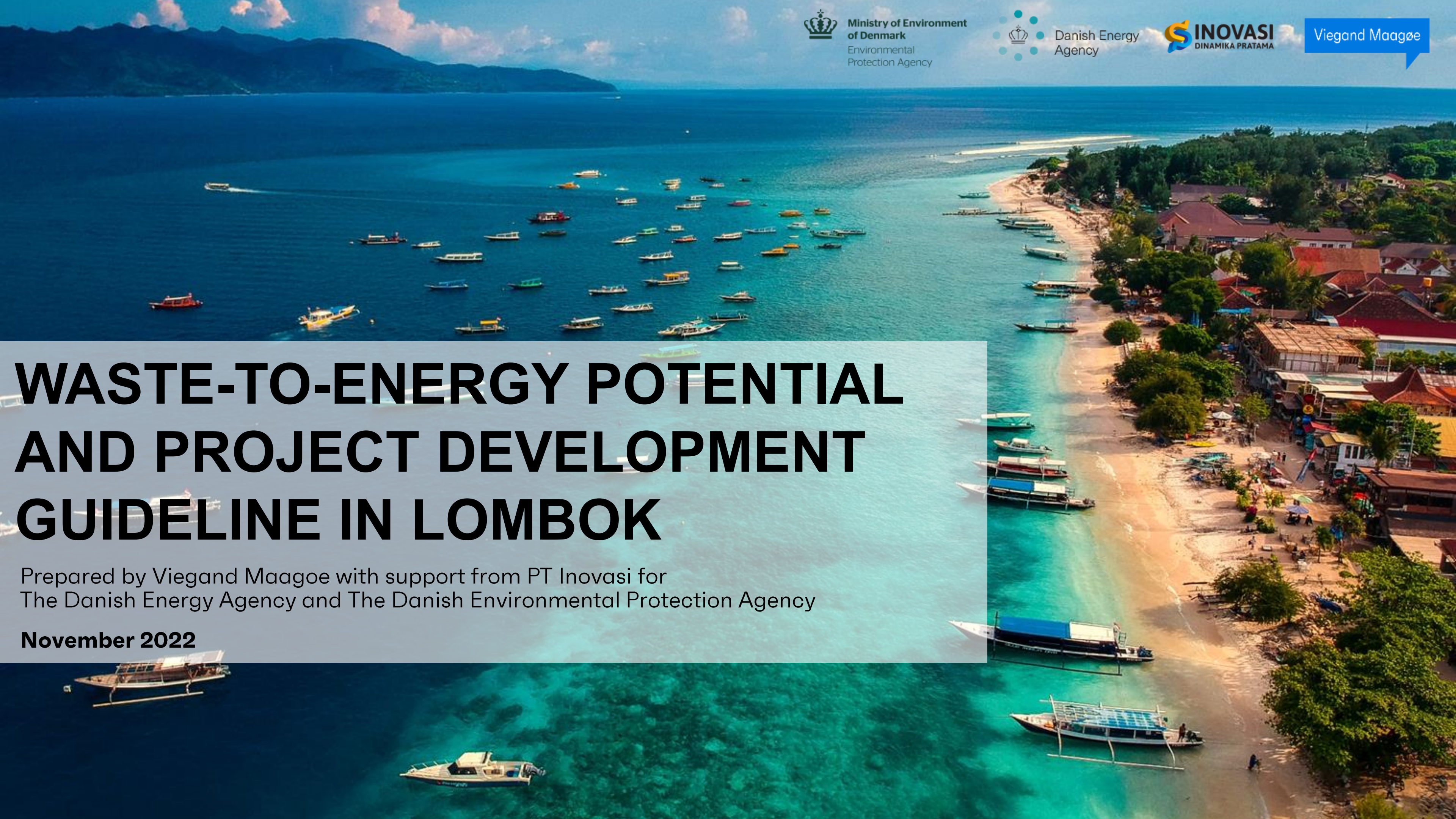

WASTE-TO-ENERGY POTENTIAL AND PROJECT DEVELOPMENT GUIDELINE IN LOMBOK

Prepared by Viegand Maagoe with support from PT Inovasi for
The Danish Energy Agency and The Danish Environmental Protection Agency

November 2022

SCOPE OF REPORT

Indonesia's National Waste Policy sets increasingly high standards with regards to the handling of solid waste streams to reduce the environmental and climate impacts of waste. On top of that, the government of Indonesia has an ambition to integrate higher shares of renewables while preserving the supply of power in a time where demand for power is increasing due to high economic growth.

Waste-to-energy has the potential to address both issues: generation of renewable energy and waste management. However, the deployment of waste-to-energy technologies in Lombok remains low.

The purpose of this report is to enhance local knowledge in Lombok - concerning the island's waste-to-energy potential, the benefits and challenges of different waste-to-energy solutions and the critical steps when developing a waste-to-energy project.

This report is part of the Sustainable Island Initiative (SII), an add-on initiative to the energy partnership program between Indonesia and Denmark. SSI concerns sustainable waste management and waste-to-energy on two islands: Lombok and Batam.

This report, which focuses on Lombok, is divided into three chapters:

1) Screening of the waste-to-energy potential in Lombok
2) Assessment of four waste-to-energy technologies
3) Project development guideline for waste-to-energy development

The ambition with this report is to synthetize existing knowledge concerning waste-to-energy when it comes to different WtE solutions and aspects that are critical to a WtE project development process.

Four WtE solutions are assessed: Waste Incineration, Anaerobic Digestion (AD), Landfill gas power generation and Mechanical Biological Treatment (MBT). Each technology is evaluated according to environmental impact and overall feasibility.

In order to facilitate and enable investments into the waste-to-energy sector, the report also provides a "10-step project development guideline" for waste-to-energy technologies.

Data

The assignment is a combination of desk top research and primary data collection. The report partly builds upon earlier existing work, e.g.:

1. Danish Environmental Protection Agency (DEPA), Danish Energy Agency and Ramboll (2022): Pre-feasibility study (waste) of Lombok
2. Danish Energy Agency and COWI (2021). Technology catalogue for solid waste management and waste to energy – Lombok and Batam/Kepri

Additional interviews and site visits have been completed with a range of local stakeholders in Lombok. (See Appendix 1).

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1. SCREENING OF WASTE-TO-ENERGY POTENTIAL IN LOMBOK

POLITICAL MOMENTUM FOR WASTE-TO-ENERGY IN LOMBOK

Renewable energy target of Indonesia

The national government of Indonesia has set a goal of reaching 23% renewable energy supply in the power sector in 2025 and 31% in 2050. During COP26, West Nusa Tenggara province, which incudes Lombok, announced a political goal of 60% renewable energy in the power sector by 2030 and net-zero emissions in all sectors by 2050. According to PLN's grid development plan (RUPTL) for Lombok, 200 MW of additional renewable energy is planned to come online in the period 2026-2028. This additional capacity is going to increase the share of renewables in the system from 4% in 2021 to 33 % in 2030. However, to meet the Lombok's political goal, Lombok will need to double the share of renewables in 2030 compared to the current RUPTL.

National Waste Policy of Indonesia

Presidential Regulation No.97/2017 is the regulatory framework behind Indonesia's national waste policy and strategy, which sets a 30% waste reduction target and a 70% waste handling target by 2025 compared to the base year in 2017. According to available data from the provincial government, Lombok has a handling rate of ~40 % and a waste reduction rate of 2% in 2022 and Lombok is therefore far from fulfilling the national target. In addition to this, overfilled landfills provide a physical and very practical problem.

The strong political momentum for renewable energy and the lack of progress – both when it comes to waste reduction and waste handling, provides a rationale for looking into new ways to handle waste, which at the same time support Lombok in its efforts to fulfil renewable energy goals.

The purpose of this study is therefore to provide a high-level understanding of the potential for waste-to-energy technologies in Lombok.

President Joko Widodo (Jokowi) outlining Indonesia's commitment to addressing climate change issues at the 2021 United Nations Climate Change Conference, in Glasgow in November 2021.

Source: Antara News, https://en.antaranews.com/news/197217/cop26-indonesia-reiterates-commitment-to-tackling-climate-change

PERPRES no. 97/2017 (2017); PT PLN (2021); Antara News (2022); Viegand Maagoe Analysis (2022)

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LOMBOK GENERATES 0.7-1 MIO. TONS OF WASTE PER YEAR WITH A WASTE HANDLING RATE OF 43%

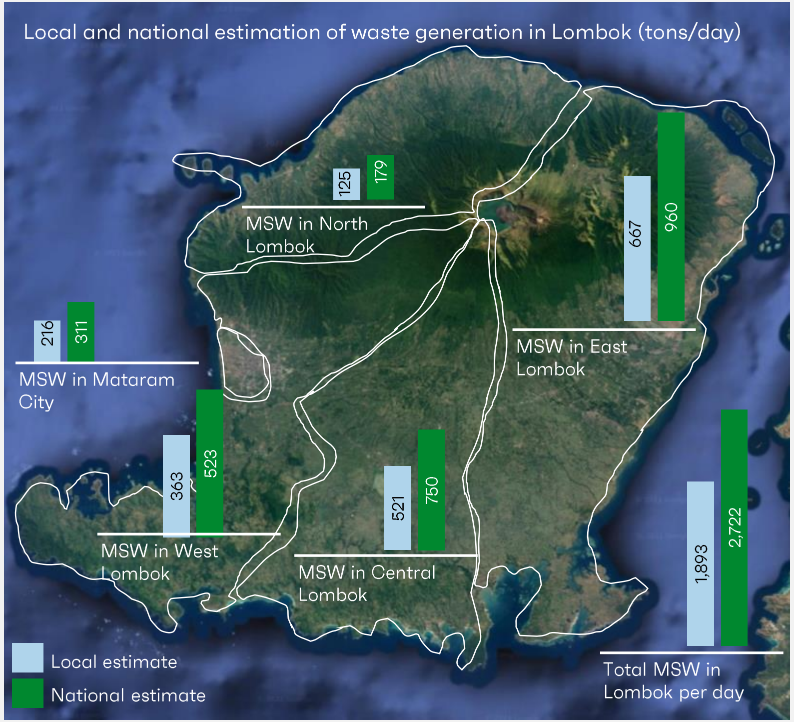
Waste generation in Lombok

The main source of waste in Lombok is households and traditional markets. According to Lombok Provincial Government, Lombok generates on average 0.4 kg. waste per capita per day, corresponding to around 1,900 ton per day. The national government's estimation is around 2,700 tons per day. On an annual basis, Lombok generates between 700,000 and 1,000,000 tons of waste. The Eastern and Central regencies generate the highest waste volumes.

Around 43% of Lombok's waste is collected. Of the total amount of waste collected, 9% is undergoing pre-sorting before being sent to landfills. Lombok is thus far from fulfilling the national waste policy of 70% waste collection in 2025. In terms of waste reduction, the national policy sets a waste reduction target of 30% in 2025 compared to 2017. Between 2017-2020, Lombok reduced the total waste with 2.41% and is thus far from fulfilling the national goal.

Lombok's waste composition includes 77% organics. As a result, the moisture level of waste is 53% and the calorific value is only 5.8 MJ/kg, compared to European levels of 9-11 MJ/kg.

Figure: Waste composition in Lombok



Google Earth

DEPA, DEA & Ramboll (2022); PT Inovasi (2022); Viegand Maagoe Analysis (2022);

LOMBOK'S WASTE HANDLING SYSTEM IS DOMINATED BY LANDFILLS

Waste collection and handling in Lombok

Waste collection starts with temporary shelters (TPS), where waste from the villages is dumped. There is a total of 854 TPS facilities in Lombok. After the waste has been picked up, it either goes to TPS 3R facilities, which are larger facilities serving around 400 households, waste banks or landfills. "3R" stands for reuse, reduce and recycling. At the TPS 3R facilities, the organics may be separated and composted while the recyclables are sold to aggregators. At the waste banks valuable recyclables are collected by waste collectors and sold in the market.

Households pay a service fee (also called retribution fee) of ~0.5 USD/month to the government for waste management services.

Some waste banks are located physically on the landfills. As a result, waste collectors are active on the landfill and typically live adjacent to the landfill. Scavengers at Ijobalit landfill earn on average 5.6 USD per day. There is a risk that by upgrading the waste management system, by e.g. by introducing more formal recycling processes, scavengers loose their main source of income.

Lombok has four landfills the largest being Kebon Kongok, which is located in the Western Regency. It receives waste from the Western Lombok Regency and Mataram City. Kebon Kongok, Ijobalit and Jugil landfills are reaching capacities.

Google Earth

ZOOMING IN ON KEBON KONGOK LANDFILL – STATUS AND LONG TERM INITIATIVES

Kebon Kongok Landfill

The Kebon Kongok landfill handles 324 tons of waste per day. The plan is to reduce the daily waste handling to 120 tons/day and recycle 80% of the waste. Below table is a break down of the different recycling options included in the plan.

Bio, Paper	Plastic for pyrolysis	Compost	Metals recycling	Glass recycling	Landfill
40.19 ton/day	20.84 ton/day	28.02 ton/day	7.49 ton/day	1.76 ton/day	21.7 ton/day

The landfill is currently running a pilot for the conversion of dry biowaste into RDF. The RDF is used as feedstock for co-firing in the Jeranjang coal power plant in the Western part of Lombok. The daily production of RDF is currently 200 kg, with plans is to expand to a daily production capacity of 15 tons with government support. Jeranjang power plant is estimated to use about 700,000 kg coal per day.

The total area of the landfill is 8.4 ha, including the actual landfill and offices, etc. The plan is to expand the area with additional 4.8 ha.

The landfill has a methane capture system, and the power generated from the methane is used for heating of offices at the landfill. The total methane potential is 9.7 mil. Nm3. Of this, only 5% is currently captured and utilized.




Photo 1) Landfill in Western Lombok (TPA Kebon Kongok), Photo 2) Methane capture system at TPA Kebon Kongok landfill); Photo 3) RDF Handling equipment, photo 4) RDF Credit: PT Inovasi

DEA, DEPA & COWI (2021); DEPA, DEA & Ramboll (2022); PT Inovasi (2022); Viegand Maagoe Analysis (2022)

LOMBOK'S POWER SYSTEM IS EXPANDING AND FEASIBILITY STUDIES FOR AN INTERCONNECTION TO BALI IS UNDER WAY

The power system in Lombok

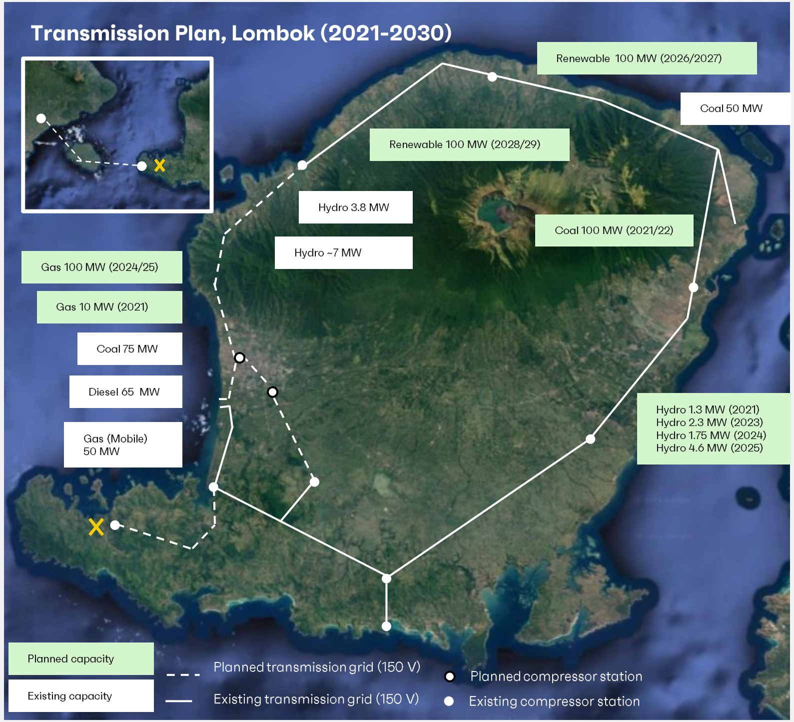
In 2018, all villages in Lombok except for one has access to electricity. However, locational differences in access to electricity remain, and rural areas have fewer hours in a day with access to electricity. This therefore yields an electrification rate of 90%. The mid/southwestern part of Lombok is the most populated areas and most commercial businesses are located along the western coast of Lombok.

As shown on the map, Lombok's power system is dominated by fossil fuel generation from coal, gas and diesel (See Appendix 2).

PLN is planning to expand the transmission grid (dotted line on the map), which will mean Lombok's power system will cover most of its coastal line, which is where most of the population resides.

A more interconnected system could lower the power generation costs and support a higher integration of renewable energy as was also mentioned in a study by KPMG from 2019.

The average power generation costs (BPP) of Lombok is 11.77 cUSD/kWh in 2020. This is significantly higher than Bali and Java, where BPP is around 6 cUSD/kWh. The electricity price on Lombok could decrease by connecting to the Java-Bali system.



Google Earth

PT PLN (2021); Umbra (2021); DEA & KPMG (2019); Viegand Maagoe Analysis (2022)

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A LOCATION AT OR ADJACENT TO KEBON KONGOK LANDFILL AND FUTURE TRANSMISSION GRID IS RECOMMENED

Recommendation for location of WtE

In assessing sites for WtE in Lombok, access to resources and grid as well as the potential for adding capacity at interconnection points are important. Site location however also depends on technology and waste type. Generally, it is recommended to reduce long distance transport of waste due to cost. There are also infrastructure challenges in the form of hilly roads, which aren't suitable for heavy duty truck transport.

Waste incineration requires a min. of 3-5 ha, while anaerobic digestion takes up 1-2 ha. In the meantime, pre-sorting is assumed to be necessary, which increases the space required for developing an AD facility. Landfill power generation based on methane capture does not require much space and could be located as part of the planned expansion of the Kebon Kongok Landfill.

Google Earth

DEPA, DEA & Ramboll (2022); DEA, DEPA & COWI (2021); Viegand Maagoe Analysis (2022)

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2. ASSESSMENT OF WASTE-TO-ENERGY TECHNOLOGIES

SCREENING OF WASTE-TO-ENERGY OPTIONS IN LOMBOK

Technologies producing energy from MSW

In the previous pages, an assessment of Lombok's waste management situation with respect to volume, location and waste characteristics, is provided. It is concluded that Lombok has a range of possibilities for waste-to-energy.

In 2021, COWI published for the DEA a Technology Catalogue for Solid Waste Management and Waste to Energy, which covers all possible technologies, including but not limited to, landfill gas extraction, gasification, pyrolysis, retrofit of coalfired blocks, anaerobic digestion and incineration. In 2022, Ramboll published for the DEPA and DEA a prefeasibility study on Waste for Lombok where they recommend mechanical biological treatment (MBT) in combination with anaerobic digestion (AD) and composting for treatment of the organic fraction of the waste, bio-drying of RDF for energy production in a co-firing process (power plants or cement kilns) and material recycling to separate plastic, metal, glass, paper and cardboard.

On the following pages, a range of waste-to-energy options is assessed with respect to the environmental impact, costs, requirement for source separation and maturity of technology. The technologies chosen are 1) Incineration, 2) Landfill gas power generation, 3) Anaerobic Digestion (AD) and 4) Mechanical Biological Treatment (MBT).

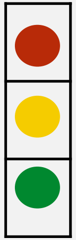
Existing experience with WtE in Lombok

1. Kebok Kenon landfill has a small RDF pilot plant, where the RDF is used in co-firing process in a coal power plant in Western Lombok
2. Kebok Kenon landfill captures 5% of the methane potential and convert it to power for local use on the landfill.
3. Lombok has 5000 household biogas plants across the island with capacities of 4-5 Nm^3/plant per year.

High-level assessment of WtE technologies

- The four selected WtE technologies are assessed according to their environmental impact and overall attractiveness with respect to a number of parameters such as costs, residues and complexity of technology.

- A traffic light system is used to illustrate how one technology performs on different parameters relative to the other technologies. Red indicates a low score and green indicates a high score.



DEPA, DEA & Ramboll (2022); DEA, DEPA & COWI (2021); Viegand Maagoe Analysis (2022)

INCINERATION IS AN EFFECTIVE WASTE MANAGEMENT TECHNOLOGY PRODUCING BASELOAD "RENEWABLE ENERGY"

Overall sustainability assessment of incineration

Incineration is part of the modern waste management system and a very effective technology for handling of waste streams that are difficult or too costly to recycle. This includes:

1. Non-recyclables fractions of waste from material recovery facilities;
2. Contaminated and greasy household waste;
3. Some fibers lose their ability to be recycled if recycled too many times (e.g. paper fibers);
4. Different materials (e.g. plastics from paper or foil from plastic) is sometimes impossible or too costly to recycle.

CO_2 is emitted from the combustion process, however up to 50% is biogenic CO_2, which can be reused for other purposes, such as carbonized beverages or synthetic fuels if captured. It can also be stored permanently in geological structures. Some of these technologies are however in the emerging stage and thus not fully commercial.

Incineration contributed to reduction of green house gases if it replaces it replaces fossil-based energy sources.

Energy generation	• Incineration is a base-load power capacity that produces all year around.	(green)
Climate and enviromental impact	• Production of power from incineration emits CO_2, however compared to coal power plants, it has a lower carbon footprint, since approximately 50% derives from the biogenic part of the waste. • Modern incineration is equipped with advanced flue gas cleaning capable of complying with the most stringent air emission requirements, e.g. the EU Industrial Emission Directive.	(yellow)
Reduction and handling of waste	• Very suitable for large scale waste management as incineration can handle MSW (general/residual waste)/C&I waste.	(green)

DEPA, DEA & Ramboll (2022); DEPA, DEA & COWI (2021); Viegand Maagoe Analysis (2022)

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INCINERATION IS COSTLY – BUT CAN HANDLE LARGE WASTE AMOUNTS AND DOESN'T REQUIRE PRE-TREATMENT

Overall assessment of incineration

Incineration based on grate fired combustion technology is a well-proven technology, which has been developed and refined over decades, and more than 2000 plants exist worldwide. Still, many countries, including Indonesia, have very little experience with incineration. The lack of experience and high complexity of the technology makes it costly to build and operate. Due to limited incineration experience, finding the required staff may prove difficult. Besides, environmental planning is often a challenge and takes time (5-6 years from planning to operation).

Electrical efficiency depends on steam data but is typically 25-30%. The financial feasibility of incineration can be improved by utilizing surplus energy as process steam for industrial applications.

Modern incineration has advanced flue gas cleaning technology and does not constitute a problem to the environment or human health. Bottom ash and flue gas cleaning residues need to be handled. Bottom ash can be used for road construction purposes while flue gas cleaning residues must be treated as hazardous waste although options also exist to use it as aggregate for special brick production or extract valuable metals.

cdoesn't require source separation nor pre-treatment of the incoming waste. This is an advantage in places like Indonesia where source separation is still in the early stages. It is however important that the calorific value of the waste is reasonable high (at least > 6 MJ/kg).

Environmental impact	High energy generation potential. Could potentially treat all MSW/C&I waste and solve some of the waste problem.	Green
CAPEX/OPEX	High investments dependent on quality level. Large and highly trained/ experienced staff and high maintenance	Red
Land requirement	3-5 hectares or even more dependent on plant size or storage needs	Red
Complexity of technology	Complex technology that requires high skilled labour	Red
Maturity of technology in Indonesia	Well-proven technology in developed countries, but so far little experience with incineration in countries like Indonesia. However, the first incineration plants in Indonesia are in the planning phase.	Yellow
Require pre-treatment	Incineration does not require pre-treatment of waste. However, the heating value might be too low, or need to be dried.	Yellow
Residue Management	High amount of bottom ash (150-200 kg/tons of waste) that could potential be used for construction purposes and a smaller amount of flue gas cleaning residue (30-50 kg/tons of waste) that needs to be landfilled/stored (treated a hazardous waste	Red

DEPA, DEA & Ramboll (2022); DEPA, DEA & COWI (2021); Viegand Maagoe Analysis (2022)

METHANE CAPTURE FROM LANDFILL GAS CAN PRODUCE ENERGY, BUT IT DOESN'T HELP LOMBOK'S WASTE SITUATION

Overall sustainability assessment of landfill gas

In the waste management hierarchy, landfills should be used only as a last resort. However, in many countries, including Indonesia, landfills are the dominant waste handling system. Where landfills are in place, methane can be collected, vented, flared or utilized for production of power, heat or renewable natural gas, either partly or fully. The latter requires removal of CO_2.

Landfills generate effluents from rainfalls and decom-position of organic waste. The effluents should be collected in a leakage pool to avoid leakage of waste-water into ground water.

Some landfills have waste-water treatment. The photo to the left shows a wastewater pond from Ijo Balit landfill, which is located in Eastern Lombok.

Landfill gas power has some climate mitigation potentials where it replaces uncontrolled releases of methane, however this technology has no impact on Lombok's waste reduction or waste handling goals.

Energy generation	• Methane from landfill gas is a source of renewable energy. • Power generated from landfill gas is cleaner source of energy than e.g. coal and oil, and could thereby support the green transition of Lombok's energy supply, however the power generation potential is low compared to other WtE technologies.	
Climate and enviromental impact	• Energy production from landfill gas reduce Lombok's green house gas emissions through reduction of methane from uncontrolled decomposition of organic materials and the replacement of fossil-based energy sources. • Exhaust emissions (PM, SOx and NOx) • To reduce the environmental impact of landfills both in terms of emissions and contamination of the water environment, it is advisable to install leachate and gas collection systems and surface sealing systems.	
Reduction and handling of waste	• Utilizing methane for power generation from existing landfills, does not adress Indonesia's waste reduction and waste handling goals.	

 DEPA, DEA & Ramboll (2022); DEA & COWI (2021); Viegand Maagoe Analysis (2022)

LANDFILL GAS POWER GENERATION IS A SIMPLE AND COST-EFFECTIVE TECHNOLOGY WITH FAVOURABLE ENVIRONMENTAL IMPACTS

Overall assessment of landfill gas

Harvesting and utilization of landfill gas (methane) for power generation is a well-proven technology and exists at many landfills worldwide. Lombok has 4 operating landfills, which can be utilized for power production. To produce power from landfills, you need a methane capture system and a gas engine. You also need an emergency flare in case of e.g., maintenance of the gas engine.

Electrical efficiency is lower compared to incineration (high efficiency on gas engine but efficiency per ton waste treated is lower due to the harvesting yield). The power production potential of landfills is proportionate to landfill's age and the share of organics disposed on landfills. The older the landfill the more organic waste has already been decomposed resulting in lower methane potential.

For the same reasons, the landfill gas power potential is higher in countries like Indonesia where source separation is at an early stage, since it means the share of organics on landfills is higher.

Landfill gas power generation is a relatively simple technology, and O&M costs are therefore low compared to other WtE technologies.

Methane gas is 27-30 times more potent than CO_2. Landfill gas therefore has significant green house gas (GHG) emissions effects

Environmental impact	Reduces uncontrolled methane emissions from landfills. While some landfill already have methane collection systems, most of the gas is flared and not utilized. Power generated from landfill gas could replace other (fossil) sources of power. However, landfill gas alone does not contribute to reduction of waste or improved waste handling in Indonesia.	
CAPEX/OPEX	Relatively low investment and low maintenance. Does not require high-skilled labor.	
Land requirement	The area needed for land fill gas is less than 1 hectare, corresponding to the land required for the gas engine.	
Complexity of technology	Relatively simple technology, which consists of a methane collection system, emergency flare and gas engine.	
Maturity of technology in Indonesia	Mature technology, which is already used in Indonesia. Lombok could tap into experiences with land fills gas power production from other provinces in Indonesia.	
Requires pre-treatment	Not required.	
Residue Management	Landfills generates effluents or wastewater from rainfall and aerobic and anerobic digestion of waste. This should be treated in wastewater treatment plants before final disposal. This is a case with or without the methane collection system.	

DEPA, DEA & Ramboll (2022); DEA, DEPA & COWI (2021); Viegand Maagoe Analysis (2022)

AD IS A RENEWABLE ENERGY SOURCE THAT REDUCES METHANE EMISSIONS FROM ORGANIC WASTE STREAMS

Overall sustainability assessment of anaerobic digestion

Anaerobic digestion (AD) is considered CO_2 neutral, since it reduces methane emissions from organic waste and converts it to renewable energy. In the case of Lombok, where only a small fraction of organic waste from households and industries is recycled, AD could reduce the amount of organic waste that is disposed of on landfills.

The climate impact of AD however depends on how the AD system is operated, how digestate is stored, and what type of fuel is used for process energy and transport of feedstock.

AD system may have some leakage of methane from the gas pipes, gas storage or the reactor itself. This can however be mitigated in the design process.

Modern AD plants have flue gas cleaning systems for removal of emissions of acid gases, NOx etc. will be higher.

Energy generation	• AD is renewable gas (biogas). When processed in a gas engine, it generates renewable power.	
Climate and enviromental impact	• AD reduces the amount of organic waste that ends on landfills, leading to methane emissions reduction from the decomposition of organic materials from e.g. household waste. • Some methane leakages from AD technology should be expected. The more advanced the AD technology is, the lower is methane leakage. • In case digestate is stored in an open pit before it is sent for disposal, there will be emissions of methane	
Reduction and handling of waste	• AD is a solution for organic waste streams, which is currently not handled or disposed of in landfills.	

IEA (2017); DEA, DEPA & COWI (2021); Viegand Maagoe Analysis (2022)

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SIMPLE AD TECHNOLOGIES CAN HANDLE ORGANIC WASTE STREAMS AT RELATIVELY LOW COSTS

Overall assessment of anaerobic digestion

Anaerobic Digestion (AD) is a well-proven technology and exists all over the world in various sizes from farm scale to industrial facilities. AD can in principle treat all types of organic waste, however depending on the complexity of the waste stream, pre-treatment, pasteurization and more advanced stirring and mixing systems may be required.

More advanced technologies, like continuous stirred tank reactors (CSTR) has the potential to generate higher yield. Box-based systems are suitable for waste with a high dry matter content. In some cases, a simple lagoon digester system may be suitable. A lagoon digester is most suited for feedstock with high moisture levels.

Aside from methane gas, AD produces degassed biomass also known as digestate. Digestate can be separated into a solid fraction and liquid fraction, and it can be used as agricultural fertilizer or bedding. When sourcing feedstock for AD, it is therefore important to measure phosphor and nitrogen values, as too high contents of P and N in the digestate can lead to nutrient run-offs and groundwater contamination.

In cases where organic waste is derived from MSW, there is a higher risk of plastic, metals and other contaminants in the digestate. It is therefore advisable to only use source separated waste for AD.

Environmental impact	With AD, Lombok could reduce the share of organics that ends up in landfills. This leads to reduction of methane emissions and production of a baseload renewable energy, which can substitute fossil-based energy generation.	
CAPEX/OPEX	Relatively low investments depending on technology. Limited but trained/experienced staff. Sorting, transport and logistics require large staff	
Land requirement	AD takes up 1-2 hectares. This includes trucks access, biomass storage and the AD plant itself incl. gas engine.	
Complexity of technology	Both advanced and less advanced technologies for AD exist, however it would be possible to start with a relatively simple technology such as a covered lagoon and later upgrade the system by adding mixers and more advanced pumping equipment.	
Maturity of technology in Indonesia	Already used in Lombok but only at a very small scale. The type of technology most commonly used in Indonesia, is covered lagoon systems.	
Require source seperation	If digestate is distributed on farmland, source separation of organic waste used for AD is necessary.	
Residue Management	Residues from an AD plant comprises digestate, which can be a source of revenue for the plant owner, however depending on the level of source separation it could be contaminated.	

DEA, DEPA & COWI (2021); Viegand Maagoe Analysis (2022)

MBT IS SUITABLE FOR HANDLING OF MSW AND CAN BE AN INTERMEDIATE STEP IN THE PRODUCTION OF "RENEWABLE ENERGY"

Overall sustainability assessment of MBT

An MBT (Mechanical and Biological Treatment) plant typically consists of a mechanical part a biological part. The mechanical part could be in the form of a Material Recovery Facility (MRF) for sorting of the incoming waste into various fractions such as an organic fraction and other waste fractions such as plastic, metals, glass, paper, cardboard and residues.

The organic fraction can go for further treatment in the biological part such as an AD and/or Composting facility. Bio-drying is a process that can be used for both the residue fraction (RDF) from the mechanical part and for digestate and/or compost. RDF can be utilized in a co-firing process at either power or cement plants.

MBT is useful in resource recovery, designed to optimize the use of resources remaining in residual waste and could be used in an integrated waste management program.

Energy generation	• If AD on the organic fraction is included, it is renewable gas (biogas). When processed in a gas engine, it generates renewable power. • RDF can be used for co-incineration in cement plants or power plants. • Does not add to Indonesia's renewable energy target alone
Climate and enviromental impact	• The organic part can be used to produce biogas and is thus considered green biogas. RDF produced is normally sold to offtakes in the cement or power industry.
Reduction and handling of waste	• Suitable for large scale waste management as MBT can handle MSW (general/residual waste)/C&I waste

WELL PROVEN AND FLEXIBLE TECHNOLOGY FOR HANDLING OF MIXED WASTE BUT REQUIRES SKILLED LABOR

Overall assessment of mechanical biological treatment

Mechanical Biological Treatment (MBT) technology consists of a Material Recovery Facility (MRF) that could be either "clean" or "dirty". A dirty MRF is a waste processing facility, accepting deliveries from a mixed solid waste streams (otherwise known as residual waste or general waste). A clean MRF accepts only source separated materials.

MBT can be done more or less advanced dependent on different factors like costs, product quality and the need for separation.

The easy digestible organic fraction from food waste and residues can be handled in an AD facility and converted to biogas (energy) and fertilizer (nutrients). The digested fraction from the AD facility can be mixed with garden and green waste in a composting facility.

Materials like plastic, metal, glass, paper and cardboard can be sorted out and recycled. Non-recyclable residues can be used as RDF for cofiring in power plants, cement industry or stored for export.

In the Western Regency of Lombok, RDF is already produced at small scale and used as a supplementary feedstock for power generation in a coal power plant.

A small portion of the MSW cannot be utilized in any of the above solutions. This fraction has to be disposed at existing landfill or sent for incineration if available.

Environmental impact	MBT can treat and separate almost all waste types, including plastic, metals and organics. A higher availability of MBT systems could help Indonesia fulfil its waste handling and reduction goals. In cases where the organics part is used for energy production, MBT indirectly increased Indonesia's renewable energy generation potential.	
CAPEX/OPEX	Medium to high investments dependent on sorting options and quality level. Relatively high skilled labour and maintenance costs should be expected.	
Land requirement	2-3 hectares however very dependent on size, sorting options, etc.	
Complexity of technology	Could be complicated depending on the steps/options in terms of sorting and energy production.	
Maturity of technology in Indonesia	Well proven technology, however very little experience with commercial scale MBT in Indonesia	
Require source seperation	It depends on whether it is a clean or dirty MBT. A clean MBT requires source separation of waste.	
Residue Management	A residue from MBT facilities is a fraction that can neither be recycled, used for RDF or used in the AD plant. This fraction needs to be either disposed at a landfill or incinerated if an incineration plant is available	

DEA, DEPA & COWI (2021); Viegand Maagoe Analysis (2022)

THE FOUR TECHNOLOGIES SOLVE DIFFERENT PROBLEMS – A COMBINATION IS THE MOST LIKELY SCENARIO

Conclusion: none of the 4 technologies should be ruled out

On the previous pages, we presented a methodology for assessing waste-to-energy technologies. Public decision makers may draw inspiration from this methodology when formulating selection criteria for public tenders.

It has not been possible to conclude, which technologies are more feasible, because in the end, it depends on the weight assigned to each assessment criteria. In addition, the technologies solve different problems. While incineration is an efficient technology for removing a large mixed waste stream while producing electricity, anaerobic digestion (AD) technology is suitable for handling bio-waste. AD also produces power, but the generation potential is lower compared to incineration. Opposed to incineration, AD and landfill power, mechanical biological treatment (MBT) does not generate power, but MBT could act as an enabler of other technologies while improving waste sorting and handling. Lastly, landfill gas power is simply utilizing the methane, which is generated from the decomposition of waste in landfills. In other words, landfill power does NOT contribute to waste reduction, which is one of Lombok's priorities when it comes to waste management.

In conclusion, Lombok will most likely need a combination of all four technologies in order to meet government goals. In any case, it is necessary with more detailed information on the potential of the four technologies. To that end, we recommend following four typical steps related to project maturation.

The project maturation for a WtE project can be broken down into four phases as illustrated below.

1 Identication	• Screening of project and technology ideas.
2 Concept Development	• Pre-feasibility and feasibility studies.
3 Business Development	• Waste supply, permits, off-take contracts and sites, etc.
4 Project Execution	• Civil works, construction and commissioning

Having completed the identification phase, the next step is a pre-feasibility study comparing and pricing realistic options in a local context. A pre-feasibility study can be used to rule out unattractive investments.

WtE project development is complex, and it is therefore recommended to follow a **Project Development Guideline** as the one outlined in Chapter 3.

IFC (2017); Viegand Maagoe Analysis (2022)

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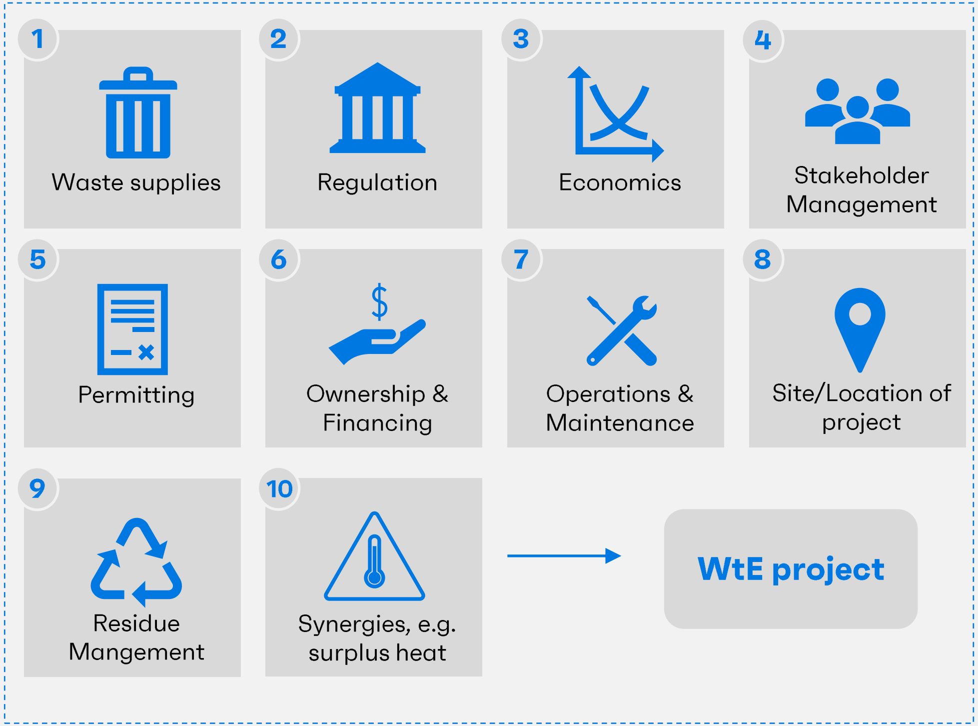
3. PROJECT DEVELOPMENT GUIDELINE

DEVELOPMENT OF A WASTE-TO-ENERGY PROJECT SHOULD INCLUDE ASSESSMENT OF 10 IMPORTANT STEPS

Project Development Guideline

- This brief project development guideline provides an overview of the steps a developer needs to consider when developing a Waste-to-Energy (WtE) project in Indonesia.
- The guideline is in principle generic but does include country as well as technology specific considerations for Indonesia. Some local context information is provided for Lombok.
- The following pages unfold the 10 topics that as a minimum should be covered when embarking on project development for Waste-to-Energy projects.



TECHNOLOGY CHOICE DEPENDS ON WASTE VOLUME, SHARE OF ORGANICS AND CALORIFIC VALUE OF WASTE

Waste characteristics and technological fit

The calorific value of waste is important when assessing whether a given feedstock is suitable for incineration, and approx. 5.5-6 MJ/kg is considered a minimum to keep the combustion process going without using any auxiliary firing (e.g. natural gas, LPG or oil).

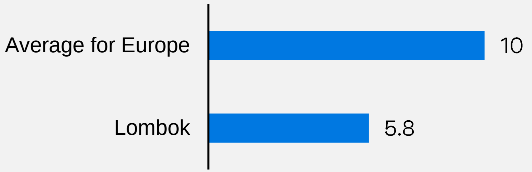
The average calorific value of MSW in a European country is around 9-11 MJ/kg depending on the share of organics. In a country like Indonesia the share of organics is estimated to be around 75% resulting in a very low calorific value (<6 MJ/kg for Lombok). Source separation, upfront separation or additional C&I waste to boost the caloric value could potentially be an answer to this challenge.

Anaerobic digestion (AD) can be based on source separated organics from MSW but could be supplemented by other organic fractions from the industry or the agriculture (waste streams from dairies, breweries, chicken farms, food markets, etc.). Since organic waste constitutes a large portion of the total waste composition in Lombok, the potential for power generation from AD is high.

Due to the high share of organics in Lombok, resulting in low calorific values, non-source-separated waste is most suited for wet AD technology.

Lastly, when designing plants and on-site storage capacity, it is important to keep in mind the availability of waste.

Calorific value of MSW (MJ/kg.)



Difference between wet and dry AD technology

- Wet anaerobic digestion systems are designed to process biodegradable feedstock into a digestate slurry with typically less than 15% total solids. Consequently, wet systems is based on tank systems using mixers/agitators.
- Using dry anaerobic digestion, the feedstock can be stacked (over 15% solids), with leachate sprayed over the top of it which percolates through the material, breaking it down over a longer retention time.
- The main advantage of wet AD and the continuous process is that it produces higher biogas production over a shorter time period.

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DEPA, DEA & Rambøll (2022); Viegand Maagoe Analysis (2022)

REGULATION SUPPORTING WASTE-TO-ENERGY PROJECT DEVELOPMENT

National Waste Policy

Presidential Regulation No.97/2017 is the regulatory framework behind Indonesia's national waste policy and strategy, which sets a 30% waste reduction target and a 70% waste handling target by 2025 compared to the base year in 2017. It is obligatory for local, regional and provincial governments to implement strategies, which are adapted to the local context. It is required to form a strategy, monitor, evaluate and report on progress to the national government.

According to available data from the provincial government, Lombok has a handling rate of ~40 % and a waste reduction rate of 2% in 2022 and Lombok is therefore far from fulfilling the national target.

In practice, assessing waste handling ratios proves difficult. One of the reasons being that a large portion of waste collection is handled by the informal sector like scavengers. Scavengers also often operate in more regencies, which create a risk of double counting.

As stipulated in **Presidential Regulation No 35/2018**, 12 cities in Indonesia are eligible for additional support for waste-to-energy in the form of higher feed-in-tariffs for electricity and tipping fee contributions from the national government. However, Lombok is not (yet) covered by this regulation.

Waste-to-energy regulation: Perpres No. 35/2018

Perpres No. 35/2018 is a specific regulation for accelerating waste incineration implementation in Indonesia in 12 strategic cities (DKI Jakarta Province, The City of Tangerang, Bandung, Semarang, Surakarta, Surabaya, Makassar, Bekasi, Manado, Tangerang Selatan, Palembang and Dempassar).

Perpres No. 35/2018 includes a specific feed-in-tariff for power generated from waste-to-energy and a subsidy from the government to cover the costs of feedstock (so-called tipping fee). **For prioritized cities under Perpres No 35/2018, feed-in tariffs of 13.35 cUSD/kWh for power plants with a capacity of less than 20 MW.**

In addition, projects in prioritized cities may receive a contribution from the state budget to cover the tipping fee – in case the contribution from the local government is insufficient to make the business case financially viable. **The maximum tipping fee for projects located in one of the 12 cities is 500.000 IDR/ton, corresponding to 38.5 USD/ton.**

DEPA, DEA & Rambøll (2022); PERPRES (No. 35/2018); DLHK NBT Province (2022); Viegand Maagoe Analysis (2022)

REGULATION SUPPORTING CLEAN/RENEWABLE ENERGY

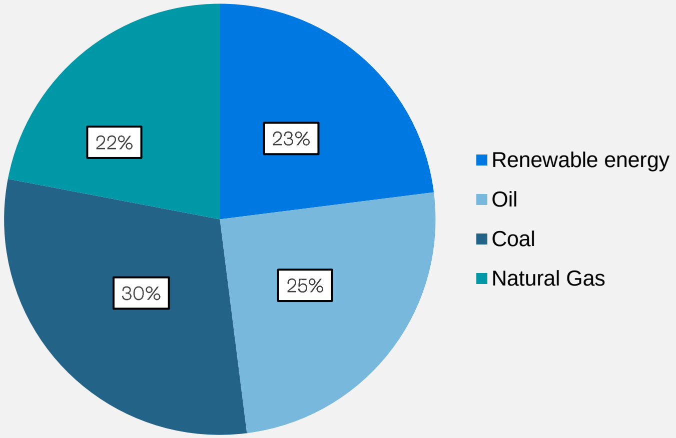
Regulatory drivers for renewable energy

The national government of Indonesia has set a goal of reaching 23% renewable energy supply in the power sector in 2025 and 31% in 2050. In 2020, only 5% of Lombok's power supply came from renewables. Nusa Tengara Barat (NTB) Province, which includes Lombok, has set a political target of 60% renewable energy in the power sector by 2030 and net-zero emissions in all sectors by 2050. Lombok's renewable energy target is not reflected in the current RUPTL for Lombok.

The prices for electricity purchased from renewables is set by the national Ministry of Energy and Mineral Resources (MEMR). The most up-to-date regulation, No. 50/2019, sets the pricing regime per power producing technology type (see also page 28).

In the North Lombok Regency, the municipal government has initiated a cost-sharing program for household scale biogas, where 30-40% of the investment costs can be covered. The average size of these is 3-4 nm^3. Around 5000 mini-scale biogas plants exists across Lombok. Since fuel is not produced locally in Lombok, these biogas plants help households become independent of imported LPG.

National Energy Mix in 2025 according to Government Regulation 79/2014



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ECONOMICS – ASSESSING CAPEX/OPEX ELEMENTS

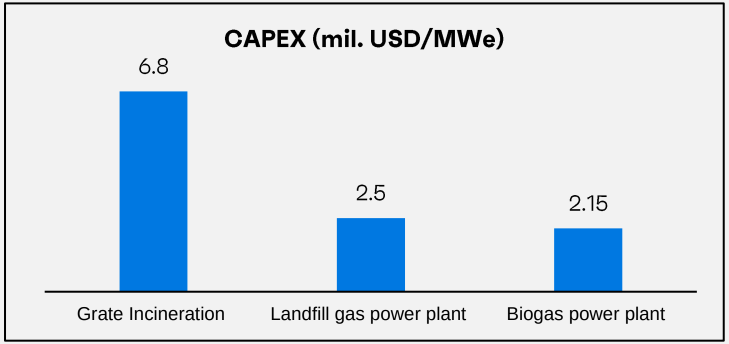
Plant quality must be determined

CAPEX varies across technologies with incineration being the most expensive at around 7 mil. USD/MWe. AD technologies can be acquired for 2-2.5 mUSD/Mwe also dependent on complexity. Due to high investment costs for incineration, access to feedstock and gate fees is determining for the economic feasibility of a project.

For incineration there is economies of scale, and the minimum size is around 10 tonnes per hour. The price/ton treated will decrease up to a unit size of 35-40 tonnes per hour which is the largest unit size available. This economy of scale also applies for other technologies.

Both high quality/high-cost suppliers and low-cost suppliers are available at the world market and thus the quality level of the equipment could vary substantially . For an incineration plant cost for the electromechanical part ~~could~~ may vary several hundred percent between cheapest and most expensive, however also with a difference in quality and execution. For the procurement it is important to decide the quality level while drafting technical tender specifications.

OPEX includes elements like manning, administration, insurance, maintenance, consumables and handling of residues. All this could also be included in a long-term O&M contract with a contractor.



	Incineration power plant	Landfill gas power plant	Biogas power plant
CAPEX	6.8 Mil. USD/MWe	2.5 mil. USD/MWe	2.15 mil. USD/MWe
Fixed O&M	243.700 USD/MWe/year	125.000 USD/MWe/year	97.000 USD/MWe/year
Variable O&M	24.1 USD/MWh	13.5 USD/MWh	0.11 USD/MWh

DEA, DEPA & COWI (2021); DEA & EA (2021); Viegand Maagoe Analysis (2022)

ECONOMICS – TIPPING FEES AND RESIDUES ARE SOURCES OF REVENUE FOR THE WTE PLANT OWNER

Tipping fee is important for waste incineration

Tipping fees, which is also called gate fees, typically constitute a critical source of revenue in a waste-to-energy project.

Due to the high investment costs of incineration, a high tipping/gate fee of ~500,000 IDR/ton is needed to realize a financially sound business case. The tipping fee would be covered by the government who controls the waste and the waste management facilities. However, due to budgetary constraints, it is not deemed realistic to negotiate a tipping fee with the government above ~180,000 IDR/ton.

Without a sufficiently high tipping fee, the electricity price needs to be heavily subsidized in order to make the business case financially attractive.

Tipping fees are less sensitive to the bankability of landfill gas projects and biogas projects since these technologies are less capital intensive.

Residues in the form of digestate from AD or RDF is another potential source of revenue from waste-to-energy plants.

It should be noted that residues from incineration may imply cost as especially flue gas cleaning residues needs to treated as hazardous waste (treatment cost in Europe are typically 150 USD/ton).

What is a tipping fee?

A tipping fee is a charge for waste disposed of at a landfill or other waste handling facility. The tipping fee is based on the weight of the waste that is disposed of. The tipping fee helps to cover the operational costs of a waste handling facility. The tipping fee is paid by anyone who disposes waste at a landfill or WtE facility.

Sales of by-products

Waste-to-energy plants generate a number of by-products or residues, which depending on regulation, level of post-treatment and demand, can be monetized and sold in various markets. Digestate, which is a by-product from AD, can for instance be used as crop fertilizers or animal bedding. The market demand for digestate for use as biological fertilizers often depends on the availability and costs of synthetic fertilizers. Depending on the composition of feedstock in AD, digestate may also have higher nutritious value for farmers.

ECONOMICS – ASSESSING OFF-TAKE OPPORTUNITIES WITH REGARDS TO SALES OF ELECTRICITY

PPA price for renewable energy in Lombok

While the primary source of income typically comes from tipping fee contributions, feed-in-tariffs for electricity produced from waste-to-energy is also an important condition for securing a financially sound business case.

Lombok follows the national regulation regarding price-setting of renewable energy generation where the regional power purchasing price (PPA) of Independent Power Producers (IPP) is benchmarked according to the regional generation costs also referred to as BPP (Biaya Pokok Pembangkitan).

Calculation of tariffs: In case a local BPP is higher than the national average, the PPA price between PLN and the developer of biogas can maximum be 85% of the local BPP, corresponding to 10.01 cUSD/kWh. For incineration projects, the maximum tariff is 100% of the local BPP corresponding to 11.77 cUSD/kWh.

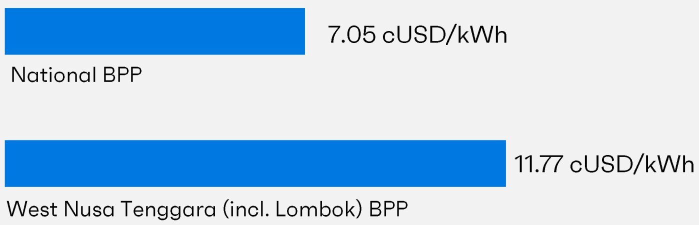
In the meantime, PLN is not obligated to accept the maximum tariff, and in the absence of specific mandates concerning the share of waste-to-energy in the power mix, waste-to-energy will need to compete with other renewable sources such as solar PV.

Another challenge is that the BPP must decrease from year to year. From 2018-2020, BPP has decreased with 8 percent point

Tariffs based on current regulation

Current regulation (No.50/2019 and revisions)	Max. tariff of local BPP (%)	Expected PPA price*
Biogas	85%	10.01 cUSD/kWh
Waste-to-Energy (incineration)	100%	11.77 cUSD/kWh

BPP in 2022 (PLN)



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PLN RUPTL(2020); Viegand Maagoe Analysis (2022)

MAP STAKEHOLDERS AND IDENTIFY NECESSARY PERMITS

Stakeholders and agreements in a WtE project

To complete a WtE project, several agreements, permits and contracts should be in place. This could include a loan agreement with financiers, grid interconnection agreement, waste supplies contracts and sales contract. Depending on the ownership model, the sales contract would typically be a PPA Agreement with PLN. Others include contracts with consultants, construction companies etc.

All aspects are vital for a financially sustainable project. If these agreements are missing, the project developer faces large risks. While some processes run in parallel, others are overlapping and interdependent. For example: most financial institutions want to see waste supply agreements and off-take agreements before they want to commit to a loan. Similarly, a developer should expect to front load costs related to permitting before a financial investment has been made, simply because environmental permits tends to be a lengthy process.

Negotiating terms of contracts and obtaining permits require a significant degree of stakeholder management to ensure that attractive pricing is achieved, and significant project risks are observed early in the process so these can be mitigated. The more complex the WtE project is, the more stakeholder engagement and management is needed.

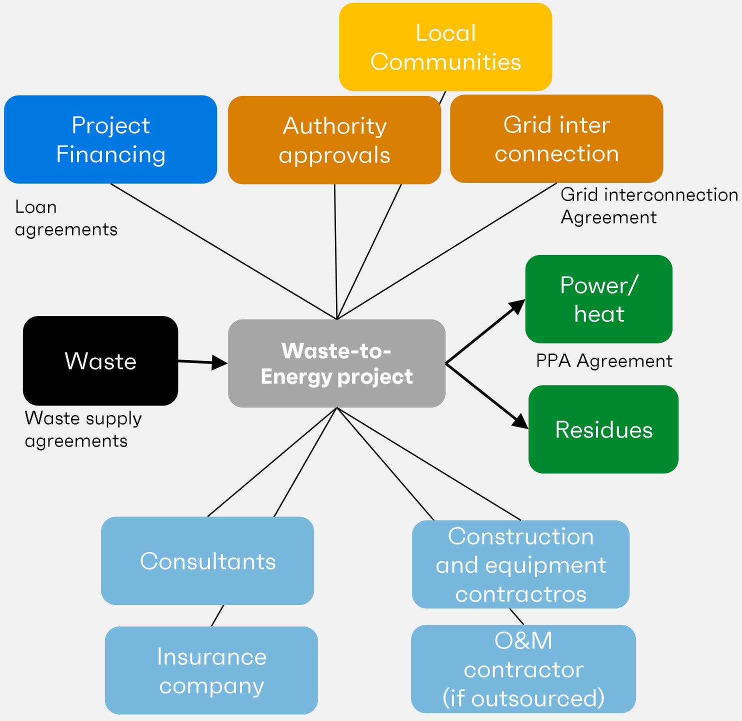

Figure: Converting Waste to Energy, Viegand Maagoe

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IFC (2017); Viegand Maagoe Analysis (2022)

STAKEHOLDER ENGAGEMENT AT THE PROVINCIAL AND LOCAL LEVEL IS NECESSARY

Selected key stakeholders in Lombok

Waste-to-energy generation in Indonesia involves a large group of stakeholders and public agencies. A natural starting point is to liaise with **Dinas LHK and Bappeda** as those organizations are responsible for the planning and managing of solid waste in Lombok. They could connect developers with large waste generators or community organizations in charge of the local waste management around the island. **The public works and spatial agency (DPUPR),** is authorized to undertake infrastructure planning and may facilitate funding for CAPEX expenditures. Besides, **DPUPR** is responsible for approval of sites for WtE.

It is also advisable to talk to the technical operating units under Dinas LH/LHK in charge of the landfills in Lombok to obtain a hands-on experience of the waste composition and waste system of Lombok and to learn about future plans concerning WtE.

It is recommended to understand the provincial priorities and potential support for renewable energy by talking to **Dinas ESDM for NTB province. PLN** is important for negotiating the PPA agreement and connection to the grid.

Stakeholder	Role in the waste-to-energy project development
Dinas LHK - NTB province (Environmental office)	Dinas LHK undertakes management of the waste sector and is the mains responsible for the Zero Waste Strategy. A special unit in Dinas LHK is responsible for the management of the regional landfill Kebon Kengok.
Dinas LH (city and regency levels)	Each regency of Lombok and Mataram City assume responsibility for the local waste management, including operation of landfills (except Kebon Kongok) and collection and transfer of waste.
Dinas ESDM NTB Province (Energy Agency)	Regulator of energy planning and integration of renewables for NTB. Responsible for implementation of national renewable energy targets in the NTB province including Lombok
Dinas PUPR (Public Works and Spatial Planning Agency)	DPUPR is responsible for large-scale infrastructure provisions and approval of funding for capital expenditures related to WtE. DPURP also approves sites for WtE energy plant
Bappeda (NTB province)	Responsible for the long-term development plan of NTB province, including planning of government budget and development activities related to waste management.
PLN	Vertically integrated power company. PLN is responsible for grid connection and the PPA contract.

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PERMITTING REQUIREMENTS SHOULD BE IDENTIFIED AT AN EARLY STAGE

Permits for a waste-to-energy project

Waste and energy projects typically require several approvals, some of them with a long lead time and thus the application process must be planned well in advance before they are needed. The permitting process typically gives the critical path in a project up to financial close.

Three types of permits are common in a waste to energy project 1) Environmental Impact Statement and Environmental Approval (EIS/EIA), 2) Building Permit and the 3) Operational permit.

Local conditions may tricker other applications like connection to the grid, sewage, etc.

Especially Environmental Impact Statement (EIS) and Environmental Approval may be costly as specialized consultants are needed and the public involvement process may be challenging. Transparency with the authorities and public is normally a key to success in the permitting process.

It is recommended to get a full overview of permits needed at an early stage and to liaise closely with the authorities and the community stakeholders from the very beginning.

Environmental Approval (EIA)

An EIA permit is granted when the government have approved that the design of the facility lives up to environmental standards and regulation related to, e.g. emissions, exhausts, and groundwater protection.

Building/construction permit

The building permit is the developer's right to build in a specific location. The approval of the building permit is typically more smooth if the location of the project is an industrial zone or even better – if it has previously been used for waste management activities.

Operational permit

The operational permit is the the developer's license to operate. In the case of a waste-to-energy project, an operational permit involves the right to operate as a waste management and electricity provider.

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DECIDE ON PROJECT OWNERSHIP STRUCTURE

Typical project ownerhip structures

The ownership structure of a WtE projects can be divided into three overall categories:

1) A public project developed, owned and financed by the local council or other public entities (operation can either be with own staff or outsourced)

2) A Public-Private-Partnership (PPP) between a private investor/ contractor and the local waste authorities signing long term waste supply agreements.

3) Merchant/commercial project (also known as IPP when it comes to power production) developed, owned, financed and operated by a private entity based on long term waste supply agreements (also with private waste management companies) and Power Purchase Agreements

Since 2017, developers of renewable energy in Indonesia were required to transfer their assets to PLN upon expiry of the PPA contract. This project model, also known as "BOOT" (build-own-operate and transfer) was scrapped in 2020, since the requirement to transfer the renewable asset to the state compromised the bankability of the project. This regulatory change is expected to increase the investments into renewable energy and waste-to-energy projects in Indonesia.

Weighted Average Cost of Capital (WACC) = 12%

$WACC = \%D \; x \; i\_D \; (1 - t) + \%E \; x i\_E$

Share of debt of total project financing (%)	%D	70%
Cost of debt (commercial loan interest rate)	i_D	13%
Tax rate	t	25%
Share of equity of total project financing (%)	%E	30%
Costs of capital using CAPM formula	i_E = rf+B(rm-rf)	17%
Risk free return	Rf	6%
The risk of conducting business expressed as Beta (B)	B	1.2
Market return	rm	15%

The ownership and financing model for a WtE project depends on the developers' access to capital, regulation and risk profile. Where project financing depends on both equity and loan, the costs of capital can be calculated by using the WACC formula. The costs of capital for renewable projects in Indonesia is assumed to be 12%.

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ADB (2020); DEA & KPMG (2019); Viegand Maagoe Analysis (2022)

DECIDE O&M STRATEGY: IN-HOUSE OR OUTSOURCING?

Who should conduct O&M?

A developer/owner of the waste-to-energy facility should decide on how to perform Operations and Maintenance (O&M). One option is outsourcing by engaging a long-term O&M contractor and another having O&M resources in-house.

There are however several options in between, for example maintenance can be fully or partly outsourced to external contractors as this mainly takes place in the few weeks of the major overhaul. We often see owners taking responsibility for the operation with their own staff including a few maintenance staff responsible for the day-to-day maintenance. Larger maintenance jobs including insulation, scaffolding, boiler and refractory repair, etc. are outsourced to local and specialist contractors.

Another way is to contract maintenance on a component/plant basis, e.g., sign a maintenance contract with the original equipment suppliers on specific components like turbine, boiler and gas engines.

Local content requirements and local competences should be considered when deciding on outsourcing or in-sourcing of O&M activities.

In-house O&M	Outsourcing O&M
• Control of Operation with own staff that improves skills and knowledge of the plant (could be utilized in other plant later) • The long-term maintenance level may be secured better than if outsourced (O&M contract is typically fixed in time) • To a large degree independence of external assistance (time and cost wise)	• The responsibility/risk of O&M is taken by a contractor that typically gives guarantees on e.g., availability and treatment capacity. Use of spare parts is normally the contractor's responsibility • More expensive as the O&M contractor requires an overhead and a risk premium. On the other hand, the experienced contractor may introduce a high operation efficiency that is otherwise difficult to achieve.

FIND LOCATION AND CONSIDER INFRASTRUCTURE, WASTE VOLUMES AND ENVIRONMENTAL RESTRICTIONS

Important questions when it comes to location

A critical step in developing a WtE project is finding a suitable location. Location must therefore be considered at an early stage in the development process, in order to assess whether it is worthwhile to spend more resources on project development. With regards, to location, the following questions should be investigated:

1. Is the required waste resources available in reasonable distance and with the requested quality (waste supply agreements must be explored)?
2. Does the site have reasonable planning conditions, preferable a brown field site?
3. Are there any environmental limitations (e.g. nature reserve)?
4. Does the site have reasonable ground conditions (easy foundation) and hereunder no or little contamination?
5. Does the site have good access roads for waste trucks and other trucks?
6. Are there any noise sensitive neighbors nearby?
7. Is grid connection available at a close distance (should be able to absorb all exported power without upgrades)?
    1. It is also important to investigate who is paying for the grid connection (PPA and grid connection agreement must be explored)
8. Are the necessary utilities available nearby (water, sewer, etc.)?

Below table shows indicative space requirements for different technologies. It should be noted that space requirements are very dependent on the need for e.g., treatment capacity and storage capacity. The values are therefor not directly comparable and should be read merely as a best guess.

Incineration power plant	**Landfill gas power plant**	**AD power plant**	**MBT plant**
3-5 hectars or more dependent on size	<1 hectar (only power plant w. gas engine)	1-2 hectars dependent on size	2-3 hectars dependent on size

Anaerobic digestion (AD) requires less land than incineration while MBT also requires substantial land especially if combined with an Anaerobic digestion plant and power production using gas engines.

Additional land may be needed for storage, preassembly, welfare facilities and carpark during construction, bottom ash storage, sorting as well as fly ash storage.

It is advised to conduct a thorough site selection investigation in the a very early stage of the development phase.

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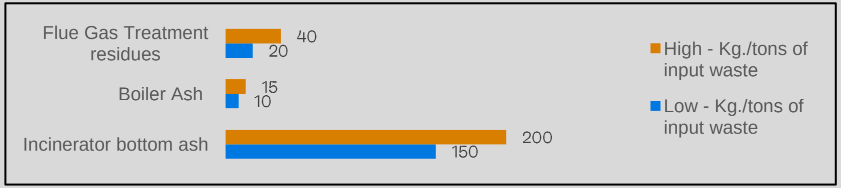
RESIDUE MANAGEMENT FOR SOME TECHNOLOGIES IS SUBJECT TO REGULATORY CONSTRAINTS AND AMENDMENTS

Residues from Waste-to-Energy plants

Waste-to-energy technologies generate residues. Residues are by-products, which may be reused or disposed of. In this respect, it is important to get familiarized with the regulation and costs associated with disposal of waste products. Some residues may have market value, in which case it becomes important to investigate potential off-takers and their willingness to pay. Incinerator bottom ash can for instance be reused for construction purposes and in some European countries it is used for road construction as a base layer substituting natural gravel. Denmark reuses approx. 99% of all bottom ash for road construction purpose. It is also possible to extract valuable metals (e.g., gold and silver) from the bottom ash using advanced sorting plants. In some cases, changes in regulation are required in order to enable the sales of residues. It is therefore advisable to investigate the rules and potentials and liaise with authorities early in the project development phase.

The graph below shows indicative volumes of residues generated from incineration showing a low and a high estimate.



Typical residues from three WtE technologies

Incineration

Incineration plants generate three types of solid residues:

- Incombustible matter (ash) that remains on the grate is referred to as Incinerator Bottom Ash. I may be used for construction purposes.
- Solid residues generated from the flue gas treatment process also called Air Pollution Control (APC) residues is a mixture of activated carbon and lime and it contains hazardous substances like heavy metals and dioxin/furans.
- Boiler ash or fly ash is collected in the boiler.

Mechanical biological treatment (MBT)

A residue from MBT facilities is a fraction that can neither be recycled, used for RDF or used in the AD plant. This fraction needs to be either disposed at a landfill or incinerated if an incineration plant is available.

Anaerobic Digestion (AD)

The residues from Anaerobic Digestion is called digestate. Digestate can be separated into a solid fraction and a liquid fraction. The liquid fraction can be upgraded and used in fertilizing industry or be applied directly as fertilizer on farmland. The solid fraction can be used as soil amendment. It is important check if the quality of the digestate is sufficiently good to ensure that the use for fertilization purposes comply with relevant regulation.

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3 Economics
4 Stakeholders
5 Permitting
6 Ownership & financing
7 Operation & Maintenance
8 Site/Location
9 Residue Management
10 Synergies e.g. surplus heat

UTILIZING SURPLUS HEAT CAN BOOST THE BUSINESS CASE

How can the heat be utilized?

Incineration produces high pressure steam that can run a steam turbine/generator producing electricity that can be exported to the high voltage grid.

The surplus heat in the steam leaving the turbine backend needs to be cooled away, typically in an air-cooled condenser.

The surplus heat could potentially be used either as low-pressure steam for industrial purposes (intermedium extraction at the steam turbine) or as hot water for industrial purposes, e.g., process industry, absorption cooling, desalination, etc. In order to ensure a sound basis for the business case, it is critical that the developer can secure a stable offtake agreement of surplus heat with e.g., a desalination plant, a mall or a public building.

The electrical efficiency of incineration is 25-30% but if the surplus heat is utilized, the total efficiency of the plant could be 90% or higher.

Gas engines also offers the opportunity to produce steam/heat (exhaust gas, oil cooler, etc.) besides from the power itself.

Pros of utilizing surplus heat

- Increases the overall plant efficiency
- Increases revenue from sales of steam/hot water

Cons of utilizing surplus heat

- The electrical efficiency will decrease slightly but might be outweighed by sales of heat/steam
- Is slightly more capital intensive
- The financial viability of a business case, which includes surplus heat utilization, may not be robust enough considering the risk of off-takers go bankrupt or close.

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4. REFERENCES & ADDITIONAL MATERIALS

REFERENCES

Asian Development Bank (ADB) (2020). *Renewable energy tariffs and incentives in Indonesia - Review and recommendations.* Link

Danish Energy Agency (DEA) & Ea Energy Analyses (EA) (2019). *Lombok Energy Outlook*. Accessed 13 January 2022. Available at Link.

Danish Energy Agency (DEA) & KPMG (2019). *Pre-feasibility studies on RE solutions*. Accessed 13 January 2022. Available online at Link.

Danish Energy Agency (DEA) & Ea Energy Analyses (EA) (2021). *Technology Data for the Indonesian Power Sector. Catalogue for Generation and Storage of Electricity*. Link.

Danish Energy Agency (DEA), Environmental Protection Agency of Denmark (DEPA) & COWI (2021). *Development of cross-sectorial tehcnology catalogue for SWM and energy*. Accessed 13 January 2022. Available online at: Link.

Environmental Protection Agency of Denmark (DEPA) & Ramboll (2022). *Pre-feasibility study (waste) of Lombok. Accessed 19 September 2022. Available online at Link*.

International Finance Corporation (IFC) (2017). Convertering Biomass to Energy. Accessed 20 September. Available online at Link

International Energy Agency (IEA) (2017). *Methane emissions from biogas plants*. EIA Bioenergy. Accessed 1 May 2022. Available online at: Link.

Dinas Lingkungan Hidup dan Kehutanan, Nusa Tenggara Barat - DLHK NBT Province (Interview, 2022).

Presidential Regulation (PERPRES) (No. 35/2018). *Presidential Regulation (PERPRES) concerning the Acceleration of Construction of Waste Processing Installations into Electrical Energy Based on Environmentally Friendly Technology*. Accessed 19 September. Available online at Link.

Presidential Regulation (PERPRES) (No.97/2017). *Presidential Regulation (PERPRES) concerning National Policies and Strategies for the Management of Household Waste and Similar Waste to Household Waste. Accessed 20 September 2022. Available online at Link*.

PT PLN (2021). *Rencana usaha penyediaan tenaga listrik (RUPTL) 2021-2030*. Accessed 6 January 2022. Available at Link.

Umbra Strategic Legal Solutions (2021). *The 2020 PLN Electricity Generation Costs (BPP) published*. Accessed 6 January 2022. Available at Link

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LIST OF INTERVIEWEES

1 Office of Environment and Forestry of West Nusa Tenggara (Dinas Lingkungan Hidup dan Kehutanan, Nusa Tenggara Barat/NTB)
2 Regional Research and Innovation Agency of NTB (Badan Riset dan Inovasi Daerah/BRIDA NTB)
3 Office of Technical Services Unit of Ijo Balit Landfill (TPA Ijo Balit)
4 West Nusa Tenggara Energy and Mineral Resources Office (Dinas Energi dan Sumber Daya Mineral Provinsi Nusa Tenggara Barat)
5 Intermediate treatment facility of Ijo Balit
6 Office of Technical Services Unit of Kebon Kongok Landfill (TPA Kebon Kongok)
7 Bintang Sejahtera Waste Bank
8 The Development Planning, Research, and Regional Improvement (Badan Perencanaan Pembangunan Daerah/BAPPEDA) of NTB Province

EXISTING CAPACITY IN LOMBOK'S POWER SYSTEM (RUPTL 2021-2030)

Type of plant	Name of plant	Capacity (MW)	Fuel
PLTU	Lombok Timur	50	Coal
PLTM	Kokok Putih	3,8	Hydro
PLTMH	Santung	0,85	Hydro
PLTM	Segara	5,8	Hydro
PLTD	Ampenan	55	Diesel
PLTD	Taman	9,6	Diesel
PLTU	Lombok APBN	25	Coal
PLTU	Lombok FTP (1)	25	Coal
PLTU	Lombok FTP (1)	25	Coal
MPP	MPP Lombok	50	Gas

PT PLN (2021)

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FUTURE CAPACITY IN LOMBOK'S POWER SYSTEM (RUPTL 2021-2030)

Type of plant	Name of plant	Capacity (MW)	Fuel	COD	Status	Ownership
PLTMGU (Gas)	Lombok Peaker	10	Gas	2021	Under construction	PLN
PLTMG	Lombok 2	100	Gas	2024/2024	Planned	PLN
PLTM	Sedfau Kumbi	1,3	Hydro	2021	Under construction	IPP
PLTM	Lombok (kuota) Tersebar	1,75	Hydro	2024	Planned	IPP
PLTM	Lombok (kuota) Tersebar	4,58	Hydro	2025	Planned	IPP
PLTU	Lombok FTP2	100	Coal	2021/2022	Under construction	PLN
PLT EBT Base	Lombok 3	100	Renewable Energy	2026/2027	Planned	PLN
PLT EBT Base	Lombok 4	100	Renewable Energy	2028/29	Planned	PLN

PT PLN (2021)


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