GGGI TECHNICAL REPORT NO. 24

Unlocking potential for large-scale waste treatment plants with a focus on energy recovery and modular project design

Lessons learned from Cambodia, Lao PDR, and Vietnam

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Lessons learned from Cambodia, Lao PDR, and Vietnam

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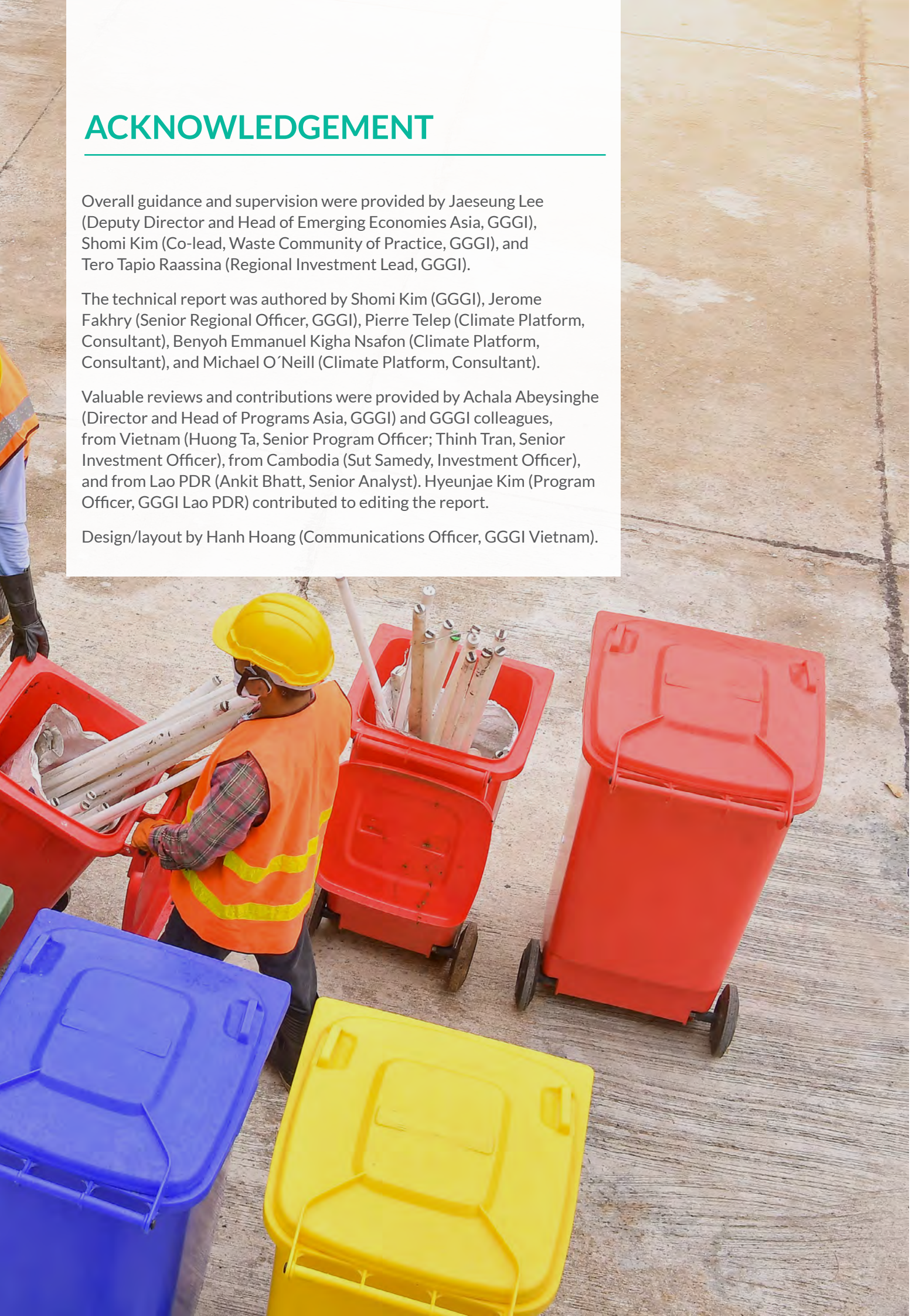

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LIST OF ACRONYMS

Abbreviation	Definition
AD	Anaerobic Digestion
ADB	Asian Development Bank
BAU	Business-as-usual
BOOT	Build–own–operate–transfer
BOO	Build–own–operate
BOT	Build–own–transfer
CAPEX	Capital Expenditure
CO_2e	Carbon dioxide equivalent
DFI	Development Financial Institution
EVN	Vietnam Electricity Corporation
FIT	Feed-in-Tariff
GHG	Greenhouse Gas
HCMC	Ho Chi Minh City
IPP	Independent Power Producer
IW	Industrial Waste
IRR	Internal Rate of Return
$ktCO_2e$	kilotonnes of carbon dioxide equivalent
LSWM	Large-scale Waste Management
LSWTP	Large-scale Waste Treatment Plant
MBT	Mechanical and Biological Treatment
MoC	Ministry of Construction Vietnam
MoNRE	Ministry of Natural Resources and Environment
MPWT	Ministry of Public Works and Transport Lao PDR
MSW	Municipal Solid Waste
MSWTE	Municipal Solid Waste to Energy
$MtCO_2e$	Metric tons of carbon dioxide equivalent
MWe	Megawatt electrical
NDC	Nationally Determined Contribution
OECD	Organization for Economic Cooperation and Development
O&M	Operation and Management
PPA	Power Purchase Agreement
PPP	Public–Private Partnership
W2E	Waste to Energy
W2F	Waste to Fuel
RDF	Refuse Derived Fuel
RE	Renewable Energy
SOE	State-Owned Enterprise
SWM	Solid Waste Management
TPA	Tons Per Annum
TPD	Tons Per Day
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar
VCOMS	Vientiane City Office for Management and Service

EXECUTIVE SUMMARY

The urban share of the world's population is projected to reach two-thirds by 2050. As the increase of waste generation in low-middle income countries is three times higher than upper middle- and high-income countries, management of municipal solid waste (MSW) has become one of the most pressing urban issues for many developing nations. In addition, many of the developing nations still take the "collect and dump" approach in MSW management with an absence of adequate waste treatment facilities. The traditional way of landfilling in an uncontrolled manner is costly both economically and environmentally, as valuable resources are being thrown away without being recovered which contributes to the release of methane from decaying organic waste in ever-increasing quantities. Leachate discharged without proper treatment is polluting the environment in the communities around landfill sites while regular open burning causes health problems for the residents in these communities.

The 3-R practices ("Reduce, Reuse, Recycle") are promoted globally, but implementation is complex and slow, and recycling activities in developing nations are still small scale and highly informal. Efficient recycling requires source separation at the household level and therefore long-term behavior change. Despite ongoing efforts, there are still large amounts of unsegregated waste arriving at landfill sites, most of which has little recycling value. Against this backdrop, the Global Green Growth Institute (GGGI) has developed projects that target large-scale MSW treatment with a focus on energy recovery and modular project design in three countries in the Mekong region suitable for Public–Private Partnership (PPP) arrangements.

This technical report aims to present lessons learned from Mechanical Biological Treatment (MBT) projects in Cambodia and Lao PDR and Waste to Energy (W2E)[i] projects in Vietnam. This report also assesses the market potential, policy frameworks, as well as implementation challenges and risk management with regard to turning the waste issues into an opportunity that will deliver environmental, climate and socioeconomic impacts in the respective countries under discussion. This report also aims to provide guidance and insights to policymakers from countries with similar socioeconomic profiles and international development agencies on unlocking the potential for large waste treatment infrastructure by identifying the most appropriate policy instruments, technology, and financing options. Key learnings can be summarized as follows:

1 *Enabling policy environment and financial instruments are critical in making large waste treatment infrastructure bankable.*

In Vietnam, the government has created an enabling environment for the W2E plant model. The Vietnam Electricity Corporation (EVN) has the responsibility to buy 100% of energy generated by renewable energy (RE) generators including from W2E projects from MSW. In addition, the generally high landfill gate fees at US$20/ton and feed-in tariff (FIT) set at 10.05 US cents/kWh favor project bankability, which led to the development of a 500 TPD W2E facility in Bac Ninh province.

Current low gate fees and the absence of a feed-in-tariff scheme do not enable economically feasible W2E projects in Cambodia and Lao PDR[1]. It was assessed that the most financially and technically viable modular design in the given operating environments is the MBT plant model. The main product of MBT is Refuse Derived Fuel (RDF) which can be used as coal replacement in cement factories. The cement-making process, which includes very high temperatures and long residence times, effectively replaces the very expensive pollution control equipment required for a purpose built W2E plant, therefore keeping the cost of MBT and corresponding gate fees relatively low.

i In this report, waste to energy (W2E) refers to combustion of waste in a purpose-built facility to generate electricity.

2 *Ensuring supply of good feedstock through source separation mechanisms should be emphasized when developing large waste treatment facilities.*

While an MBT facility will process unsegregated MSW, some level of waste feedstock source segregation will increase the quality of the final product and decrease operational costs. The quality of the final products such as RDF and organic compost will have a direct impact on the market prices, and thus, on the financial viability of the plant. Source separation mechanisms should be progressively introduced starting with large waste generators such as markets and businesses. All three countries currently have a high share of organic matters in their MSW and very limited source separation.

3 *Having an offtake agreement in place is a key success factor for financial sustainability of the project.*

Whether MBT or W2E plant models, sustainable waste management projects with a focus on energy recovery can generate positive financial returns, under the condition that the offtake agreement is made at a favorable market price for investors, making such investments attractive to the private sector. For W2E plants, a power purchase agreement (PPA) is a prerequisite condition as shown in Vietnam. For MBT, securing long-term offtake agreements for RDF is critical for sustainable operations of the plant. Through consultations with cement manufacturers, the following conditions are prerequisites: i) consistent supply of feedstock throughout the year, ii) RDF of a good standard that will not affect the quality of the cement produced, iii) unaffected air emissions from using RDF, and iv) in some cases, financial support for up-front investment costs to cover engineering adjustments to be able to receive RDF.

4 *Blended finance and climate finance can mitigate the risks for private sector investment and improve financial viability.*

Waste management is an area in which private investments could have a transformational impact including through Public Private Partnerships (PPP) and concessions, especially due to the technical and financial complexity in developing and operating such treatment facilities. However, the sector is often considered too risky by potential investors. Blended finance, such as the use of concessional loans or guarantees, can be used as a tool to share risks and unlock private investments. Diverting waste towards Large-scale Waste Management (LSWM) facilities can greatly reduce GHG emissions associated with decaying organic waste at landfills. Therefore, climate finance resources, in the form of equity, loans or grants, should be pursued, together with carbon credits to enhance financial returns.

CHAPTER

01

CURRENT SITUATION OF MUNICIPAL SOLID WASTE IN MEKONG COUNTRIES

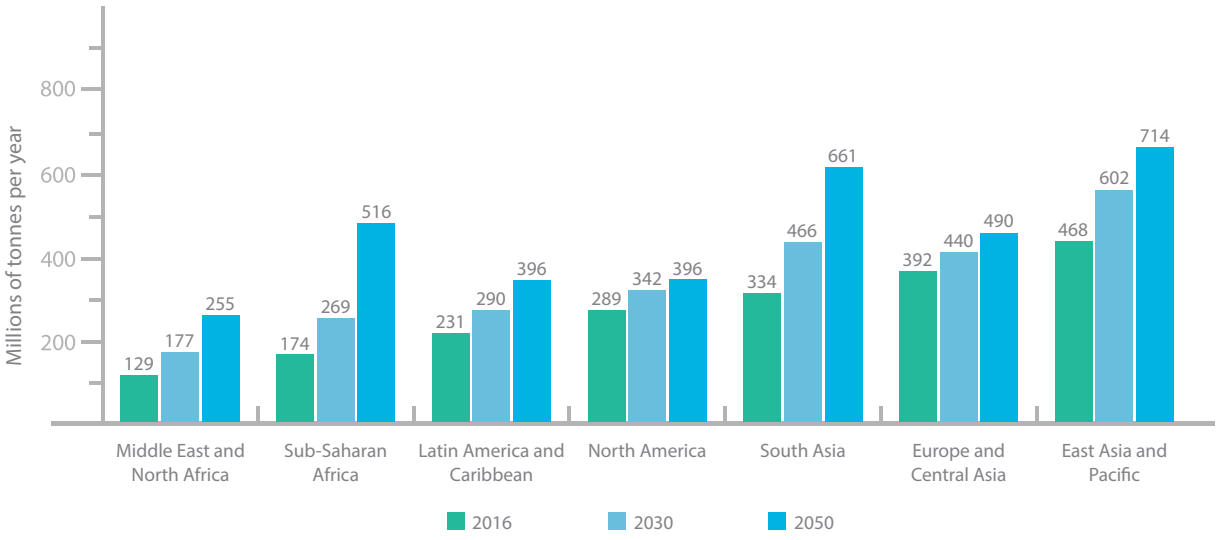
1.1 Large-scale waste treatment

MSW generation is rapidly rising around the world, with over 2 billion tons generated annually. This amounts to a footprint of 0.74 kg per person per day[2]. Global annual solid waste generation is expected to grow to 3.40 billion tons by 2050, driven by rapid population growth and urbanization[3]. MSW is growing even faster than the rate of urbanization and presents multiple environmental, climate and social threats. It is estimated that the number of urban residents generating MSW globally will increase from 3 billion to 4.3 billion between 2012 and 2025, and the amount of MSW generated per capita per day will also increase from 1.2 kg (1.3 billion tons per year) to 1.42 kg (2.2 billion tons per year), respectively[4]. While waste minimization and source separation should be prioritized and increased overtime, part of the solution is also to develop downstream large-scale waste treatment plants (LSWTP) to manage the increasing quantity of unsegregated MSW with a low value.

There have been several successful implementations of W2E and MBT plant models in Southeast Asia[5]. These modern downstream waste management technologies have proven so far to be efficient in managing large quantities of unsegregated MSW. Modular plant designs include mechanical separation infrastructure, energy recovery technologies for the non-organic fraction and biogas or compost for the organic fraction. The project design can be tailored to fit in the policy environment, investor risk appetite, and local offtake arrangements. This approach presents an additional opportunity for professional quality control in waste handling, as well as improved emissions from disposal sites.

Innovative waste management techniques are gaining interest in Asian megacities[6], and it is a matter of urgency that action is taken regarding the management of MSW. The fast-growing cities of Cambodia, Lao PDR, and Vietnam in the Mekong region are no exception. There is a need for large-scale solutions for the treatment of waste that are both financially and environmentally sustainable. Sustainable treatment of MSW does not only offer an opportunity to reduce the quantities of waste landfilling, but it also provides an opportunity for circularity, with the creation of new revenue streams. This is the case for instance, where waste is converted to biogas or when organic waste is recovered into composted materials to improve agricultural outputs, and thus, positively contributing to climate mitigation.

Figure 1. Projected waste generation, by region[3]



While waste minimization and source separation should be increasingly prioritized over time, MSW disposed at landfills in most developing nations currently needs to be managed as a mixture of waste. This gives rise to the need for large-scale waste treatment plants. Such facilities can minimize the environmental impacts and maximize resource recovery from MSW.

1.2 Outlook of MSW in Cambodia, Lao PDR, and Vietnam

MSW is a mixture including food waste, paper, plastic, rags, glass, textile, rubber, leather, metal, stones, and ceramics generated from residential, municipal, community, commercial, and institutional activities. The composition of MSW can vary from one country to another, but organic materials are generally the largest component of MSW which accounts for up to 60–70% in low-middle income countries. Rapid population growth, urbanization, and change in consumption patterns in Cambodia, Lao PDR, and Vietnam have resulted in an increase in the amount of MSW generation.

Cambodia

In 2016, it was estimated that 4.24 million tons of MSW was generated across the country[7]. On average, every Cambodian is currently estimated to generate about 0.73 kg per day of solid waste[8].

MSW collection and transportation is generally contracted to private companies, under the supervision of local authorities and technical line agencies. The collection rate varies greatly depending on the city, and collection is generally focused on city centers and roads large enough to accommodate collection trucks. In Phnom Penh, the capital city, to address growing difficulties in waste collection, the city was divided into three zones serviced by three separate private waste contractors, with an online payment system currently being established.

In 2019, around 1 million tons of MSW was sent to the Dangkor landfill in Phnom Penh, growing at an annual rate of 12%[9]. Dangkor is the only MSW landfill to service the entire city, it is located about 10 km from the city center and is reaching full capacity which puts immense pressure on establishing adequate waste treatment facilities[10]. Another smaller landfill is used for industrial waste, such as garments. The last detailed composition of MSW arriving at the Dangkor landfill was conducted in 2015 and is presented in Table 1 below.

Lao PDR

According to the survey conducted by GGGI, the average waste production per capita in Vientiane in Lao PDR is estimated at 0.75 kg per day[11], amounting to 5,400 TPD and approximately 2 million tons per year for an estimated population of 7.2 million nationwide. Waste composition at the landfill is presented in Table 1[11].

Waste generation has increased significantly in urban centers of Lao PDR, with only about 30% being collected in Vientiane[11]. In Vientiane, solid waste is managed jointly by a public company established under the Vientiane City Office for Management and Service (VCOMS) and ten private companies directly contracted by VCOMS. There is no formal source separation mechanism. The high waste collection fee, lack of waste treatment facilities, and inadequate waste management practices have prompted open dumping and burning as the most common practice for waste disposal[12].

Vietnam

Vietnam has experienced a rapid growth, along with industrialization and urbanization that has led to significant shifts in production and consumption patterns. Vietnam produces more than 27.8 million tons per year of waste from various sources[13], and the volume of waste is projected to increase by 10–16% per year[14]. The composition of waste in Vietnam varies widely from one city to another. However, waste composition in big cities in Vietnam show a high content of organic materials.

Waste collection in Vietnam is still managed in a traditional way and travel distances to landfill sites are long due to a shortage of transfer stations. Households mostly dispose of waste in plastic bags in front of

homes, which are collected by waste workers' handcarts. According to the MONRE National Environment Report in 2019[14], the waste collection rate was 78% of total waste generation, of which 71% was landfilled, and the remainder treated by either incineration without energy recovery or composting. Among the available 904 landfills, only 20% are sanitary.

Table 1. Composition of MSW at landfills in capital cities in Cambodia, Lao PDR, and Vietnam

Composition	Fraction (%)		
	Cambodia[15]	Lao PDR[11]	Vietnam[16]
Organic waste	55.9	56	57.3
Plastics	21.1	27	10.9
Paper	6.5	6	5.9
Textile	8.0	3	3.8
Nappies	2.9	NA	NA
Glass	1.4	2	3.5
Rubber and leather	0.7	NA	0.2
Metal	1.1	NA	0.6
Stones and ceramics	1.5	NA	NA
Hazardous waste	0.2	NA	0.5
Others*	0.7	6	17.3

*Others refers to all other waste not listed on the table

CHAPTER

02

OPPORTUNITIES WITH LARGE-SCALE TREATMENT FOR MUNICIPAL SWM IN THE MEKONG REGION

On a global scale, technological innovation has improved the successful deployment of solutions for large-scale waste treatment. The application of technological innovation and consequent modular design depends on the specific conditions of each county. Conducting a technology feasibility is the initial process to determine the likelihood of operational and financial success when implementing a project. This chapter aims to explore the feasibility of developing large-scale MSW treatment facilities by evaluating the implementation costs for different technologies. GGGI conducted studies in Cambodia, Lao PDR, and Vietnam to analyze the techno-economic, environmental, and social sustainability of different large waste treatment technologies that are proposed to respective governments.

2.1 Technology and infrastructure options for large-scale treatment for municipal MSW

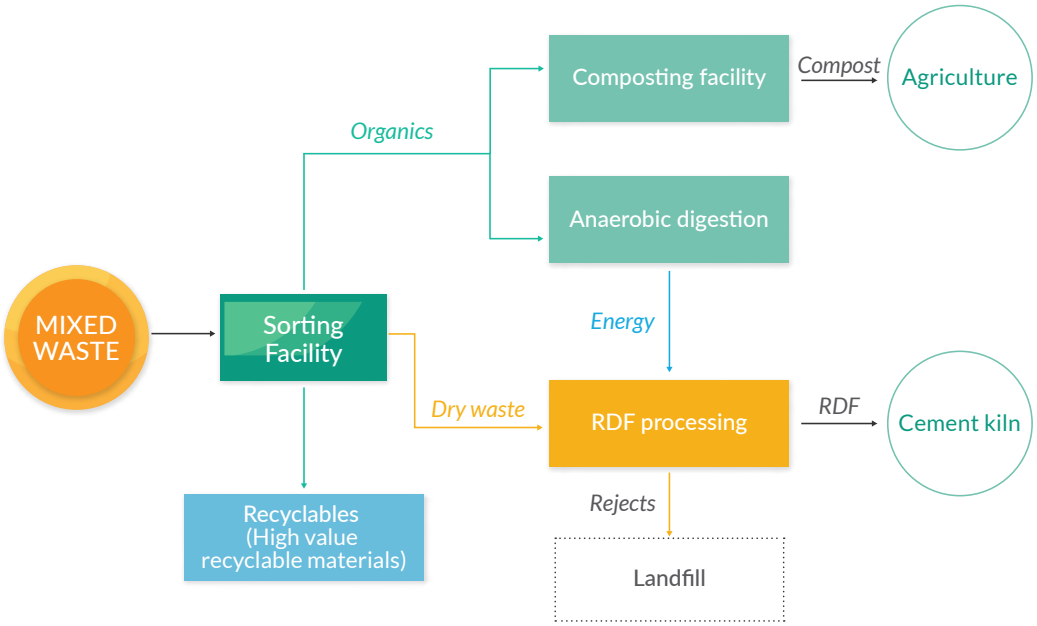
2.1.1 Mechanical and Biological Treatment (MBT)

MBT is the mechanical processing of unsegregated waste combined with a form of biological treatment such as composting or anaerobic digestion (AD). The mechanical processing recovers recyclable materials, removes inert materials and contaminants (glass, stones, etc.), removes moisture, and increases the calorific value. The main output is RDF which can partially replace coal in cement plants or be used in a standalone W2E facility. This approach is considered financially and environmentally more sustainable in comparison to incineration in a country where the largest share of the municipal waste is organic[17]. Biological pre-treatment process can also be used to reduce moisture content in the RDF fraction.

The AD component breaks down micro-organisms to produce biogas which can be used to produce heat or electricity. In the case of Cambodia, a suitable MBT set up is to combine RDF as the main output, with a small AD module without grid connection to self-power the system. An AD module for its own consumption at the plant was considered due to the high tariff for electricity in Cambodia. Depending on the size of the site and the quality of the organic fraction, composting is another option that could be incorporated into the system to generate organic compost for soil improvement, which is the preferred option for the Lao PDR project. The organic fraction that is too contaminated for use for agricultural soils can be applied to old landfills for soil rehabilitation. In both countries, RDF can be used as a partial replacement for coal in cement factories.

RDF use in cement kilns is suitable because toxic organic compounds are destroyed in the flames at temperatures of up to 2000°C with a long residence time, effectively replacing the very expensive pollution control equipment required for a purpose built W2E plant. In addition, clinker reactions at around 1450°C allow a complete incorporation of ashes, including heavy metals, into the clinker material. Given the offtake potential for RDF in the proximity of Phnom Penh and Vientiane, MBT facilities are a more financially viable waste management solution for Cambodia and Lao PDR compared with more capital-intensive incineration plants.

Figure 2. Schematic illustration of MBT plants options. Anaerobic digestion is preferable in Cambodia due to the high cost of electricity, while composting plant is considered for Lao PDR.

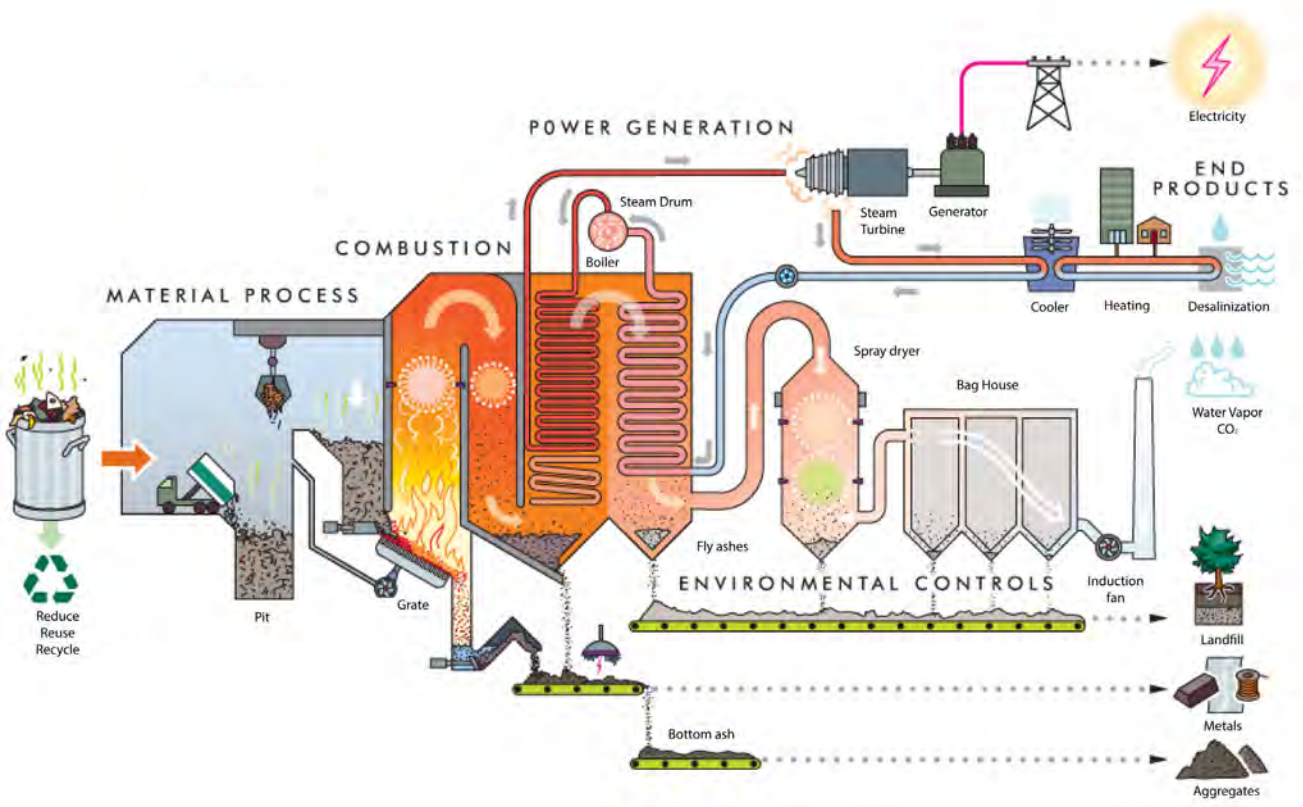


2.1.2 Waste to energy technology

Different energy recovery processes are available from MSW. RDF is one of them and recovers the calorific value of solid waste. RDF is made of combustible solid wastes such as plastics, paper, wood, and other dry organic matter which are not recyclable due to cross-contamination[18], and the composition varies with the seasons, location of waste collection, and efficiency of MSW sorting[19]. Though incineration of waste is one of the most common methods being investigated for waste management in Asia due to its perceived simplicity[20], mass burning of waste can be inefficient if the moisture content is high. The waste first must be pre-processed before combustion, effectively turning it into RDF, with the heat produced being used to produce steam which is then used to turn turbines and generate electricity. This process requires a relatively high upfront capital expenditure and making it commercially viable would require high gate fees and adequate feed-in-tariffs. While this is currently unrealistic for Cambodia and Lao PDR, it is a possibility for Vietnam. A study conducted in Bac Ninh province, Vietnam, concluded that such process would be financially viable with a gate fee of US$20/ton and FIT of 10.05 US cents/kWh which is aligned with Vietnam's policies.

About ten different active W2E projects exist in Vietnam and several other projects are currently under development. The Soc Son W2E project in the Nam Son waste treatment complex will be the largest in Vietnam and second largest in the world upon completion in 2021, with a capacity for handling 4,000 tons of MSW per day. It is expected that 75 MW of power will be generated at the facility. According to EVN[21], Vietnam has signed PPA as of early 2019 with three W2E developers including the Go Cat project HCMC (2.4 MW), the Can Tho project (6 MW), and the Nam Son project (0.6 MW).

Figure 3. Typical schematic illustration of W2E incineration plant with pre-procession mechanism[22]



BOX 1: Selected schemes for MSW treatment technology

LSWTP has been identified by GGGI as part of a standard set of policy prescriptions for MSW management in Cambodia, Lao PDR, and Vietnam. The selection of a particular waste treatment technology depends on the overall enabling framework in each selected country. An overview of the selection criteria is presented below:

- Cambodia – MBT with RDF and AD
  - Proximity of four cement factories (<120 km) from Phnom Penh are potential offtake partners that currently depend on coal and are ready to consider RDF as an alternative source of energy. The potential market for RDF is estimated at about 420,000 tons annually for all cement plants, assuming that 20% of the coal is replaced with RDF.
  - Conversely, the cost of retailed electricity (about US$0.12–US$0.15 per kWh) in Cambodia is high, while proposed FITs are low, impeding the development of W2E facilities. Therefore, the electricity generated from biogas can be used for plant production only and not for sale, hence reducing operational expenditure.
  - In terms of calorific value, 2 tons of RDF is generally needed to replace 1 ton of coal. Moreover, the long-term average price of coal is estimated at US$80 per ton compared to projected price of US$25 per ton for RDF.
  - Gate fees are not common practice, limiting the scope of more expensive technologies. However, a gate fee of about US$5 per ton is required for financial viability of the MBT project.

- Lao PDR – MBT with RDF and composting
  - W2E technologies like incineration are not feasible due to low gate fees and low-price electricity generated from hydroelectric power. It is important to note that Électricité du Laos would offer less than US$0.05 as part of a PPA, contrarily to at least US$0.08–US$0.12 per kWh requested by investors to make W2E investments bankable.
  - Agriculture is the main activity in Lao PDR with high demand for fertilizer. Imports of chemical fertilizers to Lao PDR cost an average US$500 per ton, compared to US$200–US$270 per ton for locally produced organic fertilizer[23].
  - The market price for imported coal is between US$90–US$120 per ton[23], which makes RDF attractive in price. However, plants located closest to Vientiane are not familiar with RDF and further engagement is required. Plants with a stronger offtake are located further away, which is a viable option but would increase operational costs.

- Vietnam – W2E
  - The government has established an enabling environment for W2E investments. Landfill gate fees vary by province and can be high (up to US$22 per ton in some provinces) compared to Cambodia and Lao PDR. The government has put in place a FIT of US$10.05 cent/kWh that makes W2E projects feasible.
  - The market potential for MSWTE in Vietnam was estimated at 630 MW in 2020. With the growing amount of MSW, this potential is projected to reach 815 MW to 1155 MW by 2025 and 2030, respectively.
  - Unlike the case of Cambodia and Lao PDR, there are enabling policies to offtake energy from the W2E project. Moreover, EVN has the responsibility to buy 100% of energy generated by RE generators, including W2E.

2.1.3 Techno-economic considerations

Techno-economic viability is used as a measure to assess the operational and financial sustainability potential of a project. The volume, composition, and energy content of the MSW, as well as the capital expenditure, enabling framework, and perceived project risks are strong determinant factors in deciding a suitable waste management technology solution. A project site often builds up gradually towards becoming a fully integrated infrastructure, and investment in modular phases can be a good solution to reduce the perceived risks. Retrofit and other improvement investments are common, following a mechanical separation plant as a first investment phase.

Cambodia

The results of a pre-feasibility study on the development of an MBT in Cambodia that combines RDF production with AD to self-power the plant showed that it is a feasible option for sustainable management of MSW in Phnom Penh. Electricity generation from AD was considered due to the high price of electricity in Cambodia. The study assumed that the plant would be operating with a capacity of 1,100 tons of waste per day. Results show that for a projected concession period of 30 years, the project will cost close to US$20 million with an RDF output of 500 tons per day over 288 days of running time, resulting in an equity IRR to the tune of 12–19%. Locating the plant at the current landfill site will also enable the process of mining the most combustible legacy waste, which in turn, will improve the overall RDF output rate. The business model foresees sales of RDF to cement factories while additionally generating revenues from gate-fee collection. The technical and economic breakdown of the pre-feasibility study is presented in Table 2.

Lao PDR

In Lao PDR, GGGI conducted a pre-feasibility study on the development of an MBT that combines RDF production and open windrow composting. The project assumed that at peak capacity, the plant will process 700 tons of unsegregated MSW including up to 200 tons of old waste mined from the landfill during the first ten years. The business model which combines sales of RDF, compost, and gate-fee collection has an indicative financial viability of both project and equity IRRs in the 13–19% range under the condition that the final products are sold at the estimated market prices. The aerobic treatment offers a sustainable waste management strategy that combines waste stabilization and nutrients recovery into composting. The separated organic fraction from the MBT plants will be combined with other source separated organic wastes, including drier garden and agriculture wastes, for composting. It is worth noting that about 80% of the population in Lao PDR lives in rural areas and most are subsistence farmers engaged in agriculture[24], so the compost produced from organic waste could be utilized for soil improvement. The study results show that, assuming a 25% conversion rate, 200 TPD of organic waste will yield up to 50 TPD of compost.

A high level of source separated organics input will be important to achieve a good quality compost product to balance out potential contamination within the organic waste processed through the mechanical sorting process. Compost that is too contaminated for agricultural lands can be used for the rehabilitation of damaged soils[25]. MBT is considered very cost-effective for Lao PDR because compared to other MSW treatment technologies, MBT requires a gate fee of around US$2–US$5 per ton, compared to US$15 per ton and US$20 per ton for controlled landfill and W2E respectively[26].

For both Cambodia and Lao PDR projects, it is preferable to select a semiautomated plant to keep the investment cost down and retain jobs for the informal waste pickers at the landfill sites. Typically, 35% of MSW is turned into RDF and the percentage of RDF can be increased by adding waste mined from the landfill and possibly drier industrial waste (IW) such as textiles. Up to 5% can be recovered for recycling and around 30% residue is returned to landfills (too heavy and too light fractions, inert materials, and hazardous materials). It should be noted that due to the large-scale waste input needed for financial viability, such projects are currently only limited to Phnom Penh in Cambodia and Vientiane in Lao PDR.

Table 2. Technical and economic breakdown of MBT plants in Cambodia and Lao PDR

Component	Description	
	Cambodia[27]	Lao PDR[28]
Designed capacity	1,100 TPD input	700 TPD input
RDF-to-MSW ratio	46% (fresh MSW, landfill mining, or IW input)	39% (fresh MSW, landfill mining, or IW input)
Technology	Semiautomated and AD self-powered RDF plant	Semiautomated RDF plant and open windrow composting
RDF market price	US$25/ton	US$30/ton
Coal market price (in early 2020)	US$80/ton	US$90/ton
RDF-to-coal caloric ratio	3,000/5,500 or 1/2	3,000/5,500 or 1/2
RDF-to-coal ratio (based on CV)	20/80	20/80
Organic fertilizer market price	NA	US$200–US$270
Organic compost market price	NA	US$170
Investment size (excl. land)	US$19.62 million	US$15.07 million
Capital structure	70/30 debt/equity	70/30 debt/equity
Gate fee	US$5/ton (based on 1,100 TPD input)	US$4.4/ton applied to 40% of the waste disposed
Project IRR	c. 12.54%	c. 13.30%
Equity IRR	c. 18.93%	c. 19.50%

Vietnam

Waste incineration with energy recovery had earlier been practiced in Vietnam to treat hazardous waste in hospitals and this approach can deliver benefits in terms of peoples' safety in times of the COVID-19 pandemic, especially in the absence of enforcement measures for disposal of testing devices. It should also be noted that incineration is getting to be a more attractive option for waste disposal for many city authorities[29]. The provision of Decision 491/QD-TTg dated May 7, 2018, that aims to significantly reduce MSW landfilling by applying incineration as well as other waste treatment solutions encouraged the development of more W2E facilities[30]. In terms of those capable of offtake, EVN remains the sole buyer who has the responsibility to acquire 100% of electricity generated from W2E projects. In order to support the existing efforts made by the government of Vietnam, GGGI supported a US$60 million W2E project in Bac Ninh province with a treatment capacity of 500 TPD of waste which reached financial closure in 2021. The technology is a viable option for MSW management in Vietnam thanks to enabling policy mechanisms in the country such as the available FIT for W2E projects and the high gate fees. This project is considered to be technically and financially viable and has attracted investment from the private sector and Development Finance Institutions (DFI). Building on this success, additional support for local developers and financiers are needed to catalyze investments in W2E.

Table 3. Technical and economic breakdown of W2E plant in Bac Ninh province in Vietnam[31]

Component	Description
Designed capacity	500 TPD (input), 10 MWe (output)
Technology	MSW to RDF technology and Circulating Fluidized Boiler
Investment size	US$60 million
Indicative capital structure	65/35 debt/equity
Applicable gate fee	US$20/ton (based on 500 TPD input)
Applicable FIT	US$10.05 cents/kWh
Expected operation days	350 days per year
Expected project IRR	c. 13%

2.2 Potential benefits and environmental and social impacts

2.2.1 Environmental benefits, including GHG reduction

These projects bring many environmental benefits, especially due to the current lack of environmental controls at the landfills. Diverting MSW away from landfills reduces the risk of groundwater and surface water contamination with landfill leachate. It also reduces the risk of landfill fires during the hot season, which emit toxic fumes and oils. These landfills also create odors and attract vermin and mosquitoes, which affects local communities and the health of the populations in these communities.

These projects also offer a solution for mitigating GHGs emissions, mostly methane released from the decaying organic waste under anaerobic conductions. For example, the study "Mass balance to assess the efficiency of a mechanical–biological treatment"[17] investigated GHG emissions from an MBT plant and concluded that, adopting MBT has the potential to cut down GHG emissions (primarily from landfill gas avoidance) by 287 kg of CO_2e and 764 kg CO_2e per ton of waste as compared to open dumping and traditional landfilling, respectively.

Also, compost applied to soil has long-term potential to mitigate GHG. It is estimated that about up to 79 kg CO_2e is saved per ton of composted waste applied to land[32]. In addition, compared to open dumping, RDF, composting, or incineration helps to reduce odor and the accumulation of flies which can be a media for many diseases.

BOX 2: Climate rationale for LSWTP according to NDC

- Cambodia: Considering business-as-usual (BAU) emissions without forestry and other land use, the waste sector would contribute 3.3 $MtCO_2$e (4.1%) emissions by 2030. However, the development of modern MSW treatment facilities as outlined in the Nationally Determined Contribution (NDC) scenario would reduce 0.6 $MtCO_2$e by 2030, that is about an 18% decrease in the country's GHG emissions. The establishment of the MBT project at the 1,100 TPD scale is included in the NDC[33].
- Lao PDR: According to the updated NDC, in 2020, Lao PDR reached around 82 $MtCO_2$e of GHG emitted which would be expected to reach 104 $MtCO_2$e in 2030 under a BAU scenario. The MBT project is included in the NDC conditional scenario, aiming to mitigate a minimum of 40 $ktCO_2$e on average per year[34].
- Vietnam: The BAU emissions for the waste sector is projected at 46.3 $MtCO_2$e by 2030. With domestic resources mobilized for modern waste treatment facilities by 2030, the waste sector is expected to reduce 9.1 million tons of CO_2e, about 19.7% of the BAU scenario. Also, with international support as well as through the implementation of new mechanisms under the Paris Agreement (2015), there is potential for a reduction of 33.2 million tons of CO_2e, approximately 71.7% compared to the BAU scenario[35].

2.2.2 Job creation

Such projects have the potential to provide positive socioeconomic benefits in the form of employment opportunities, depending on the size of the facility. Both unskilled and professional opportunities would be created. In Cambodia and Lao PDR for instance, these have been estimated at up to 50 new positions per facility. According to the study "Mechanical Biological Treatment of Municipal Solid Waste"[36] about eight direct jobs would be created for an MBT plant of 50,000 tons per annum (TPA) capacity, 40 for a 265,000TPA plant, and 85 for a 417,000TPA plant, without mentioning other positions that would be created along the waste management chain from collection, storage, and transportation. The development of more RE facilities could help Southeast Asia meet about 41% of all its energy needs by 2030 and create an additional 6.7 million green jobs by 2050. Typical employment for an incineration plant of 50,000TPA capacity would be up to 8 direct positions[37]. Many other jobs would be created during the stages of structuring, designing, and construction of W2E plants.

2.2.3 Security of energy supply

W2E can contribute to energy security by diversifying the energy mix. Ensuring a reliable supply of energy is an important priority in developing W2E markets and this can be guaranteed by sustainable energy infrastructures and national polices. In the case of W2E projects, the power system also needs to be large enough to meet the energy demand of the potential customers. Vietnam has made significant improvements in its energy infrastructure with just about 9% of energy lost along the transmission and distribution line[32]. This impressive statistic assures that energy generated would reach different end-user sectors.

Security of supply of fuel is also important for cement manufacturers, especially if they rely on imported coal. Securing offtake of good quality RDF can help mitigate this fluctuation risk associated with coal.

CHAPTER

03

IMPLEMENTATION CHALLENGES AND RISK MANAGEMENT

3.1 Access to waste feedstock supply

As waste collection services are generally fragmented, with the involvement of both public and private sectors, it is important that the relevant government agencies take the lead on streamlining access to waste. In addition to access required for daily quantities, some basic improvements in feedstock management through source separation mechanism being put in place should be considered in order to produce a good quality final product, while meeting the targeted revenue generation from sales of this final product. Source separation at the household level is commonly challenging in developing nations and requires a longer-term approach. Targeting specific sectors that generate high levels of organic waste, such as markets, restaurants, agro-processing businesses, and industries producing waste of high calorific value such as textile, can be impactful.

Waste collection in Vietnam is also managed by small private companies that can sign a contract with the waste treatment company to secure a given quantity of feedstock. In addition, the introduction of an incentive framework as a dominant tool to promote the supply of feedstock can play a significant role in feedstock management. These systems for waste collection have already paved the way for LSWTP as they can be used to mitigate waste supply chain associated risks.

3.2 Long-term offtake agreements with cement plants

While electricity offtake is secured in Vietnam, the long-term involvement of product offtake in Cambodia and Lao PDR within a reasonable distance is critical for the sustainable operation of the plant, especially for RDF. While cement multinationals with experience in RDF are present in Cambodia, Lao PDR has a more challenging environment, with the plants located closest to Vientiane having no track record in alternative fuel use. The case from Thailand was benchmarked to present the calorific value and the market price of RDF. The lower price of RDF in comparison to coal is an attractive factor for cement factories however, consistent supply of feedstock, impact on cement quality, and air emissions need to be carefully controlled. Some cement plants will also need equipment upgrades with a reasonable pay-back period in order to use RDF efficiently.

3.3 Business model development challenges

A challenge facing the implementation of LSWM facilities in the Mekong region is the lack of experience of local stakeholders in MSW projects, in particular developers and financiers (commercial banks). Such stakeholders are pivotal to the scaling-up of LSWM facilities, both in the country and regional contexts. LSWM projects are capital intensive, and their returns are long term, which requires that financiers be knowledgeable with the pricing, terms, and conditions for such projects. In addition, the traditional method of treating waste in the region has been landfilling[38]. These methods do not provide attractive financial returns and financiers have learned over time to shy away from waste management-related projects. It also created a lack of experienced local project developers. Therefore, this requires strong support and technology transfer to build up the capacity of local developers to ensure the sustainable operation of the LSWM projects. Likewise, local commercial banks are also lacking in experience for assessing LSWM projects, given the lack of demonstration projects for reference in the region. As a result, this situation hinders the confidence of local/international financiers in financing LSWM projects and raises an urgent need for blended finance. As the government of Vietnam is engaged to actively create an enabling framework that would incentivize investments in LSWM facilities, a growing opportunity for developers and financiers to invest in such projects is rising.

CHAPTER

04

FINANCING OPTIONS

The management of MSW is an essential public service. In lower-middle income countries such as Cambodia, Lao PDR, and Vietnam, the public is often apathetic about waste management, and they are not inclined to make regular payments for waste collection services. Greater expenditure is needed to encourage a paradigm shift in public attitudes. The more perceived social benefits that are evident to the public regarding sustainable waste management, the more likely attitudes will change. In this section, three possible financing options are discussed.

4.1 Blended financing to de-risk private sector investment

In Vietnam, the lending interest rate applied by commercial banks ranges from 7–11%. With over 30 commercial banks operating in the country, commercial finance is a vital source for project developers to mobilize finance for their projects. In obtaining these commercial loans, additional collaterals may typically be required to secure funding from commercial banks. With funding sources leveraged from international DFIs through on-lending programs, Vietnam's local commercial banks have recently made concrete steps in financing project developers in green infrastructure. Accordingly, projects that have environmental benefits can also be eligible to access these lending facilities with more preferential terms.

Cambodia's Ministry of Economy and Finance set the market interest rates for 2020 loans based on an average of the interest rates set by Cambodia's eight commercial banks: 8.92% for KHR-denominated loans and 8.45% for US$-denominated loans. In case of Lao PDR, the interest rate for project financing marks at 4%[39] for the government approved projects, which is lower than the average interest rate of 6.69% from 1992 to 2021[40].

The GGGI supported projects in Lao PDR and Cambodia show a debt/equity split of 70%/30%. In Vietnam, regarding MSWTE power plants, the private sector appetite is more acute, GGGI supported the project developer on financial structuring for the W2E project in Bac Ninh province, of which 35% equity commitment comes directly from the investors. Such commercial finance resources can be leveraged through available climate finance under the blended finance mechanisms to de-risk the project or more broadly enhance its bankability.

Solid waste management is an area in which private investments could have a transformational impact, however the sector is often considered too risky by private investors. Blended finance has emerged as a tool for reducing risks and promoting private investments in LSWM facilities. Blended finance combines concessional financing, loans that are extended on more generous terms than market loans, and commercial funding[41]. It is an approach that helps to get projects off the ground. In the context of LSWM facilities, blended finance can help reduce associated risk borne by private stakeholders, as well as encourage developers and financiers to invest in a sector in which they have limited experience in. Accordingly, blended finance for private sector projects is fast becoming one of the most transformative tools that development finance institutions can use, in cooperation with development partners, to mitigate risks and to help mobilize private investment in LSWM facilities[42].

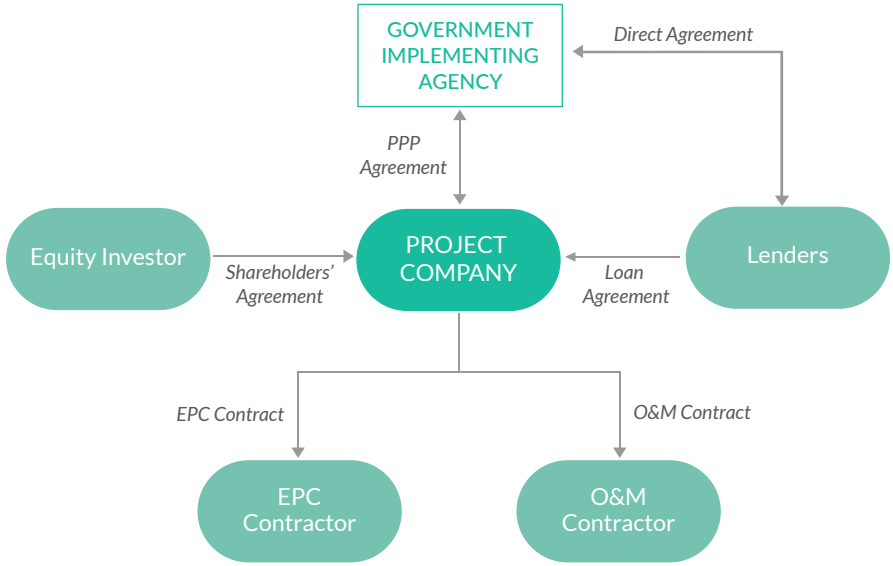
GGGI's contribution in terms of transaction advisory and facilitation play a vital role in utilizing available public and climate finance to leverage private sector investment through the blended finance mechanism.

4.2 Public private partnerships with municipalities

Most developing countries have limited technical and financial capacity to develop and operate LSWM facilities. Well-structured and commissioned projects can mobilize financial and technical resources from the private sector seeking new and bankable investment opportunities. Public-private partnerships (PPPs) are mechanisms for government to procure and implement public infrastructure and/or services using the resources and expertise of the private sector. The most common PPP models practiced around the world include build–own–operate–transfer (BOOT) model; build–own–operate (BOO) model; and build–own–transfer (BOT) model[43]. Cambodia, Lao PDR, and Vietnam have implemented several infrastructure projects via the PPP finance model. In Cambodia, projects via PPP have been implemented since 1993 mostly in the energy sector using BOT and BOO models[44]. The government of Lao PDR however has a long-term vision to establish PPPs as a regular procurement mechanism to be used by all government agencies[45]. Vietnam has implemented several power projects under Asian Development Bank (ADB) technical assistance with PPP content, and ADB private sector PPP portfolios. In 2018, the ADB signed a US$100 million loan facility agreement with China Everbright International Limited to develop the first W2E PPP project in Vietnam[46].

A schematic diagram of a typical PPP structure is presented in Figure 4 below.

Figure 4. Schematic layout of PPP structure[47]



4.3 Climate finance

Landfills are major emitters of GHG in the waste sector, especially of methane, which is 28 times more potent to climate change than carbon dioxide[48]. These emissions can be greatly reduced by diverting the waste towards LSWM facilities. Climate finance can support mitigation actions that result in environmental and socioeconomic benefits[49]. There are different types of financial instruments that could be sought through climate finance to improve LSWM practices and deliver climate mitigation. Those include equity, guarantees, loans, and grants.

Equity investments can act as a catalyst because of their ability to support early and growth-stage businesses that would otherwise not be able to take on debt. Direct equity could also allow investees to scale operations more efficiently to achieve a greater sustainable development impact. Equity enables the de-risking of partner investments and can be a good source of incremental finance when commercial debt provision is still shallow for MBTs like in the case of Cambodia and Lao PDR.

Concessional loans from climate finance institutions could be blended with local commercial loans to share the risk, catalyze the private investment, and achieve a better cost of capital for project financing. Highly concessional loans could help scale-up LSWM projects in the three Mekong River countries, though there is a consensus that far too much climate finance coming from governments and development finance institutions is in the form of loans. According to the OECD report "Climate Finance Provided and Mobilized by Developed Countries," by 2018 loans represented 74% (US$46.3 billion) of public climate finance, up from US$19.8 billion in 2013. Grants represented just 20% (US$12.3 billion) of public climate finance.

Grants can help transaction advisory and capacity building around LSWM projects. For LSWM projects to be successful in Cambodia, Lao PDR, and Vietnam, support will be needed from climate finance flows either as public grants without repayment contingencies or through technical assistance improving advisory and de-risking efforts. In Vietnam, GGGI provided financial advisory on a pro-bono basis to support a private sector developer to successfully obtain funding for the W2E project. The financial advisory from an international organization helped local developers design an appropriate financial structure to reduce the risk and access to sources of finance. In Lao PDR, GGGI is seeking grant support from international climate funds to lower the private sector investment risks associated with product offtake.

Carbon market (Voluntary or bilateral) based on Article 6 of the Paris Agreement (2015) also provides an opportunity for financing LSWM projects. Some pre-requisites however would be carbon credit pricing as well as the development of frameworks through which these impacts can be generated. For the Lao PDR project, this could create an additional annual revenue of US$760,000–US$950,000, if selling carbon credits at the price of US$20–25 per ton.

Programmatic blending of climate finance with municipal co-financing is a promising financing option. Individual projects can often have a high transaction cost and can be complex in nature. Aggregation of projects through a programmatic approach that builds on local ownership will provide an opportunity for action at scale while being more sustainable.

Finally, the strategic use of climate finance can also include *credit guarantees* and *subordinated debt* that can buffer potential losses for senior lenders by lowering the number of senior claims on assets. An additional credit guarantee enables the domestic banks to share risks and support projects. It also opens a door for project developers to receive softer loans on non-recourse terms.

CHAPTER

05

CONCLUSIONS AND RECOMMENDATIONS

This technical report demonstrates that LSWM facilities can be financially viable in the big cities of Cambodia, Lao PDR, and Vietnam, with private sector involvement. The deployment of such infrastructure requires clear enabling government policies and incentives. Vietnam is one step ahead with an enabling framework such as landfill gate fees, FIT, and clear electricity offtake options, which resulted in financial closure for the W2E project in Bac Ninh province, with technical support from GGGI. The country also offers incentives such as tax holidays, exemption of import duties for equipment, and land rent exemptions.

While there is support for MBT type facilities in Cambodia and Lao PDR as outlined in the NDCs, implementation mechanisms and roles and responsibilities could be further clarified. Incentives are also offered by these two countries, but often on a case-by-case basis instead of being made publicly available, which may attract further interest from international developers and financiers.

Good quality feedstock ensures high prices of the by-products of MBT plants while lowering the operational cost. Setting up basic source separation systems is often neglected in developing large waste treatment facilities, but can have a meaningful impact in lowering operational costs and increasing product quality. Waste collection services are often privatized, and strong government leadership to secure good quality waste feedstock is required. For these facilities to materialize, the provision of land concessions from the government to establish the MBT plants is also important.

The general lack of landfill gate fees and low or the total absence of a FIT are barriers both in Cambodia and Lao PDR. It is an important tool, not only to improve financial viability of LSWM projects as they can charge similar or slightly lower rates, but also to ensure appropriate landfill Operation and Management (O&M). In Vietnam, the pricing difference for gate fees in each province (US$12–US$22 per ton)[39] still makes it difficult for some regions to develop bankable W2E projects. An increase to a uniform gate fee of US$20 per ton would pave the way for further investments for large waste treatment infrastructure. The Ministry of Construction (MoC) regulates a ceiling price for the gate fee with provisions for incineration, though investors can work with provinces and the relevant provincial government can ask the MoC for approval in increasing the gate fee.

The risk perception of domestic banks is a barrier that has impeded investments in LSWM projects in the region. Therefore, there is an urgent need for capacity building and more targeted advisory services in designing bankable integrated MSW projects that are replicable. Projects can also leverage blended finance mechanisms to unlock access to domestic finance and mitigate risks, for example, by setting up a financing facility to enhance best practice and scalability of the sector. With the climate mitigation impact derived from organic waste processing, climate finance resources should be pursued, including selling carbon credits.

This report demonstrates that LSWM facilities can be financially viable in the big cities of Cambodia, Lao PDR, and Vietnam, with private sector involvement.

REFERENCES

1 Asian Development Bank. (2019). Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map. Retrieved from https://www.adb.org/sites/default/files/institutional-document/547396/lao-pdr-energy-assessment-2019.pdf

2 World Bank. (2019, September 23). *Solid Waste Management.* Retrieved from https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

3 World Bank. What a Waste 2.0: A global snapshot of solid waste management to 2050. Retrieved from https://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html

4 Hoornweg, D., and Bhada-tada, P. (2012). What a Waste: A Global Review of Solid Waste Management. Retrieved from https://openknowledge.worldbank.org/handle/10986/17388

5 Tun, M.M., Palacky, P., Juchelkova, D., and Sitar, V. (2020). Renewable Waste-to-Energy in Southeast Asia: Status, Challenges, Opportunities, and Selection of Waste-to-Energy Technologies. Applied Science 10(20), 7312. https://doi.org/10.3390/app10207312

6 Castaldi, M., van Deventer, J., Lavoie, J. M., Legrand, J., Nzihou, A., Pontikes, Y., Py, X., Vandecasteele, C., Vasudevan, P.T. and Verstraete, W. (2017). Progress and Prospects in the Field of Biomass and Waste to Energy and Added-Value Materials. *Waste Biomass Valorization*, 8, 1875–1884. https://doi.org/10.1007/s12649-017-0049-0

7 Kingdom of Cambodia. National Council for Sustainable Development & Ministry of Environment. (2020). *First biannual update report of the Kingdom of Cambodia to the United Nations Framework Convention Climate Change.* Retrieved from https://ncsd.moe.gov.kh/resources/document/cambodia%E2%80%99s-1st-BUR

8 GIZ. (2019). Partnership Ready Cambodia: Waste management. Retrieved from https://www.giz.de/en/downloads/GBN_Sector Brief_Kambodscha_Waste_E_WEB.pdf

9 Global Green Growth Institute. (2020). Large-scale Management of Unsegregated Municipal Solid Waste in Phnom Penh: A Cost Comparison of Three Options. Retrieved from https://gggi.org/report/large-scale-management-of-unsegregated-municipal-solid-waste-in-phnom-penh-a-cost-comparison-of-three-options/

10 Seng, B., Kaneko, H., Hirayama, K., and Katayama-Hirayama, K. (2011). Municipal solid waste management in Phnom Penh, capital city of Cambodia. *Waste Management & Research*, 29(5), 491–500. https://doi.org/10.1177/0734242X10380994

11 Global Green Growth Institute. (2021). Sustainable Solid Waste Management Strategy and Action Plan for Vientiane 2021–2030.

12 Climate and Clean Air Coalition Municipal Solid Waste Initiative. (n.d.). Solid Waste Management City Profile: Vientiane Capital, LAO People's Democratic Republic. Retrieved from https://www.waste.ccacoalition.org/sites/default/files/files/vientiane-_city_profile_vientiane_capital_lao.pdf

13 Schneider, P., Anh, L.H., Wagner, J., Reichenbach, J., and Hebner, A. (2017). Solid Waste Management in Ho Chi Minh City, Vietnam: Moving towards a Circular Economy? *Sustainability*, 9(2), 1–20. https://doi.org/10.3390/su9020286

14 Socialist Republic of Vietnam. Ministry of Natural Resources and Environment. (2019). *National Environment Report 2019*. Retrieved from http://vea.gov.vn/detail?$id=1026

15 Yim, M., Fujiwara, T. and Sour, S. (2014). A Study of Commercial Solid Waste Generation and Composition in Phnom Penh City, CAMBODIA. *Journal of Natural Sciences Research*, 4(13), 49–54.

16 Luong, N.D., Giang, H.M., Thanh, B.X. and Hung, N.T. (2013). Challenges for municipal solid waste management practices in Vietnam. *Waste Technology*, 1(1), 6–9.

17 De Araújo Morais, J., Ducom, G., Achour, F., Rouez, M. and Bayard, R. (2007). Mass balance to assess the efficiency of a mechanical–biological treatment. *Waste Management*, 28(10), 1791–1800.

18 Habib, M.A., Ahmed, M.M., Aziz, M., Beg, M.R.A. Hoque, M.E. (2021). Municipal solid waste management and waste-to-energy potential from Rajshahi City Corporation in Bangladesh. *Applied Science*, 11(9). https://doi.org/10.3390/app11093744

19 Rezaei, H., Panah, F. Y., Lim, C. J and Sokhansanj, S. (2020). Pelletization of refuse-derived fuel with varying compositions of plastic, paper, organic and wood. *Sustainability*, 12(11), 1–11. https://doi.org/10.3390/su12114645

20 Zhu, J. and Chou, M. (1997). A Review of Emerging Techniques on Generation Expansion Planning. *IEEE Transactions on Power Systems*, 12(4), 1722–1728.

21 EVN - Vietnam Electricity Corporation. (2019, February 25). Adding garbage to power projects to the National Electricity Development Plan. [Press release]. https://www.evn.com.vn/d6/news/Bo-sung-2-du-an-dien-rac-vao-Quy-hoach-phat-trien-Dien-luc-Quoc-gia-141-17-23184.aspx

22 Alam, Q. (2019). *Valorization of municipal solid waste incineration bottom ash – Chemical nature, leachability and treatments of hazardous elements* [Doctoral dissertation, Eindhoven University of Technology]. Eindhoven University of Technology. https://pure.tue.nl/ws/files/137826988/20191105_Alam.pdf

23 Kim, S. and Fakhry, J. (2021) Challenges and opportunities with Mechanical biological treatment (MBT) facility: Case from Lao PDR, 2021. Unpublished manuscript.

24 Food and Agriculture Organization. (n.d.). *Laos at a glance.* Retrieved from http://www.fao.org/laos/fao-in-laos/laos-at-a-glance/en/

25 Farrell, M. and Jones, D.L. (2009). Critical evaluation of municipal solid waste composting and potential compost markets. *Bioresource Technology*, 100(19), 4301–4310.

26 World Bank. (2018). *Solid and industrial hazardous waste management assessment: options and action area to implement the national strategy.* Retrieved from https://documents1.worldbank.org/curated/en/352371563196189492/pdf/Solid-and-industrial-hazardous-waste-management-assessment-options-and-actions-areas.pdf

27 Global Green Growth Institute (2021). Investment opportunity: Municipal Solid Waste to Fuel in Phnom Penh. Unpublished report.

28 Global Green Growth Institute (2021). Pre-feasibility Study Report: Mechanical and biological treatment facility investment in Vientiane, Lao PDR. Unpublished report.

29 Hoang, M. G., Fujiwara, T. and Pham Phu, S., T. (2017). Municipal waste generation and composition in a tourist city - Hoi An, Vietnam. *Journal of Japanese Society of Civil Engineers*, 5(1), 123–132.

30 Government of Vietnam. Prime Minister Office. (2009). Decision on approving the National Strategy of Integrated Solid Waste Management up to 2025, vision towards 2050. Retrieved from https://www.uncrd.or.jp/content/documents/PM%20Decision%20of%20Approval%20of%20NSISWM%20(Eng).pdf

31 Global Green Growth Institute (2019). Municipal solid waste to energy: Vietnam market overview. Unpublished report.

32 Boldrin, A., Andersen, J. K., Møller, J., Christensen, T. H. and Favoino, E. (2009) Composting and compost utilization: accounting of greenhouse gases and global warming contributions. *Waste Management Research*, 27(8), 800–812.

33 Kingdom of Cambodia. National Council for Sustainable Development & Ministry of Environment. (2020). Cambodia's Updated Nationally Determined Contribution (NDC). Retrieved from https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Cambodia%20First/20201231_NDC_Update_Cambodia.pdf

34 Lao People's Democratic Republic. (2021). Nationally Determined Contribution (NDC). Retrieved from https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Lao%20People%27s%20Democratic%20Republic%20First/NDC%202020%20of%20Lao%20PDR%20(English),%2009%20April%202021%20(1).pdf

35 Socialist Republic of Vietnam. (2020). Updated Nationally Determined Contribution (NDC). Retrieved from https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Viet%20Nam%20First/Viet%20Nam_NDC_2020_Eng.pdf

36 United Kingdom. Department for Environment, Food & Rural Affairs. (2013). Mechanical Biological Treatment of Municipal Solid Waste. Retrieved from https://www.gov.uk/government/publications/mechanical-biological-treatment-of-municipal-solid-waste.

37 United Kingdom. Department for Environment, Food & Rural Affairs. (2013). Incineration of Municipal Solid Waste. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221036/pb13889-incineration-municipal-waste.pdf

38 Climate Bonds Initiative. (2020). Green Infrastructure Investment Opportunities: Vietnam 2019 Report. Retrieved from https://www.climatebonds.net/files/reports/final_english_giio_vietnam_report.pdf

39 CEIC Data. (n.d.). Laos lending rate: Bank of the Lao PDR [Data file]. Retrieved from https://www.ceicdata.com/en/laos/lending-rate-annual/lending-rate-bank-of-the-lao-pdr

40 Trading Economics. (n.d.). *Laos Interest rate* [Data file]. Retrieved from https://tradingeconomics.com/laos/interest-rate

41 World Bank. (2020, January 27). What is blended finance, and how can it help deliver successful high-impact, high-risk projects? Retrieved from https://ieg.worldbankgroup.org/blog/what-blended-finance-and-how-can-it-help-deliver-successful-high-impact-high-risk-projects

42 International Finance Corporation. (n.d.). Blended Concessional Finance. Retrieved from https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/bf

43 Asian Development Bank. (2015). Business Models to Realize the Potential of Renewable Energy and Energy Efficiency in the Greater Mekong Subregion. Retrieved from https://www.adb.org/sites/default/files/publication/161889/business-models-renewable-energy-gms.pdf

44 Sar, B., Chea, M. and Ung, C. (2020). Public-Private Partnerships in Cambodia: Issues and Solution. *Open Journal of Business and Management*, 8, 1216–1225.

45 Asian Development Bank. (2018). Lao PDR Public-Private Partnership Policy. Retrieved from https://www.adb.org/sites/default/files/linked-documents/46059-002-sd-06.pdf

46 Asian Development Bank. (2018, February). ADB, China Everbright International Facilitate Clean Waste-to-Energy PPP in Viet Nam. Retrieved from https://www.adb.org/news/adb-china-everbright-international-facilitate-clean-waste-energy-ppp-viet-nam

47 World Bank, Asian Development Bank, Inter-American Development Bank. (2014). *Public-Private Partnerships Reference Guide Version 2.0.* Retrieved from https://documents1.worldbank.org/curated/en/600511468336720455/pdf/903840PPP0Refe0Box385311B000PUBLIC0.pdf

48 Saunois, M et al. (2020). The global methane budget 2000–2017. *Earth System Science Data*, 12(3), 1561–1623. https://doi.org/10.5194/essd-12-1561-2020

49 United Nations Framework Convention on Climate Change. (n.d.). Introduction to Climate Finance. Retrieved from https://unfccc.int/topics/climate-finance/the-big-picture/introduction-to-climate-finance

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