

THESIS

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**Assessing the Potential of Waste to Energy Solutions for
Vientiane's Landfills**

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Contents

Chapter 1: Introduction	1
1. Introduction	1
Chapter 2: Literature Review	5
2.1 The Global Solid Waste Management Challenge	5
2.2 Waste to Energy (WTE) Technologies and Global Application	7
2.3 Environmental and Economic Impacts of WTE	11
2.4 Institutional and Policy Framework for WTE in Laos	16
Chapter 3: Materials and Method	20
3.1 Current Waste Management in Vientiane: Status and Problems	20
3.2 Analytical Approach: Scenarios and Feasibility Criteria	22
3.3 Scenario 1: Baseline (Continued Landfilling)	24
3.4 Scenario 2: Introducing Waste to Energy Facility	25
3.5 Feasibility and Operating Conditions for Success	29
Chapter 4: Results and Discussion	33
4.1 Results of Technical Feasibility Study	33
4.2 Environmental Results	35
4.3 Economic and Financial Results	37
4.4 Institutional and Social Results	40
4.5 Summary of Comparative Results	41
4.6 Comparative Discussion with Regional Examples	43
Chapter 5: Conclusion	45
Chapter 6: Summary	47
References	49
Table of Figures	57
Table of Tables	57
List of Abbreviations	58

Chapter 1: Introduction

1. Introduction

Figure 1: KM32 landfill in Vientiane's Maps (Source: World Bank, 2025)



Solid waste management has become an urgent urban issue in Vientiane, capital of Lao PDR. The city, where rapid growth in population size, urbanization, and per capita consumption have resulted in increasing volume of this category of waste under the name of municipal solid waste (MSW). However, the waste management infrastructure and services have not is keeping up to this growth. Currently, over half of the waste in Vientiane remains uncollected causing unacceptable rates of illegal dumping and open burning of waste by residents (Kim et al., 2021). Even the waste that does get collected is disposed in an uncontrolled landfill which is nearly 32 km from the city, where minimal environmental precautions are being taken (Kim et al., 2021). These practices create major environmental and public health issues open burning of rubbish emits toxic pollutants which impact respiratory health, and disposal of organic waste produces methane, which is a powerful greenhouse gas contributing to climate change (Kim et al., 2021). In addition, not recovering usable materials from the waste stream is a lost economic opportunity for the city. The background makes evident that the problem statement is as follows: Vientiane's current waste

management practices are unsustainable, whereby over reliance on landfill and uncontrolled waste disposal was negatively affecting the environment while also restricting the opportunities for resource recovery (Alelula et al., 2018).

To address this, there are significant levels of localised interest within municipalities to move away from the traditional 'collect and dump' approach to a more sustainable 'waste to resource' model. With assistance from international partners, an Action Plan and a Sustainable Solid Waste Management Strategy for Vientiane 2021-2030 was produced and officially adopted by the city in 2021 (Kim et al., 2021). This Strategy outlines a vision for the enhancement of collection, source separation, recycling and ultimately of reaching the maximum potential for waste to resource opportunities across Vientiane. In this scenario, Waste to Energy (WTE) technologies have recently drawn attention as one of the elements of the future waste management system in the city (Kim et al., 2021). Examples include: WTE technologies have the potential to eliminate landfills by turning waste into electricity, heat, or fuel, thereby decreasing waste polluting, greenhouse gas emissions, and increasing medicinal energy or other usable byproducts (Noudeng et al., 2024). However, its actual implementation within Vientiane should be conducted carefully, taking into consideration the technical viability, environmental implications, economic sustainability as well as the compatibility with the local policy and institutional settings.

To meet this aim, the following are the research objectives of the research and those are:

Objective 1: Identify the status quo of the solid waste management in Vientiane, and in particular of the issues of city's relations with landfills.

Objective 2: Analyze the characteristics of the solid waste stream in Vientiane (e.g. waste composition and generation trends) and see how the factors are relevant for the choice of appropriate WTE technologies.

Objective 3: Introduce existing WTE technologies and global case studies and which technologies would be a good fit for the situation in Vientiane (definition of key words such as refuse derived fuel (RDF) and anaerobic digestion).

Objective 4: On a WTE project, examine environmental and economic impact implications of adoption of WTE solutions in Vientiane related to possible reductions in greenhouse gas levels

and landfill pollution as well as considerations affected by costs, financing needs and possible returns or savings.

Objective 5: Investigate institutional and policy framework in Laos relevant to waste management and energy to identify opportunities and barriers for implementing WTE projects in Vientiane.

In line with the above goals of the research, the following are the research questions:

1. Limitations of Current System What are the major limiting factors of the current landfill based waste management system in Vientiane?
2. Waste Profile and WTE Viability What is the makeup of the city's MSW and how will their volume increase? The problem to be addressed is, what do these characteristics mean for the viability of various WTE options?
3. Appropriate WTE Technologies: What form of WTE technologies (e.g. incineration, RDF, anaerobic digestion etc.) have been implemented elsewhere and what of these are most suitable to Vientiane's waste and situation.
4. Environmental and Economic Trade offs What are the expected environmental implications and risks and the economic costs and benefits of adopting WTE in Vientiane?
5. Policy and Institutional Context: How conducive or unconducive are the current policy, regulatory and institutional frameworks in Lao PDR for promoting the WTE solutions development in Vientiane?

By answering these questions, we will be able to be leading understand to what extent WTE can be a logical and supportive strategy to address Vientiane's increasing waste crisis.

This study is confined to the municipality of Vientiane Capital as well as municipal solid waste as already existed and disposed of in open dumps or landfills. Industrial, hazardous or biomedical waste is excluded apart from those that appear incidentally in the municipal waste stream. The analysis is presented from a technical, environmental, economic, and institutional point of view, which is of interest for the implementation of WTE technologies. Geographically, it focuses on the capital city of Vientiane and its main landfill at Km 32, whereas temporally it is referred to the city waste management strategy planning timeframe based on 2021-2030 (Kim et al., 2021).

Figure 2: KM32 landfill site from satellite (Source: World Bank, 2025)



Chapter 2: Literature Review

2.1 The Global Solid Waste Management Challenge

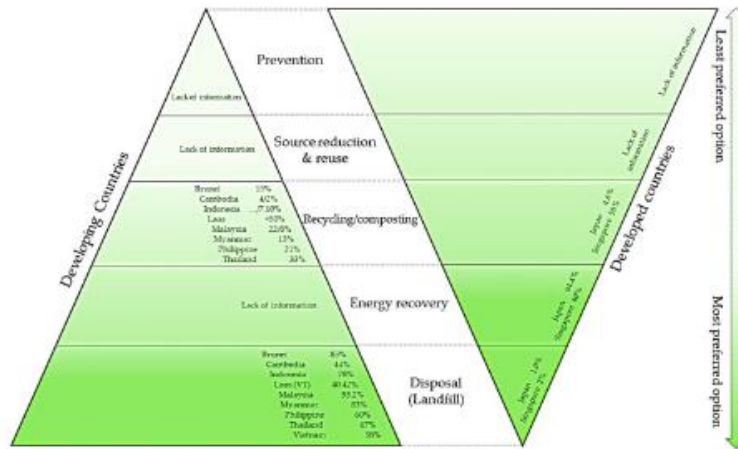
Rapid urbanization, population increase and a shift in consumption patterns have resulted in unprecedented levels of solid waste generation across the world (Noudeng et al., 2024). According to the recent assessment by United Nations Environment Programme (UNEP), and with the suspected lack of radical interventions, municipal solid waste (MSW) generation will increase from approximately 2.1 billion tonnes during 2023 to 3.8 billion tonnes in 2050 (Lenkiewicz., 2024). This doubling rate is well ahead of the ability of many countries to manage waste safely creating a challenge in solid waste management that is of monumental magnitude and complexity. The financial burden is similarly huge, it already costs hundreds of billions of dollars each year to manage the world's waste (which is estimated at USD 252 billion in direct costs in 2020), and may well double to USD 600 billion by 2050 when considering hidden costs such as pollution, health impacts and climate effects (Lenkiewicz., 2024). These trends stress the importance of accelerating waste management infrastructure and practices or else many regions will be afflicted by mounting economic, environmental, and public health crises associated with waste.

A central problem concerns the fact that in most of the world waste production is outpacing the development of proper waste management systems. High income countries (with only around 16% of the global population) produce about a third of the global waste (Kaza et al., 2025) yet tend to have set up the collection service and have regulated the disposal or treatment. In comparison, waste services and infrastructure are challenging in low and middle income countries. In the poor countries, an estimated 93% of waste is mismanaged (disposed in open dumps or burned openly), compared to only 2% in rich countries (Kaza et al., 2025), compared to only 2% in rich countries (Kaza et al., 2018). Globally, one third to 40% of all the waste generated is not collected or treated in an appropriate way and ends up polluting the environment through open dumping or uncontrolled burning (Kaza et al., 2018). Such practices lead to "toxic mountains" of garbage that pollute soil and water, release noxious smoke and breed disease vectors. For example, in Latin America an estimated 145,000 tonnes of urban waste, around a third of all the waste in the region, is dumped every day without any form of treatment (Lenkiewicz., 2024), which poses serious risks to public health and ecosystems. Similar or worse situations are seen in parts of Africa and Asia where blooming cities usually do not have enough landfills or recycling systems and then

the entire problem is dumping on most of the riverbanks, wetlands, and roadsides (Zhang et al., 2024).

Lack of proper waste management plays a big role in causing climate change and pollution. Organic waste decaying in landfills generates methane (a greenhouse gas over 80 times more potent than CO₂ over 20 years) (Lama, 2024), something we humans generate at China "doubling down" about 20 percent of the human produced methane emissions worldwide (Lama, 2024). Without action, the waste sector could account for about 10 per cent of total greenhouse gas emissions by 2025 because of increasing landfills and open dumps (Lenkiewicz, 2024). Open burning also releases toxic particulates and cancer causing substances that damage local air quality and health (Ferronato et al., 2019) and leachate contaminates soil and groundwater (Gupta et al., 2024). Plastics are a pervasive issue suffering from a lack of proper waste management and disposal resulting in millions of tons of plastic entering the oceans every year, breaking down into microplastics, and impacting food chains and ecosystems (Jambeck et al., 2015).

Figure 3: Hierarchy in MSW management between developing and developed countries (Source: Noudeng et al, 2024)



Solving this crisis will require integrated approaches based on the "waste management hierarchy," which calls for waste prevention, reuse, recycling, then energy recovery, and, finally, disposal to be regarded as the last measure (Zhang et al., 2022). As countries are moving towards circular economies, waste is increasingly used as a resource (Lenkiewicz, 2024). Despite the success of recycling and reduction, residual waste is always left, and WTE solutions are increasingly brought into consideration for mitigating landfill loadings in combination with energy production (Chandel et al., 2014). This paper discusses WTE technologies, worldwide applications

and their environmental and economic impact and thereafter focuses on their potential in Laos and Vientiane.

2.2 Waste to Energy (WTE) Technologies and Global Application

Waste to energy (WTE) is a general term that is applied to any of a variety of technologies that process solid waste materials to recover energy in the form of electricity, heat or fuel. Simply put, WTE is the process of setting the calorific content of a waste to work in the form of power and in the process, the waste is being treated as a resource and not refuse. Time, technology, and economic factors. Different types of waste to energy technology processes may be suitable in different waste streams and in different types of situations. The key WTE technologies are:

- **Incineration with Energy Recovery:** is the most prevalent WTE technique globally which is the combustion of municipal solid waste (MSW) at high temperature (generally above 850C) to produce combustion heat and electricity (Kim et al., 2021). The process helps to reduce the waste volume by approximately 85-90 percent and converts approximately 2,000 pounds of waste to 300-600 pounds of ash thereby relieving the burden on landfills (Noudeng et al., 2024). Modern mass burn plants such as grate and fluidized bed furnaces are capable of handling heterogeneous waste with minimal waste pretreatment and have sophisticated pollution control equipment to capture pollution particulates and toxic waste (Roy et al., 2022). Incineration has become an integral part of the waste management strategy of highly populated cities with small landfill area, such as Singapore, Japan, and several European capitals, where it makes it possible to reduce the waste and to recover the energy efficiently (Makarichi et al., (2018); Letsrecycle (2011); CNA (2023)).
- **Advanced Thermal Technologies (Gasification and Pyrolysis):** are advanced thermal WTE technology which involves the thermal breakdown of waste into fuel gases or liquids by means other than direct combustion (Noudeng et al., 2024). **Gasification:** Gasification involves the application of heat in a low oxygen environment and converts waste into a syngas composed mostly of CO, H₂ and CH₄ that can be used for heat or electric power (Segneri et al., 2022). **Pyrolysis:** This process applies heat under anoxic conditions to convert waste into char, oil and syngas (Sharuddin et al., 2016). These processes are typically more energy and lowest pollutant emitting than direct combustion but only perform best with homogeneous, high calorific feedstocks such as plastics, tyres or biomass

(Hasan et al., 2021). Although the results may seem promising, the technology is still in its fledgling stage, making it hard to get it to the scale necessary for it to be economically viable for mixing municipal solid waste as it comes from homes and commercial businesses, with most plants being small scale or proof of concept programs (Kumar et al., 2017).

- **Anaerobic Digestion (Biological Conversion):** is a biological WTE process, where organic matter and wet waste such as food waste, yard wastes, agriculture residues and sewage sludges are treated (Noudeng et al., 2024). In this process, microorganisms digest the organic matter under sealed conditions with no contact with oxygen thus releasing biogas, which consists of about 50-70% methane and the remainder CO₂ (Mao et al., 2015), and a rich digestate, which is the nutrient rich end product. The biogas can be used to produce electrical and heat energy or can be upgraded to biomethane to be used for cooking and as fuel for vehicles (Mao et al., 2015). AD replicates the natural decomposition which occurs in landfills but under controlled conditions in order to achieve maximum gas recovery and minimum emissions (Appels et al., 2011). It has a dual benefit by removing (displacing) organic waste from landfill, so reducing emissions of methane, and producing renewable energy (Appels et al., 2011). It is very common in Europe and is more commonly associated with dairy operations since milk production can be linked to energy supply and recycling of waste (Igini, 2022); the digestate produced can also be used as a fertilizer or soil conditioner if properly treated (Möller et al., 2012).
- **Landfill Gas Recovery (LFG):** captures methane gas produced in anaerobic decomposition of organic waste in landfills and it uses it to generate energy. Most sanitary landfills have gas wells and vacuum systems that will draw out the LFG (methane rich gas) and it can be burned in engines or turbines to generate electricity and heat (Twi-Yeboah et al., 2024). Although not a waste treatment process in itself, LFG to energy projects are a transitional WTE solution that both helps to decrease greenhouse gas emissions and captures useful energy (Un, 2023). For instance, more than 500 landfills in the United States use such systems (Chandel et al., 2014). While LFG recovery usually only recovers a fraction of the total gas produced within it and is not as efficient as purpose built WTE establishments (Amini et al., 2013), it can still be used for the mitigation of methane emissions generated

by existing landfills, and on sites where development for full scale WTE facilities is not immediately possible.

Table 1: Comparison of Key WTE Technologies (Source: own editing based on Noudeng et al. (2024), IEAGHG (2020), (Twi-Yeboah et al., 2024))

Technology	Core Process	Suitable Waste	Key Output	Suitability and Considerations
Incineration	Controlled combustion of waste at high temperatures (>850°C) to generate steam for turbines.	Unsorted, mixed Municipal Solid Waste (MSW).	Electricity Heat Bottom Ash (Inert) Fly Ash (Hazardous)	Pro: Reduces waste volume by 85-90%. Mature, proven technology. Con: Very high capital cost. Requires sophisticated air pollution control, inefficient for Vientiane's high moisture (67% organic) waste.
Advanced Thermal Technologies	Biological breakdown of organics by microbes in an oxygen free environment.	Segregated high moisture organic waste (e.g., food scraps, agricultural residue).	Biogas (Methane) Digestate (Fertilizer)	Pro: Ideal for Vientiane's wet, organic rich waste, produces renewable fuel and a valuable soil conditioner. Con: Absolutely requires effective source separation of organics to avoid contamination.
Anaerobic Digestion	Thermal breakdown of waste in a low oxygen (Gasification) or no oxygen (Pyrolysis) environment.	Homogeneous, high calorific feedstocks (e.g., plastics, biomass, tires). Not ideal for mixed MSW.	Syngas (Fuel gas) Char Oil	Pro: Potentially cleaner emissions than mass burn. Con: Technologically complex and sensitive to input waste, not commercially proven for mixed MSW at a large scale.

Landfill Gas Recovery	Capturing methane produced naturally by decomposing organic waste in a landfill.	Organic waste already deposited in an engineered sanitary landfill.	Methane (for electricity/heat)	Pro: Mitigates GHG emissions from existing/new sanitary landfills. Con: This is not a waste treatment method, only a mitigation measure. Con: Not feasible for Vientiane's current open dumpsite (Km 32).
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Each of these technologies of WTE is a part of integrated solid waste management, of which incineration stands out as the predominant means worldwide due to its effectiveness in quickly reducing the volume of mixed waste. According to the International Energy Agency's Greenhouse Gas Programme (IEAGHG), there are almost 2,100 WTE plants in 42 countries that process around 360 million tonnes of waste each year and the sector is dominated by Asia and Europe (IEAGHG, 2020). It remained well over 2,800 active and scheduled WTE plants on a global scale with a total disposal capacity of about 576 million tonnes annually by early 2024. East Asia and most notably China has become the primary growth region and to address their shortage of landfill space hundreds of modern waste incineration plants have been constructed (Noudeng et al., 2024). The World Bank states that in upper middle income countries, the share of waste treated by WTE increased from almost zero in 2012 to slightly over 10 percent in 2018, most likely driven by China's rapid expansion of WTE (Kaza et al., 2018). However, there remain extensive global disparities in WTE utilization where high income countries stand at an average utilization rate of around 22% of municipal waste with lower income nations primarily relying on dumping and open disposal of waste with little to no energy recovery.

The use of WTE technologies around the world has a strong correlation with the economic development level and the availability of land. Some European countries such as Sweden, Denmark, and the Netherlands have for many years incorporated WTE within the national waste strategies as a means to decrease landfill (Ellis, 2018). In the UK, for example, more than sixty percent of household waste now goes through WTE plants which convert it into electricity and district heating, and in Sweden less than 1% of household waste is now sent to landfill. In countries where urban space is limited and sanitary regulations strict, similar to Japan, where approximately

70% of municipal waste is incinerated, WTE plants are also used in highly densely populated countries such as Singapore, Taipei and Hong Kong as space saving and locally produced power plants (Ellis, 2018).

By contrast, other areas, where land is plentiful and environmental regulations are looser, such as parts of Africa and South Asia, still use a lot of dumping. However, developing countries with waste crises are increasingly interested in WTE and projects have sprung up in Thailand, Vietnam and Ethiopia, frequently with the backing of international donors or private investors (Ellis, 2018). The World Bank states that although WTE is capable of playing an important part in urban waste reduction and energy recovery, it must act as a complement and not a substitute for more suitable and priority strategies in waste recycling and waste minimization. Overall, the broad and diverse use of WTE, from large scale to small scale incineration in industrialized countries and biogas digester systems in rural communities, represents its flexibility to a range of economic, space, and environmental conditions (Kaza et al., 2018).

2.3 Environmental and Economic Impacts of WTE

Waste to Energy (WTE) technologies make a significant contribution to reducing environmental pollution through diversion of waste from landfill and open dumps. Incineration has the possibility of reducing the volume of waste by tools between 85-90%, which reduces the needs to occupy land surfaces and the potential risk of contaminating leachates (Noudeng et al., 2024). In addition, due to the high temperatures of incomplete combustion, pathogens and harmful organic substances are destroyed, which is a sanitary alternative to uncontrolled disposal on landfills (Brunner et al., 2015). Moreover, WTE can be seen as an alternative to the use of fossil fuels in that it is recycling energy from waste, resulting in reduced greenhouse gas emissions (particularly with disposal of waste materials that are of biogenic origin like food waste, paper waste, etc.).

At the same time, this process stops methane that would have been released from the decomposition of the organic carbon in the landfill and releases the carbon as CO₂ back into the natural carbon cycle. Modern WTE plants in combination with recycling schemes have proven to have lower overall carbon footprints than conventional landfilling and generate around 500-600 kWh of electricity per tonne of waste (Joshi, 2021). Also, controlled burning prevents the open burning that is common practice in many developing cities, which minimizes local air pollution.

Another benefit of recovery is that the metals can be recovered from the bottom ash and recycled, and the remaining ash used as construction aggregate. In addition, the digestate of anaerobic digestion can be used harmlessly as fertilizer. Altogether, WTE provides an integrated and environmentally friendly waste treatment option for achieving climate mitigation and circular economy goals.

Environmental challenges that need to be addressed in the strict context of waste management systems are the environmental burden that these technologies particularly incineration present to the overall environment despite their advantage. Combustion of mixed municipal waste may emit pollutants like particulate matter compounds, acid gases (SO₂, HCl), nitrogen oxides (NO₂), heavy metals and organic compounds including dioxins and furans (Noudeng et al., 2024). Emissions of dioxins have historically been an issue but are now largely controlled by advanced air pollution controls such as electrostatic precipitators, scrubbers and catalytic reduction systems used by the modern WTE plants operating in industrialized countries today (Vehlow., 2015).

Under heavy legislative constraints such as the EU Waste Incineration Directive, waste gas emissions of dioxins from European plants are now less than 0.2% for total industrial emissions (CEWEP, 2022); also, several studies have demonstrated low to no health effects near modern plants (Jose, 2025). However, areas with no regulatory enforcement, or locations with old incinerators, may still have air quality risk. Another problem is carbon emissions: burning one tonne of waste generates around 0.7-1.7 tonnes of CO₂ (IEAGHG, 2020), which is half of it from materials derived from fossil fuels like plastics. As such, WTE is not carbon neutral on its own, it requires carbon capture systems to be fully carbon neutral. Finally, ash residues are still a disposal problem, bottom ash (15-20% of waste weight) can frequently be reused after processing, but the fly ash (2-5%) is toxic and must be treated in a special way (US EPA, 2025b). Therefore, despite the availability of modern technology to reduce pollution, the effective regulation of its use and the willingness of the public to participate in the proposal and implementation are important factors for ensuring public safety for the environment.

A further issue is that overreliance on WTE may well have the perverse effect of discouraging waste reduction and recycling if not carefully embedded as part of a wider waste strategy (US EPA, 2025a). Incineration plants need a steady supply of waste feedstock and so, to

keep the plant running, operators may generate what can be described as a 'waste hungry demand', which means they prefer high calorific materials like plastics and paper, such materials may otherwise have been recycled (Guberman, 2021). There is some evidence that, at least in some countries, overcapacity in WTE is associated with lower recycling rates, and as a result, the SAP has introduced safeguards for recycling by setting a recycling target of 55% for 2025 and issuing guidance to restrict new incineration capacity. In modern systems such as Germany and the Netherlands, WTE is becoming a complement to recycling that are passed to treatment only after the non recyclable residues are separated from the recycle stream of materials (Guberman, 2021). When it has been designed in this manner, WTE is actually advancing the circular economy ideals instead of destroying them. On the other hand, lack of policy checks can lead to misguided use of recyclable resources and undermine people's involvement in waste segregation. Anaerobic digestion is a more synergistic model and aims at organic waste which cannot be easily recycled to yield biogas and waste to fertilizer (Pilarska et al., 2023). Ultimately, WTE should work within a hierarchical framework alongside the importance of waste prevention, reuse, and recycling and energy recovery should supplement and not compete with material recovery (US EPA, 2025a).

As it requires a high capital investment and complex working conditions, the WTE projects are considered to be economically challenging. A modern incinerator plant will cost hundreds of millions of US dollars to build, much more than traditional landfill development (Kim et al., 2021). In addition to their high construction costs, WTE systems require skilled operator training, sophisticated maintenance and monitoring, and result in high operation and maintenance cost (Ashraf et al., 2024). As a result, the cost of treating to WTE per tonne of waste is normally higher than landfills, especially in areas where land is cheap and no consideration is given to externalities to reflect costs associated with managing the environment. According to the IEAGHG, WTE is usually capital intensive with a high specific treatment cost and operates typically below optimal economies of scale (IEAGHG, 2020). To survive, such plants need diversified revenues, which are generated principally by municipal tipping fees and also by the generation and sale of energy in one of the following forms: electricity, heat or biogas. In terms of financial sustainability, continuity and reproducibility of waste input and plant availability are also key factors; changes in both feedstock or process performance can build up financial costs easily (IEAGHG, 2020). To avoid these risks, many operators enter into long term contracts with their municipal waste providers to ensure a minimum waste supply and long term power purchase agreements with

utilities (GIHUB, 2019). These mechanisms stabilize income but also point to the fact that WTE is incapable of operating without strong institutional and market frameworks for its operation.

WTE plants are typically funded using public private partnership structures or municipal bonds in developed countries based on the idea of a double role to manage waste as well as renewable energy (Cao et al., 2022). In contrast, the funding of such projects in the developing world is much more challenging since of the limited municipal budgets and competing priorities. In many poor cities, waste is already taking 10-20% of the local operating budgets (Ellis, 2018), mostly for collection and disposition, with few resources available for major capital expenditures. As a result, without external funds, remitting a WTE project would do much harm to public finances.

In an attempt to fill this void, WTE and solid waste projects have been increasingly targeted in international development banks and climate funds as part of sustainable infrastructure/climate mitigation portfolios. However, even when financial resources have been received, the most problematic remains financial sustainability. One problem is establishing tipping fees high enough to break even. WTE is economically viable only for high income countries that have landfill taxes and stringent environmental standards, while in lower income countries that have low or free dumping, the need to implement WTE strongly suggests that waste tariffs will need to increase significantly, a politically sensitive step. The reason is that private households and enterprises may not feel any inclination or no opportunity to pay enough for waste management; thus, government subsidy and public education are necessary to achieve proper use of facilities or reduction of illegal dumping. Therefore, the economic viability of WTE in the developing context requires access not just to technology and capital but also policy frameworks and designing tariffs as well as long term institutional support (Kalyani et al., 2014)

Aside from the challenges, WTE projects also have significant economic benefits: Energy from residual products of waste can earn substantial revenue, replace energy imports and contribute to national energy security (United Nations, 2025). Most WTE plants feed electricity or heat to the grid, and in several jurisdictions, such as the European Union, the biogenic part of the waste is considered as renewable energy and this status gives the operator an access to incentive schemes (feeds in tariffs, renewable energy credits, etc.) (IEA, 2024). Such acknowledgement adds economic value to WTE by associating it with climate and renewable energy objectives. In

addition, WTE plants provide superior job opportunities both during construction and operation (Lama, 2024). A medium capacity facility would have employed the services of about one hundred technical and other staff while indirectly stimulating local industries involved in the fabrication of equipment, maintenance services and the use of ash in building materials.

On a more macro level, WTE and better waste management reduces long term societal costs by reducing degradation of the environment, health impact and damages to sectors like tourism and agriculture (Ashraf et al., 2024). Studies in Southeast Asia have shown that external costs of unmanaged waste going beyond a factor of several times the cost to adequately treat the waste in a regulated manner are likely to mean that investments in WTE can have a net economic benefit when pollution and health externalities are factored in (Ellis, 2018). In addition, WTE helps to reduce the amount of waste that has to be finally disposed of by extending the landfill life and delaying the need for expensive new landfill development. These factors add up to the potential of WTE as an environmental and economic approach to sustainable urban development.

However, with multiple government policies and subsidies, the economic viability of WTE projects could be highly influenced. In most cases, WTE facilities will not be economical without support from regulatory measures to include the environmental costs of landfill in the price for solid waste or financial incentives for renewables generation. Typical policy instruments include landfill taxes which make landfill more expensive while increasing the competitive stance of WTE; renewable energy credits for the electricity produced from biogenic sources; carbon finance for avoided methane emissions; and also direct public subsidy or grants for plant construction (Li et al., 2014).

Market driven use of WTE, especially in poor nations, is so far limited. Experience with some WTE projects in developing countries has shown that there have been problems due to underestimated operating costs or overestimation of the energy potential of locally available wastes. Further, municipal solid waste, especially in such environments is likely to be associated with higher moisture and organic contents leading to lower calorific value and plus, need for additional fuel injection to sustain combustion temperatures (Gebreslassie et al., 2024). This in turn will raise costs and lower energy efficiency. Moreover, things such as certain metals and plastics with high chloride content can rise the rate of equipment corrosion and maintenance costs (Marx et al., 2024). Therefore, before implementation of WTE, a thorough feasibility study should

be conducted and should include waste characterization, long term waste supply projections, reliable power purchase agreement, and skilled operating and maintenance provision (Geosyntec Consultants, 2019).

In comparison, WTE plants that were installed in countries like Denmark and Sweden, in the past, have shown that under favourable conditions, WTE can become economically sustainable. With strong waste management legislation in place, these countries have also developed a double mechanism of stable tipping fees and energy revenues, and in some cases even import waste to effectively maximise plant capacity utilization (ReportLinker, 2025). As these models and examples verify with the proper policy collaboratives, technical know how and waste streams, WTE can be two fold in nature, offering not only effective waste management but power generation thereof. However, for cities intending to embark on their first WTE projects, these successful projects have one definite requirement: they must be well planned, have strong policy support and secure long term financial commitment for their viability.

In short, WTE has both positive and negative impacts on the environment and the economy: WTE provides ways of addressing some critical waste problems (volume reduction, energy recovery, reduced methane emissions) but must be controlled to avoid pollution and not compete with waste minimisation strategies. Although WTE can be economically viable in delivering value and employment, it requires high initial investment costs and requires continuous revenues to be profitable, this is problematic in lower income settings without external financing or good governance. These lessons from international experience provide a backdrop for considering how WTE approaches and techniques could be implemented in place, in this case, Laos, and what institutional and policy context is necessary for WTE to be optimized.

2.4 Institutional and Policy Framework for WTE in Laos

Taking specific reference to Laos, WTE is still in its early stages and is subject to institutional and policy issues. In theory, the Lao government has shown interest in so called 'waste to resource' strategies as part of the planning for urban environmental issues. For instance, the Vientiane Capital Solid Waste Management Strategy (2021-2030) specifically demands a 'paradigm shift from waste management to resource management', with WTE solutions to be trialled as part of that (Kim et al., 2021). Although the present vision is in line with national green growth objectives, formal policies have been lacking. Especially, there is no comprehensive solid

waste management legislation in Laos yet (JICA, 2021). The relevant environmental laws (Environment Protection Law, Public Health Law, etc.) have allusions to waste, but no separate WTE law is found (MOIC, 2024). The UN report indicates that no fundamental law exists on waste management in Lao PDR, and only provisions related to waste can be found in different Acts (MOIC, 2024). As a consequence, solid waste management is fragmented and there is a sharing of responsibility for waste problems.

At the national level, two ministries handle waste issues nominally: the Ministry of Public Works and Transport (MPWT) and the Ministry of Natural Resources and Environment (MONRE) (JICA, 2021). MPWT takes care of infrastructure (e.g. sanitation systems), and MONRE creates environmental regulations. In addition, the roles are badly defined. In reality, MONRE seldom issues specific waste regulations but only rules for chemicals and pollution in general (EPF, 2025). Urban Development and Administration Authorities (UDAAs) within the provinces and local governments are responsible for the implementation of waste collection and disposal in reality, but they do not have explicit mandates and budgets (JICA, 2021). For instance, UDAAs have no specific national budget for waste services; they are dependent on local fees (paid to private minded contractors) and achieve partial coverage on many occasions (EPF, 2025). One result is that even city agencies find it hard to fund sophisticated treatment: with the lack of stable income the only disposal that makes financial sense is the most crude treatment (open dumps or simple landfills).

In conclusion, commentators address the state of the country's solid waste management by pointing to the "absence of a clear legal framework" and "weak enforcement and capacity constraints throughout the system." (EPF, 2025). A report from Environment Protection Fund (EPF) (2025) on the Lao Pollution and Waste Management Project outlines the following challenges: No specialized SWM law; low level of management control; low level of monitoring, and weak financial sustainability at all levels. Most of the collection is done without any clear tariff, hence providing for unsustainable operations and poor coverage of households. A number of systemic issues mean that WTE introduction will need supporting policy interventions. For example, obtaining the waste feedstock for the plant requires a secure supply (Business Times, 2025), which may involve collection, and some plants are likely to require source separating (separating out recyclables). Unless there are legislative requirements or disincentives for

households to pay for waste service, then illegally dumped waste will be a big problem and there will also be no incentive for waste treatment operations to be set up.

Overcoming these challenges there are signs of improvement. For Vientiane, this was to be tested in the Vientiane SWM Strategy, which, approved in 2021, actually envisages a pilot project for "decentralised waste treatment (waste to energy)" for selected locations. However, in practice a small scale Refuse Derived Fuel (RDF) facility was actually set up in 2023 on Vientiane Waste Management Company premises processing around 200 tonnes per day of sorted mixed waste into a fuel that can be used directly by cement plants (EPF, 2025). This RDF plant can be said to represent incrementalism: initially separation of high calorific fractions for industrial fuel, then full incineration for electricity. Indeed, a year later as of early 2024, the city authorities announced that a larger 13MW WTE power plant (operating on around 700 tonnes/day) is in the development stage, and it is subject to a power purchase agreement with the national utility (EPF, 2025).

The various project plans being developed, aided by studies being conducted by private developers, reflect the increasing institutional interest in considering WTE within the context of a PPP. (The technical design will be adapted to local circumstances and risk appetite of investors.) (Nsafon et al., 2022). The products of such a plant would be some electricity to be sent to the grid and fly/bottom ash (around 15.6 t/day), which would be fed into the existing landfill. National political policies are also changing. In the middle of 2025, a Lao Pollution and Waste Management Project (2025-2031) was loaned by the World Bank for the improvement of waste service in Vientiane, and enhancement of regulations (EPF, 2025). The \$38million project (funded by IDA and a global clean up plastics fund) will invest in the collection trucks, waste transfer stations and treatment (e.g shift of the landfill to modernize it) (World Bank, 2025). Importantly also, it seeks to "strengthen the legal framework for waste management" by improving monitoring and enforcement systems (World Bank, 2025). This could lead to the facilitation of WTE, through the clarification of standards and ensuring waste inputs. The project is being implemented by the Lao Environment Protection Fund and the Ministry of Public Works and Transportation (MPWT), indicating a high level of commitment. On the same note, Laos has established a National Plastics Action Plan to minimise plastic waste and increase recycling which can complement WTE by ensuring that waste reduction & segregation take place upstream (Vongthavilay, 2022).

Institutional wise, Laos has also pledged to regional and international programmes which have implications for waste policy. It is involved in the ASEAN model on green cities (GGGI, 2025) and signed multi lateral environmental agreements (e.g. Basel Convention). Vientiane's Green City Action Plan (2023-2030), a project undertaken by GGGI, declared that solid waste is one priority sector that emits 75% of the emissions in urban areas of Vientiane (GGGI, 2023). The plan provides goals for waste reduction and resource recovery (but prescriptions as to application of technological solutions) and sees the city as a "model" for waste practices. Meanwhile, technical assistance projects (e.g., by JICA and GGGI) have indicated that there are ways to do it: a GGGI technical report on WTE states that by far, feedstock with good quality is a function of source separation (Nsafon et al., 2022). Experts emphasize that for WTE to be successful in Laos, it will take integrated policies, such as establishing the standards for the composition of waste to be processed, the need for power purchase contracts to be in place for plants, and the need for financial incentives or guarantees to investors.

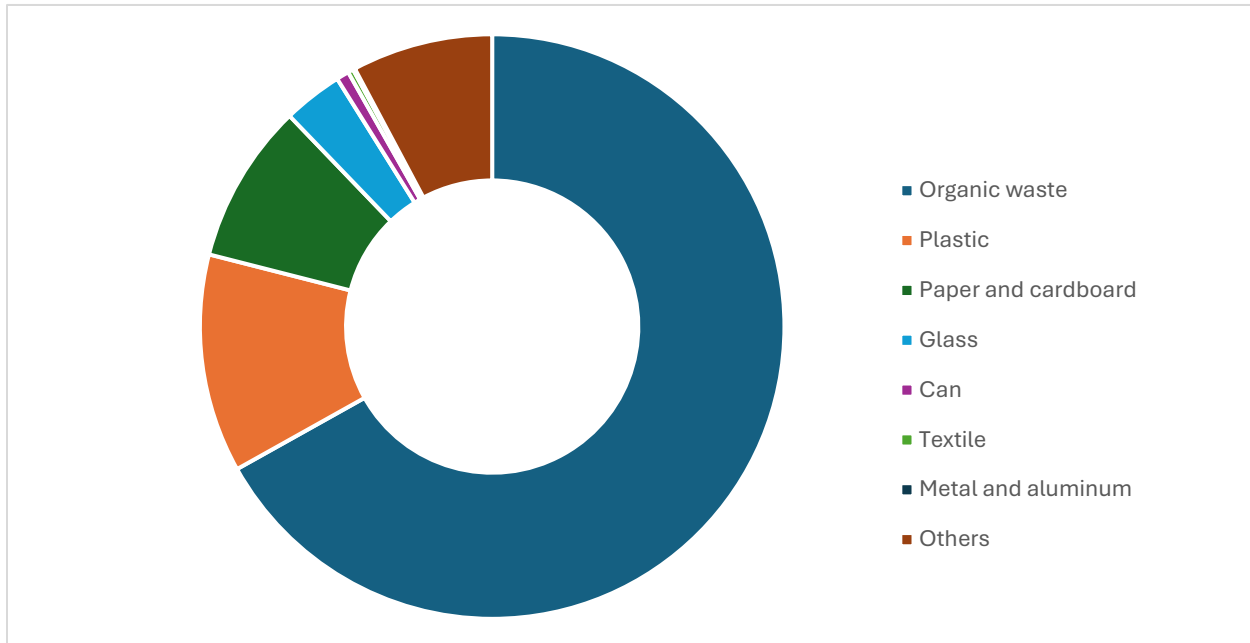
In conclusion, Laos's policy framework for WTE is in developmental stage but is underdeveloped. There is institutional interest (e.g. city strategy, WB projects) and pilot projects implemented, but there is no proper legislation or regulation dedicated to WTE. The recent engagement of the World Bank and GGGI suggests there is momentum but huge capacity and finance gaps are still existent. For instance, without a national legislation on waste, it is challenging to implement cities targets or compulsory waste fees. Any WTE plants will require UDAs to be trained and funded to operate them. Also, regulatory aspects such as emission limits for incinerators or landfill requirements for ash will have to be defined (Kwon et al, 2024). These institutional constraints need to be overcome if waste to energy is to have a promising role in Laos' waste management portfolio.

This review of global waste issues, WTE options and Lao policy provides the context for the ensuing methodology. In the next chapter, these insights will be utilised further to develop a feasibility analysis of specific WTE scenarios for landfills outside Vientiane, making sure that technical, environmental and economic aspects are based in the reality of Lao institutional structures.

Chapter 3: Materials and Method

3.1 Current Waste Management in Vientiane: Status and Problems

Figure 4: Waste Composition of MSW in Vientiane 2020 (Source: Kim et al, 2021)



Vientiane's municipal solid waste (MSW) generation is on the fast track. Studies are reporting around 232,500 tonnes of waste in 2011 (0.69 kg per person per day) (Babel & Vilaysouk, 2016), and this will rise to around 144,000 tonnes in 2020 (0.75 kg/capita/day) (Noudeng et al., 2024). Recent official and media data point to the same trend: in 2025 and over, Vientiane generates more than 700 tonnes of MSW every day, but only collects between 450-500 tonnes per day (25% more than collected) (Visapra, 2025). The remaining 33% of waste goes uncollected, so often burnt or thrown on the streets and empty lots, contributing to continued air and land pollution (Visapra, 2025). Official reports mention the formally collected are only around 31% which is 353 of 481 villages (EPF, 2025). Most people do not subscribe to waste collection (either because of low service fees or lack of awareness) and therefore uncollected waste is accumulating or being burned despite bans.

The stream of waste that enters Vientiane is dominated by organics. Around 67% of MSW is organic (food and green waste), while plastics (around 12%), paper/cardboard (around 8%), glass (around 3%) and other materials comprise the remaining portion of MSW (Noudeng et al., 2024). These numbers are taken from current surveys and confirm city estimates. Because the organic waste is decaying anaerobically in the dumps, there are large quantities of landfill gas

(methane) production in the uncontrolled Km 32 landfill. Babel and Vilaysouk (2016) have estimated that under the "business as usual" scenario in 2011 (open dump with minimal collection), the waste sector in Vientiane was responsible for around 110,000 tonnes CO₂ equivalent per year (around 0.15 t/capita) (Babel & Vilaysouk, 2016). In other terms, current practices account for the significant amount of greenhouse gas emissions.

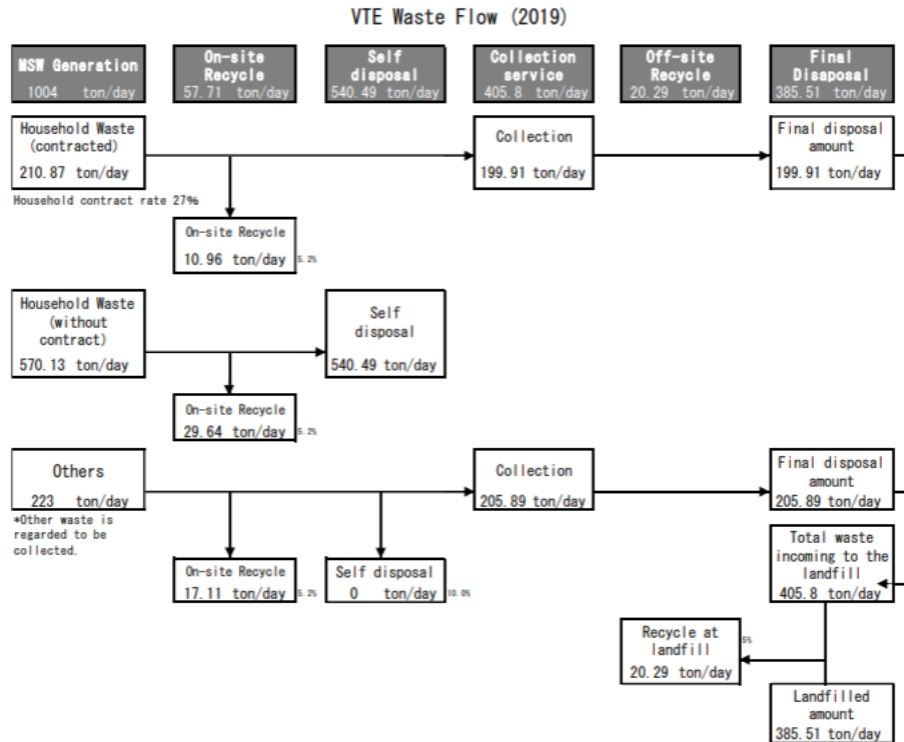
The Km 32 landfill itself is an unsanitary open dump with approximately 400 tonnes of waste per day being dumped without the design of engineered liners and leachate controls (EPF, 2025). Waste pickers (about 264 individuals) are manually recovering 10-15 tonnes/day recyclables (plastics, metal, paper) for sales (EPF, 2025), but the majority thereof is being simply buried. The place is susceptible to fires (last recorded in 2022) along with open burning on the dumps (EPF, 2025). These uncontrolled emissions are a public health risk (respiratory illness, vermin) and pollute the soil and water next to the operation. With current disposal rates, the landfill is projected to fill up in 5-7 years unless disposal practices can change (EPF, 2025). Vientiane's authorities have set a "100% collection" target by 2030 (EPF, 2025), but the increase in tariffs without a new treatment capacity means an inevitable need to enlarge outlet space, a costly and unsustainable plan.

Table 2: Waste collection coverage and rate in each Vientiane district as of 2020 (Source: own editing based on Kim et al, 2021)

District	Total No. village	Total No. Household	Serviced Areas				Non Serviced Areas		Collection Rate (%)	
			Village	No. of HH	Contracted	Non Contracted	No.of Village	No. Household	HHs with Contract	HHs without Contract
Chanthabouly	30	13535	30	13535	7946	5589	0	0	59	41
Xaysettha	48	24064	46	23593	9730	13863	2	471	40	60
Sikhottabong	60	26656	59	26600	8129	18471	1	56	30	70
Sisattanak	37	11993	37	11993	7922	4071	0	0	66	34
Hadxaifong	60	21444	56	20491	8206	12285	4	953	38	62
Xaythany	104	34397	73	29119	7037	22082	31	5278	20	80
Naxaithong	54	13413	40	10595	1200	9395	18	2818	9	91
Sangthong	35	6187	1	394	38	356	32	5793	1	99
Pakngum	53	9966	9	2458	416	2042	44	7508	4	96
Total	481	161655	351	138778	50624	88154	132	22877	31	69

In conclusion, the waste management system for Vientiane is under pressure; extremely high waste volumes, poor service coverage (around 30-69%), a predominantly organic and wet waste stream and dependence on an overloaded open dumpsite. Illegal dumping and open burning regularly occur despite a 2025 city ordinance banning and imposing a fine (Visapra, 2025) These facts highlight the urgency to find an alternative to "collect and dump" practices, and have motivated the look at waste to energy (WTE) as a possible alternative.

Figure 5: Waste Flow in Vientiane 2019 (Source: JICA, 2021)



3.2 Analytical Approach: Scenarios and Feasibility Criteria

This chapter presents two scenarios for Vientiane to the year 2030: (1) the Baseline, business as usual: the process of collection expansion and landfilling; and (2) the WTE Scenario, the addition of a modern incineration plant (around 700 t/day) to the waste system. The analysis is conducted using data from government sources, technical studies and examples from around the world. It measures each scenario on a variety of criteria:

Technical Feasibility: Will the technology be able to handle the garbage of Vientiane? Incineration can only be implemented where there is a sufficiently high calorific value, high moisture content may require drying or refuse derived fuel (RDF) preprocessing, or co digestion of organics. According to studies, MSW of Vientiane, Laos is being just about 67% (wet) organic

material (Noudeng et al., 2024). Mechanical biological treatment, MBT, or anaerobic digestion, AD, could be used as a pretreatment for organics feedstocks to ensure quality feedstocks. (Noudeng et al., 2024) stress the importance of the integration of WTE with source separation (e.g. separate food waste) and recycling to efficiently operate (Noudeng et al., 2024).

Environmental Impact Compare Pollution and Greenhouse Gases. The baseline leads to the methane of anaerobic decay & to the toxic air of burning dump fires. By contrast, incineration emits CO₂ (mainly biogenic) instead of methane and only pollutes at controlled emissions out of the stacks. The U.S. Environmental Protection Agency (EPA) documents controlled combustion as "reducing the amount of solid waste sent to landfills" and "reduces the production of methane from landfills menaces the environment" (US EPA, 2025b), but controlled combustion facilities need high efficiency pollution controls (e.g. baghouse filters capturing >99% of particulates) in place (US EPA, 2025b).

Economic/Financial Viability: Comparison of cost and revenues. The capital requirements for a stillbirth of nuclear waste landfills are low, but their hidden costs are enormous (future landfill development, decommissioning, health impacts). A WTE plant requires high upfront investment (tens of millions of USD) but has the ability to generate revenue through tipping fees and electricity sales. Achieving cost recovery in Laos is difficult: on what is currently being collected, household fees are barely sufficient for collection (World Bank, 2025). Under WTE, the "polluter pays" principle needs to be strengthened, e.g. raising waste tariffs & setting stable tipping fee for the plant.

Institutional and Policy: Legal and Governance, Level of preparedness Laos does not have a comprehensive law that relates to solid waste and law enforcement has been weak (Visapra, 2025). The ordinance to be enacted in Vientiane by 2025 against open burning and illegal dumping is a good sign (Visapra 2025). The World Bank's new project (2025-2031) will focus on achieving 100% collection in Vientiane and will support the National Plastics Action Plan (World Bank, 2025), which is in line with any WTE project. Successful WTE will require clear contracts guaranteeing supply of waste (typical in WTE PPPs) and capacity building with respect to environmental oversight.

These criteria are applied to carrying out a scenario based analysis to evaluate trade offs between the two futures in Vientiane's waste sector.

3.3 Scenario 1: Baseline (Continued Landfilling)

In the Baseline case, Vientiane places a bet on expanded waste collection (done by the end of 2030 to close to 100% coverage) but no new WTE technology. Collected waste still being directed to landfills (mainly Km32, potential new cells/spots). Under this scenario:

Waste volume and landfill needs with further increase in the urban population as well as consumption, MSW generation is expected to increase from 1,115 t/day approximately in 2023 to around 1,512 t/day by 2030 (Noudeng et al., 2024). Unless recycling and/or reduction improves dramatically most of this is going to landfill. At present, around 400 t/day fills Km 32. Without incineration Vientiane would have to expand existing dumps or develop new landfill cells constantly. On the World Bank's website, it is noted that Km 32 would be at capacity by around 2027 at current rates (EPF, 2025).

Environmental consequences keeping organics in landfills means huge methane emissions. As noted, a 2016 study found the baseline GHG footprint (landfill + burning) was around 110,000 tCO₂e/year (Babel & Vilaysouk, 2016), by extrapolation, this would increase as the amount of waste increased. Local pollution also gets worse: dumping leads to leaching (groundwater poisoning) of soil and groundwater, and open burning (without control, of illegal dump fires or household pile dump fires) cause the release of toxic smoke (dioxins, fine particulates). Although open burning is officially banned, the practice is weakly enforced, and people in rural areas continue to burn garbage when service is not accessible. Around 33% of the waste currently gets uncollected or burnt (Visapra, 2025), causing air quality and health issues.

Economic and fiscal impacts at first glance, the baseline is better in terms of cost, as there is neither any huge plant built. However, it has hidden and long term costs. Vientiane would be constantly spending to develop new landfill cells, to purchase land as well as to remediate old dumps. The city's budget on waste is getting tight; a hearing from the World Bank states Lao waste services are not financially sustainable under low tariff models (World Bank, 2025). Expanding collection to 100% without new revenues means that fees have to increase or subsidies. Public health costs from pollution (estimated to be around 14.6% of Lao's GDP in 2017 from air/water pollution) (World Bank, 2025) are in part caused by waste mismanagement. Valuable resources are also lost, organics that could be composted; organics that could be digested, and recyclables

sold. From a future economic perspective, the wastes simply lost material and energy value within the waste stream and essentially just transfer costs.

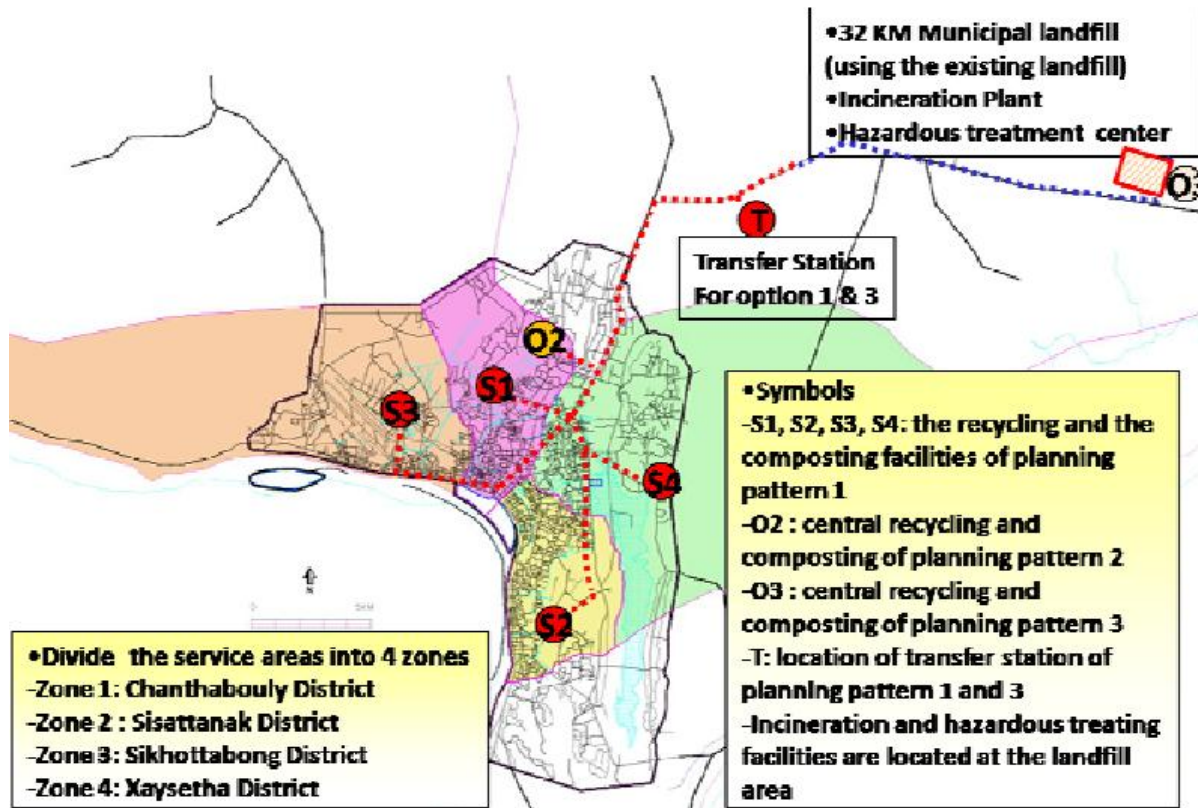
Social and institutional factors in the baseline scenario there is little to alter public behavior. It conveniently takes the lack of convenient alternatives to take preventive measures against continued illegal dumping and burning of waste. Waste pickers will continue to informally recover some of the recyclables (around 10-15 t/day (EPF, 2025)), but the vast majority of citizens are not incentivized in any way to engage in formal collection. This status quo also places no new demands on policy or governance; but it fails to address practices which are illegal. In actuality, the frustration among residents to deal with large amounts of uncollected garbage, which is unhealthy and smells, reduces the sense of civic pride among residents.

In general, the continuing use of landfills will mean that there will be more and more waste and often it will be polluting at the dump site (fires, leachate, etc.) and increasingly difficult to finance waste management services. As this cannot achieve any environmental or public health outcomes by 2030, then it is important to identify other alternatives for waste management such as WTE.

3.4 Scenario 2: Introducing Waste to Energy Facility

Scenario 2 is the development of a new modern Waste to Energy (WTE) incineration plant and improved collection of municipal waste in Vientiane. The plan (supported by feasibility studies) is for a 13MW mass burn incinerator taking in around 700t/day of unsorted MSW (EPF, 2025). It is estimated that this plant will be built by approximately 2027 and will operate under a public private partnership in which the city (through Vientiane Waste Management Co.) contracts for delivery of waste and a private person/actor carries out the operations and sells the electricity to Electricite du Laos.

Figure 6: Location of the planning of facilities of incineration plant that plan in 2005 to illustrates the planning of the WTE in the same pattern and location (Source: JSCE, 2005)



Technical Feasibility: Vientiane's MSW requires some technical difficulty for incineration, as the materials have a very high moisture content: around 67% organic content (Noudeng et al., 2024). Dry waste typically must have a calorific value around 7-8 MJ/kg to be burned efficiently. In practice, the city already operates a small RDF plant in which some plastics and paper are extracted to be used as fuel, thus showing potential feedstock preparations. The envisioned WTE plant is a mass burn moving grate plant, which can also handle mixed and heterogeneous waste. It would partake in moisture management (e.g. waste pre drying on the grate) auxiliary burners. In addition, Vientiane would have the option of the Mechanical Biological Treatment (MBT) process: to separate the organics for compost or anaerobic digestion (biogas) and combust the remaining dry fraction. Such integration is in accordance with recommendations for tropical cities (e.g. segregation of wet waste for improved feedstock) (Kwon et al., 2024). Even without perfect segregation, however, empirical experience demonstrates that well designed incinerators in Southeast Asia can be operated in mixed waste situations with perhaps additional fuel consumption or drying in wet seasons.

Waste Volume Reduction and Landfill Diversion: Mainly, the implementation of scenario 2 is the significant reduction of inputs to the landfill. In the case of Vientiane this would mean that burning 700 t/day would produce less waste (bottom ash plus captured fly ash) for disposal. This means that the 255,000 tonnes/year that is processed by 2030 would mostly not be going to landfill. Only the inert ash (and whatever small, unsorted residue) would be landfilled. That translates into a significantly increased lifespan for landfill acronyms: While Km 32 would have been fully exploited (filling up) wise by now (around 2027), it can take it up more years with WTE.

Environmental Impacts: The WTE scenario has a significant impact on the profile of Vientiane's pollution. By firing up the organic waste, the production of methane gas at the landfill is drastically reduced. (Biogenic carbon in organics is released as CO₂ when it is burned and so this is absolutely climate neutral in accounting terms whereas if it went to landfill it would actually release CH₄ which would then have a much higher warming potential.) The EPA stated that incineration "can limit the production of methane from landfills" (US EPA, 2025b). Since around 60-70% of Vientiane is waste from organic origin (Noudeng et al., 2024), which reduces landfill CH₄ when diverted to combustion, similar reductions from landfill CH₄ could be realized in future. In fact, Babel and Vilaysouk's modelling (2016) showed that recycling and composting when added could reduce GHG emissions by about 47%, (Babel & Vilaysouk, 2016) (and incineration would also belong in this category of "improved treatment." In addition, around 13 MW of electricity is produced from the WTE plant offsetting some generation from fossil fuels. The electrical grid in Laos is primarily hydroelectric, and although domestic carbon offset is modest, anything displaced in electric power into Laos would decrease CO₂ in the region.

On the other hand, stack emissions occur with incineration. CO₂ is produced from plastics and organics during combustion and pollutants are also produced (NO_x, SO₂, particulate matter, dioxins, metals, etc). In addition, all modern WTE designs contain extensive pollution controls, such as acidic gas scrubbers and fabric filter type baghouses for particulate, and rapid flue cooling and activated carbon injection to forestall dioxins from forming. The EPA outlines the ability of >99% of particulate matter to be captured using these filters (US EPA, 2025b). If operated and regulated properly, emissions can be held to international air quality standards. However, this requires good oversight and regular monitoring, a capacity that Laos needs to develop. Without effective enforcement, there is the possibility that the pollution exceedances will occur.

The plant will also produce ash residue; bottom ash (larger debris) and fly ash (toxic concentrate). Bottom ash can usually be used for reclaimed material (e.g. construction fill) after removing metals. Fly ash that has high concentrations of the heavy metals and dioxins must be stabilized and buried in secure landfill sites. In Scenario 2, all ash would travel to a dedicated landfill cell at Km 32(or other site) with linings to prevent leachate (US EPA, 2025b). While not trivial, this is much less waste than dealing with 700t/day of unburned garbage. Overall, the net environmental impact of WTE is positive: avoidance of methane and decay and burning pollution, in exchange for irresponsible emissions that can be avoided with a technology. The EPA's guidance underscores the fact that energy recovery from MSW is above open dumping in the waste hierarchy (EPA, 2025b) and if conducted using clean technology, is environmentally sound as compared to uncontrolled landfilling.

Economic and Financial Considerations: To build a WTE plant is expensive. A 13 MW plant (including waste handling, air pollution equipment, grid connection etc) could cost on the order of \$50-100 million. Its continued operations also require skilled maintenance, consumables (e.g. reagents for scrubbers) and labor. To be financially sustainable the project needs to be able to access the revenue stream: primarily tipping fees and electricity sales. In practice, the government may have to increase waste disposal fees (household waste tariffs) to ensure it is able to receive a stable gate fee (possibly subsidized by government guarantees) for the plant. In the high income countries tipping fees are often \$50-\$100/ton; now, the Lao fees are far lower. The World Bank notes that waste fees in Laos currently recover a fraction of costs (World Bank, 2025) so that fiscal reforms (gradual rises in costs, cross subsidies or grants) will be required. On the upside, the plant's output of 13 megawatts (100,000-110,000MWh/year) can be sold to the Electricite du Laos. While electricity prices are low in Lao (because of abundant hydro), every bit of revenue is beneficial for O&M. For WTE, the return is better if it can get struck with a feed in tariff or a power purchase agreement (PPA) that recognises its inherent environmental value.

Social and Institutional Effects: A WTE facility alters engagement amongst the public. Building such a plant would likely be accompanied by awareness camps (promoting proper disposal, recycling) and can improve civic pride by making the streets cleaner. It's also enforcing the open burning ban, with effective treatment available, less people will resort to backyard burning. In fact, a solid waste treatment system makes the 2025 ordinance (banning

burning/dumping) much more enforceable (Sisounonth, 2025) (World Bank, 2025). Residents are generally less trusting than they were of landfills in incineration at the first stage (because of fears about odour or smoke), so it is important for authorities to be open about what they do. If there is public monitoring of emission controls, citizens will gain confidence. Importantly, the WTE project serves as a catalyst for global reforms: for the project to develop, it is necessary to have transparent laws on waste management (for example, specifying the authority of VCOMS), to ensure enforcement of the use of collection services and contractual guarantees of waste supply. In the last few years there has been policy momentum in Laos through approval of fines for dumps (Sisounonth, 2025) as well as the support of national plastics reduction plans by the World Bank (World Bank, 2025) in a good way, reflecting the institutional prerequisites needed.

3.5 Feasibility and Operating Conditions for Success

The above analysis clearly illustrates that a WTE plant would be able to solve the waste crisis in Vientiane, but only if a number of important conditions would be fulfilled:

Waste Feedstock & Technology Match: The selected incineration technology should be matched with the wet waste type found in Vientiane with a low calorific value. This means putting in place possible pre treatment, promoting the separation of wet organics at household/business level, the upscaling of the existing RDF plant, or divorcing incineration from anaerobic digestion of organics. According to Noudeng et al. (2024), such integrated technologies (segregation + WTE + AD) are important for tropical cities. If these things are not done, then the plant may need additional fuel and face more operational problems. Thus, with better source separation and recycling, the efficiency of the WTE plant will only increase and its auxiliary energy costs will decrease.

Environmental Management: There are no compromises on pollution control. Efficient regulation is absolutely essential, but the abstraction of the intended WTE design already incorporates the latest filters and scrubbers (US EPA, 2025b). Government needs to set clear emission standards and to have continuous stack monitoring. For instance, the plant operator might need to install continuous emissions monitoring systems (CEMS) and report regularly. International best practice could be implemented (e.g. EU or Chinese WTE emission limits). On ash management: it is necessary to stabilize the hazardous fly ash and deposit it in a secure landfill

(in the best case encapsulated). Enforcement by environmental agencies will also ensure that the overall impact of the plant is positive (much better than uncontrolled landfill leaks and fires).

Financial Sustainability: The project must have a viable financial model. Moreover, Vientiane needs to move closer to 'full cost recovery' in waste services (World Bank, 2025). This would mean changing waste tariffs so that households/businesses must contribute towards treatment. There is also likely to be a need for some public subsidy, particularly for the capital costs: World Bank investment in this sector (US\$37.85M) is indicative of the willingness of donors to support the financing of solid waste facilities (World Bank, 2025). The project will be based on tipping fees for waste inflow and electricity sales. A commitment for minimum waste delivery (usually in a long contract) will secure income for the investors. Because of the existence of a PPA with Electricite du Laos, there is a regular power economic income. In short, the combination of municipal budget, private capital and international aid/loans will need to be found in ways that take account of the environmental (and social) benefits of the finance deal.

Policy and Institutional Support: The Lao government needs to offer an enabling environment. Positive initiatives have already been taken: the 2025 municipal taxation sanctions dumping and burning (Sisounonth, 2025), and the project supported by the World Bank has a specific target and focuses on achieving 100% collection and legal reforms (World Bank, 2025). Should WTE be fully exploited, Laos will ideally need a specific waste management legislation or updated regulations in place that will help clarify responsibilities (e.g. VCOMS, private operators, regulators) and place WTE within the energy context. Also, WTE needs to be integrated with other programs: for example, there are National Plastics Action Plans (2020/2025) (World Bank, 2025), recycling programs within which valuable recyclables should not be unintentionally incinerated. Capacity building (training of local engineers to operate the plant and officials to manage it) and public awareness (explaining the benefits of proper waste management) are also key aspects of acceptance. Encouragingly, donors and the government appear to be fully committed: the new Lao waste project contains institutional strengthening and monitoring components.

Table 3: PESTEL analysis for WTE implementation in Vientiane (Source: own editing)

Factors	Key Findings	Implications for WTE

Political	Governmental commitment to reform and reduce pollution is strong, Laos' Green Growth Strategy goals are being supported by various international donor organizations such as the World Bank and GGGI.	Political support makes it easier to maintain the continuity of policies and to obtain concessional financing for WTE infrastructure.
Economic	Limited municipal budget; low tariffs on waste collection; high capital cost (US\$50-100M) for WTE plant; reliance on PPP and external assistance.	Relies on the following: Stable funding (e.g., tipping fees, subsidies, climate finance) Power purchase agreements (PPAs) that span the long term.
Social	Low public awareness concerning waste separation; informal waste picking; rising awareness of pollution	Public acceptance and education are important to ensure that new WTE facilities are accepted and that that waste separation regulations are adhered to.
Technological	Low national experience with higher quality WTE systems; waste moistness pattern; advancement of RDF and MBT demonstrations;	Need for robust technology in optimized form for tropical, high organic waste, high maintenance capabilities building.
Environmental	Severe landfill emissions (methane, leachate & GHG contribution); increasing GHG contribution (waste); local air pollution.	WTE can make a big difference in terms of methane reduction and air quality improvement if emission controls are enforced.

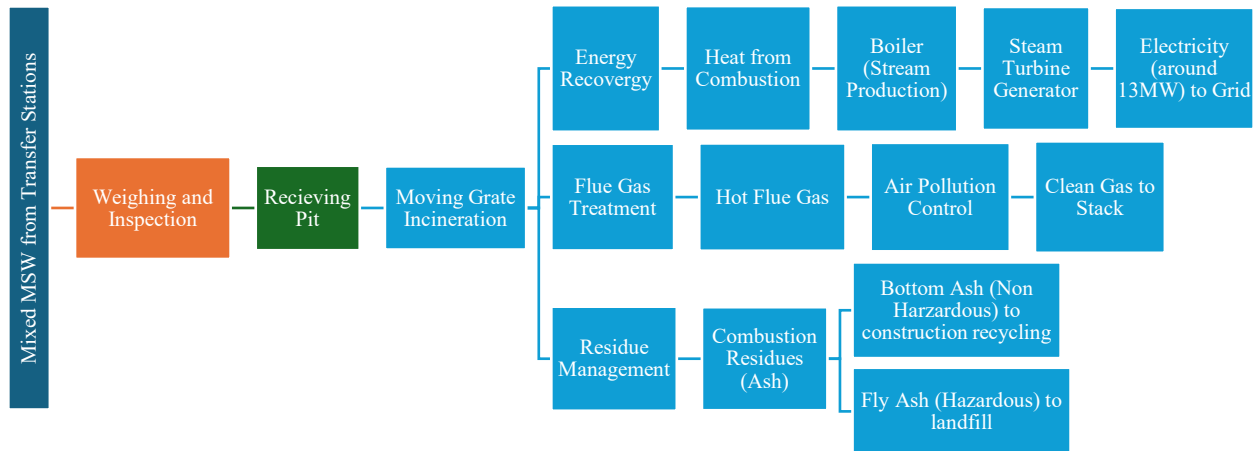
Legal	No decent waste law; new 2025 Vientiane ordinance against burning and dumping still going on with World Bank	Any sustainable governance of WTE requires modernization of the law and its consistent implementation.
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In conclusion, the feasibility study has shown the potential for waste to energy to change Vientiane's waste management from a sustainable landfill model to a cleaner and resource recovering waste management system. The WTE plant would greatly reduce the landfill burden and pollution and offer power generation. It is not a standalone silver bullet though. Its achievement relies on free market policies: strict environmental regulation, a new financing system (polluter pays), ongoing preference to reduce waste and recycle, and sound governance. If Vientiane can put these protections in place, many of which are already being made in its 2021-2030 waste strategy, then WTE becomes not only feasible but a natural progression to a sustainable solid waste circular economy for the city.

Chapter 4: Results and Discussion

4.1 Results of Technical Feasibility Study

Figure 7: Process flow of the proposed Waste to Energy system in Vientiane (Source: own editing)



Under the WTE scenario, the incinerator with a capacity of 700 t/day suggested here would handle the majority of the municipal solid waste (MSW) collected in Vientiane. By 2030 this will be about 255,000 t/yr. As mentioned in Chapter 3, the waste stream of Vientiane consists of at least about 67% of organics (high moisture content, low heating value). Self sustaining combustion is only possible above a minimum heating value (7-8 MJ/kg). During the rainy season pure mixed waste in Vientiane can be lower than this limit. However, experience throughout the world demonstrates that moving grate mass burn incinerators can be designed to accept heterogeneous waste if a proper design is followed. Modern plants have auxiliary burners on grate drying to ensure temperatures (850°C). Thus, although the feed stream is wet, a properly designed WTE plant could be technically feasible in Vientiane. Other possible measures, for instance, expansion of the small scale RDF plant in operation (currently 200 t/day) or piloting source separated organic material for anaerobic digestion, would facilitate a higher quality of feedstock as well as energy recovery (Noudeng et al, 2024).

Another important outcome is the waste weight reduction of WTE. Incineration has been shown to reduce the volume of MSW by some 85-90% (Noudeng et al., 2024). From a 700 t/day feed, only ash is produced (locally, around 15-20 t/day, around 2-3% by weight). (In contrast the US EPA states that typical plants have ash yield of 15-25% of input weight) (US EPA, 2025b) but the project shows that ash yield will be even lower because of the high moisture content. By 2030,

around 1,200-1,500 t/day of waste would need to be disposed of by landfill, which would increase sufficiently to meet the target. WTE, on the other hand, would leave only about 15-20 t/day of ash for landfill if 700 t/day were directed to the plant (and slightly less than that as a leftover fraction if coverage or plant capacity is less than 100%). The effect of the WTE scenario is to improve the volume of waste to landfill by some 85-90%. This hugely relaxes land space requirements. With WTE it would be possible to have a landfill that would last for several decades without expanding it (the current landfill, Km32 is now 5 to 7 years from its capacity) while the Baseline estimates would require new dumpsites in a few years time.

Table 4: Comparison of MSW quantities under Baseline vs. WTE scenarios (circa 2030). Data approximate; baseline range reflects uncertainty in waste growth (Source: own editing)

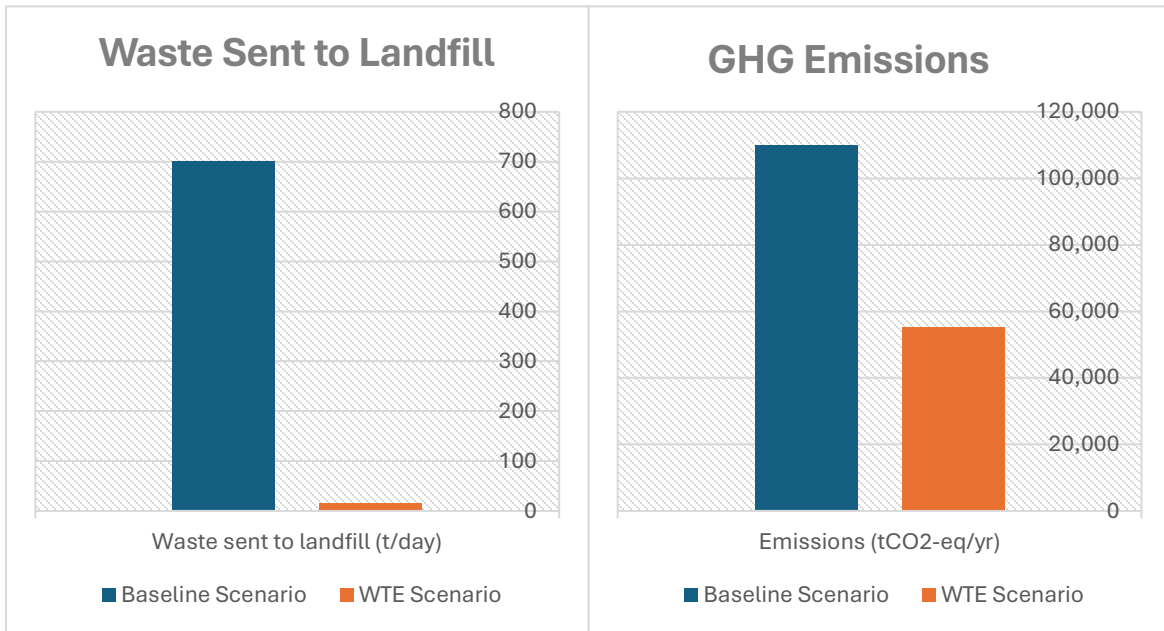
Metric/Scenario	Baseline (Landfills only)	WTE incineration
Waste generated (Expected 2030)	1200-1500t/day	1200-1500t/day (same overall MSW)
Waste collected and treated	Around 85% of total (rising)	Around 100% (assumed full collection)
Waste sent to landfill	Around 1000-1200t/day	Around 15-20t/day
Waste incinerated (new plant)	0	700t/day (13MW)
Reduction in landfill volume	-	Around 85-90% reduction (Noudeng et al., 2024)
Landfill lifetime (Km32)	≤5-7 years (2028)	Decades (no new site needed)
Ash to landfill	-	15.6t/day (ash)
Electricity generated	0	Around 13MW (around 100.000MWh/year)
Energy recovered	None	Around 550kWh/ton (around 20-30USD/ton value) (US EPA, 2025b)

This comparison reflects the technical feasibility of the WTE option. In conclusion, the characteristics of the waste in Vientiane are at the boundaries of the limits of exploitation of mass burn incineration, but, through robust technology (moving grate, flue controls, possible

pretreatment) it can be used. The WTE plant would need to be operated carefully (e.g. auxiliary fuel in wet periods) but is practicable; indeed, many developing cities (Thailand, Vietnam etc) operate such incinerators with similar profiles well. In the Baseline case, technical viability is taken to mean that landfilling is carried out and open burning is done intermittently, which is a low tech solution but not practical as a long term proposition.

4.2 Environmental Results

Figure 8: Diagram shows reduction of Waste sent to landfill and GHG emissions between Baseline scenario and WTE scenario (Source: own editing)



The environmental effects are very different between scenarios. Analogue open dumping and open burning lead to increasing methane emissions, pollution from leachate, and toxic smoke, when waste is continued to be landfilled (and open dumped or open burned) as a means of final disposal under Baseline. The landfill in Vientiane is currently releasing large amounts of methane (a GHG 25-30x more potent than CO₂) due to its unmanaged and unlined state (Babel & Vilaysouk, 2016). If the waste were sent to landfill at 1,000-1,200 t/day (which seems likely with the growing population growth rate of Vientiane) then these emissions would significantly increase. For reference, from Babel and Vialysouk (2016), one study estimated that the MSW generated in 2011 in Vientiane (232,500 t/yr) would result in approximately 110,000 tCO₂e/yr in the "business as usual" scenario. With waste rising by 2030 baseline emissions could easily double. Furthermore, open burning of approximately 33% of waste (according to local reports)

(Sisounonth, 2025) is responsible for the addition of toxic particulates and dioxins into the air and exacerbates health issues with regards to respiratory problems.

By contrast, net environmental benefits result from the WTE scenario by avoiding disposal of most landfilled organics. The combustion of 700 t/day prevent methane formation for close to 100%. The organic carbon converts during combusting into CO₂, but due to the fact that nearly 67% of the carbon is biogenically produced, it is generally considered carbon neutral. In effect, methane release from landfill becomes virtually non existent when the organic waste is combusted instead of landfilled. Perhaps surprisingly, the plastic (fossil carbon) fraction emits only CO₂ and thanks to the very high global warming potential of methane, replacing combustion and anaerobic decomposition is a climatic bonus. Also, some of the grid electricity is offset by WTE. Given that the majority of Lao's grid is hydropower, selling around 100 GWh/yr is displacing some fossil fired generation on the region. On a life cycle basis modern WTE will typically beat open dumping in GHG terms (methane avoidance). One of the reviews sees using incineration coupled with energy recovery, generally, just decreasing the amount of waste by about 90% while achieving net reductions in GHG emissions relative to energy offsets (Noudeng et al., 2024).

However, there are emissions from the WTE plant that would need to be controlled. Combustion flue gas emissions are particulates, NO_x, SO₂, acid gases and trace dioxins/furans. If operate correctly, emissions can achieve international limits. The major result is that local conditions would be improved: uncontrolled burning and landfill smoke (baseline) would disappear, and instead one point source emission with a filter would be used. Similarly, the new municipal waste ordinance (2025) also prohibits open burning and waste dumping (Sisounonth, 2025) which can be enforced when the WTE comes online after WTE has enough waste disposal capacity.

Another difference there is the way the ash is handled. The quantity of WTE ash (around 15.6 t/day) is relatively small and manageable due to the heavy metals contained in the fly ash but poses a manageable problem in relation to the hundreds of tons of leachate as well as the polluted odorous waste generated in the dump. Bottom Ash (mainly glass, metal, silica), which could potentially be recycled (e.g. in construction); fly ash, must be immobilized in the case, ash is housed in an appropriately lined compartment (probably at the landfill) with appropriate treatment. This eliminates the widespread pollution of the soil and water due to leachate. In summary,

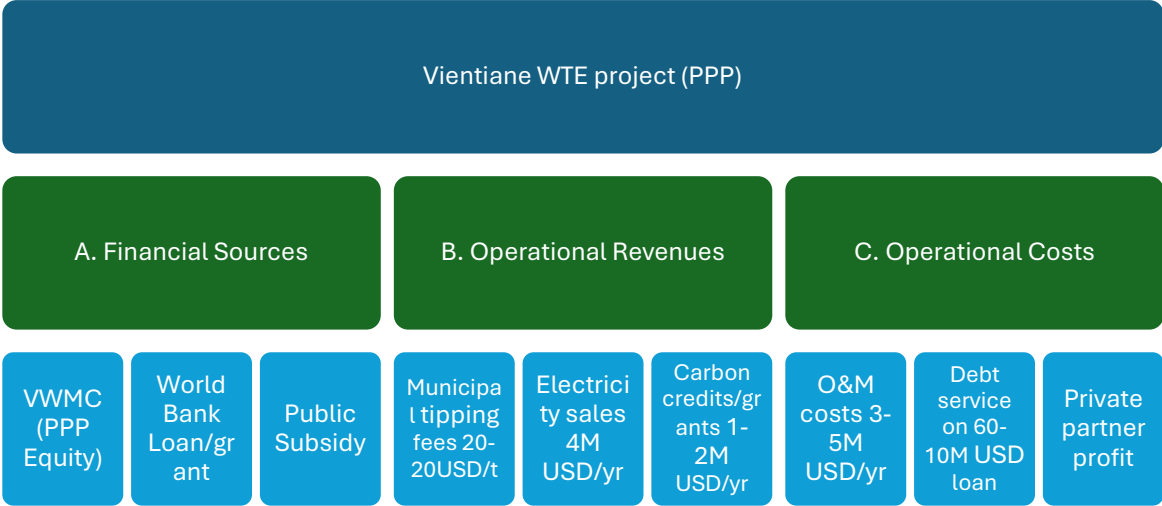
therefore, WTE results in localised emissions (dealt with by controls), and a dramatic reduction in landfill pollution and methane.

Cleaner and healthier environment would be created for the urban population. With the WTE plant being able to absorb the majority of the waste, there would be a reduction in illegal dumps and street fires. The existence of an alternative disposal would moderate the incentive to burn rubbish and decrease attraction of vermin at the landfill. In short, WTE can help get to the source of Vientiane's pollution crises (see summary) and help transform the waste sector from an increasingly uncontrolled emission sector into a more controlled system.

Compared to the baseline scenario, the WTE case produces large reductions in reliance on landfills, decreases in methane emissions, and increases in renewable electricity. Implementation of real world WTE will be contingent upon stringent emissions controls (modern Air Pollution Control technologies) and consistent supportive policies (tipping fees, and enforceable emission limits). Furthermore, recycling and composting must continue to play significant roles; WTE should only treat non-recyclable residue residuals. This is aligned with the Vientiane 2021–2030 plan to increase separation and material recovery and ensure that environmental benefits of WTE are not offset by upstream diversion of recyclables.

4.3 Economic and Financial Results

Figure 9: Simplified Financial Flow of Proposed WTE (Source: own editing)



The WTE scenario is economically challenging and needs a huge initial investment. A mass burn plant of this size can with reasonable expectation be cost at \$60-100 million (including land,

construction and infrastructure) by 2025 (US EPA, 2025b). Operating costs are also higher compared to a landfill, skilled labor, furnaces and scrubbers maintenance, ash handling and the cost of operating fuel surcharges during wet periods. By contrast, with the Baseline path, new capital investment will be deferred in the short term (extend the size of the dump). But that cheapness is deceptive, with dumping, there are costs that are not so hidden (purchase of space for new dumps; later removal of pollution; health payments; loss of land value).

Under WTE, the revenues and savings have to pay for the costs. Main sources of income are tipping fees and electricity sales. WTE projects in other parts of the world are made possible by stable tipping fees. In the rich world, charges of \$50-100/ton are typical. Another of the study's findings is that in Laos today, households today are being charged fees under \$5 per month, far below the level needed to achieve cost recovery. Our analysis indicates that Vientiane will have to significantly increase waste tariffs to pay for WTE. For instance, a relatively small tipping fee of \$20/ton and 700 t/day will still only yield \$5-6 mil per year. This will have to help finance O&M and debt service. Selling electricity generates more revenue: at the rate of about 550 kWh per ton of waste (US EPA, 2025b) the plant could produce about 100,000 MWh/year. This revenue amounts to approximately \$4-5 million per year (US EPA, 2025b), at an avoided cost tariff (say \$0.04/kWh [14]). In practice, the feed in tariff for WTE might be higher. Metal recovery is the other source of revenue: The incinerator bottom ash includes scrap iron/aluminum which can be sold in the market, but this is also a low stream.

Thus, to make it break even, the WTE plant would require total revenue (tip + power + byproducts) of perhaps \$10-15 million/year. This may not cover costs completely and so there is an implication of public support. In practice, the project is being organized as a PPP, and foreign funds are also used. The World Bank's Lao Waste Management Project is funding collection and landfill upgrades and the private partner (VWMC) is looking into concessional loans and climate funds for the plant. These subsidies would help to cover capital costs. Also, the WTE plant would add economic benefits in the long term: savings on development of new landfill sites (land and construction costs), avoidance of landfill remediation, and employment in operation. Chapter 3 pointed out that if well managed, WTE can become profitable based on the right tariff/regulatory regime.

In comparison, the Baseline case eventually becomes more expensive. The dump at Km32 has reached near capacity, therefore Vientiane needs another dump site soon. Land had to be bought (and we had to build a new engineered landfill, tens of millions more dollars if they could afford it) Any failure to invest will lead to ongoing open dumps and burning with public health and environmental remediation expenses to follow. The cost from a city budget perspective is shifted from future landfill capital to a one time plant investment, which can be spread out over decades of time with WTE.

Table 5: General Economic Comparison (Source: own editing)

Metric/Scenario	Baseline	WTE
Tipping Fee	Pays rather small fees (currently c. \$1-2/household/month).	WTE would need a formal tip (c. \$20-30/t or more) for it to be feasible.
Electricity	No recovery.	Could receive around \$0.04/kwh on order of 100GWH/yr (US EPA, 2025b).
CapEX	caps out waste sector CapEX (although new dump likely around US\$20-50M)	WTE demands about \$60-100M as an initial investment (US EPA, 2025b)
O&m	Expensive to remediate while landfill O&M is cheap (\$/ton).	O&M is technology intensive, but it is very likely that the costs will be shared in a public private structure.
External Funding	Will rely on episodic funding (World Bank) contributes only to small improvements	Gathering interest of donors and private finance.

Scenario 2 offers long term savings, less money has to be spent on purchasing/preparing land for the landfill, and less money has to be spent on its remediation. The plant itself could also spawn employment in construction and operation, and local engineering capacity. If structured well, Vientiane's WTE project could be attractive to concessional finance (e.g. climate funds), as it addresses both waste and clean energy issues. On the other hand, the financial risks need to be deal with in the event the waste supply is too low (less waste generated, or higher recycling), it is possible the plant will miss often.

Increases in financial performance are in favour of WTE in the long term, if cost recovery mechanisms are implemented. The waste sector can change towards a polluter pays principle (increasing tariffs proportionally with increased service). In case Vientiane signs a power purchase agreement and waste supply contract, the plant would have guaranteed sources of income. Otherwise, the WTE plant will be underutilized (if the collection does not keep pace) or even insolvent.

4.4 Institutional and Social Results

The WTE scenario would lead to important institutional and social changes in comparison with baseline. Under the Baseline little has changed: enforcement is weak, illegal dumping is still taking place, and many households still choose not to be collected (Sisounonth, 2025). The recently issued municipal decree (Sisounonth, 2025) that prohibits burning and bans its practice and imposes severe fines and penalties cannot work effectively without an alternative waste treatment. In Baseline the city has no strong institutions and no waste services to adhere to more stringent regulations. As a result, there is a low level of public involvement.

By comparison, the WTE project is a reform process. An important result is an improvement of waste governance framework. For instance, compulsory collection agreements or prescriptions of collection routes would almost certainly be imposed to ensure that the plant has a feedstock. Environmental regulators would require clear standards for WTE emissions and disposal of ash (ascertain which are currently in development). It also promotes capacity building: there is an incinerator manager that has to be trained, as well as testing stack monitors. Our analysis finds that several institutional supports are already in place in that respect: Vientiane's PPP with VWMC, and activities of the World Bank showcase an emerging trend in coordinated planning and funding of waste services.

Public acceptance can be achieved in the WTE scenario, which is socially constructed. As stated in Chapter 3, the modern WTE plants are often challenged by the fatefully named "Not In My Back Yard" concerns but these could be dealt with. In practice, most communities come to consider WTE plants symbolic of a cleaner city. Indeed, introducing WTE is accompanied by public information campaigns about recycling and proper throwing away. Overall, our findings suggest to further work along similar lines: Under WTE, authorities would probably encourage source separation (e.g. separate organics) and to explain the health benefits of moving away from open burning. If handled in a transparent manner the plant can help to increase civic pride through cleanliness in the city. However, emission of air will still be of concern to some residents. This highlights the importance of continuous participation by stakeholders, real time emissions reporting and visible pollution controls (e.g. filters, tall stacks). Lesson of the US EPA, which says, the root of the distrust of the community is in the absence of controls (US EPA, 2025b). Here, the future fine monitoring regime (Sisounonth, 2025) are good signals that can create trust.

Institutional pressure is also a force at work with WTE. This will require the city's decision makers to combine WTE in a general waste policy: by enforcing collection (to supply the plant), by continuing recycling systems (to supply RDF or reduce combustion of premium waste fractions) and aligned with the national policies (e.g. the plastics reduction plan in 2020). Our scenario is based on the assumption that the groundwork of regulations and public education will occur such that the WTE plant is part of a coherent system rather than a standalone project by 2030.

Overall, the institutional results from the WTE scenario are a step change from the Baseline. Where Baseline accepts loopholes and informal practices, WTE will ask Vientiane to formalize its waste management. It opens space for regulatory reform (e.g. solid waste legislation), capacity building (VCOMS, VWMCo.) and citizen participation. These results are more difficult to measure but are confirmed by the advances already observed in 2023-2025 (new legislation, World Bank, PPP frameworks etc.).

4.5 Summary of Comparative Results

Table 6: Summary of Comparative Results Between Two Scenarios (Source: own editing)

Metric/Scenario	Baseline	WTE
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Waste Volume & Land Use	Continuously extending the capacity for dumping.	85-90% of the waste is not brought to the landfill, which reduces considerably the land pressure.
Environmental Impact	Produces high levels of methane gas & local pollution (open dumps, fires).	Avoids most of the methane gas problem, but creates stack emissions, and stack emissions must be controlled (i.e. modern filters remove >99% particulates (US EPA, 2025b)). If managed efficiently, will be a cleaner technology, and in line with Lao climate aspirations.
Energy/Resource Recovery	Does not recover anything, loss of value of waste.	Generates renewable power at a rate of roughly 13 MW that can generate power for tens of thousands of homes, in addition to being able to recover metals from ash. This is value added and diversifies the energy mix.
Economic Factors	Apparently less expensive but obscures future costs (needed landfill space, clean up, health care).	Requires capital investment and increases the operating cost but saves money in the long run (no need to build a landfill, remediation) and job creation. Increase of its economic viability: it will require supportive policies (tipping fees, subsidies). Experiences show that with efficient regulation, WTE can be competitive on its own. For instance, in European countries such as Denmark and Sweden WTE is operated profitably under mandatory fee and energy price regimes.
Social & Institutional	Provisions under little incentive for public	Associated with public education, more rigorous enforcement (of bans) and

	cooperation and maintaining the waste governance.	institutional strengthening (e.g., waste laws, monitoring systems). A WTE project can therefore act as a driving force for the comprehensive reform of the waste sector in Vientiane.
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4.6 Comparative Discussion with Regional Examples

The findings of the Vientiane WTE impact assessment are in close agreement with experience in other cities in Southeast Asia which are developing such technologies. In technology terms, the proposed 700 t/day incineration facility exhibits similar parameters to the On Nuch WTE plant in Bangkok and Soc Son plant in Hanoi, which are both working on mixed municipal solid waste with a similar high organic and high moisture content. These regional examples clearly show that despite the challenges of waste composition, moving grate incineration at high mass burning rates can overcome tropical conditions provided that proper pre logistics with drying and air pollution controls and the establishment of waste supply contracts can be ensured. Therefore, the suggested Vientiane system seems technically feasible in the regional scenario (World Bank, 2025) (US EPA, 2025b).

Compared to other waste management technologies for Vientiane, WTE is in line with global practice in that there is strong evidence of major methane mitigation benefits from replacing free air combustion in open dumps with controlled combustion. Cities in ASEAN region have reported more than 80 per cent decrease in landfill methane generation after partial adoption of WTE (Noudeng et al, 2024). Also, the type of emission control system prescribed for Vientiane; baghouse filter, scrubber, and activated carbon injection, is best practice pollution control that can reduce the particulates and acid gases to the international standards (US EPA, 2025b). In this context, the environmental performance for the Vientiane plant is on par with existing WTE plants in their neighbors, but the success of the project is additionally reliant upon the proper monitoring of results.

From an economic point of view, the projected capital cost of the facilities in Vientiane of USD 60-100 million and a tipping fee of USD 20-30 per ton is of the same order as the other countries in the region. Thailand and Vietnam have made use of comparable tariff structures to reconcile operating expenses and electricity earnings. However, the lower electricity tariffs and

smaller waste stream in Lao PDR will likely restrict profitability at least initially which underlines the importance of gradual tariff reform supported by donor co financing (World Bank, 2025). The process of favors shifting to a WTE model reflects more familiar experience in Hanoi and Phnom Penh where projects catalysed formalization of waste collection and institutionalisation of informal recyclers. This is the pattern that is being followed in the policy and capacity building initiatives now under way in Vientiane and provides the institutional base for sustainability.

The comparative evidence indicates that Vientiane's WTE project is in line with the technical, environmental and financial performance that has been realized in a similar Southeast Asian context and that the success of the project over the long term will require adherence to environmental standards and financial sustainability through steady policy support.

Table 7: Comparative Summary of WTE Performance of Vientiane's Proposed with Regional Examples (Source: own editing based on results, Joshi. (2021), Noudeng et al. (2024), JICA (2021), Nsafon (2022), Urban Core (2025), Areeprasert (2023), Vietnamplus (2022))

Parameter/Indicator	Vientiane (Proposed)	Bangkok, Thailand	Hanoi, Vietnam
Waste treated (t/day)	Around 700 (Estimated)	Around 500 (Nong Khaem Plant)	Around 4.000 (Soc Son Plant)
Technology type	Moving Grate	Moving Grate	Moving Grate
Electricity output	Around 13MW (Scaled from 500-700kWh)	Around 9.8MW	Around 75MW
Landfill reduction	Around 85-90%	Around 85%	Around 80%
Estimated GHG reduction	High (methane avoided)	High	High
CapEX (USD)	60-100	-	300
Tipping fee (USD)	20-30	-	20-50
Policy/institutional maturity	Developing	Moderate (Operating Since 2022)	Moderate-High (Largest In Asean)
Overall feasibility	Feasible with support	Proven	Proven

Chapter 5: Conclusion

Vientiane's rapid urbanization, the increasing consumption rate and the lack of expansion for the landfill make solid waste management an urgent concern. Based on the World Bank (2025), the municipal solid waste generation could reach more than 1,500 tonnes per day by 2030 and the available landfill at Km 32 is approaching capacity. Within this framework, this study was carried out to assess the feasibility of a WTE systems implementation as an alternative to landfilling, considering the technical, environmental, economic and institutional aspects.

The results show that WTE is a viable and sustainable solution to Vientiane's waste problem. Technically, an incineration plant with a moving grate of 700t/day is possible given the composition of the waste from the city, which has a high calorific value when pre treated. The plant has the potential to produce about 100GWh of electricity each year along with reducing the amount of waste sent to the landfill by about 85-90 percent. Untreated decomposition would result in large reductions to methane emissions that contribute to the country's climate targets (Babel & Vilaysouk, 2016; US EPA, 2025b).

Economically After initial WTE development occurs, there are long term savings to be made by reducing further landfill expansion, avoiding cost of remediation of land and potential electricity revenues. It would also generate construction and operating employment for local economic development. The recent pledge made by the World Bank (2025) to invest in building capacity of workers in the waste sector shows that such capacity building will increase social inclusion within the waste sector.

Institutionally, the success of WTE is dependent on a policy and governance support. Sustainability of operation depends on stable supply of waste, proper segregation of waste and strict enforcement of environmental regulations. Local acceptance and knowledge is just as important as well, since community involvement and transparency are; in turn, directly related to long term success. WTE should work in addition to current recycling and composting programs to ensure that the city is heading toward a more circular and sustainable waste system.

Overall, this paper concludes that WTE has the potential to play a significant role in Vientiane's integrated waste management scheme. It is an element that provides a way to mitigate pollution, generate renewable power and increase waste management. Through the appropriate policy

frameworks, institutional coordination and community participation, Vientiane has a real chance of becoming a prime example of sustainable urban development for Lao PDR and the region.

Chapter 6: Summary

This study presented an attempt to evaluate the potential WTE technology as a sustainable alternative of landfill at Vientiane. The study methodology adopted a comparative scenario analysis based on a baseline scenario of continued landfilling against a WTE scenario based on a 700t/day moving grate plant. Based on many research from many resources, the analysis involved the technical feasibility, environmental and economic impacts, and institutional and social considerations.

The findings proved that the existing landfill based system is not sustainable. Continuously dumping would soon run out of capacity, put pressure on available land, and add a lot of methane to the atmosphere. In comparison, a WTE facility could decrease landfill waste by up to 90%, extend landfill useful life by over 20 years and produce renewable electricity equivalent to servicing tens of thousands of households for the same. As a result, community air pollution control systems, if operated correctly, can reduce regional emissions and ensure conformance with modern environmental standards.

Larger initial investment is required but WTE is economical in the long months on reduced landfill growth and health related costs. The project has also significant social and institutional advantages. It would regularize waste workers, create skilled employment, and facilitate peoples' participation in waste reduction and segregation. These aspects are consistent with the Development Plan in Vientiane for the period 2021-2030 and Lao PDR's Nationally Determined Contribution to the Paris Agreement.

The study has several limitations, however. Since the model data are based on secondary data, actual waste characteristics & energy recovery rates may differ slightly from model results. Additionally, further field based measurements, life cycle analyses and financial assessments should be conducted under the range of tariff scenarios in order to refine the analysis.

In summary, it may be said that WTE is a technically feasible and environmentally beneficial complement of landfill management in Vientiane. If appropriate policy design, finance and public acceptance is in place, it can take the leading role in the city's sustainable waste management and renewable energy goals. After discussing and analyzing the results, this Final

Work concludes that all the research questions in Chapter 1 have been answered and confirmed that WTE is a feasible and sustainable solution to solve the solid waste issue of Vientiane.

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Table of Figures

Figure 1: KM32 landfill in Vientiane's Maps (Source: World Bank, 2025)	1
Figure 2: KM32 landfill site from satellite (Source: World Bank, 2025)	4
Figure 3: Hierarchy in MSW management between developing and developed countries (Source: Noudeng et al, 2024).....	6
Figure 4: Waste Composition of MSW in Vientiane 2020 (Source: Kim et al, 2021).....	20
Figure 5: Waste Flow in Vientiane 2019 (Source: JICA, 2021).....	22
Figure 6: Location of the planning of facilities of incineration plant that plan in 2005 to illustrates the planning of the WTE in the same pattern and location (Source: JSCE, 2005)	26
Figure 7: Process flow of the proposed Waste to Energy system in Vientiane (Source: own editing)	33
Figure 8: Diagram shows reduction of Waste sent to landfill and GHG emissions between Baseline scenario and WTE scenario (Source: own editing).....	35
Figure 9: Simplified Financial Flow of Proposed WTE (Source: own editing)	37

Table of Tables

Table 1: Comparison of Key WTE Technologies (Source: own editing based on Noudeng et al. (2024), IEAGHG (2020), (Twi-Yeboah et al., 2024)).....	9
Table 2: Waste collection coverage and rate in each Vientiane district as of 2020 (Source: own editing based on Kim et al, 2021)	21
Table 3: PESTEL analysis for WTE implementation in Vientiane (Source: own editing)	30
Table 4: Comparison of MSW quantities under Baseline vs. WTE scenarios (circa 2030). Data approximate; baseline range reflects uncertainty in waste growth (Source: own editing)	34
Table 5: General Economic Comparison (Source: own editing)	39
Table 6: Summary of Comparative Results Between Two Scenarios (Source: own editing)	41
Table 7: Comparative Summary of WTE Performance of Vientiane's Proposed with Regional Examples (Source: own editing based on results, Joshi. (2021), Noudeng et al. (2024), JICA (2021), Nsafon (2022), Urban Core (2025), Areeprasert (2023), Vietnamplus (2022)).....	44

List of Abbreviations

WTE - Waste to Energy

MSW - Municipal Solid Waste

US EPA - United States Environmental Protection Agency

MDPI - Multidisciplinary Digital Publishing Institute

RDF - Refuse Derived Fuel

CO₂ - Carbon Dioxide

GGGI - Global Green Growth Institute

GHG - Greenhouse Gas

USD - United States Dollar

UNEP - United Nations Environment Programme

IEAGHG - IEA Greenhouse Gas R&D Programme

US - United States

AD - Anaerobic Digestion

LFG - Landfill Gas

MPWT - Ministry of Public Works and Transport (Laos)

PPP - Public-Private Partnership

CH₄ - Methane

EPF - Environment Protection Fund (Laos)

IFC - International Finance Corporation

JICA - Japan International Cooperation Agency

MBT - Mechanical-Biological Treatment

MONRE - Ministry of Natural Resources and Environment (Laos)

MW - Megawatt

PDR - People's Democratic Republic (as in Lao PDR)

kWh - kilowatt-hour

PPA - Power Purchase Agreement

SO₂ - Sulfur Dioxide

ASEAN - Association of Southeast Asian Nations

CEMS - Continuous Emissions Monitoring System

EU - European Union

MJ - Megajoule

tCO₂e - tonnes of CO₂ equivalent

CEWEP - Confederation of European Waste to Energy Plants

IDA - International Development Association

VCOMS - Vientiane City Office for Management and Service

VWMC - Vientiane Waste Management Company

SWM - Solid Waste Management

MATE Organizational and Operational Regulations

III. Requirements for Students

III.1. Study and Examination Regulations

Appendix 6.13: The MATE Uniform Thesis /thesis / final thesis / portfolio guidelines

Annex 4.2: Declaration of public access and authenticity of the thesis/thesis/dissertation/portfolio

DECLARATION

the public access and authenticity of the thesis

Student's name: Anosith Khammounheuang
Student's Neptun code: DYDSNV
Title of thesis: Assessing the Potential of Waste to Energy Solutions for Vientiane's Landfills
Year of publication: 2025
Name of the consultant's institute: Institute of Environmental Sciences
Name of consultant's department: Environmental Analysis and Technologies

I declare that the thesis submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography. Furthermore, I declare that the artificial intelligence tools (e.g. text generation, linguistic correction, translation, data analysis) used during the preparation of the thesis did not substitute my own research and creative work; their use was indicated either in the list of sources or in the methodology section, and I acted in accordance with professional and ethical expectations.

If the above statement is untrue, I understand that I will be disqualified from the final examination by the final examination board and that I will have to take the final examination after writing a new thesis.

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Date: 2025 year October month 31 day


Student's signature

DECLARATION

Anosith Khammounheuang (name) (student Neptun code: DYDSNV)
as a consultant, I declare that I have reviewed the final thesis/thesis/dissertation/portfolio and that I have informed the student of the requirements, legal and ethical rules for the correct handling of literary sources.

I recommend the final thesis / dissertation / portfolio to be defended in the final examination.

The thesis contains a state or official secret: yes no

Date: 2025 year October month 31 day



insider consultant

Declaration of Students and Doctoral Candidates on the Use of Artificial Intelligence (AI)”

1. general information:

Name of the student:	Anosith Khammounheuang
Neptun ID:	DYDSNV
Level of program (mark with X):	<input checked="" type="checkbox"/> BSc/BA <input type="checkbox"/> MSc/MA <input type="checkbox"/> Doctoral School (PhD) <input type="checkbox"/> Other:
Name and code of the subject*:	Environmental Engineering, B-GOD-N-EN-KORNY
Title of the work:	Assessing the Potential of Waste to Energy Solutions for Vientiane’s Landfills

* Not required to be completed in the case of a doctoral dissertation.

2. Declaration on the Use of AI

I, the undersigned, fully aware of my ethical responsibility, make the following declaration:

(Please choose one of the options below!)

A) I have not used any artificial intelligence system or service.

(If you selected this option, completing the subsequent tables is not required.)

B) I have used an artificial intelligence system or service.

(Please fill in the relevant tables!)

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TABLE I: Assistant or Minor Usage (e.g., translation, language proofreading, brainstorming, etc.)

(For these uses, attaching the specific prompts and responses is not required.)

Purpose of Use	Name and Version of the AI Tool Used	Affected Section (if not applicable to the entire text)
Brainstorming, finding materials, information and literature for the writing	ChatGPT-5	Part of Literature Review and part of Materials

TABLE II: Significant Content Contribution (e.g., generating an entire figure or a longer text section)

(In these cases, documenting the key prompts used and the raw responses provided by the AI, and attaching them as an appendix to the work, is required.)

Purpose of Use	Name, Version, and Access Information of the AI Tool Used	Exact Number of the Affected Chapter / Figure / Table	Entry Number of the Appendix Containing the Prompt Log

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If the instructor or supervisor of the course has established specific rules or expectations regarding the use of AI tools, please summarize them in the field below:

For example: prohibition of AI use for certain types of tasks; only specific tools are permitted; different citation requirements; documentation format, etc.

Rules Prescribed by the Lecturer or Supervisor

.....
.....
.....
.....

4. Declaration Applicable to All Students:


I declare that I have critically reviewed, edited, and incorporated any content potentially generated by AI in all cases. I take full responsibility for every element of the submitted work, including its originality and scientific validity. I acknowledge that the Hungarian University of Agriculture and Life Sciences may check the submitted work with an artificial intelligence detector and may initiate proceedings if my declaration is found to be false or incomplete.

Place and Date: Gödöllő, 2025. October month 31 day



.....

Signature of the Student



.....

Signature of the Advisor/Supervisor