its waste management practices with ICAO's environmental standards and Nepal's sustainability goals, ensuring compliance, reducing environmental impact, and improving energy recovery. The ICAO sets global guidelines for sustainable aviation, including waste management. Key standards relevant to incineration and Nepal's Ministry of Forests and Environment (MoFE) regulates emissions from incinerators under the Environmental Protection Rules (EPR), 2020.

The data in the table compares the emissions of the waste-to-energy (WtE) plant with the ICAO standards at 11% O₂ concentration. In general, and with some significant caveats, the plant operates within regulatory limits. Particulate emissions (PM) were higher than

the maximum limits given by the International Civil Aviation Organization (ICAO) for modern waste-to-energy (WtE) plants (37.5 mg/Nm^3 , $\leq 10 \text{ mg/Nm}^3$), denoting that better filtration systems (e.g. high-efficiency fabric filters or electrostatic precipitators) should be required. Meanwhile, carbon monoxide (CO) emissions are orders of magnitude below the limit of $\text{CO} \leq 50 \text{ mg/Nm}^3$ at $\text{CO} \leq 12.5 \text{ mg/Nm}^3$, which is an indicator of better combustion getting done. Likewise, emissions of nitrogen oxides (NO_x) and sulfur oxides (SO_x) are also in compliance, measuring 120 ppm (vs. $\leq 200 \text{ ppm}$) and $<5 \text{ ppm}$ (vs. $\leq 50 \text{ ppm}$) respectively, possibly due to proficient flue gas treatment. The absence of heavy metals like lead, cadmium, and mercury highlights effective waste management.

Changes, such as implementing SCR systems, wet scrubbers, activated carbon filters, and CEMS, are needed to achieve PM10 criteria. However, with better combustion parameters and improved segregation of waste, the efficiency of the incinerator can also be increased, leading to reduced emissions.

These changes would allow the incinerator to comply with environmental standards, minimize the harm it does to the environment, and promote sustainable waste management at TIA.

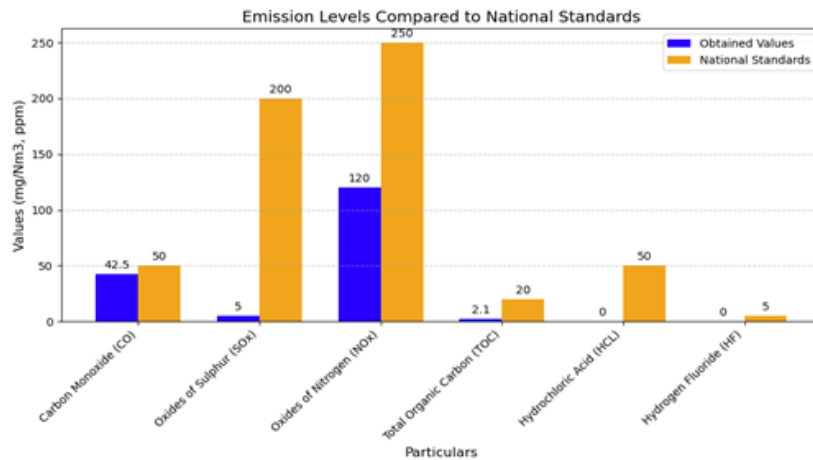


Figure 4.5: Emission Levels Compared to National Standards

4.4 Energy Potential

4.4.1 Official Paper (Sample 1)

The calculation for the performance of the incinerator based on Sample 1 (Official Paper Waste), with a daily waste collection of 20 kg. The overall system efficiency was only 1.96% since very low and outdated incinerator technology and the incinerator operation hour was only 0.1 hr per day which was not suitable financially as well. The details of

energy potential and their calculations of Official Paper Waste (Sample 1) as shown in Table 4:3

Table 4.3: Energy Potential Calculation of Official Paper Waste (Sample 1)

Energy Potential calculation of Airport Waste					
Official Paper Waste (Sample 1)					
Steps	Parameters	Formula	Calculated Value	Unit	Remarks
Step 1	Energy from Waste	Waste Processing Capacity \times Calorific Value of Waste	625,275.00	kcal/hour	Waste Processing Capacity is 200kg/hr but total official waste collected per day is only 20kg and Calorific Value of Waste: 3,126.37 kcal/kg
	Energy from HSD	Mass of HSD Consumed per Hour \times Calorific Value of HSD	318,750.00	kcal/hour	Mass of HSD Consumed per Hour is 31.87 and Calorific Value of HSD: 10,000
	Total Energy Input	Energy from Waste + Energy from HSD	944,025.00	kcal/hour	
	Total Energy Input in kWh/hr	Total Energy Input/860	1,097.70	kWh/hr	1 kWh = 860 kcal
Step 2	Energy Output:	Total Energy Input \times Combustion Efficiency	802,421.25	kcal/hour	(85% combustion efficiency)
Step 3	Recovered Energy:	Energy Output \times ORC Efficiency	160,484.25	kcal/hour	(20% ORC efficiency)
Step 4	Electrical Energy Output:	Recovered Energy/860	186.61	kWh/hour	1 kWh = 860 kcal
Step 5	Incinerator Operation Hour	Daily Waste Generation/Waste Processing Capacity \times No of Incinerator	0.10	Hour	Daily Waste Generation is just 20Kg and 2 no of Incinerator Plant operating in TIA so per day is 20 hrs
	Daily Energy Generation:	Electrical Energy Output \times Incinerator Operation hour	18.66	kWh/day	
	Annual Energy Generation:	Daily Energy Generation \times 365 days	6,811.25	kWh/year	Waste generated and collected daily so that everyday plant run
Step 6	Overall System Efficiency:	Electrical Energy Output/Total Energy Input \times 100	17%		
Step 7	Fuel Efficiency:	(Energy from Waste/Energy from HSD) \times 100	196%		

4.4.2 Aggregate Waste (Sample 2)

The calculation of the performance of the incinerator based on Sample 2 (Aggregate Waste), with a daily waste collection of 8,000 kg, assuming the incinerator operates for 20 hours/day. The incinerator has a high fuel efficiency (167.2%), indicating that the energy from waste is significantly higher than the energy input from HSD. The overall system efficiency is low 1.98%. This suggests that there is room for improvement in energy recovery technologies. The annual energy generation of 1,474,658.4 kWh/year is

substantial and can contribute to reducing the airport’s reliance on external energy sources. The details of energy potential and their calculations of Aggregate waste (Sample 2) as shown in Table 4: 4.

Table 4.4: Energy Potential Calculation of Official Paper Waste (Sample 2)

Energy Potential calculation of Airport Waste Aggregate Waste (Sample 2)					
Steps	Parameters	Formula	Calculated Value	Unit	Remarks
Step 1	Energy from Waste	Waste Processing Capacity × Calorific Value of Waste	532,882.40	kcal/hour	Waste Processing Capacity is 200kg/hr and Calorific Value of Waste: 2,664.41
	Energy from HSD	Mass of HSD Consumed per Hour × Calorific Value of HSD	318,750.00	kcal/hour	Mass of HSD Consumed per Hour is 31.87 and Calorific Value of HSD: 10,000
	Total Energy Input	Energy from Waste + Energy from HSD	851,632.40	kcal/hour	
	Total Energy Input in kWh/hr	Total Energy Input/860	990.27	kWh/hr	1 kWh = 860 kcal
Step 2	Energy Output:	Total Energy Input × Combustion Efficiency	723,887.54	kcal/hour	(85% combustion efficiency)
Step 3	Recovered Energy:	Energy Output × ORC Efficiency	144,777.51	kcal/hour	(20% ORC efficiency)
Step 4	Electrical Energy Output:	Recovered Energy/860	168.35	kWh/hour	1 kWh = 860 kcal
Step 5	Incinerator Operation Hour	Daily Waste Generation/Waste Processing Capacity × No of Incinerator	40.00	Hour	Daily Waste Generation is 8000Kg and 2 no of Incinerator Plant operating in TIA so per day is 20 hrs
	Daily Energy Generation:	Electrical Energy Output × Incinerator Operation hour	6,733.84	kWh/day	
	Annual Energy Generation:	Daily Energy Generation × 365 days	2,457,850.72	kWh/year	Waste generated and collected daily so that everyday plant run
Step 6	Overall System Efficiency:	Electrical Energy Output/Total Energy Input × 100	17%		
Step 7	Fuel Efficiency:	(Energy from Waste/Energy from HSD) × 100	167%		

4.4.3 Mixed Waste 7 days Sun Dry (Sample 3)

The calculation of the performance of the incinerator based on Sample 3 (Mixed Waste with seven days Sun dry), with a daily waste collection of 8,000 kg, assuming the incinerator operates for 20 hours/day. The details of energy potential and their calculations of Mixed Waste 7 days Sun Dry (Sample 3) as shown in Table 4: 5.

Table 4.5: Energy Potential Calculation of Official Paper Waste (Sample3)

Energy Potential calculation of Airport Waste					
Mixed 7 days Sun Dry Waste (Sample 3)					
Steps	Parameters	Formula	Calculated Value	Unit	Remarks
Step 1	Energy from Waste	Waste Processing Capacity × Calorific Value of Waste	828,624.20	kcal/hour	Waste Processing Capacity is 200kg/lr and Calorific Value of Waste: 4,143.12 kcal/kg
	Energy from HSD	Mass of HSD Consumed per Hour × Calorific Value of HSD	318,750.00	kcal/hour	Mass of HSD Consumed per Hour is 31.87 and Calorific Value of HSD: 10,000
	Total Energy Input	Energy from Waste + Energy from HSD	1,147,374.20	kcal/hour	
	Total Energy Input in kWh/hr	Total Energy Input/860	1,334.16	kWh/hr	1 kWh = 860 kcal
Step 2	Energy Output:	Total Energy Input × Combustion Efficiency	975,268.07	kcal/hour	(85% combustion efficiency)
Step 3	Recovered Energy:	Energy Output × ORC Efficiency	195,053.61	kcal/hour	(20% ORC efficiency)
Step 4	Electrical Energy Output:	Recovered Energy/860	226.81	kWh/hour	1 kWh = 860 kcal
Step 5	Incinerator Operation Hour	Daily Waste Generation/Waste Processing Capacity × No of Incinerator	40.00	Hour	Daily Waste Generation is 8000Kg and 2 no of Incinerator Plant operating in IIA so per day is 20 hrs
	Daily Energy Generation:	Electrical Energy Output × Incinerator Operation hour	9,072.26	kWh/day	
	Annual Energy Generation:	Daily Energy Generation × 365 days	3,311,375.31	kWh/year	Waste generated and collected daily so that everyday plant run
Step 6	Overall System Efficiency:	Electrical Energy Output/Total Energy Input × 100	17%		
Step 7	Fuel Efficiency:	(Energy from Waste/Energy from HSD) × 100	260%		

The above tables summarizes three waste samples (Official Paper Waste and Aggregate Waste and 7-day Sun-Dried Mixed Waste) in terms of key energy recovery parameters. Here's a summary of the results: The highest GCV, 816 kcal/kg, built by Sun-Dried Mixed Waste (Sample 3), follow by Sample 1 (GCV 3,126 kcal/kg), & Sample 2 (GCV 2,664 kcal/kg). When we sun-dry, we are reducing moisture content, which creates higher combustible content. The higher the GCV, the more energy extraction per kg of waste.

Total energy output (975,268 kcal/hour) due to higher GCV. Low GCV and high HSD dependency (fuel efficiency 0.82%) together makes Sample 1 (Paper Waste) the worst performer. Sample 3 provides 260% fuel efficiency, in other words, energy from waste is higher than the HSD input. The highest electrical energy generation from the sample 3 is (259.9 kWh), follow by Sample 2 (168.34 kWh) and Sample 1 (6.8 kWh)

4.5 Financial Analysis

Financial Analysis for Upgradation of Incinerator Plant of TIA for Sample 1

This table presents a financial analysis for the upgradation of an incineration plant installed at TIA using Official Paper Waste (Sample 1) as the feedstock. The analysis focuses on capital expenditures (CAPEX), operational expenditures (OPEX), electricity generation, revenues, and financial feasibility over a 10-year project life.

Table 4.6: Financial Analysis for Upgradation of Incinerator for Plant for Sample 1

Financial Analysis for Upgradation of Incineration Plant Installed at TIA		
Official Paper Waste (Sample 1)		
CAPEX	Value	Unit
SCR System	7,000,000.00	NPR
Wet Scrubber	5,600,000.00	NPR
Heat Exchanger	2,100,000.00	NPR
ORC System	21,000,000.00	NPR
CAPEX Total	35700000	NPR
OPEX		
Maintenance Cost	1,785,000.00	NPR/year
Labour Cost	1,200,000.00	NPR/year
Fuel Cost	8,103,000.00	NPR/year
OPEX Total	11088000	NPR/year
Annual Electricity	6811.250145	kWh
Electricity Rate	9.95	NPR/kWh
Annual Elec. Rev.	67,771.94	
Annual Revenue	67,771.94	NPR/year
Net Revenue	-11020228.06	
Discount Rate	8%	
Project Life	10	years
IRR	NA	
Payback	NA	
Remarks	Financially Not Viable	

The financial analysis clearly shows that the current configuration of the upgraded incineration plant at TIA, using official paper waste as fuel, is not financially viable. The net revenue is negative, with an annual deficit of NPR 19 million, driven primarily by the high OPEX, particularly the fuel cost.

- **High Capital Cost:** The ORC system alone consumes over 58% of the CAPEX, which is justified by its role in energy recovery, but this needs to be weighed against the actual energy output.

- **Low Electricity Output:** Despite high capital investment, the electricity generation is only 6.8 MWh/year, which results in a meager NPR 67,771.94 in annual revenue.
- **Inefficient Revenue Recovery:** With such a low annual revenue, it is impossible to recover the initial investment over the 10-year project life, even before accounting for O&M costs.
- **Fuel Cost Concern:** The fuel cost is over NPR 8.1 million/year, suggesting either the official paper waste is expensive to collect/process or the combustion process is not efficient.
- **No Diversified Revenue:** The model assumes revenue only from electricity sales. Potential revenues from waste disposal fees, carbon credits, or heat recovery for district heating are not considered, which could improve feasibility.
- **Need for Optimization:** Energy recovery efficiency must be improved—either by increasing waste calorific value, improving ORC efficiency, or reducing losses.

4.5.1 Financial Analysis for Upgradation of Incinerator Plant of TIA for Sample 2

The following table evaluates the financial aspects of upgrading the incineration plant at TIA this time with Aggregate Waste (Sample 2) instead of only official paper waste. This includes all the detailed numbers for CAPEX, OPEX, electricity produced, and the associated Net Revenue over the 10-year project life period at an 8% discount rate.

Table 4.7: Financial Analysis for Upgradation of Incinerator for Plant for Sample 2

Financial Analysis for Upgradation of Incineration Plant Installed at TIA		
Aggregate Waste (Sample 2)		
CAPEX	Value	Unit
SCR System	7,000,000.00	NPR
Wet Scrubber	5,600,000.00	NPR
Heat Exchanger	2,100,000.00	NPR
ORC System	21,000,000.00	NPR
CAPEX Total	35700000	NPR
OPEX		
Maintenance Cost	1,785,000.00	NPR/year
Labour Cost	1,200,000.00	NPR/year
Fuel Cost	16,260,750.00	NPR/year
OPEX Total	19245750	NPR/year
Annual Electricity	2457850.717	kWh
Electricity Rate	9.95	NPR/kWh
Annual Elec. Rev.	24,455,614.64	
Annual Revenue	24,455,614.64	NPR/year
Net Revenue	5209864.636	
Discount Rate	8%	
Project Life	10	years
IRR	8%	
Payback	6.85	
Remarks	Financial Viable	

Based on the results of Sample 2. we conclude that the incineration plant economical parameters are preferable with the aggregate parameter instead of the official paper waste. This modification allows for a much greater yield of electricity and thus, economic return. Electricity Generation Boost: Uptake of aggregate waste results in a 361x increase in annual generation from 6,811 kWh (Sample 1) to 2,457,851 kWh. This indicates a comparable higher calorific value, combustion efficiency, or volume of aggregate waste available for incineration. Same CAPEX – Improved Utilization: The capital investment is unchanged: the enhanced returns are simply a result of better using existing equipment with a different feedstock. The project is now very profitable, with a reported annual revenue of NPR 24.45 million and net revenue of NPR 5.20 million/year after costs are accounted for. The project can recover its investment well under the 6.85 years, which is economically viable.

4.5.2 Financial Analysis for Upgradation of Incinerator Plant of TIA for Sample 3

This table presents a financial analysis for an upgraded incineration plant at TIA using Mixed Waste (7 Days Sun Dry) Sample 3 as input. It explores the same categories as prior analyses: CAPEX, OPEX, electricity generation, revenue, and net financial outcome over a 10-year period with an 8% discount rate.

Table 4.8: Financial Analysis for Upgradation of Incinerator for Plant for Sample 3

Financial Analysis for Upgradation of Incineration Plant Installed at TIA		
Mixed Waste 7 Days Sun Dry (Sample 3)		
CAPEX	Value	Unit
SCR System	7,000,000.00	NPR
Wet Scrubber	5,600,000.00	NPR
Heat Exchanger	2,100,000.00	NPR
ORC System	21,000,000.00	NPR
CAPEX Total	35,700,000.00	NPR
OPEX		
Maintenance Cost	1,785,000.00	NPR/year
Labour Cost	1,200,000.00	NPR/year
Fuel Cost	16,260,750.00	NPR/year
OPEX Total	19,245,750.00	NPR/year
Annual Electricity	3,311,375.31	kWh
Electricity Rate	9.95	NPR/kWh
Annual Elec. Rev.	32,948,184.31	
Annual Revenue	32,948,184.31	NPR/year
Net Revenue	13,702,434.31	
Discount Rate	8%	
Project Life	10	years
IRR	37%	
Payback	2.61	
Remarks	Financial Viable	

This scenario, using sun-dried mixed waste, presents the most financially favorable outcome among all the samples analyzed so far. Massive Energy Recovery Potential: Electricity output is 3.3 million kWh/year, surpassing Sample 2 (aggregate waste) by nearly 35%, and Sample 1 (paper waste) by almost 500x. Sun-drying for 7 days significantly improves the waste's calorific value by reducing moisture content, thus enhancing combustion efficiency.

High Net Profitability: With an annual net revenue of NPR 13.7 million, the payback period would be less than 2.61 years, making this a highly profitable investment. This net return is nearly 2.62x higher than Sample 2 (Aggregate Waste).

Same Cost, Better Returns: Despite identical CAPEX and OPEX across all samples, the choice and pretreatment of feedstock (in this case, sun-drying) greatly impact output. Fuel cost remains the same, implying that drying does not significantly increase collection or processing costs.

The use of 7-days sun-dried mixed waste is economically superior and operationally efficient compared to both paper-only and untreated aggregate waste scenarios. This underscores that feedstock preparation (pre-treatment) is just as critical as feedstock selection in waste-to-energy projects.

4.6 Environmental Impact Assessment

This Table 4: 9 presents an Environmental Impact Analysis of the proposed incineration upgradation at TIA. It quantifies the benefits of the improved system across three environmental dimensions:

Table 4.9: CO₂ Emission Reduction of Incineration Upgradation installed at TIA

Environment Impact Analysis of Incineration Upgradation installed at TIA		
CO₂ Emission Reduction		
Current Emission	1.5	KgCO ₂ /Kg waste
Emission reduction	20%	by improved incineration
Annual CO ₂ reduction	438,000.00	KgCO ₂ /year
	438.00	tCO ₂ /year
Nox Emission reduction		
Current Emission	120	ppm
Emission reduction	85%	by SCR system
Actual Nox Emission reduction	102.00	ppm
Landfill Diversion		
Current contribution	40%	
Dependency reduction	40%	by improved incineration
Actual landfill dependency reduction	16.00%	

The environmental impact analysis of the incineration plant upgradation at TIA demonstrates significant ecological benefits across three major areas: carbon dioxide (CO₂) emission reduction, nitrogen oxides (NO_x) emission control, and landfill dependency minimization. Starting with CO₂ emissions, the analysis indicates that current emissions from waste incineration stand at 1.5 kg CO₂ per kilogram of waste processed. The upgraded incineration system, which features improved combustion efficiency and energy recovery, is projected to reduce these emissions by 20%. This reduction translates to an annual saving of 438,000 kg of CO₂, equivalent to approximately 43 metric tons. Such a substantial reduction highlights the plant's potential contribution toward Nepal's national

commitments under international climate agreements, especially the Paris Agreement. It is also significant in the context of urban climate action plans that emphasize lowering greenhouse gas emissions from waste management practices.

Regarding NO_x emissions, the current level of 120 parts per million (ppm) is expected to be reduced by 85% through the implementation of a Selective Catalytic Reduction (SCR) system. This translates to an actual emission reduction of 102 ppm, reducing the final NO_x output to just 18 ppm. NO_x gases are known contributors to respiratory diseases, acid rain, and the formation of ground-level ozone, which exacerbates urban air pollution. Therefore, this substantial reduction not only meets environmental compliance requirements but also contributes directly to improving air quality in and around the airport area a region with high human traffic and sensitive ecological surroundings. In terms of landfill diversion, the current dependency on landfills is about 40%, indicating that nearly half of the waste generated is disposed of through landfilling. The improved incineration system is expected to reduce this dependency by 40%, although the actual landfill dependency reduction achieved is 16%. While this may seem lower than the target, it still represents a meaningful shift in waste management practices. Diverting waste from landfills helps reduce the production of methane a greenhouse gas far more potent than CO₂ and minimizes leachate-related groundwater contamination risks. It also extends the operational life of existing landfills, reducing the need for new landfill sites, which are often challenging to establish due to space constraints and public opposition.

4.7 Discussions

The study highlights the urgent necessity for TIA transitioning to a sustainable waste management approach. The environmental and operational challenges posed by TIA can be effectively tackled through modernization of incinerators, installation of state-of-the-art waste segregation and energy recovery devices and robust emission control technologies. Adopting global best practices and working in tandem with the ICAO environmental standards set out, TIA can help upgrade its waste processing and management infrastructure into a budding example of sustainability in the South Asian aviation market. These developments not only accelerate resource optimization and decrease greenhouse gas emissions but also make TIA a leading airport for sustainability.

This analysis makes it evident that the upgradation of the incinerator is not only economically viable as shown in financial analysis but also offers profound environmental advantages. However, it's important to note that these projections rely on optimal operation and maintenance of new systems like the ORC unit and SCR scrubbers. Any lapses in

performance monitoring or waste segregation at source can reduce the effectiveness of these systems.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- The waste composition at TIA over a year was observed and analyzed since Falgun 2080 to Magh 2081. The waste types are categorized into Glass (6.8%), Metal (0.4%), Official Paper Waste (0.9%), Organic Waste (18.0%), Others (18.3%), Paper Waste (38.8%), Plastic Waste (18.3%), and Rubber & Textile Waste (8.3%). The percentages indicate the proportion of each waste type in the total waste collected.
- The gross calorific value of waste materials, official paper waste and aggregate waste from TIA were tested at RETS, of NAST. Official Paper Waste (Sample 1): The calorific value of 3126.375 kcal/kg is relatively high, indicating that paper waste has a significant energy content. This is consistent with the fact that paper is primarily composed of cellulose, which is a good source of energy when burned. Aggregate Waste (Sample 2) calorific value of 2664.412 kcal/kg is lower than that of paper waste. With a high calorific content (39% paper and 18% plastics), the waste stream is ideally suited for incineration. Organic waste (7%) has composting opportunities, however, it is less viable for energy recovery. Among the all three samples Sample 3 had the highest calorific value among the sun-dried aggregate waste (4,143 kcal/kg), highlighting the importance of pre-processing to improve the efficiency of the combustion.
- The Emission analysis provides the results of stack emission monitoring conducted for an incinerator installed at TIA, Kathmandu, Nepal. The incinerator, with a capacity of 200 kg/hr, was tested for various pollutants, and the results were compared against the National Standards for Chimney Height and Emission for Incinerators. The CO (42.5 mg/Nm³), PM (37.5 mg/Nm³), Sulfur oxides SO_x (<5 ppm) and NO_x (120 ppm) numbers matching national limits but need to be reduced for ICAO compliant.
- The incinerator has a high fuel efficiency (167.18%), while using the sample 2 and with sample 3 (Seven-day Sun Dry of mixed combustible waste) fuel efficiency increased to (259.97%) indicating that the energy from waste is significantly higher than the energy input from HSD. The overall system efficiency is low (17%), primarily due to the low efficiency of the outdated system. This suggests that there is room for improvement in energy recovery technologies. The annual energy

generation of 3,311.3 MWh/year is substantial and can contribute to reducing the airport's reliance on external energy sources.

- The initial capital investment for the upgraded incineration system at TIA (TIA) is NPR 35.7 million. The consistently negative annual net revenue of approximately NPR -109 million. For Sample 2 financially viable with the investment recoverable within 6.85 years. And with Sample 3 is the most financially favorable scenario, with payback in under 2.61 years. The pretreatment through sun-drying enhances calorific value, leading to electricity generation of over 3.3 million kWh/year, resulting in high profitability at the same cost level. Thus full utilization of incinerator is must for making it a financial viable technology.

5.2 Recommendations

- Selective Catalytic Reduction (SCR) and electrostatic precipitators to reduce NO_x and PM emissions need to be installed to reduce emissions significantly and meet ICAO's requirement. The Continuous Emission Monitoring Systems (on pollutants (CO, NO_x, dioxins) ensures emissions compliance at real time.
- The implementation of ORC (Organic Rankine Cycle) systems for indirect waste heat recycling is suggested to enhance the efficiency of the system with potential 65% energy recovery .
- Pre-treatment (shredding, solar drying, etc.) of waste is recommended to enhance waste calorific value and decrease use of auxiliary fuel. Also the waste segregation at source through stringent source is suggested to limit the non-combustible waste feed in incinerator for improving its efficiency.
- The proposed upgrades (SCR systems, scrubbers, ORC) come at the cost of a large CAPEX outlay (NPR 182 million) in the first years, but due to reduced emissions and potential energy recovery, the total NPV becomes positive providing an opportunity of series of positive cash flow in future. The full utilization of upgraded incinerator is crucial as it not just reduced emissions but also reduce the expected landfill dependency by 16%.

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ANNEX A: IMAGES FROM RESEARCH



Figure A.1: Pictures of Site Location and Equipment's Set-up



Figure A.2: Pictures of Waste Sampling and Preparation for GCV Testing



Figure A.3: Some Pictures of Waste Segregation at TIA

ANNEX B: STANDARD DATA AND ASSUMPTION TAKEN FOR THE CALCULATION

1. Exchange Rate: 1 USD = 136.46 NPR (Reference: Nepal Rastra Bank March 30, 2025).
2. SCR System: NPR 7,000,000 (based on similar projects in developing countries) [Reference: India Mart, 2025].
3. Wet Scrubbers: NPR 5,600,000 (for a 200 kg/hr incinerator) (based on similar projects in developing countries) [Reference: India Mart, 2025].
4. Heat Exchangers: NPR 2,100,000 (for waste heat recovery) (based on similar projects in developing countries) [Reference: India Mart, 2025].
5. ORC System: NPR 21,000,000 (for electricity generation) (based on similar projects in developing countries) [Reference: India Mart, 2025].
6. Annual Maintenance Costs: 5% of CAPEX [Reference: World Bank, 2020].
7. Labor Costs: NPR 1,200,000/year [Reference: Nepal Labor Market Report, 2022].
8. Fuel Costs: NPR 148.5/liter for High-Speed Diesel (HSD), with a consumption of 37.5 liters/hour [Reference: Nepal Oil Corporation, March 30, 2025 Kathmandu].

ANNEX C: TECHNICAL DATA SHEET OF INCINERATOR PLANT

Technical Data Sheet: EE-200 Incinerator Plant (Tribhuvan International Airport)

General Information

- **Manufacturer:** Enhance Envirotech Pvt. Ltd.
- **Model:** EE-200
- **Capacity:** 200 kg/hr
- **Type:** Floor Mounted Horizontal
- **Maximum Connected Electric Load:** 30 HP / 22.5 KW
- **Fuel Consumption (HSD):** 30–45 l/hr
- **Dimensions (L×W×H):** 2500 mm × 1430 mm × 2200 mm
- **Weight:** 3500 kg
- **Fuel Type:** Diesel (HSD)
- **Fuel Tank Capacity:** 200 Liters

Primary Chamber

- **MOC:** Mild steel, 3 mm thick, heat-resistant aluminum paint (250°C)
- **Refractory Lining:** Up to 1000°C
- **Water Column Pressure Measurement:** Provided
- **Thermocouples Location:** End of secondary chamber or before dilution air

Primary Burner

- **Quantity:** 1 (HSD)
- **Temperature:** 800°C ± 50°C

- Control: Auto ON/OFF
- Features: Spark igniter, blower with motor, Siemens sequence controller, flame view port, filter
- Flame Positioning: Toward hearth center without impinging refractory

Forced Draft Fan (FD Fan)

- Quantity: 1 (Centrifugal)
- Capacity: 700 CFM, Static Pressure: 150 mmwg
- MOC: Mild Steel, Dynamically and Statically balanced
- Motor: 2 HP, 1440 RPM
- Air Supply Regulation:
 - Primary Chamber: 30–80% of stoichiometric air
 - Secondary Chamber: 120–170%

Secondary Chamber

- **MOC:** Mild steel, 3 mm, aluminum-painted (250°C)
- **Refractory Lining:** Up to 1200°C
- **Residence Time:** 1 second

Secondary Burner

- Quantity: 1 (HSD)
- Temperature: 1050°C ± 50°C
- Control: Auto ON/OFF
- Features: Spark igniter, blower with motor, Siemens sequence controller, flame view port, filter

- Flame Positioning: Ensures gas passes through flame

Induced Draft Fan (ID Fan)

- Quantity: 1 (Centrifugal)
- Capacity: 7500 CFM, Static Pressure: 350 mmwg
- MOC (Body and Impeller): Mild Steel
- Balancing: Dynamically and Statically balanced
- Motor: 20 HP, 1440 RPM
- Drive: Belt-driven

Chimney

- Quantity: 1 Set
- MOC: Mild Steel
- Height: 30 M
- Features: Platform, aviation lamp with raincowl, lightning protection

Ducting and Control

- **Ducting MOC:** Mild Steel, 3 mm thick, refractory-lined
- **Control Panel:** Powder-coated, pre-wired with PLC (Omron/Mitsubishi)
- **Indicators:** Temperature (Primary, Secondary, Flue Gas)
- **Alarm:** Audio-Visual for abnormal operations

Feeding and Venting System

- **Feeding:** Automatic hydraulic bucket type, 3 HP motor
- **Emergency Vent:** Mild Steel, 3 mm, with damper control and insulation

Pollution Control Units

- **Cyclone Separator:** 1 Set, MS, refractory lined
- **Lime Treatment System:** 1 Set, MS, refractory lined
- **Droplet Separator:** Removes water droplets from flue gas
- **Activated Carbon System:** Removes hydrocarbons, oxides, odors
- **Flow Meter:** For both primary and secondary ducts

Key Brands and Features

- **Burner:** Flamco
- **Motors:** Crompton Greaves / Bharat Bijlee
- **Fans:** Aravali (ID and FD Fans)
- **Electricals:** L&T / Siemens / ABB / Hager
- **Alarms:** Vaisno
- **PLC:** Omron / Mitsubishi
- **PID Controllers:** Selec
- **Special Features:**
 - Auto cut-off for ID/FD Fans and burners if scrubber temp > 80°C
 - Interface selector switch, voltmeter, contactors, relays, MCBs included

Other Provided Accessories

- Virtually clean smoke emission
- Quick heat-up and high burn rates (up to 300 kg/hr)
- MOEF Compliance

- Light Arrestor with Stand
- Gyrope
- Easy installation and maintenance

ANNEX D: CAPITAL AND OPERATIONAL EXPENDITURE (CAPEX AND OPEX) CALCULATION FOR SAMPLE 3

a) CAPEX Calculation:

$$\begin{aligned}\text{CAPEX} &= \text{SCR System} + \text{Wet Scrubbers} + \text{Heat Exchangers} + \text{ORC System} \\ &= 7,000,000 + 5,600,000 + 2,100,000 + 21,000,000 \\ &= \text{NPR } 35,700,000\end{aligned}$$

b) OPEX Calculation:

Maintenance Costs:

$$\begin{aligned}\text{Maintenance Costs} &= 5\% \times \text{CAPEX} \\ &= 0.05 \times 35,700,000 \\ &= \text{NPR } 1,785,000/\text{year}\end{aligned}$$

Labor Costs:

$$\text{NPR } 1,200,000/\text{year}$$

Fuel Costs:

$$\begin{aligned}\text{Fuel Consumption} &= 15 \text{ liters/hour} \times 20 \text{ hours/day} \times 365 \text{ days/year} \\ &= 109,500 \text{ liters/year} \\ \text{Fuel Costs} &= 109,500 \times 148.5 \\ &= \text{NPR } 16,260,750/\text{year}\end{aligned}$$

Total OPEX:

$$\begin{aligned}\text{OPEX} &= \text{Maintenance} + \text{Labor} + \text{Fuel} \\ &= 1,785,000 + 1,200,000 + 16,260,750 \\ &= \text{NPR } 19,245,750/\text{year}\end{aligned}$$

c) **Financial Metrics:**

Electricity Generation:

3,311,375.31 kWh/year (from 7-day Sun Dry Aggregate Sample)

Electricity Tariff:

NPR 9.95/kWh

[Reference: Nepal Electricity Authority, 2025 Commercial]

Revenue from Electricity:

$$\begin{aligned}\text{Revenue} &= 3,311,375.31 \times 9.95 \\ &= \text{NPR } 32,948,184.33\text{year}\end{aligned}$$

Discount Rate:

8% (based on Nepal's average cost of capital)

[Reference: Nepal Rastra Bank, 2025]

Project Lifespan: 10 years

ANNEX E: ENVIRONMENT IMPACT ANALYSIS FOR INCINERATION INSTALLED AT TIA

Environmental Impact Reduction Calculations

1. CO₂ Emissions Reduction

Reference: IPCC (2019) **Current Emissions:** 1.5 kg CO₂/kg waste **Reduction by Improved Incineration:** 20% (EPA, 2020)

$$\begin{aligned}\text{Reduction in CO}_2 \text{ per kg waste} &= 1.5 \times 0.20 = 0.3 \text{ kg CO}_2/\text{kg waste} \\ \text{Annual CO}_2 \text{ Reduction} &= 0.3 \times 200 \text{ kg/hr} \times 20 \text{ hr/day} \times 365 \text{ days/year} \\ &= 438,000 \text{ kg CO}_2/\text{year} \\ &= \boxed{438 \text{ tons CO}_2/\text{year}}\end{aligned}$$

2. NO_x Emissions Reduction

Reference: TIA Emission Test Report (2021), US EPA (2020) **Current NO_x Emissions:** 120 ppm **Reduction by SCR System:** 85%

$$\text{Reduction in NO}_x \text{ Emissions} = 120 \times 0.85 = \boxed{102 \text{ ppm}}$$

3. Landfill Diversion Improvement

Reference: Nepal Waste Management Report (2022), World Bank (2020) **Current Landfill Contribution:** 40% **Reduction in Landfill Dependency via Incineration:** 40%

$$\text{Reduction in Landfill Dependency} = 0.40 \times 0.40 = \boxed{16\%}$$

Table A.1: Monthly Waste Collection at TIA for the month of Magh 2081

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Magh 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	10/1/2081	4	750	2000	4500	1000	5	850		2000	11105
2	10/2/2081	4	720	2200	4400	950	8	900		2100	11278
3	10/3/2081	6	720	2000	4600	950	5	900		2000	11175
4	10/4/2081	4	720	2000	4200	1000	8	950		2200	11078
5	10/5/2081	5	745	2150	4300	1050	5	900	80	2300	11530
6	10/6/2081	4	780	2000	4400	920	8	950		2000	11058
7	10/7/2081	6	790	2000	4000	982	6	1000		2000	10778
8	10/8/2081	4	777	2500	4800	950	9	900		2100	12036
9	10/9/2081	5	900	2000	4200	950	10	930		2000	10990
10	10/10/2081	4	820	2000	4300	950	5	900	60	2150	11185
11	10/11/2081	7	720	1950	4450	950	6	1000		2000	11076
12	10/12/2081	4	720	2150	4720	950	8	1000		2000	11548
13	10/13/2081	6	720	2000	5100	950	7	1050		2000	11827
14	10/14/2081	4	720	2200	4175	950	9	1050		2200	11304
15	10/15/2081	4	720	1950	4521	950	5	900		2000	11046
16	10/16/2081	5	720	2150	4711	950	8	1000	55	2150	11744
17	10/17/2081	4	720	2000	4531	950	5	1050		2150	11406
18	10/18/2081	6	720	2200	4600	950	8	1100		2150	11728
19	10/19/2081	6	775	2000	4961	950	5	1200		2000	11891
20	10/20/2081	6	760	1900	4600	950	8	900		2000	11118
21	10/21/2081	6	830	2000	4700	950	6	900	55	2000	11441
22	10/22/2081	4	920	2100	4500	950	9	1100		2200	11779
23	10/23/2081	5	720	1950	4400	950	10	1000		2000	11030
24	10/24/2081	4	720	2000	4400	950	5	950		2000	11025
25	10/25/2081	4	720	2100	4300	950	6	900	100	1950	11026
26	10/26/2081	4	720	2000	4452	950	8	1000		1900	11030
27	10/27/2081	6	720	2200	4521	950	7	1100		1950	11448
28	10/28/2081	5	720	2100	4500	950	9	900		2000	11179
29	10/29/2081	5	720	2150	4450	950	7	1000		2000	11277
30	10/30/2081	4	720	2200	4871	950	9	1000	50	2100	11900
Total		145	22527	62150	135163	28702	214	29280	400	61600	340036

Table A.2: Monthly Waste Collection at TIA for the month of Falgun 2081

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Poush 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	9/1/2081	5	800	1950	4400	900	6	1000	60	2000	11116
2	9/2/2081	4	750	2200	4400	950	8	950		2100	11358
3	9/3/2081	4	720	2100	4550	1000	7	850		2100	11327
4	9/4/2081	4	730	2000	4300	1100	8	900		2200	11238
5	9/5/2081	6	745	2200	4300	1050	6	900		2300	11501
6	9/6/2081	4	780	2000	4400	920	8	850	70	2000	11028
7	9/7/2081	4	780	2150	4500	982	6	950		2000	11368
8	9/8/2081	4	775	2500	4800	950	9	900		2100	12034
9	9/9/2081	5	900	2000	4300	940	8	930		2000	11078
10	9/10/2081	5	820	2150	4300	950	5	900		2150	11275
11	9/11/2081	6	800	1950	4500	900	6	950		2000	11106
12	9/12/2081	4	720	2000	4720	950	7	984	80	2000	11461
13	9/13/2081	4	720	2000	4700	900	7	1030		2000	11357
14	9/14/2081	4	850	2100	4175	950	9	1050		2200	11334
15	9/15/2081	5	800	1950	4521	930	6	950		2000	11157
16	9/16/2081	5	720	2100	4750	935	8	980		2150	11643
17	9/17/2081	4	750	2000	4531	950	5	1000		2150	11386
18	9/18/2081	4	720	2200	4500	940	10	1150		2150	11670
19	9/19/2081	6	775	2200	4630	950	5	1180	100	2000	11840
20	9/20/2081	6	760	1900	4600	950	8	900		2000	11118
21	9/21/2081	5	840	2000	4750	1000	6	900		2000	11496
22	9/22/2081	4	900	2100	4600	950	9	1100		2200	11859
23	9/23/2081	5	720	2000	4400	950	8	1000		2000	11078
24	9/24/2081	4	750	2000	4450	850	5	950	90	2000	11095
25	9/25/2081	4	720	2100	4300	1000	6	900		1950	10976
26	9/26/2081	5	750	2150	4452	1000	8	1050		1900	11310
27	9/27/2081	6	720	2200	4520	950	7	1060		1950	11407
28	9/28/2081	5	805	2150	4500	900	9	900		2000	11264
29	9/29/2081	4	710	2150	4430	950	10	1000	70	2000	11320
	Total	135	22330	60500	130279	27647	210	28164	470	59600	329200

Table A.3: Monthly Waste Collection at TIA for the month of Chaitra 2081

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Mangsir 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	8/1/2081	5	800	2150	4450	950	6	830	60	2080	11326
2	8/2/2081	4	700	2200	4400	1000	7	1000		2100	11407
3	8/3/2081	5	720	2000	4550	950	5	950		2150	11325
4	8/4/2081	4	750	2150	4200	850	6	950		2200	11106
5	8/5/2081	4	745	2100	4400	1050	5	900		2200	11400
6	8/6/2081	4	800	2000	4400	950	7	950	70	2000	11177
7	8/7/2081	5	790	2100	4500	982	6	950		2150	11478
8	8/8/2081	5	777	2400	4600	960	8	900		2100	11745
9	8/9/2081	5	850	2100	4200	800	9	940		2000	10899
10	8/10/2081	4	820	2000	4400	950	5	900		2200	11275
11	8/11/2081	6	800	1900	4450	950	8	960	80	2000	11148
12	8/12/2081	4	720	2150	4650	1000	8	1000		2100	11628
13	8/13/2081	5	850	2150	5000	950	8	1050		2000	12008
14	8/14/2081	4	720	2200	4175	950	8	1100		2150	11303
15	8/15/2081	5	720	1950	4650	900	5	900		2000	11125
16	8/16/2081	5	830	2100	4711	950	8	1050		2150	11799
17	8/17/2081	4	720	2000	4630	850	6	1050	100	2100	11456
18	8/18/2081	4	720	2200	4500	950	8	980		2150	11508
19	8/19/2081	6	750	2150	4956	950	6	1200		2000	12012
20	8/20/2081	6	760	1980	4650	900	7	900		1950	11147
21	8/21/2081	5	820	2000	4700	950	6	950		2000	11426
22	8/22/2081	4	950	2100	4450	950	8	1100		1980	11538
23	8/23/2081	5	750	1950	4500	1000	9	1000	70	2000	11279
24	8/24/2081	4	720	2000	4400	950	5	1000		1985	11060
25	8/25/2081	4	720	2150	4300	900	7	900		1950	10927
26	8/26/2081	5	750	2000	4650	950	6	1050		2000	11406
27	8/27/2081	6	720	2150	4521	1050	7	1100		1950	11498
28	8/28/2081	5	750	2100	4450	950	10	900		2000	11160
29	8/29/2081	4	720	2100	4650	900	7	1000	80	2100	11557
30	8/30/2081	5	800	2160	4800	1000	8	1050		2100	11918
Total		141	23042	62690	135893	28392	209	29510	460	61845	342041

Table A.4: Monthly Waste Collection at TIA for the month of Baisakh 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Kartik 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	7/1/2081	4	800	2200	4500	900	6	830		2100	11336
2	7/2/2081	5	750	2150	4400	900	7	1000	90	2100	11397
3	7/3/2081	5	720	2000	4550	950	8	1000		2150	11378
4	7/4/2081	4	730	2160	4300	850	6	1000		2100	11146
5	7/5/2081	4	745	2100	4400	950	5	900		2200	11300
6	7/6/2081	4	780	2150	4550	950	10	950		2000	11390
7	7/7/2081	4	790	2100	4500	980	6	1000	80	2150	11606
8	7/8/2081	5	765	2350	4550	960	8	900		2100	11633
9	7/9/2081	6	850	2300	4200	980	9	940		2100	11379
10	7/10/2081	4	820	2150	4500	950	8	950		2200	11578
11	7/11/2081	5	790	2020	4450	980	8	960		2000	11208
12	7/12/2081	4	720	2150	4650	950	8	950		2100	11528
13	7/13/2081	5	790	2080	4800	950	9	1050	100	2000	11779
14	7/14/2081	4	720	2200	4175	1000	10	1050		2200	11355
15	7/15/2081	4	720	1950	4650	900	5	1050		2000	11275
16	7/16/2081	5	900	2160	4650	950	8	900		2150	11718
17	7/17/2081	5	720	2000	4630	1000	6	950		2200	11506
18	7/18/2081	4	720	2200	4500	950	9	980		2150	11509
19	7/19/2081	5	760	2150	4400	950	6	1100		2000	11366
20	7/20/2081	6	760	2000	4650	980	7	900		1950	11247
21	7/21/2081	5	790	2000	4650	950	6	950		2100	11446
22	7/22/2081	4	890	2200	4450	950	7	850	100	1980	11427
23	7/23/2081	6	750	1950	4500	950	9	1150		2100	11409
24	7/24/2081	4	720	2000	4400	1000	5	1000		1985	11110
25	7/25/2081	5	720	2150	4500	900	7	950		1950	11177
26	7/26/2081	4	780	2200	4450	1000	8	1050	85	2050	11623
27	7/27/2081	4	720	2150	4521	950	7	950		1950	11248
28	7/28/2081	5	798	2100	4450	950	9	900		2100	11307
29	7/29/2081	4	720	2100	4650	850	7	950		2100	11377
30	7/30/2081	4	790	2200	4600	950	10	890	780	2200	12420
Total		137	23028	63620	135176	28430	224	29000	1235	62465	343178

Table A.5: Monthly Waste Collection at TIA for the month of Jestha 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Ashoj 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	6/1/2081	5	900	2150	4550	850	6	830		2200	11486
2	6/2/2081	4	850	2200	4400	850	8	1000	50	2100	11458
3	6/3/2081	4	850	2100	4550	900	8	1050		2150	11608
4	6/4/2081	4	730	2100	4200	850	7	1000		2200	11087
5	6/5/2081	6	750	2100	4500	950	6	900		2200	11406
6	6/6/2081	4	780	2150	4550	950	9	1050		2000	11489
7	6/7/2081	5	800	2050	4500	1000	6	950	120	2000	11426
8	6/8/2081	5	765	2090	4600	960	8	900		2100	11423
9	6/9/2081	5	860	2200	4200	980	8	1000		2100	11348
10	6/10/2081	4	820	2150	4500	950	8	950		2200	11578
11	6/11/2081	5	800	2020	4600	980	10	1000		2000	11410
12	6/12/2081	6	720	2200	4650	950	12	950		2200	11682
13	6/13/2081	7	790	2080	5000	1000	11	1100	80	2000	12061
14	6/14/2081	4	780	2150	5000	1050	10	1000		2150	12140
15	6/15/2081	6	720	2300	5000	1050	12	1105		2200	12387
16	6/16/2081	7	850	2350	5000	950	8	1050		2200	12408
17	6/17/2081	5	720	2300	4630	1050	8	1100		2200	12008
18	6/18/2081	7	720	2250	4450	950	9	980	100	2150	11609
19	6/19/2081	5	750	2150	4400	950	6	1200		2200	11656
20	6/20/2081	4	800	2000	4650	1000	8	900		2000	11358
21	6/21/2081	5	800	2200	4500	950	6	1200		2100	11756
22	6/22/2081	4	800	2200	4450	850	10	850		2152	11312
23	6/23/2081	5	750	2200	4500	850	12	1150		2100	11562
24	6/24/2081	4	720	2150	4400	1000	5	1000	90	987	10352
25	6/25/2081	5	720	2150	4600	900	7	890		1950	11217
26	6/26/2081	5	900	2300	4450	1050	8	890		2080	11678
27	6/27/2081	5	720	2150	4650	1000	7	950		1950	11427
28	6/28/2081	5	850	2300	4450	1000	10	900		2100	11610
29	6/29/2081	4	720	2100	4650	850	7	980		2200	11507
30	6/30/2081	6	750	2350	4700	1000	12	895	110	2200	12017
	Total	150	23485	65190	137280	28620	252	29720	550	62369	347466

Table A.6: Monthly Waste Collection at TIA for the month of Ashadh 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Bhadra 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	5/1/2081	4	780	2000	4400	920	8	950		2000	11058
2	5/2/2081	6	790	2000	4000	982	6	1000		2000	10778
3	5/3/2081	4	777	2500	4800	950	9	900		2100	12036
4	5/4/2081	5	900	2000	4200	950	10	930		2000	10990
5	5/5/2081	4	820	2000	4300	950	5	900	60	2150	11185
6	5/6/2081	7	720	1950	4450	950	6	1000		2000	11076
7	5/7/2081	4	720	2150	4720	950	8	1000		2000	11548
8	5/8/2081	6	720	2000	5100	950	7	1050		2000	11827
9	5/9/2081	4	720	2200	4175	950	9	1050		2200	11304
10	5/10/2081	4	720	1950	4521	950	5	900		2000	11046
11	5/11/2081	5	720	2150	4711	950	8	1000	55	2150	11744
12	5/12/2081	4	720	2000	4531	950	5	1050		2150	11406
13	5/13/2081	4	780	2000	4400	920	8	950		2000	11058
14	5/14/2081	6	790	2000	4000	982	6	1000		2000	10778
15	5/15/2081	4	777	2500	4800	950	9	900		2100	12036
16	5/16/2081	5	900	2000	4200	950	10	930		2000	10990
17	5/17/2081	4	820	2000	4300	950	5	900	60	2150	11185
18	5/18/2081	7	720	1950	4450	950	6	1000		2000	11076
19	5/19/2081	4	720	2150	4720	950	8	1000		2000	11548
20	5/20/2081	6	720	2000	5100	950	7	1050		2000	11827
21	5/21/2081	4	720	2200	4175	950	9	1050		2200	11304
22	5/22/2081	4	720	1950	4521	950	5	900		2000	11046
23	5/23/2081	5	720	2150	4711	950	8	1000	55	2150	11744
24	5/24/2081	4	720	2000	4531	950	5	1050		2150	11406
25	5/25/2081	6	720	2200	4600	950	8	1100		2150	11728
26	5/26/2081	6	775	2000	4961	950	5	1200		2000	11891
27	5/27/2081	6	760	1900	4600	950	8	900		2000	11118
28	5/28/2081	6	830	2000	4700	950	6	900	55	2000	11441
29	5/29/2081	4	920	2100	4500	950	9	1100		2200	11779
30	5/30/2081	5	720	1950	4400	950	10	1000		2000	11030
31	5/31/2081	6	750	2350	4700	1000	12	895	110	2200	12017
	Total	153	23689	64300	140277	29504	230	30555	395	64050	353000

Table A.7: Monthly Waste Collection at TIA for the month of Shrawan 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Shrawan 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	4/1/2081	4	800	2100	4300	910	9	850	10	2500	11479
2	4/2/2081	4	820	1950	4250	925	8	875		2000	10828
3	4/3/2081	5	780	2500	4700	950	10	900	30	2100	11970
4	4/4/2081	5	850	2200	4200	955	9.5	920		2000	11134.5
5	4/5/2081	4	820	2200	4300	933	8	910	60	2150	11381
6	4/6/2081	5	800	1950	4500	945	10	900	35	2000	11140
7	4/7/2081	4	750	2150	4720	920	8	850		2000	11398
8	4/8/2081	4	750	2200	5100	917	7	890		2200	12064
9	4/9/2081	4	720	2100	4100	922	8.5	900		2400	11150.5
10	4/10/2081	4	730	2000	4500	933	9.5	895		2000	11067.5
11	4/11/2081	5	720	2150	4700	960	10	930	55	2150	11675
12	4/12/2081	4	720	2100	4531	923	9.5	910		2230	11423.5
13	4/13/2081	5	750	2000	4400	955	10	935		2100	11150
14	4/14/2081	6	750	2600	4800	960	13	1000	50	2300	12473
15	4/15/2081	4	789	2500	4800	918	9	930		2100	12046
16	4/16/2081	5	785	2100	4300	936	10	935		2100	11166
17	4/17/2081	4	795	2000	4300	919	9.5	895	60	2150	11128.5
18	4/18/2081	6	785	2400	4500	965	12	1050		2200	11912
19	4/19/2081	4	790	2150	4700	925	8	900		2000	11473
20	4/20/2081	5	775	2150	5005	937	9	950		2000	11826
21	4/21/2081	4	798	2200	4100	920	8.5	890	30	2200	11146.5
22	4/22/2081	4	760	1950	4521	922	8	900		2000	11061
23	4/23/2081	5	820	2150	4711	936	9.5	950	55	2150	11781.5
24	4/24/2081	6	860	2480	4600	963	13	1100		2230	12246
25	4/25/2081	5	840	2200	4600	935	11	1050	35	2150	11821
26	4/26/2081	5	890	2000	5000	933	10.5	1060		2232	12125.5
27	4/27/2081	5	760	1900	4980	937	10	1070		2000	11657
28	4/28/2081	6	850	2350	5100	966	13	1200	55	2220	12754
29	4/29/2081	4	920	2100	4500	916	9	980		2200	11625
30	4/30/2081	5	750	2100	4400	929	10	1000		2222	11411
31	4/31/2081	4	750	2350	4800	922	8.5	900	70	2200	12000.5
32	4/32/2081	5	750	2400	4850	936	10.5	1020		2200	12166.5
	Total	149	25227	69680	146868	29923	309	30445	545	68684	371681

Table A.8: Monthly Waste Collection at TIA for the month of Bhadra 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Asar 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	3/1/2081	5	885	2200	4500	850	8	980	70	2100	11593
2	3/2/2081	4	830	2110	4200	860	9	980		2000	10989
3	3/3/2081	5	888	2550	4550	8900	7	990		2110	19995
4	3/4/2081	5	855	2530	4554	800	8	990	80	2111	11928
5	3/5/2081	4	820	2200	4400	780	8	990		2000	11198
6	3/6/2081	4	800	2200	4000	780	10	980		2000	10770
7	3/7/2081	4	750	2200	4100	780	9.5	888		2000	10727.5
8	3/8/2081	5	787	2250	4210	780	8	988		2150	11173
9	3/9/2081	6	798	2300	4590	799	10	988	85	2200	11770
10	3/10/2081	5	725	2300	4500	788	10	1000		2100	11423
11	3/11/2081	5	725	2300	4440	790	9	1111		2111	11486
12	3/12/2081	4	720	2222	4200	700	10	1012	95	2500	11459
13	3/13/2081	4	750	2222	4100	875	8	1021		2300	11276
14	3/14/2081	4	750	2322	4110	780	8	980		2400	11350
15	3/15/2081	6	790	2500	4445	902	8	1100		2340	12085
16	3/16/2081	5	760	2350	4400	850	9	1000		2350	11719
17	3/17/2081	5	760	2380	4500	850	9	980		2250	11729
18	3/18/2081	4	760	2200	4100	850	9	850		2222	10991
19	3/19/2081	5	780	2300	4511	850	9	980		2125	11555
20	3/20/2081	4	775	2121	4111	840	8	980	90	2350	11275
21	3/21/2081	4	798	2120	4111	888	7	980		2222	11126
22	3/22/2081	5	760	2200	4120	879	8	981		2350	11298
23	3/23/2081	5	810	2200	4115	897	8	985		2500	11515
24	3/24/2081	4	800	2110	4510	800	8	985		2200	11413
25	3/25/2081	4	802	2000	4200	900	9	955		2100	10966
26	3/26/2081	4	890	1980	4200	900	10	900		2100	10980
27	3/27/2081	5	760	1998	4500	980	10	910		2500	11658
28	3/28/2081	6	900	2498	4550	999	10	1100	90	2500	12647
29	3/29/2081	4	920	2100	4100	850	9	850		2240	11069
30	3/30/2081	4	750	2100	4100	888	8	865		2300	11011
31	3/31/2081	4	750	2100	4100	888	8.5	865	90	2300	11101.5
Total	142	142	24648	69163	133127	34273	270	30164	600	69031	361276

Table A.9: Monthly Waste Collection at TIA for the month of Ashwin 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Jestha 2081											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	2/1/2081	5	800	2150	4400	900	5	830	60	2150	11295
2	2/2/2081	4	700	2200	4000	950	8	1000		2200	11058
3	2/3/2081	4	720	2000	4800	1000	5	1000		2000	11525
4	2/4/2081	4	750	2150	4200	1100	8	1000		2150	11358
5	2/5/2081	6	745	2100	4300	1050	5	900		2100	11200
6	2/6/2081	4	800	2000	4450	920	8	950	70	2000	11198
7	2/7/2081	4	790	2100	4720	982	6	1000		2100	11698
8	2/8/2081	4	777	2400	5100	950	9	900		2400	12536
9	2/9/2081	5	850	2100	4175	940	10	940		2100	11115
10	2/10/2081	5	820	2000	4521	950	5	950		2000	11246
11	2/11/2081	6	800	1900	4711	900	6	960	80	1900	11257
12	2/12/2081	4	720	2150	4531	950	8	950		2150	11459
13	2/13/2081	4	850	2150	4400	900	7	1050		2150	11507
14	2/14/2081	4	720	2200	4000	950	9	1050		2200	11129
15	2/15/2081	5	720	1950	4800	930	5	1050		1950	11405
16	2/16/2081	5	830	2100	4200	935	8	900		2100	11073
17	2/17/2081	4	720	2000	4300	950	5	950	100	2000	11025
18	2/18/2081	4	720	2200	4450	940	8	980		2200	11498
19	2/19/2081	6	750	2150	4720	950	5	1100		2150	11825
20	2/20/2081	6	760	1980	5100	950	8	900		1980	11678
21	2/21/2081	5	820	2000	4175	1000	6	950		2000	10951
22	2/22/2081	4	950	2100	4521	950	9	850		2100	11480
23	2/23/2081	5	750	1950	4711	950	10	1150	70	1950	11541
24	2/24/2081	4	720	2000	4531	850	5	1000		2000	11106
25	2/25/2081	4	720	2150	4600	1000	6	950		2150	11576
26	2/26/2081	5	750	2000	4961	1000	8	1050		2000	11769
27	2/27/2081	6	720	2150	4600	950	7	950		2150	11527
28	2/28/2081	5	750	2100	4700	900	9	900		2100	11459
29	2/29/2081	4	720	2100	4500	950	7	950	80	2100	11407
30	2/30/2081	5	800	2160	4500	950	9	890		2160	11469
31	2/31/2082	4	750	2350	4444	1000	12	895	110	2200	11761
32	2/32/2081	5	750	2400	4544	1000	12	895	110	2200	11911
	Total	149	24542	67440	144665	30597	238	30790	680	67090	366042

Table A.10: Monthly Waste Collection at TIA for the month of Kartik 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Baishak 2080											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	1/1/2081	4	1000	2200	4400	1190	8	830	80	2000	11708
2	1/2/2081	4	950	2150	4000	1190	9	1000		2000	11299
3	1/3/2081	4	988	2000	4800	1111	7	1000		2100	12006
4	1/4/2081	5	980	2160	4200	1200	8	1000	70	2000	11618
5	1/5/2081	4	1000	2100	4300	1111	8	900	50	2000	11469
6	1/6/2081	5	999	2150	4450	1190	10	950		2100	11849
7	1/7/2081	4	988	2100	4720	950	9.5	1000		2000	11767.5
8	1/8/2081	4	1030	2350	5100	900	8	900		2000	12288
9	1/9/2081	4	1030	2300	4175	922	10	940		2100	11477
10	1/10/2081	5	1050	2150	4521	950	10	950	90	2000	11721
11	1/11/2081	4	1050	2020	4711	988	9	960	60	2150	11948
12	1/12/2081	4	950	2150	4531	950	10	950	60	2150	11751
13	1/13/2081	4	950	2080	4400	999	8	1050		2000	11487
14	1/14/2081	5	905	2200	4000	1150	8	1050		2000	11313
15	1/15/2081	4	999	1950	4800	950	8	1050		2100	11857
16	1/16/2081	4	980	2160	4200	980	9	900	85	2000	11314
17	1/17/2081	4	990	2000	4300	950	9	950	85	2150	11434
18	1/18/2081	4	999	2200	4450	980	9	980		2000	11618
19	1/19/2081	4	988	2150	4720	850	9	1100		2000	11817
20	1/20/2081	5	1010	2000	5100	1198	8	900		2000	12216
21	1/21/2081	4	1010	2000	4175	988	7	950	98	2000	11228
22	1/22/2081	5	1200	2200	4521	990	8	850	99	2000	11868
23	1/23/2081	4	998	1950	4711	990	8	1150		2100	11907
24	1/24/2081	4	990	2000	4531	952	8	1000		2000	11481
25	1/25/2081	5	1100	2150	4600	1000	9	950		2000	11809
26	1/26/2081	5	1155	2200	4961	1000	10	1050		2000	12376
27	1/27/2081	4	1155	2150	4600	980	10	950		2000	11845
28	1/28/2081	5	999	2100	4700	1200	10	900		2100	12009
29	1/29/2081	4	1200	2100	4500	985	9	950	110	2000	11854
30	1/30/2081	5	1200	2200	4400	1200	8	890		2000	11898
31	1/31/2081	5	1200	2400	4700	1200	8.5	895		2200	12603.5
	Total	135	32043	66020	140277	32194	270	29895	887	63250	364836

Table A.11: Monthly Waste Collection at TIA for the month of Mangsir 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Chaita 2080											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	12/1/2081	4	800	2100	4300	920	8	950		2000	11078
2	12/2/2081	4	820	1950	4250	982	6	1000		2000	11008
3	12/3/2081	5	780	2500	4700	950	9	900		2100	11939
4	12/4/2081	5	850	2200	4200	950	10	930		2000	11140
5	12/5/2081	4	820	2200	4300	950	5	900	60	2150	11385
6	12/6/2081	5	800	1950	4500	950	6	1000		2000	11206
7	12/7/2081	4	750	2150	4720	950	8	1000		2000	11578
8	12/8/2081	4	750	2200	5100	950	7	1050		2000	12057
9	12/9/2081	4	720	2100	4100	950	9	1050		2200	11129
10	12/10/2081	4	730	2000	4500	950	5	900		2000	11085
11	12/11/2081	5	720	2150	4700	950	8	1000	55	2150	11733
12	12/12/2081	4	720	2100	4531	950	5	1050		2150	11506
13	12/13/2081	5	750	2000	4400	920	8	950		2000	11028
14	12/14/2081	6	750	2600	4800	982	6	1000		2000	12138
15	12/15/2081	4	789	2500	4800	950	9	900		2100	12048
16	12/16/2081	5	785	2100	4300	950	10	930		2000	11075
17	12/17/2081	4	795	2000	4300	950	5	900	60	2150	11160
18	12/18/2081	6	785	2400	4500	950	6	1000		2000	11641
19	12/19/2081	4	790	2150	4700	950	8	1000		2000	11598
20	12/20/2081	5	775	2150	5005	950	7	1050		2000	11937
21	12/21/2081	4	798	2200	4100	950	9	1050		2200	11307
22	12/22/2081	4	760	1950	4521	950	5	900		2000	11086
23	12/23/2081	5	820	2150	4711	950	8	1000	55	2150	11844
24	12/24/2081	6	860	2480	4600	950	5	1050		2150	12095
25	12/25/2081	5	840	2200	4600	950	8	1100		2150	11848
26	12/26/2081	5	890	2000	5000	950	5	1200		2000	12045
27	12/27/2081	5	760	1900	4980	950	8	900		2000	11498
28	12/28/2081	6	850	2350	5100	950	6	900	55	2000	12211
29	12/29/2081	4	920	2100	4500	950	9	1100		2200	11779
30	12/30/2081	5	750	2100	4400	950	10	1000		2000	11210
Total		140	23727	64930	137218	28504	218	29660	285	61850	346392

Table A.12: Monthly Waste Collection at TIA for the month of Poush 2082

Sungabha- Shrestha-Sagarmatha JV											
Tribhuvan International Airport (TIA)											
Gauchar, Kathmandu											
Log Book-Daily Waste Collection and Waste Characteristics											
Falgun 2080											
S.N.	Date	Trip	Waste Characteristics								Daily Tentative Weight (Kg)
			Organic Waste (Kg)	Plastic & Plastic Products (Kg)	Paper & Paper Products (Kg)	Glass (Kg)	Metal (Kg)	Rubber & Textiles (Kg)	Official Paper (Kg)	Others (Kg)	
1	11/1/2081	4	800	2200	4500	900	6	830		2100	11336
2	11/2/2081	5	750	2150	4400	900	7	1000	90	2100	11397
3	11/3/2081	5	720	2000	4550	950	8	1000		2150	11378
4	11/4/2081	4	730	2160	4300	850	6	1000		2100	11146
5	11/5/2081	4	745	2100	4400	950	5	900		2200	11300
6	11/6/2081	4	780	2150	4550	950	10	950		2000	11390
7	11/7/2081	4	790	2100	4500	980	6	1000	80	2150	11606
8	11/8/2081	5	765	2350	4550	960	8	900		2100	11633
9	11/9/2081	6	850	2300	4200	980	9	940		2100	11379
10	11/10/2081	4	820	2150	4500	950	8	950		2200	11578
11	11/11/2081	5	790	2020	4450	980	8	960		2000	11208
12	11/12/2081	4	720	2150	4650	950	8	950		2100	11528
13	11/13/2081	5	790	2080	4800	950	9	1050	100	2000	11779
14	11/14/2081	4	720	2200	4175	1000	10	1050		2200	11355
15	11/15/2081	4	720	1950	4650	900	5	1050		2000	11275
16	11/16/2081	5	900	2160	4650	950	8	900		2150	11718
17	11/17/2081	5	720	2000	4630	1000	6	950		2200	11506
18	11/18/2081	4	720	2200	4500	950	9	980		2150	11509
19	11/19/2081	5	760	2150	4400	950	6	1100		2000	11366
20	11/20/2081	6	760	2000	4650	980	7	900		1950	11247
21	11/21/2081	5	790	2000	4650	950	6	950		2100	11446
22	11/22/2081	4	890	2200	4450	950	7	850	100	1980	11427
23	11/23/2081	6	750	1950	4500	950	9	1150		2100	11409
24	11/24/2081	4	720	2000	4400	1000	5	1000		1985	11110
25	11/25/2081	5	720	2150	4500	900	7	950		1950	11177
26	11/26/2081	4	780	2200	4450	1000	8	1050	85	2050	11623
27	11/27/2081	4	720	2150	4521	950	7	950		1950	11248
28	11/28/2081	5	798	2100	4450	950	9	900		2100	11307
29	11/29/2081	4	720	2100	4650	850	7	950		2100	11377
30	11/30/2081	4	790	2200	4600	950	10	890	780	2200	12420
	Total	137	23028	63620	135176	28430	224	29000	1235	62465	343178

ANNEX F: ACCEPTANCE LETTER FROM IOEGC



Anil Gupta <anilgupta606@gmail.com>

[IOEGC16] Editor Decision

Bhesh Karki <conference-noreply@ioe.edu.np>
To: Anil Kumar Gupta <anilgupta606@gmail.com>

Sat, 29 Mar at 8:15 PM

Anil Kumar Gupta:

We are pleased to inform you that your manuscript titled "Optimizing Waste Management at Airports: A Case Study of Tribhuvan International Airport's Sustainable Waste-to-Energy Transition: Airport Waste Management" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

Reviewer's Comments:

With Warm Regards,
IOEGC-16 Editorial Team

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