A Thermal Waste-to-Energy facility for Banteay Meanchey, Siem Reap and Battambang, Cambodia

Project description

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Contents

Glossary

WtE	Waste to Energy installation or facility
WTS	Waste Transfer Station
MSW	Municipal Solid Waste
AC	Activated Carbon
BAT	Best Available Technology
GHG	Green House Gas
Capex	Capital Expenses
Opex	Operational Expenses
FIT	Feed-in Tariff
PPA	Power Purchase Agreement
BOT	Build, Operate, Transfer
LCOE	Levelized Cost of Electricity
PV	Photovoltaic cells for solar power

1. Project Summary

UNCDF is anticipating to provide financing for a WtE initiative in Cambodia in the provinces of Banteay Meanchey, Siem Reap and Battambang in the Northwest of Cambodia. The facility will have to serve four goals: (i) to reduce waste volumes that have to be landfilled, (ii) to reduce related GHG emissions, (iii) to contribute to the country's electricity production and (iv) to contribute to the workforce in the region.

The project will consist of two transfer facilities and a central treatment facility comprising a reception station, pre-treatment, a furnace, boiler and turbine/generator and post-treatment of residues. Organics, separated in the pre-treatment, will be transported for bio-stabilization to the landfill. The overall capacity will be 215.000 tons of waste per year of which 6.000 tons eventually will be landfilled. The project will produce an annual output of 85.000 MWh of electricity, 4.000 tons of recyclable metals, 30.000 tons of re-usable slags and 20.000 tons of landfill coverage material.

Land-use is estimated at 30.000 m^2 for the WtE facility, 10,000 m^2 for the Transfer Stations and 10.000 m^2 for the Stabilization facility. Operations will need a workforce of 100 employees and an additional 250.000 in case stabilization is performed manually.

Implementing the project will lead to a reduction of landfill use of 97%. When compared to open dumping a reduction of CO_2 emissions of 45% can be expected. Compared to sanitary landfilling CO_2 emissions are reduced by 20%.

The project planning shows a 5-year period for preparations and constructions.

Financial feasibility of the project will be reached at a gate-fee above $10 per ton of waste in combination with a FIT above $0,10 per kWh.

This report describes the project in more detail. It provides preliminary input on project configuration, basic design, site layout, material flows, needed workforce, prevented GHG emissions and planning. The chapters of this report will follow this order of items.

2. Project configuration

a. Project region and site

The WtE facility will serve the three provinces as indicated in the map below. It will be located at the site of projected new landfill near Poi Pet. The waste will primarily come from the urban centers in these provinces and especially from the cities of Poi Pet, Battambang and Siem Reap. Waste from the collection routes in urban centers in Banteay Meanchey will directly be delivered at the site. Waste from the urban centers in Siem Reap and Battambang will be directed to the WtE via two waste transfer stations (WTS). Both will be located near the urban concentrations of the cities of Siem Reap and Battambang. Transport to the WtE facility will follow the highways 5 and 6 to Poi Pet.

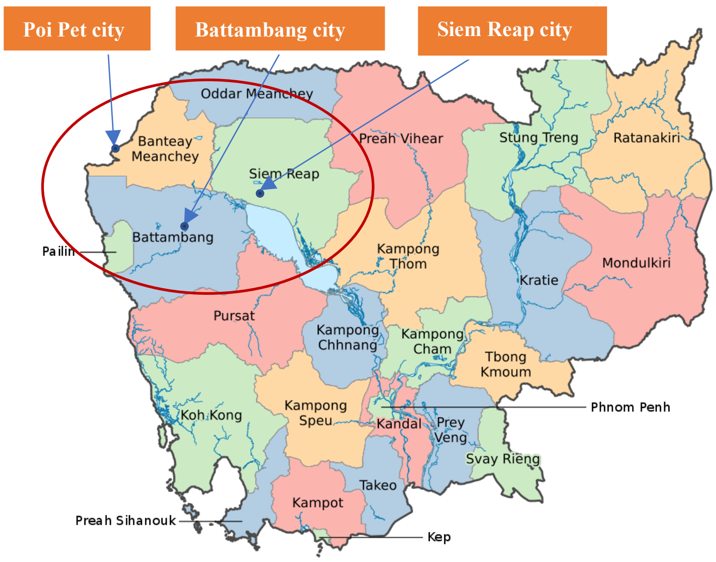


Fig. 1 Provincial Map of Cambodia

The project site is located west of Poi Pet. Accessibility from Highway 5 is good with the exception of the last part which would need investments in paved roads for 5 km and powerlines for 5 km. The site measures 20 hectares and provides ample space for siting the WtE.

Fig. 2 Areal view of the project site

b. Waste types, quantities and qualities

Waste will primarily consist of municipal solid waste (MSW) comprising household waste and similar waste from markets, parks, tourist sector, small businesses, shops, institutions, restaurants, hotels etc. Eventually, acceptable fractions of industrial and construction/demolition waste will also be allowed for treatment in the facility. At this moment it is assumed that feedstock waste will be provided by the three provinces in quantities as summarized in Table 1 (see Annex 1).
Waste from Banteay Meanchey will be delivered to the WtE site in collection vehicles and container trucks coming directly from collection routes and small agglomeration points. The average freight per vehicle will be around 3-5 tons. Waste from Battambang and Siem Reap will be delivered via the WTSs in bulk trucks with an average capacity of 15-20 tons.

Province	Tonnage per year	Number of freights per year	Max. number of freights per day
Banteay Meanchey	65.000	15.000	60
Battambang	65.000	4.000	16
Siem Reap	85.000	5.000	19
Total	215.000	24.000	95

Table 1. Provincial feedstock contributions and truck frequencies

The average composition and composition range of the waste to be received is given in Table 2 (see Annex 2). Based on this composition and an expected high moisture content of the waste, the calorific value for the feedstock in this report is set at an average of 7,5 MJ/kg and a minimum of 6 MJ/kg.

Component	Assumed composition	Assumed composition range
Organic waste	65%	55%-75%
Plastics	10%	8%-12%
Textiles	3%	1%-4%
Metals	3%	1%-4%
Paper/cardboard	5%	4%-7%
Rubber/leather	1%	0%-2%
Ceramics/stones	2%	1%-5%
Glass	4%	1%-5%
Other materials	7%	5%-10%
Total	100%	

Table 2. Assumed average composition

c. General system scope

The headlines of the general system lay-out can be summarized as follows:

- The system includes two upstream WTSs in order to facilitate optimization of waste collection and logistics.
- Because of uncertainty with regard to waste composition and calorific value, it is deemed beneficial to include a pre-treatment removing part of the organic contents in order to be able to raise the calorific value of the waste that will be fed to the furnace.
- Separated organics will be further treated through simple bio-stabilization. This treatment is included in the overall system. The product of the stabilization will be re-used on the landfill as daily cover material.
- The WtE facility will aim at electricity production and evacuation to the high-voltage power-network.
- Incineration residues will be recycled in road construction as much as possible.

The conceptual set-up of the system is given in Figure 3. The orange rectangles indicate operations that are part of the system's scope.

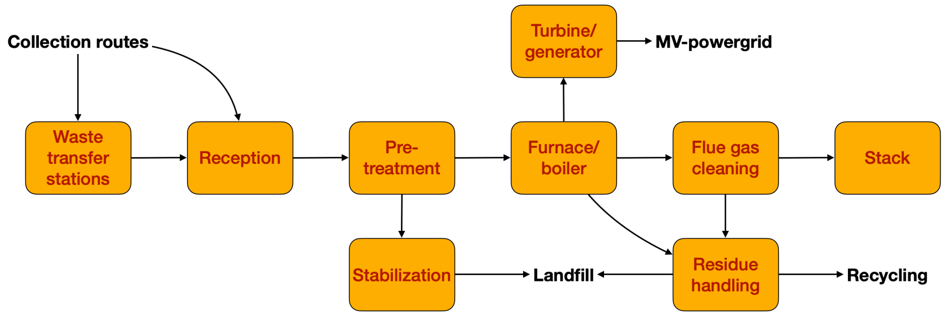


Fig. 4 Conceptual system set-up

3. Basic design

The basic design of the project is aiming at a certain flexibility in design allowing for future extension of capacity and changes in the waste composition. This flexibility may come from adjusting the pre-treatment process; a conversion that will not have strong impacts on Capex and Opex.
Extending the hot-lines (furnace/boiler/turbine/generator/cooling) of the process will be more impact-full. For this reason, the design prepares for a future doubling of this part of the WtE facility by already investing in land-use, infrastructure and bunker capacity.

a. Waste Transfer Stations

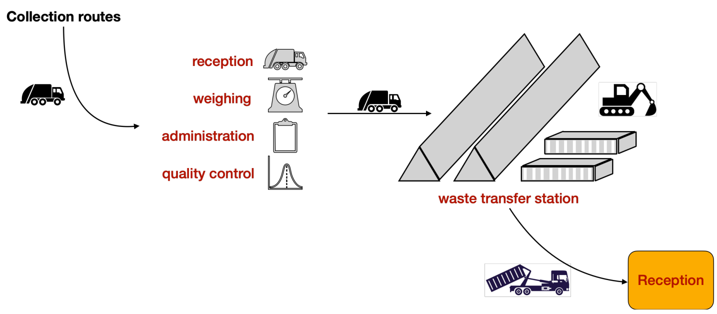


Fig.5 Schematic overview waste transfer station

- There will be two WTSs; one in Siem Reap and one in Battambang. The sites will be chosen at a later stage.
- The WTSs serve to accumulate and buffer waste coming from the collection routes. Waste will be transferred into bulk containers and picked up for transport to the WtE facility.
- The WTSs will be simple and flexible and will comprise a concrete or asphalt floor with water drained to one side and collected in a basin.
- Each WTS will have a weighing bridge, fencing and retaining walls constructed of modular concrete blocks. Both, ingoing and outgoing freights, will be weighed and administered.
- Incoming waste will be administered, weighed and checked and will then be dumped on the floor where a wheel-crane will take care of handling and loading of the containers.
- Operational hours to be decided by local authorities and may enable nocturnal and weekend operations.

Number of WTSs and locations	2, Siem Reap and Battambang
Storage capacity per WTS	300 tons
Area per WTS	5.000 m^2, outdoors.
Equipment per WTS	1 weighing bridge 60 tons. 1 wheel-crane. Containers and container-truck to be sourced out.
Employees per WTS	1 team-leader, 1 crane driver, 2 general workers

Table 3. Specifications WTS

b. Reception

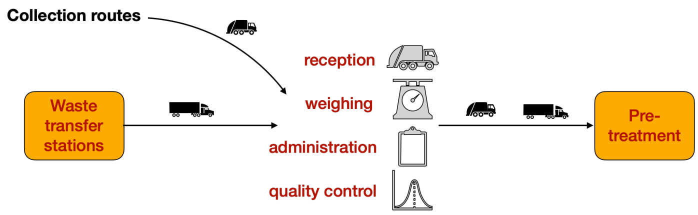


Fig.6 Schematic overview Reception

- The reception will be placed at the main entrance of the WtE site.
- It serves to provide the weighing, control and administration of all incoming and outgoing waste.
- It may be a combined facility, also serving other activities on or near the site (e.g. landfill)
- It will be equipped with entrance controls (gate/barriers), weighing bridges and an office which will also provide staff offices and employee accommodations
- After weighing, controls and administration the vehicles will be directed towards the pre-treatment reception floor.
- Both, ingoing and outgoing freights, will be weighed and administered.

Equipment	2 weighing bridges, 60 tons each
Area	1.500 m^2, outdoors
Office/accommodations floorspace	500 m^2
Operations	Per week: 6 days @ 14 hours per week
Employees	3 administrators

Table 4. Specifications Reception

c. Pre-Treatment

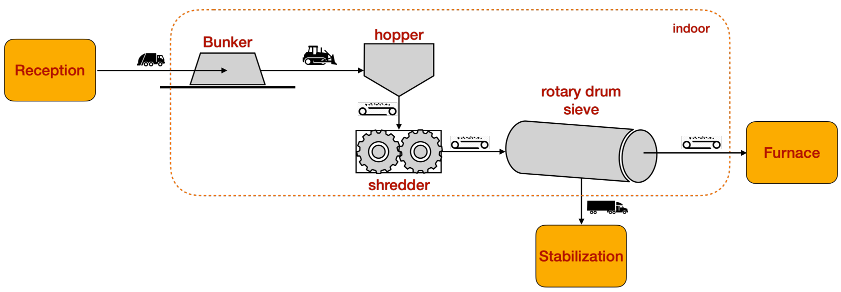


Fig.7 Schematic overview Pre-Treatment

- Pre-treatment will be performed indoor or in a roofed area.
- Waste will be tipped indoor at the bunker floor where it will be handled by a wheel-loader. Bulky, dangerous and/or obstructive components of the waste will be removed and set apart.
- The loader will charge a hopper that feeds to a shredder or hammermill through a conveyor belt.
- A conveyor belt will take the shredder's output to a rotary drum.
- The throughfall will contain organics, sand and small parts of other waste components. It will be fed into containers and hauled to the stabilization site.
- The overflow will contain most of the plastics, paper, wood, textiles, metals and other coarse components. These will be transported over a conveyor belt to the adjacent furnace bunker.

Bunker area	Flat floor. Capacity for 1 week. 5.000 tons. Area 1.300 m^2.
Machinery area	Flat floor. 200 m^2.
Area	1.500 m^2. Roofed or fully closed. Free working height 7 m^1. Concrete floor
Operations	Per week: 6 days @ 14 hours.
Shredder/hammer mill	Capacity 40 tons/hr.
Rotary drum sieve	Capacity 40 tons/hr. Mesh 50 mm^1.
Output to WtE	150.000 tons/year @ 10 MJ/kg to WtE, 65.000 tons/year to stabilization
Mobile equipment	1 wheel loader.
Employees	2 shift-leaders/operators, 2 loader drivers, 4 general workers

Table 5. Specifications Pre-Treatment

d. Stabilization

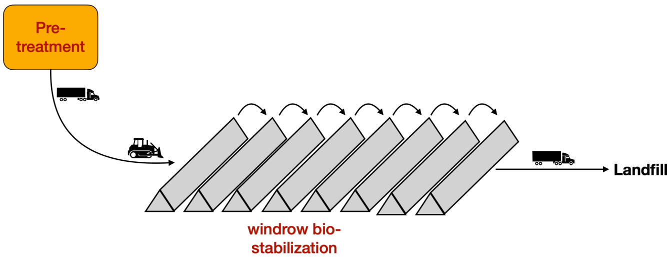


Fig.8 Schematic overview Stabilization

- Bio-stabilization (composting) will be used to aerobically degrade and mineralize all organic material thus preventing methane emissions. The resulting product is not suitable as a compost. Instead, it will be used as daily cover material at the landfill.
- Stabilization will be performed in 8 weeks. A week's input will be brought on an open windrow. Every week the windrows will be turned as indicated above.
- Windrow operations will be performed on a flat concrete or asphalt floor.
- The week-1 windrow will be filled by using a wheel loader. Successive weekly turning will be done manually by a large team of general workers. Mechanical operations by a mobile windrow turner are optional.
- The mineralized product will be used as material for daily coverage of waste at the landfill. In doing so it will replace the use of soil/gravel which normally consumes 5-10% of landfill capacity.

Windrows	8 windrows. Per row: 1.200 tons at 700 m^2. Total capacity: 70.000 tons/yr
Area	Total area 1 ha. Concrete or asphalt floor. Outdoors.
Operations	Per week: 6 days @ 8 hours.
Output product	20.000 tons/yr
Mobile equipment	1 wheel-loader including sifting bucket for product sifting
Employees	1 team-leader, 2 shift-leaders, 2 loader drivers, 250 general workers

Table 6. Specifications Stabilization

e. Furnace/boiler

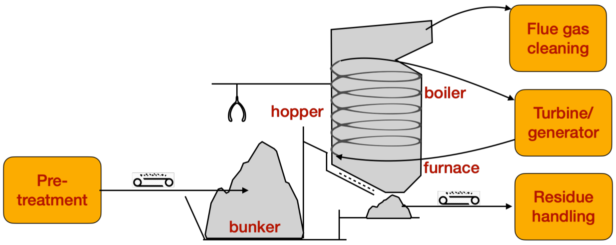


Fig.9 Schematic overview Furnace/Boiler

- The waste from the pre-treatment is fed into the bunker over a conveyor belt.
- The bunker serves to provide a needed volume buffer and to enable pre-mixing.
- Bunker capacity could normally be limited to 3 days because of the additional storage capacity in the Pre-Treatment. The design takes a 7 day capacity, thus preparing for future extensions without having to enlarge the Bunker.
- A crane feeds the hopper that feeds the moving grate furnace.
- Air is injected under the grate and into the off-gas in the boiler section in order to maintain required temperatures (>850^{0}C) and to achieve completion of combustion.
- Steam of needed pressure and temperature is produced by heat exchange over the boiler sides.
- Slag falls of the grate into a water basin and is then transported to the residue handling over a conveyor belt.

Lines	1 line of furnace and boiler
Furnace	Max. mass throughput: 20 ton/hr. Thermal capacity: 220 GJ/hr or 60 MW
Feedstock	Average 10 MJ/kg, max. 11 MJ/kg
Bunker	Storage capacity for 1 week, i.e. 3.000 tons or 10.000 m^3
Flue gas production	120.000 m^3 per hour
Area	Bunker 1.200 m^2, furnace/boiler 600 m^2
Operations	Per week: 7 days @ 24 hours. 8000 hours per year.
Output residue	20% i.e. 30.000 tons per year.
Employees (including turbine/generator and flue gas cleaning)	1 operational manager, 5 shift leaders 10 plant operators, 5 crane operators, 7 technicians, 20 general workers

Table 7. Specifications Furnace/Boiler

f. Turbine/generator

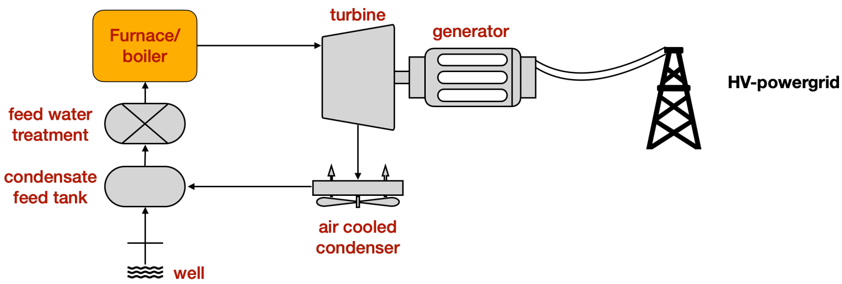


Fig.10 Schematic overview Turbine/generator

- Steam is used for e-production with connection to MV power grid through a substation.
- Maximum boiler feed-water-recycle. Needed water to be extracted from well.
- Cooling through air cooled condensers.

Lines	1 line of turbine and generator
Capacity turbine/generator	12 MW
E-production	550 KWh per ton of waste
Sub-station connection	5 km to nearest connection on Special Economic Zone
Area	Turbine and generator: 600 m^2, Condensers and substation: 500 m^2
Well depth	50 meter.
Operations	Per week: 7 days @ 24 hours. 8000 hours per year.
Employees	See Furnace/Boiler

Table 8. Specifications Turbine/generator

g. Flue gas cleaning/stack

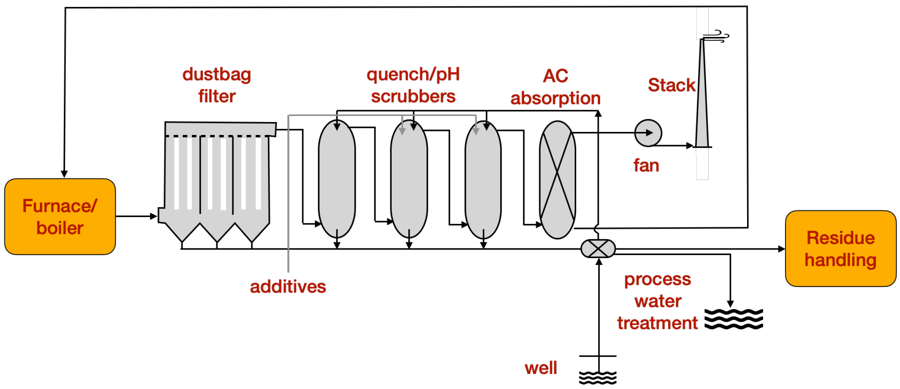


Fig.11 Schematic overview Flue gas cleaning

- Flue gas is cleaned through bag filtering, wet scrubbing and active carbon adsorption
- Needed process water to be extracted from well.
- Used AC to be incinerated in furnace

Lines	1 line of flue gas cleaning
Area	1.100 m^2
Emission limits	See Table 10
Water consumption	0,3 m^3 per ton of waste
Waste water production	0,1 m^3 per ton of waste
Operations	Per week: 7 days @ 24 hours. 8000 hours per year.
Employees	See Furnace/Boiler

Table 9. Specifications Flue gas cleaning

	Daily average in mg/Nm^3 (dioxins/furans: ng TEQ/Nm^3)
Total dust	5
Hydrogen Chloride	6
Hydrogen Fluoride	1
Sulphur Dioxide	30
Nitrous Oxides	120
Carbon Monoxide	50
Mercury (compounds)	0,02
Total Cadmium and Thallium	0,02
Sum other metals	0,3
Dioxins and Furans	0,04

Table 10. European flue gas emission limit values - BAT[1]

h. Residue handling

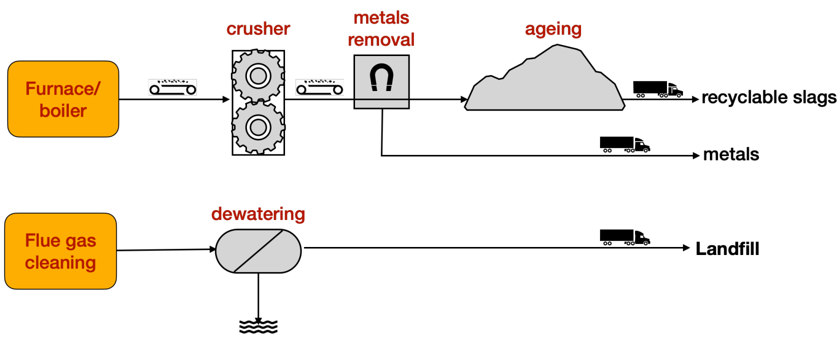


Fig.12 Schematic overview Residue handling

- Furnace slag is transported to the residue handling area where it is crushed.
- Metals are then removed and the remaining product is stored in the open air for further ageing.
- After ageing the product is fit for use as base layer in road construction.
- Flue gas cleaning products are dewatered by filter presses and then hauled to the landfill.
- Water is cleaned and reused or discharged.

Slags	20% of incinerated waste, i.e. 30.000 tons per year
Metals	2-3% of incinerated waste, i.e. 4.000 tons per year
Cleaning residues	4% of incinerated waste, i.e. 6.000 tons per year
Waste water	~0,05 m^3 per ton of input waste, i.e. 10.000 m^3 per year
Area	2.500 m^2, paved, outdoors
Mobile equipment	1 wheel loader
Operations	Per week: 6 days @ 14 hours per week
Employees	1 team-leader, 2 loader drivers, 4 general workers

Table 11. Specifications Residue handling

[1] Best Available Techniques (BAT) Reference Document for Waste Incineration, JRC Science for policy report, Industrial Emissions Directive 2010/75/EU

5. Site lay-out

A possible site lay-out is presented in Figure 12. It shows a plot of 30.000 m^2, not including the waste transfer stations (2 x 5.000 m^2) and the stabilization facility (10.000 m^2).

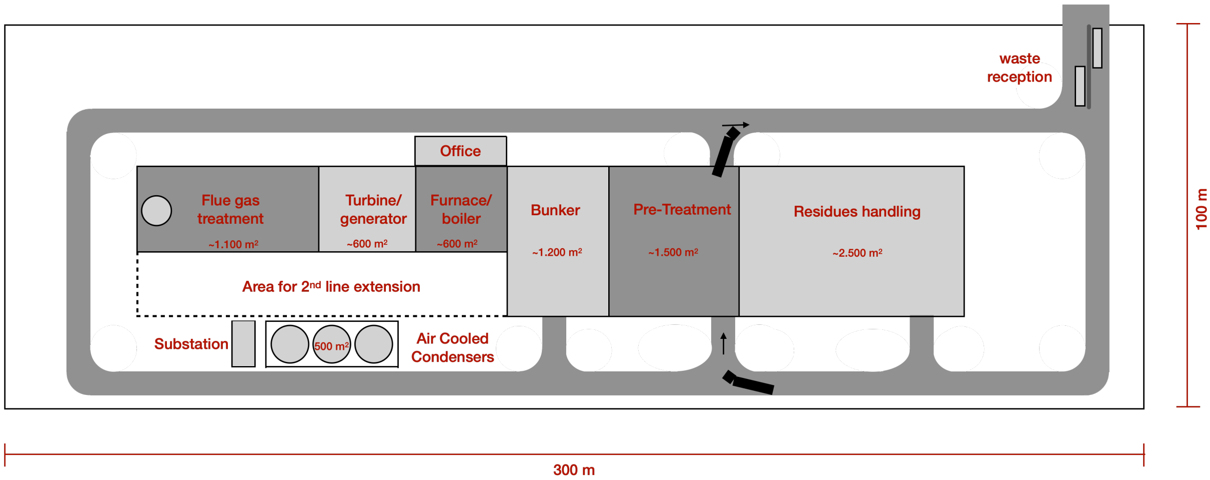


Fig.12 Schematic overview Residue handling

The built-up area of this site is 8.000 m^2, paved infrastructure is around 5.000 m^2 and fencing is 800 meters.

Routing of waste trucks is indicated in Figure 12. They will deliver the waste in the Pre-Treatment hall and leave the site via the shortest route. Separated organics will follow this same path.

The lay-out shows a set-up in which the Bunker, the Pre-Treatment hall and the area for Residues Handling are able to accommodate a double capacity. The lay-out provides space for also extending the hot-side of the processes.

The location of the site is indicated in paragraph 2.a. Currently the site is in use as agricultural land. Site preparation will need examination of bearing capacity and needed soil foundation works.

6. Workforce, material-flows, energy and GHG-emissions

a. Workforce

De workforce will add up to 100 employees. It may grow with some 250 workers in case of manual operations in the Stabilization. Management, finance and HR staff are not included in these figures.

Activity	Number of employees
Waste Transfer Stations	8
Reception	3
Pre-Treatment	8
Stabilization	5 + 250
Furnace/Boiler	
Turbine/Generator	68
Flue Gas Cleaning	
Residue Handling	7
Total	100+250

Table 12. Number of employees

Stable operations at the hot-side (furnace, boiler, turbine, generator, gas cleaning) are crucial. For this, the project must guarantee the availability of well-trained staff well before startup.

b. Material flows

The process described above will lead to material flows as schematized in the Sankey diagram of Figure 13.

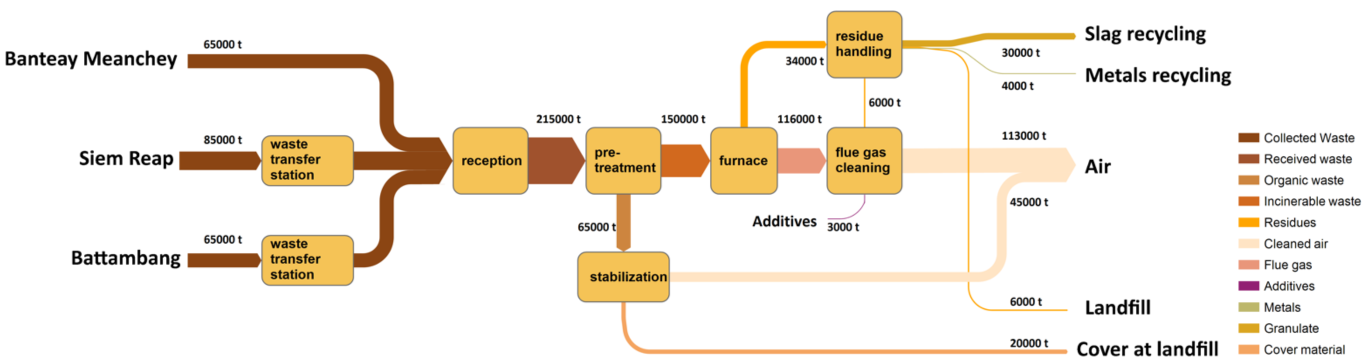


Fig.13 Sankey diagram of material flows

Overall a reduction of needed landfill space is achieved of 209.000 tons per year, equaling 97%. Of this, 67% is attributed to incineration and 30% to pre-treatment and stabilization. During a lifespan of 20 years the WtE facility may achieve a reduction of needed landfill space of 4 million m^3 or 15-20 hectares.

c. Energy efficiency

The facility will produce 85.000 MWh of electricity per year. Related to the energy contents of the waste fed to the furnace this gives and energy efficiency of 20%. Related to the energy contents of the waste fed to the pre-treatment it is 19%. These figures implicate that pre-separated organics and inerts represent a very low calorific value.

d. GHG emission prevention

For the evaluation of GHG emissions the project will be compared with open dumping and sanitary landfilling. The following assumptions are used:

- 1 ton of MSW contains 0,4 tons of carbon.
- In case of open-dumping 1 ton of waste emits 1.610 grams of CO_2 equivalents[2].
- Sanitary landfilling of waste (with flaring of landfill gas) is able to reduce open-dumping emissions by 70%.
- In composting/stabilization of organics, 50% of carbon is emitted as CO_2. The rest remains in the matrix as mineralized or non-degradable carbon.
- In incineration 100% of carbon is emitted as CO_2.
- Pre-treatment directs 20% of all carbon towards stabilization
- The GHG effect of CH_4 emissions is 25 times higher when compared to the effect of CO_2 emissions.
- The project will produce electricity which otherwise would have been produced by using oil or gas, assuming these energy sources rank lowest in Cambodia's preferred electricity production-mix. The production of 1 MWh of electricity from coal produces 987 kg of CO_2.

The calculations lead to emissions as summarized in Figure 14.

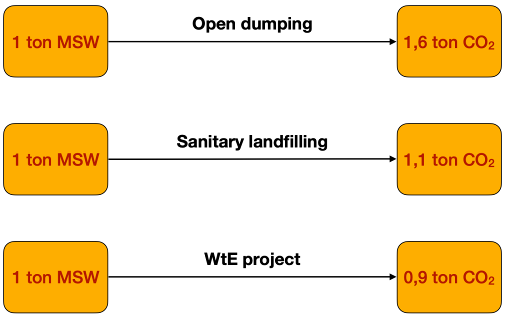


Fig.14 CO_2 emissions calculations

Implementing the project will lead to a reduction of CO_2 emissions of 45% when compared to open dumping. When compared to sanitary landfilling the reduction still is around 20%.

[2] ISWA report "Waste to Energy in Low and Middle Income Countries", August 2013

7. Planning

The first stage of implementing the project will be to reach regional governance arrangements between the public authorities concerned with the project. The agreement needs to be available before entering into tender procedures and will comprise for the three provinces and their municipalities:

- Establishing a joined waste management authority in charge of project implementation and execution.
- Definitive conclusions on scope of the WtE facility.
- Defining a protocol for permitting and ESIA.
- Defining a protocol for the tender procedure and BOT/concession principles.
- Agreement on land availability and access roads.
- Uniform long-term waste delivery contracts including volumes and gatefees.
- Agreement on implementing two WTSs including transport and including cost sharing.

A parallel trajectory will be executed between the provinces/municipalities and the energy authorities (Ministry of Mining and Energy, Electricity Authority of Cambodia and Electricité du Cambodge). It will aim at establishing the principles of the needed PPA for electricity delivery to the national grid including securities on a long-term Feed-in-Tariff. The trajectory will also include agreements on the grid connection and its costs.

Permitting, financing preparations and land acquisition will take 12 months, tender preparations and execution take 18 months and construction 30 months.

The overall planning thus shows a start of operations within 5 years from the start.

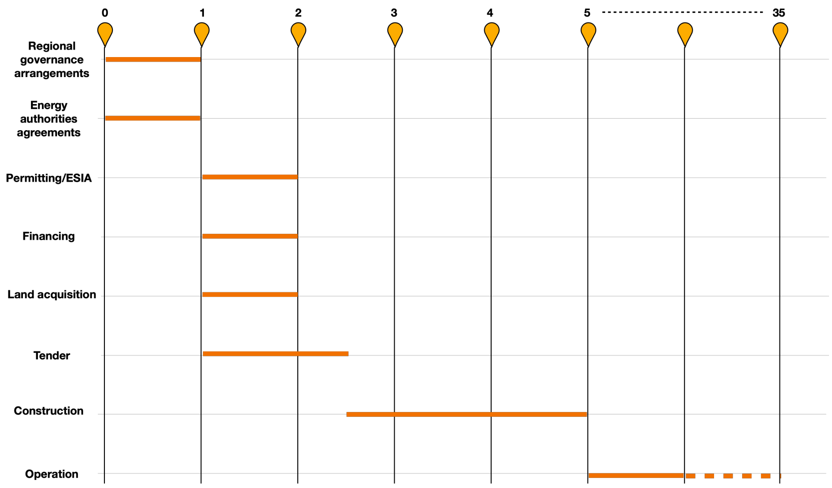


Fig.15 Overall planning

8. Financials

Spreadsheet feasibility calculations were performed. The Base Case places the facility in Poi Pet and assumes that sufficient waste can be collected in the three provinces and directed towards the facility. Transport is done using two Waste Transfer Stations and bulk trucks of which the costs are included in the model. The most important parameters are the gate fee and the FIT. In the Base Case they are aligned with the current situation being a gate fee of $1 per ton and a FIT subsidy of zero (see Annexes 3 and 4).

The list below summarizes all parameters of the Base Case.

- A WtE facility, including pre-treatment, located in Poi Pet
- An overall capacity of 215.000 tons per year and a capacity for the incineration of 150.000 tons MSW per year with a calorific value of 10 MJ/kg
- A production of 550 kWh/ton and 8000 operational hours on both the furnace and turbine side
- Slag output 20% of waste input. Residue treatment at $10 per ton
- Metal recovery from residue. Metal output 2% of waste input. Metal price at $100 per ton
- Construction time 2 years
- Investments of $ 97M with $3M in road and power connections, $20M in civil works, $80M in machinery and $14M in studies, design, project management, IT systems, permitting, working capital at start, interest during construction and debt service provision.
- Depreciation civil investments in 25 years and machinery in 15 years.
- Two waste transfer stations (WTS) included at $0,5M each. One WTS in Siem Reap and one in Battambang. WTS-WtE transport included for 60% of all waste at $10 per ton.
- Total area 3 ha, available for free
- Electricity price at $0,10 per kWh, no FIT

The following parameter-settings are used to calculate the sensitivity of the base case to changing conditions.

- Gate fee at $10 and $30 per ton
- FIT subsidy at $0,10 and $0,20 per kWh
- Investments at $80M and 110M
- E-production at 600 kWh/ton
- Doubling the waste treatment capacity

The table below summarizes the results of the Base Case and the sensitivity for changing parameter settings. IRR- and NPV-outcomes are project based. Green cells indicate positive values for IRR and NPV.

Returns on project base	IRR	NPV
Base case	1,2%	-$65M
BC + gate fee at $10/ton	4%	-$52M
BC + gate fee at $ 30/ton	8,6%	-$25M
BC + FIT subsidy at $0,10/kWh	10,4%	-$13M
BC + FIT subsidy at $0,20/kWh	16,9%	$38M
BC + investments at $80M	2,6%	-$50M
BC + investments at $110M	0,9%	-$68M
BC + e-production at 600 kWh per ton	2,4%	-$59M
BC + gate fee at $10/ton + FIT subsidy at $0,10/kWh	12,1%	-$1M
BC + gate fee at $10/ton + FIT subsidy at $0,10/kWh + double capacity	16,2%	$53M

Table 13. Sensitivity analyses

The Base Case shows a strong negative performance, indicating that current gate fee and FIT conditions don't cater for any initiative on WtE in Cambodia. Increasing the gate fee improves the financial performance but not to any acceptable level. Introducing a FIT subsidy has a stronger effect but it has to raise the combined electricity price to a level of $0,30/kWh before IRR and NPV reach acceptable levels.

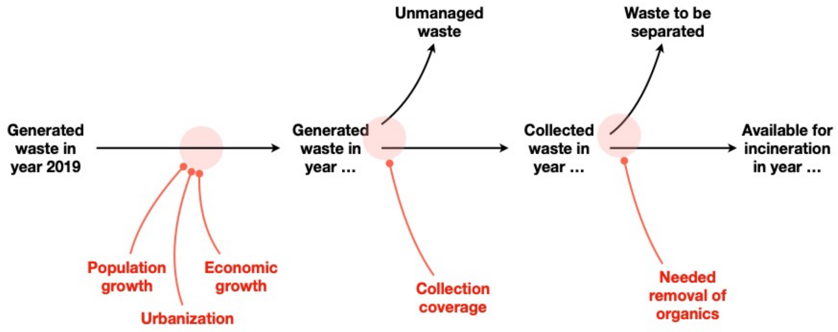
The results add the FIT as one of the pivotal parameters for the feasibility of WtE in Cambodia. The subsidy has to raise the electricity price to a level of at least $0,20-0,30 per kWh depending on the other parameter settings. An acceptable case emerges when the gate-fee is raised to $10/ton and the all-in electricity level to

$0,20/kWh and it develops to a strong case when the authorities are able to decide on a double capacity. This last case will need the involvement of other provinces.

Discussions on the introduction of FITs also bring into play the overall electrical capacity of the facility. The Base Case represents a 12,8 MW_e capacity, so above the 10 MW_e level that is suggested by the Cambodia Basic Energy Plan (see Annex 4).

Annex 1. Waste availability

Preparing a WtE needs reliable forecasting of available waste for a relevant number of years. This is done by applying the calculation model presented below.



Growth of generated municipal or household waste is in general governed by 3 parameters being population growth, urbanization and economic growth. The first parameter is evident. Urbanization is relevant because urban inhabitants produce more (almost double) waste than their rural neighbors. Economic growth translates to waste growth as more wealth leads to more waste with an elasticity of around 10%.

Not all waste is collected. Developing countries show low access of urban inhabitants to collection services and almost absent access for rural inhabitants. In situations with low urbanization like in Cambodia this leads to high volumes of unmanaged waste.

And not all collected waste is fit for incineration. High organic contents lead to low calorific values. This leads to the need to separate of a considerable part of these organics. When removed the remaining waste can be regarded as available for incineration.

The casinos of Poi Pet and Angkor Wat in Siem Reap attract millions of visitors per year. Visitors produce more waste per person per day but the number of days of their stay is often limited. The model includes estimates on numbers of visitors, expected growth, average length of stay, per-visitor waste generation and the collection coverage for this waste (normally 100%).

Lack of data and data-quality is often a bottleneck in modelling waste volumes. Even data from the World Bank need to be handled with care. Their “What-a-waste 2.0” estimate for waste generation in Cambodia is 0,2 kg/capita-day while other research claims that for example Pnom Penh was already showing almost 1 kg/capita-day in 2015. In such situations, lacunas have to be filled in by extrapolations and expert-estimates.

For this assessment the following sources were used:

- General population census of the Kingdom of Cambodia 2019 – National Institute of Statistics
- Urbanization and its linkage to socio economic and environmental issues, Cambodia 2014 – UNFPA 2014
- CIA world data on Cambodia – www.cia.gov
- Cambodia economic survey 2017 – National Institute of Statistics, 2018
- Tourism Statistics Report 2018 – Ministry of Tourism Cambodia
- Bangkok Post article on Poi Pet tourism – April 27th 2019
- UNDP Cambodia Provincial profiles for Solid Waste Management, 2017

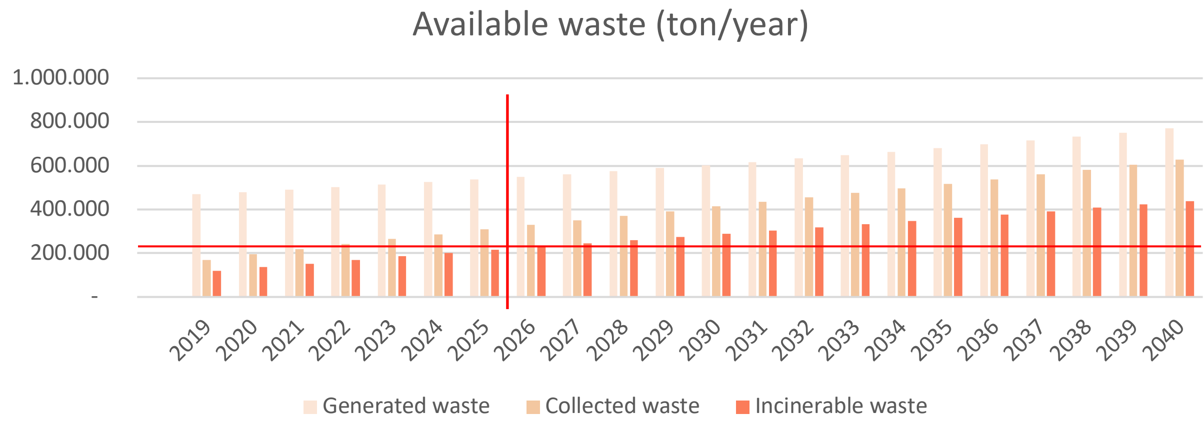
From these sources a dataset was derived. This set was further extended by extrapolations and estimates. The table below provides an overview of all parameters that were used (reported data in black, estimates and extrapolations in red.

	Unit	Cambodia	Banteay Meanchey	Battambang	Siem Reap
Population 2019	#	15.300.000	860.000	987.000	1.007.000
Populatioh growth rate 2019	%/yr	1,4%	2,2%	-0,3%	1,1%
Number of households 2019	#	4,7	4,8	4,5	4,6
Urbanization 2019	%	24%	27%	28%	20%
Urbanization growth rate 2019	%/yr	3,25%	3,25%	3,25%	3,25%
GDP	$/month-cap	118	118	118	118
GDP growth rate	%	10%	10%	10%	10%
Household consumption of GDP	%	76%	76%	76%	76%
GDP(PPP)	$/month-cap	330	330	330	330
GDP(PPP) growth rate	%/yr	7%	7%	7%	7%
Population below povertyline 2019	%	17%			
Mean disp. hh. income total	$/month-cap	87	87	87	87
Mean disp. hh. income urban	$/month-cap	108	108	108	108
Mean disp. hh. income rural	$/month-cap	80	80	80	80
Spend. housing/water/electricity total	$/month-cap	21	21	21	21
Spend. housing/water/electricity urban	$/month-cap	31	31	31	31
Spend. housing/water/electricity rural	$/month-cap	15	15	15	15
Inflation	%	2	2	2	2
	Unit	Value			
Waste generation urban	kg/day-cap	0,7			
Waste generation rural	kg/day-cap	0,35			
Waste generation visitors	kg/day-visitor	2			
Collection rate urban 2019	%	50%			
Growth rate serviced urban population	%/yr	10%			
Collection rate rural 2019	%	5%			
Growth rate serviced rural population	%/yr	5%			
Collection rate visitors	%	100%			
Average stay visitors	days/visitor	2			
Visitors Angkor Wat 2019	#	2.700.000			
Visitors Angkor Wat growth	%/yr	5%			
Visitors Poi Pet 2019	#	900.000			
Visitors Poi Pet growth	%/yr	5%			
Waste/Economy elasticity	%	10%			
Usable fraction for feeding incineration	%	70%			

Some remarks to this dataset:

- Actual population numbers exclude Cambodians living abroad.
- The parameters on urban and rural per capita waste generation are based on international experiences in similar countries (e.g., Myanmar).
- Growth rates in collection coverage are mere guesses made on the expectation that authorities will try to implement measures on increasing access to waste services for all inhabitants.
- Parameters on collection coverage must be valued as preliminary guesses. Literature gives coverage ratios of 80% for Pnom Penh, 30% in Battambang district, 17% in Poi Pet district, 23% in Siem Reap district and 0% for rural villages.
- Visitor-days are also based on preliminary guesses.

The diagram below provides the results for the dataset mentioned above.



In this graph the horizontal red line depicts the capacity of the anticipated WtE (215.000 ton/year). The vertical red line depicts the earliest moment a WtE could come into operation (2,5 years of preparations, 2,5 years of construction).

Assuming the validity of the dataset, the graph shows that by the year 2022 there could be enough waste to feed the WtE and its pre-treatment. Nevertheless, such a scenario is critical as it would need the full cooperation of all three provinces and the coordinated guidance of all waste towards the facility.

Experiences from other countries show that the introduction of WtE raises gate-fees and this effect in itself sets in motion the development of cheaper recycling initiatives. For this reason, it is deemed important to design a facility at a level that provides a buffer for the risk of "drying-up" waste volumes or undesired lock-in effects. By the year 2025 a volume of 300.000 tons of collected waste per year can be reached, providing for some of this needed buffer.

Included in the figures but not visible in the graph, is the included contribution of waste generated by visitors. With this dataset this contribution stays well below a level of 10% of all available waste. The figures only provide data for municipal and visitor waste. Industrial waste and construction and demolition (C&D) waste are not included. Their volumes can be (much) larger than municipal waste and they could be important as an additional feedstock for the WtE. Nevertheless, it must be born in mind that:

- These wastes are not controlled by public authorities and can therefore not (yet) be directed towards the WtE nor forced to pay the gatefee.
- The composition of these wastes is not known. C&D waste usually contains some 90% of mineral components which cannot be incinerated.

The validity of the dataset is of course important. When performing a sensitivity analyses, waste generation rates and collection ratios turn out to be the most important. Of all parameters the collection ratios are the only ones that can be managed through actions of public authorities.

Annex 2. Waste composition

There is no recent data on waste composition for the project region. In situations like this a first indication may come from extrapolations from earlier research and research from other regions.

Five sources with relevant information on composition could be located[3][4][5][6][7]. The table below provides an overview. The 8th column provides a best guess on the possible composition that could be encountered in the three provinces. The last two columns provide reference datasets of the World Bank.

	2008 Siem Reap	2008 Battam-bang	2008 Kampong Chhnang	2018 Koh Dambang	2019 Phnom Penh	2015 Phnom Penh	Assumed composition	World Bank Lower Middle Income	World Bank Low Income
Organic waste	65%	72%	80%	55%	65%	54%	65%	54%	57%
Plastics	9%	9%	3%	13%	18%	21%	10%	11%	7%
Textiles	4%	3%	1%	5%	2%	2%	3%		
Metals	5%	1%	8%		2%	1%	3%	2%	2%
Paper/cardboard	1%	3%	2%	27%	6%	10%	5%	13%	7%
Rubber/leather					1%	1%	1%	1%	
Ceramics/stones					1%	1%	2%		
Glass	8%	5%	1%		1%	2%	4%	3%	1%
Other materials	8%	7%	4%		4%	8%	7%	17%	26%
	100%	100%	100%	100%	100%	100%	100%	100%	100%

Some remarks to this dataset:

- The compositions resulting from specific Cambodian research don't align well with research from the World Bank. The most probable causes for the gap may be the definitions that are used and the fact that the World Bank figures are the average result of multiple countries.
- Both, organics and plastics appear to be high in Cambodia. The higher organics contents seem to resemble compositions for low-income countries whereas the higher plastics contents resemble those in high-income countries.
- When countries develop, waste generation and composition tend to change. When volumes increase organic contents go down and plastics, paper and cardboard percentages go up. This must be kept in mind when designing a WtE facility as it will affect the calorific value of the incoming waste in a positive sense. On the other hand, it may be expected that compositions will also be influenced by bans and recycling initiatives as for plastic packaging.
- The category "Other materials" is not well defined. It may for a large extent include inert material like sand, stones, ceramics, floor sweepings etc. if these are not included in other categories.
- Publications do not mention any seasonal variation of waste composition. For other countries it is known that rainy seasons can drastically increase water contents.

[3] Sustainable Asia, Chapter 15, Sustainable societies and municipal solid waste management in Southeast Asia, C. Curea, 2017

[4] Perspectives of solid waste management in rural Cambodia, Creaser et al, J. of Humanitarian Engineering 2018 (6) no. 2 18-25

[5] Analysis and Modelling of household solid waste generation, handling and management in Pnom Penh, Cambodia, dissertation Seng Bandith, 2019

[6] Assessment of public-private partnership in municipal solid waste management in Phnom Penh, Cambodia, Spoann et al, Sustainability 2019, 11, 1228, 1-19

[7] State of waste management in Phnom Penh, Cambodia, IGES/UNEP report 2020

Annex 3. Financials waste-side

Basic urban services on waste management comprise city cleaning, waste collection, transfer and transport and treatment (disposal or recycling). These services cost money and they have to be covered through the municipal or national budget and/or through waste management fees. Investments and operational expenses are high and as a consequence waste management needs to be embedded in a stable environment of financial governance. Ideally this governance shows:

- *Public authority primacy*: Public authorities are responsible for the planning, provision and fee-charging of SWM services (the production of these same services can be done by the authorities themselves but also by CBO's, by private actors or by PPP's).
- *Obligatory participation*: Citizens have no free choice in whether or not to participate and pay.
- *Full cost coverage*: all costs incurred by waste management activities must be covered by (dedicated) municipal fees for its inhabitants, institutions and businesses as much as possible.
- *Polluter pays*: Fee setting for these groups should reflect actual costs as much as possible.
- *Affordability*: In fee setting, affordability must play an important role (and fee differentiation can be an important instrument to achieve this).
- *Continuity*: Fees and related cashflows must be sufficient, stable and if possible earmarked in order to secure continuous services with adequate quality levels for all citizens.

For WtE with its high investments, gate-fees and capacities, these governance principles are even more relevant.

There's only little information on finances related to waste management in Cambodia. In 2017 UNDP produced short factsheets on waste management in every Cambodian Province[8]. The financial parts of these sheets provide the following data for the monthly waste management fees per house(hold):

- Battambang: $1-2
- Banteay Meanchey: $2-3
- Siem Reap: $1

There are some other sources of information but most of it is on Phnom Penh.

- A source[9] mentions that in 2020 the city authorities of Phnom Penh reclaimed control over the collection of waste management fees. Until this year, fee collection was in the hands of Centri (the private service producer in the capital with a 49 years contract since 2002). The article mentions fees being $1 per household per month and the possibility to pay per phone.
- A report of the Asia Foundation[10] gives some background insights in the situation in Phnom Penh. It reports fees varying from $0,80 to $1,00 per household per month while these fees have not changed since 1997. Before 2020, Centri had an agreement with Electricité du Cambodge to charge the fees as a part of the electricity bill. There has been extensive critisism of Centri charging fees without providing waste collection services. Centri claims that waste management fees are to low to cover the costs of both collection and disposal at the landfill, the latter using a gate-fee of $0,75 per ton. Centri was said to be neglecting its bleeding services to households and was focusing mostly on profitable commercial services to businesses.
- A dissertation[11] mentions the same gate-fee of $0,75 per ton for Phnom Penh's publicly operated landfill. It generates almost $35.000 per month being 90% of all expenditures for this site.

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[8] UNDP Provincial factsheets for waste management in Cambodia, https://www.kh.undp.org/content/cambodia/en/home/library/environment_energy/factsheet--status-of-solid-waste-management-in-cambodia.html

[9] Cambodianess, February 1st 2020

[10] The Asia Foundation, Working politically in practice series – case study no. 8, "Reforming solid waste management in Phnom Penh, May 2016, Lisa Denney

[11] Assessment of municipal solid waste management capacity of local government authorities and contracted waste collection service: a case study of Phnom Penh Capital Cambodia, Spoann Vin, Okayama University, August 2019

- Another dissertation[12] describes the willingness-to-pay for waste collection services in the capital. It turns out that people who are currently not serviced are willing to pay the fee when they would be serviced. Only one-third of households already receiving services are willing to pay more for improved services.

Every province seems to charge the households with some kind of waste management fee. Fees range between 1 and 3 dollar per household per month. If $2 is taken as an average and is related to household (HH) incomes then the following table can be drawn up.

	$/month-HH	SWM fee as %
GDP	555	0,3%
GDP(PPP)	1551	0,1%
Disposable income	409	0,4%
Spending on housing/water/electricity	99	2%

In general, 1% of GDP per household is considered to be an affordable level of spending on SWM. In Cambodia that would be $5 per household per month and so it can be concluded that Cambodia still has considerable room to increase waste management fees. Also, when looking at current spending on housing, water and electricity, it can be concluded that SWM takes very little from a household's budget.

Another positive observation is that most provinces seem to have some kind of fee differentiation; households with small houses pay less than neighbors with larger houses. Differentiation systems could be used more extensively to exempt poor households when increasing average fee levels.

This being said, the above-mentioned study for Phnom Penh on willingness-to-pay isn't very positive when it comes to raising fees. People seem to be used to low fees and will not easily accept increases and certainly not in situations where service quality is low.

Currently, the gate-fees of municipal dumpsites seem to be very low. A gate-fee of less than $1 per ton will not be enough to pay for the costs of even the least managed and equipped dumpsites, as shown in the example of Phnom Penh. Looking at international experiences, an engineered sanitary landfill with a large capacity, with all needed auxiliaries on soil protection, leachate- and gas-catchment and -treatment and with professional daily operations would typically need a minimum of $10 per ton. An average Cambodian household produces 1 ton of waste per year. It would mean that replacing open dumps by sanitary landfills would already need an increase of $1 for each household's monthly SWM fee.

If the 1% rule for affordability would be applied in Cambodia, an average household would be able to spend $60 per year on waste management services. Assuming that $20-30 per household would be needed for collection, transfer and transport that would leave $30-40 for treatment. With a household producing 1 ton of waste per year that household could afford a maximum gate-fee of an equivalent $30-40 per ton.

So, in theory, the assumption of a gate-fee for a WtE of $30 per ton could look realistic and affordable. In practice it would need tripling of average waste management fees, a strong increase of collection coverage and the obligatory participation of at least all urban inhabitants and all of this within a timeframe of a few years. If not deemed possible the introduction of WtE will need a substantial subvention from the local or national budget for many years.

Earlier in this memo some governance principles for SWM finances were defined. Introducing WtE would need a good score on these aspects. In the table below a first assessment is given, with in the last column scores for strong (green), intermediate (orange) and weak (red). It shows that public primacy and affordability are good but the scores on the other principles are low.

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12 Analysis and Modelling of Household Solid Waste Generation, Handling and Management in Phnom Penh, Cambodia, Seng Bandith, Okayama University, March 2019

Assessment		
Public primacy of provision	Seems to be well established. Outsourcing of actual collection to private sector seems to be poorly prepared and managed.	
Obligatory participation	Collection coverage is poor and as a result, inhabitants don't feel able nor obliged to participate	
Full cost coverage	Cost coverage is very poor. Further upgrading of services without raising fees or budget subventions will worsen this situation	
Polluter pays	There is a system of waste management fees in operation but polluters do not pay all the costs they incur	
Affordability	Households are able to afford improved waste management (but they are probably not willing to pay)	
Continuity of cashflows	Continuity of cashflows is uncertain	

Annex 4. Financials power-side

The Electricity Authority of Cambodia (EAC) is the main actor in Cambodia's power sector. This legal public entity has been granted the right to regulate the sector as an autonomous agency. The Electricity Law states that no entity can be an actor in the power sector unless it acts in accordance with a license issued by the EAC. Licenses must be in accordance with Energy policies and strategies established by the Ministry of Mines and Energy. Electricité Du Cambodge (EDC) is the only public licensee; all other licensees are private sector actors.

EAC focuses on full access to electricity for all households, on reduction of electricity tariffs and on stable and sustainable electricity provision. The authority publishes a yearly overview of its licenses and of its achievements with regard to targets[13].

Electricity tariffs in Cambodia are currently ranging between 12 and 20 $cents/kWh for households and between 11 and 17 $cents/kWh for industry and businesses. Time-of-Use tariffs (nighttime use of electricity) are around 10 $cents/kWh.

The country's power supply is mainly from coal, hydropower and imports. The levelized cost of electricity production (LCOE) for coal is currently around 10 $cents/kWh. The position of hydropower is strong and growing. Its average production cost is below 7 $cents/kWh. Solar power is supposed to be very promising for the country's future power production. Recently, a utility-scale PV production auction for 60 MW resulted in a price below 4 $cents/kWh[14]. A pipeline of 410 MW of PV has already been approved lifting the total PV capacity up to above 600 MW in a few years.

Cambodia has no system of FITs to encourage investments in the production of renewable energy. A possible argument for this is that FIT's tend to have an increasing effect on overall electricity tariffs. Recently, the Ministry of Mining and Energy issued the "Cambodia Basic Energy Plan"[15]. The plan studies policy alternatives and scenario's with regard to a number of aspects of the country's power provision. With regard to FITs the plan suggests, for the medium and long term, to study the application of FITs up to a maximum capacity of 10 MW. Without a system of FITs a WtE-plant will have to compete with coal, hydropower and PV at prices below 10 $cents/kWh.

The OECD provides a yearly overview of FITs for 68 (member and non-member) countries[16]. The 2019 dataset shows 15 countries using a FIT for energy from waste. The highest FITs are for Japan (23,8 $cents/kWh) and Switzerland (26,7 $cents/kWh). Indonesia uses a FIT of 9,1$cents/kWh. The length of the related Power Purchase Agreements is between 10 and 25 years.

As said, Cambodia is currently considering the possibility of using FITs. A maximum level of 10 MW, as contemplated at this moment, would more or less align with the anticipated capacity of 150.000 tons of waste per year. The difficulty will more likely be in the uncertainty and planning for FIT introduction and in the height of the FIT itself. Although the double motivation for WtE (energy production and waste reduction) may lead to a choice for a high FIT it is uncertain that the country will adopt a level well above what is used in other countries. For this reason, a maximum of 25 $cents/kWh should not be exceeded in scenario studies.

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[13] Report on power sector of the Kingdom of Cambodia compiled by Electricity Authority of Cambodia -2019, EAC, 2020
[14] Cambodia solar auction draws tariff of USD 38,77/MWh, Renewables Now, September 5th 2019,
[15] Cambodia Basic Energy Plan, MoME and ERIA
[16] https://stats.oecd.org/Index.aspx?DataSetCode=RE_FIT#