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Planning the Electrification of Rural Villages in East Nusa Tenggara Using Renewable Energy Generation

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Abstract. Providing accessible, affordable and renewable electricity to rural areas in developing countries like Indonesia, is arguably challenging. The higher initial cost of renewable, as compared to conventional energy technologies, is often viewed as an obstacle in the rural electrification decision-making process. This study is conducted to examine the techno-economic feasibility of renewable energy generation options to bring electricity to the rural villages in Indonesia with Belu Regency, East Nusa Tenggara (ENT) as a case study. In this study, three village electrification scenarios were generated: basic (with the demand load of 150,5 kWh/day), moderate (359,9 kWh/day) and advanced electrification (579 kWh/day). To supply the load, three energy technologies were compared: conventional technology (diesel-powered); renewables technology (solar PV, and wind turbines); and hybrid technology (combination of diesel, solar PV and wind). The Hybrid Optimization of Multiple Energy Resource (HOMER) software was selected to model the best-optimised system configuration for the scenarios with defined constraints and sensitivity analysis. The study also investigates the impact and benefit of each system on the environment, specifically on CO_2 emissions and pricing options. The results found that the renewable energy village-grid system (mostly powered by solar PV) is more competitive than the diesel-powered system in all scenarios. The levelized cost of energy (LCOE) of renewable energy system for each scenario is 0,66 USD/kWh (basic), 0,74 USD/kWh (moderate) and 0,55 USD/kWh (advance) respectively. This preliminary study concludes that rural electrification with renewables is a feasible option for a generic, modeled village in ENT. More, specific case research would be needed.

JEL Classification: Q42, Q54
Keywords: East Nusa Tenggara, electrification planning, HOMER, LCOE, renewable energy, rural electrification.

1. Introduction

As population and energy demand grow in many countries, governments are tasked to deliver accessible and affordable energy to every citizen. At the same time, there is global pressure to reduce greenhouse gas (GHG) emissions and other environmental goals. Conflicting goals for securing the energy, providing energy equity and maintaining environmental sustainability exert create an energy trilemma.

Almost all developing countries are relying on their energy supply from fossil fuel (IEA, 2017). With limited finance, capacity and resources, as well as numerous other domestic issues, managing this trilemma in developing countries, could be seen as even more challenging.

Indonesia represents a good case: as of June 2017, the national electrification ratio in Indonesia has reached 92,80 percent (MEMR, 2017), but in several provinces, e.g., East Nusa Tenggara and Papua, this is still under 60 percent. There are still thousands of villages that need to be electrified in the remote and rural area in Indonesia, which is costly and technically challenging.

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This study aims to examine the possibility of rural clean energy access and to identify the economic and environmental impacts of three energy system scenarios: business as usual (BAU), renewables, and hybrid. The research focuses on typical rural/remote village in East Nusa Tenggara Province as a case study.

2. Methodology, Data, and Information

In this project, ten different system configurations on three different load scenarios were modeled using HOMER software. To do this, the methodology was divided into three primary steps: 1) electrification scenarios and the corresponding load profiles, 2) power generation system dimensioning, 3) economic and environmental evaluation. Summary of modules and main variables for each step are shown in figure 1 below.

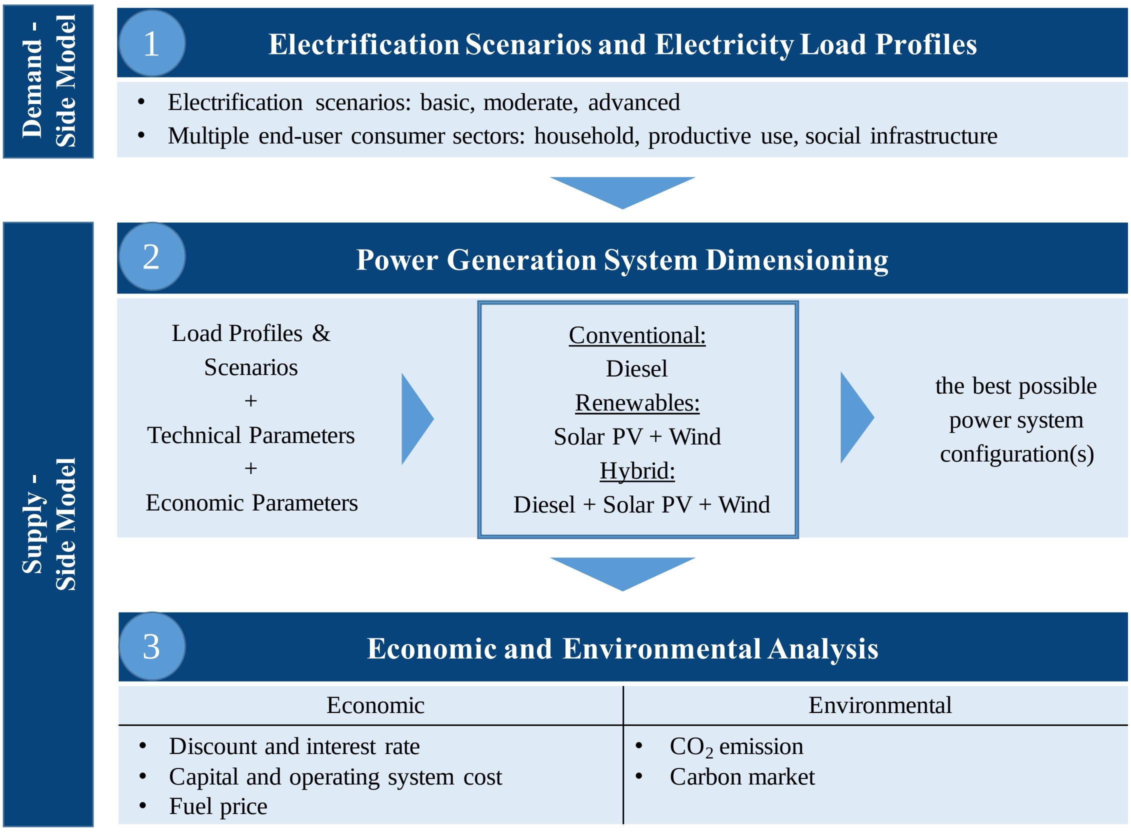

Figure 1. Schematic overview of study methodology.

Distributed power generation technologies

Small-scale, localized energy generation systems, otherwise known as Distributed Generation (DG), are becoming a common alternative in serving communities without access to the grid. Brass, Carley, MacLean, & Baldwin (2012) argue that DG systems have potential to overcome some constraints – such as geographical barriers and economic viability, in having a grid extension.

There are a variety of energy technologies which are commonly used to power the DG systems. Ackermann, Andersson, & Söder (2001) summarize nine energy sources, namely diesel, distillate oil, natural gas, geothermal, wind, biomass, micro-hydroelectric, solar, and ocean. Quantitatively, Brass et al. (2012) took 60 case study articles of DG implementation in many countries from every region of the world between 1970 and 2009. As presented in figure 2, solar PV systems were the most common form of DG (78 percent cases).

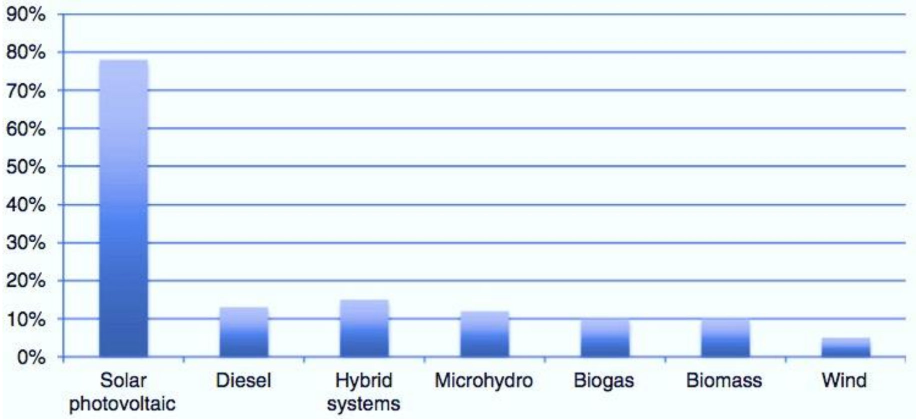

Figure 2. Percent of case studies on various types of DG technologies (Brass et al., 2012).

Diesel generation has been commonly used in DG systems, particularly in developing countries, to electrify the remote areas that cannot easily/economically be reached by the conventional grid connection. The system usually generates a nominal power and runs together with other energy systems (Kusakana & Vermaak, 2014). Brass et al. (2012) summarize some advantages and drawbacks of diesel generation systems. They state that the diesel generators are available in the market and easy to maintain. On the other hand, noise, emission, high fuel costs, and inconsistent fuel availability are some of the drawbacks for diesel generators.

Solar PV technology is one of the first among several renewable energy technologies which have been used in DG systems worldwide (Chaurey & Kandpal, 2010). In a study, Blum, Wakeling, & Schmidt (2013) mentioned other benefits of this technology such as high modularity, zero noise, and high potential solar resources in almost all developing countries. This system converts solar radiation directly into direct current (DC) electricity. This can, in turn, be stored in batteries and/or converted to alternating current (AC) to be used in different application settings. A significant drawback of the solar PV system is the intermittent power generation source during the day. The peak production pattern (daytime) often does not match the demand curve, which often occurs at night in villages. As a consequence, solar PV systems are usually deployed with batteries, increasing the investment cost of the system, and reducing the competitiveness of solar PV systems (Blum et al., 2013).

Wind turbines work by extracting and converting kinetic energy from the wind into rotational kinetic energy in the turbine. Jenkins, Ekanayake, & Strbac (2010) state that aside from site-specific availability, knowing the expected power and energy output of each wind turbine is essential regarding its economic viability. General wind systems (also for remote locations) are a bit larger than small solar home systems and are more commonly set-up for 120/240 V (mini)-grids often with battery and/or diesel back-up for periods of low wind generation. Aside from generic renewable energy generation challenges (e.g., intermittency, location specific, and uncertain energy output), this system has to deal with noise and aesthetic pollution.

Hybrid Optimization of Multiple Energy Resources (HOMER)

The U.S. National Renewable Energy Laboratory (NREL) developed the Hybrid Optimization of Multiple Energy Resources (HOMER) in 1993 to facilitate the renewable energy industry's system analysis and optimization needs (Open Energy Information, 2015). HOMER is a computer model that allows the energy modeler to design the micropower systems as well as comparing the power generation technologies, including the renewables, based on their technical and economic merits.

HOMER can model ten types of micropower system components that generates, delivers, converts or stores energy. Three electricity generation options from renewable energy sources are from solar PV, wind and hydro turbines, whereas other are dispatchable energy sources (generators, grid, and boilers).

The delivery and conversion elements consist of two types: converters and electrolyzers. Lastly, the two parts of energy storage are batteries and hydrogen storage tanks. Each of these has technical and economic properties to be defined.

Lambert, Gilman, & Lilienthal (2006) summarizes three essential technical processes that HOMER performs. They are the simulation, optimization, and sensitivity performance. Particular system configuration is tested hourly throughout the year to determine its technical feasibility and lifecycle cost in the simulation process. In the optimization process, HOMER runs all possible combinations of system configurations to satisfy the technical constraints at the lowest lifecycle cost. Lastly, to test the effects of changes or uncertainty in the model inputs, the sensitivity analysis is performed by re-running the optimization process under a range of inputs. In the end, HOMER can suggest the best-optimised system configuration for the given load, resources, economic variables, system control features, as well as constraints and sensitivity variables.

East Nusa Tenggara electricity supply and demand

East Nusa Tenggara (ENT) is one of 34 provinces in Indonesia, located in the Southeast of Indonesia. In 2016, there were about 5,1 million inhabitants in the province (with a growth rate of 5,2 percent over the last five years), spread over three main islands: Flores (52,5 percent), Timor (32,8 percent), and Sumba (14,8 percent) (BPS NTT, 2017). PLN (2017) reports that the rate of electricity growth in the last five years has been about 12.5 percent p.a., dominated by residential (60 percent), commercial (25 percent), public (10 percent), and industry (5 percent) sectors. The growing middle-class arguably has become a major driver of high demand for new and upgraded electricity connections.

As of end 2015, ENT had 612 power plants over 63 electricity grids (MEMR, 2016). Most of these power plants are powered by diesel (79,8 percent), followed by steam (14,4 percent), and geothermal (4,0 percent). ENT electrification ratio in June 2017 was 59,2 percent, but the aim is to achieve 100 percent by 2026 (MEMR, 2017). To achieve this target as well as meeting the electricity demands, the GOI has calculated ENT’s electricity demand projection to 2026, based on PLN’s power sales in the last five years, economic growth, population growth, and electrification ratio target. PLN (2017) estimates that a total capacity of 731,5 MW with about 2.288 GWh should be generated in 2026 to meet the demand.

Belu Regency, East Nusa Tenggara renewable energy potential

This study model a generic Indonesian village with renewable energy resources at Kakuluk Mesak (9^o 10’ 19,37” S, 124^o 36’ 58,33” E), one of the villages in Belu Regency, ENT. For this location, solar and wind data are derived from NASA Surface Meteorology and Solar Energy Databases.

Solar resource data associated with the amount of global solar radiation that comes to the Earth's surface in a typical year measured in kW/m^2. HOMER recognizes the solar data in three forms: hourly and monthly average global solar radiation, as well as a monthly average clearness index – the clearness index of the atmosphere ranging between zero and one. For monthly solar resource data, HOMER generates synthetic hourly solar radiation data using an algorithm developed by Graham and Hollands (Lambert et al., 2006).

The NASA Langley Research Center (2006) provides 22 years of monthly solar resource data for the site from 1983 – 2005. Throughout these years, the site has a total average solar irradiation of 6,1 $kWh/m^2/day$. In figure 3, the monthly average solar irradiation, as well as the clearness index for the site is presented. It is observed that the minimum and maximum amount of solar irradiation of 5,3 $kWh/m^2/day$ and 7,2 $kWh/m^2/day$ occurred in June and October. Regarding the clearness index, the total average index of the site is about 0,62.

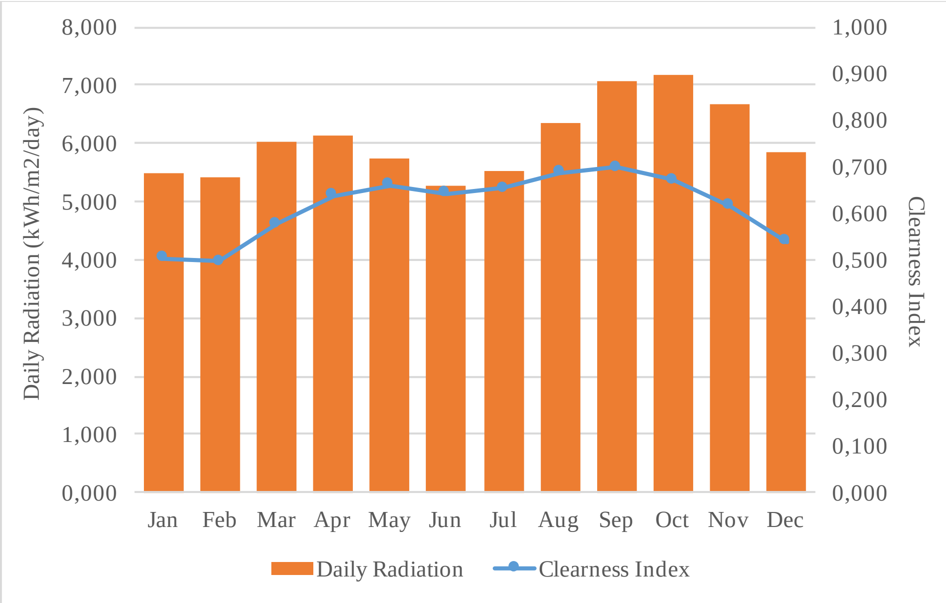

Figure 3. Average monthly solar resource data for the site from 1983-2005 (NASA, 2006).

Wind resource data, indicated by the wind speeds, is needed to model a system for wind turbines. Ideally, HOMER needs hourly wind speed data to generate a better optimization process. If monthly average wind speed data are the only data available, HOMER can generate synthetic hourly data as well as four additional statistical parameters needed: the Weibull shape factor, the autocorrelation factor, the diurnal pattern strength, and the hour of peak wind speed (Lambert et al., 2006).

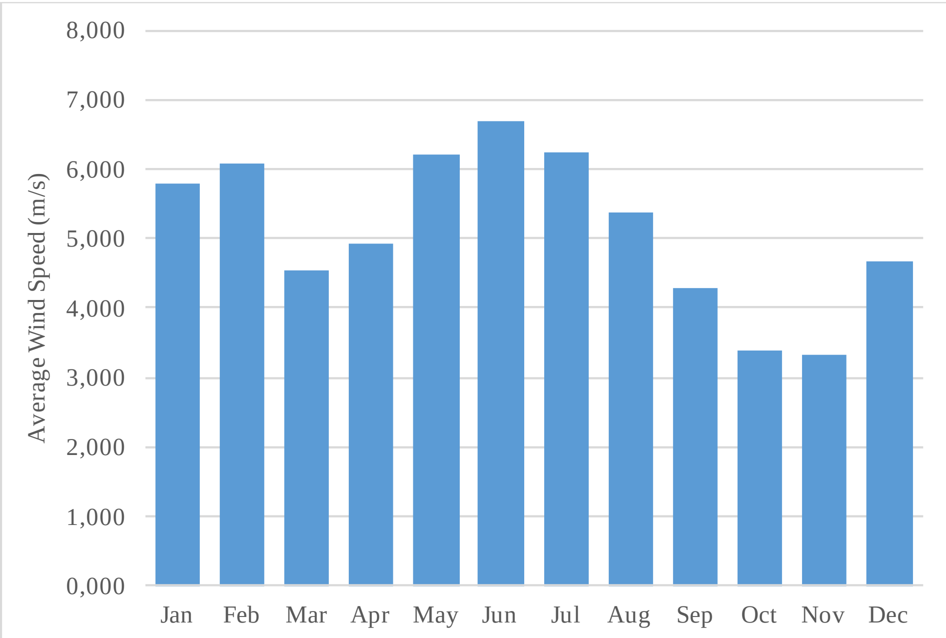

Figure 4. Average monthly wind resource data for the site from 1983-1993 (NASA, 2006).

For the wind resource data for the site, the NASA Langley Research Center (2006) has only ten years of monthly averaged wind speed data at 50 m above the Earth's surface for the site from 1983 – 1993. Throughout these years, the site has a total average wind speed of 5,1 m/s. Figure 4 presents the monthly averaged wind speed. It was observed that minimum and maximum wind speeds of 3,3 m/s and 6,7 m/s, occurring in November and June.

3. Electricity system dimensioning

Dimensioning the electricity system consists of three inputs (load profile and electricity scenario, technical parameters, as well as economic parameters) to find out the best possible power system configuration under each system and electrification scenario. Designing and dimensioning a (representative) example of an electricity system requires the size of a generic village as well as the electrification strategies, including corresponding load profiles. This study model three different system configurations under three different load scenarios.

Electrification scenarios and load profiles

The first step to dimensioning the electricity system is defining the size of a generic village. This project refers to a previous study by Feibel (2010) and Blum et al. (2013) as well as village statistic data from BPS NTT (2017) to establish a typical generic ENT village. Thus, the generic village consists of 1.610 inhabitants in 350 households with an average household size of 4,6 people.

Most rural electrification studies only consider household electricity demand (Brass et al., 2012; Hiendro, Kurnianto, Rajagukguk, Simanjuntak, & Junaidi, 2013; van Ruijven, Schers, & van Vuuren, 2012). This study considers three categories of end-consumers to incorporate local economic activity as well as its social infrastructure: households, productive use, and social infrastructure. Scenario A is a basic electrification scenario, focusing only on small-sized household consumers. Scenario B electrifies medium-sized households as well as small-scale productive use and limited social infrastructure. Scenario C plans for larger household consumers, medium to high productive use, as well as moderate social infrastructures.

Determining the electricity demand for each end-consumer sector in each scenario is arguably challenging. In one study, Casillas & Kammen (2011) stated that empirical village electricity consumption data in developing countries might be hard to find due to unemployed electricity meters. This study estimates the electricity demand by identifying a set of typical electricity appliances owned by consumers in each end-consumers sector with its daily usage. Based on assumptions elaborated in Hiendro et al. (2013) and Blum et al. (2013), the project distinguishes three electricity load profiles for each scenario as summarized in Table 1 below.

Table 1. The project's electrification scenarios overview.

	Scenario A Basic Electrification	Scenario B Moderate Electrification	Scenario C Advanced Electrification
Overview	Remote rural village, with agriculture as the main economy	Rural village with growing economic activities	Rural village with established economic activities, beyond agriculture
Power Availability	Electricity is available 18:00-06:00	Electricity is available 24 hr	Electricity is available 24 hr
End-consumer Sectors	Household	– Household – Productive Use – Social Infrastructures	– Household – Productive Use – Social Infrastructures
Load Profiles	Household: 0.43 kWh/day	Household: 0.99 kWh/day Productive Use: 10.9 kWh/day Social Infrastructures: 1.5 kWh/day	Household: 1.46 kWh/day Productive Use: 52.7 kWh/day Social Infrastructures: 15.32 kWh/day
	Total Village: 150.5 kWh/day	Total Village: 358.9 kWh/day	Total Village: 688.3 kWh/day

This study assumes that the profile remains the same throughout the year, so there is no seasonal peak load/variation. All assumptions (e.g., appliances, power consumption, quantity per customer, usage duration) from the demand-side model are summarized in Appendix B.

System dimensioning

To suggest the most suitable techno-economic power system for the case study three different system configurations are modeled, using three energy technologies (diesel generator, solar PV, wind turbine), as well as converting devices, batteries, etc. The conventional system uses diesel generator(s) as the only power source; the renewable system is only equipped with renewable energy technology (solar PV and/or wind turbine); the hybrid system combines the conventional and renewable power plants as its source of energy.

The study defined each energy technology and its supporting ancillary equipment in HOMER. For the diesel generator, a modified 10 kW generic AC is used. A 5-kW generic flat plate PV on a DC system is selected to represent the solar PV system. The study uses the modified 1 kW generic wind turbine on DC system as a wind turbine system. Table 2 shows an overview of the configurations, while Appendix A summarizes the details.

Table 2. The project's system configurations overview.

	Conventional System	Renewable System	Hybrid System
Overview	The business-as-usual system which uses a diesel generator as its main power supply	The most environmentally friendly system which uses the renewable energy power	The clean energy system which combines renewable energy with the diesel generator
Power System Configuration	Diesel generator (10 kW AC system)	Solar PV (5 kW flat plate PV) Wind turbine (1 kW) Converter (10 kW) Battery (Lead Acid – LA)	Diesel generator (10 kW AC system) Solar PV (5 kW flat plate PV) Wind turbines (1 kW) Converter (10 kW) Battery (Lead Acid – LA)

4. Electrification scenario options & analysis

From the simulation results (see table 3), solar PV is dominating wind as the preferred energy technology for both renewable and hybrid configurations. The maximum penetration of the wind turbine occurs in the hybrid energy system for the basic electrification scenario, which serves about 17 percent of the total energy supply.

Table 3. The project's system configuration results.

Electrification Scenarios and Power Systems	Diesel		Solar PV		Wind Turbine	
	Size (kW)	Load (percent)	Size (kW)	Load (percent)	Size (Unit)	Load (percent)
Basic Electrification						
Conventional	40	100.0	-	-	-	-
Renewable	-	-	50	100.0	-	-
Hybrid	25	48.9	15	34.3	16	16.8
Moderate Electrification						
Conventional	80	100.0	-	-	-	-
Renewable	-	-	300	99.8	1	0.2
Hybrid	60	27.1	100	72.9	-	-
Advanced Electrification						
Conventional	80	100.0	-	-	-	-
Renewable	-	-	300	98.8	8	1.2
Hybrid	70	36.8	100	63.2	-	-

Regarding the Levelized Cost of Energy (LCOE), wind energy has the highest cost in this study. It costs about 0,721 USD/kWh for every 1 kW system, followed by diesel (0,183 USD/kWh) and solar PV (0,087 USD/kWh) system. Therefore, the average electricity production from wind energy is also the lowest among others (i.e., 810 kWh/year ~ about half of the solar PV technology). Consequently, the solar PV almost dominated a fraction of both the renewable and hybrid system configurations. A summary of the LCOE and average electricity production from each technology is presented in table 4.

Table 4. The project's LCOE and average electricity production results.

System	LCOE (USD/kWh)	Average Electricity Production (kWh/yr)
1 kW Solar PV	0,087	1.765
1 kW Wind	0,721	810
1 kW Diesel	0,183	1.677

In addition to the LCOE, it found that the cost of all technologies decreases when higher electrification scenarios are applied. Figure 5 depicts the LCOE for a generic village's grid with three system configurations as well as its sensitivity effects. Each scenario is embedded with straight lines which represent the range results of the sensitivity effects from the low and high cases.

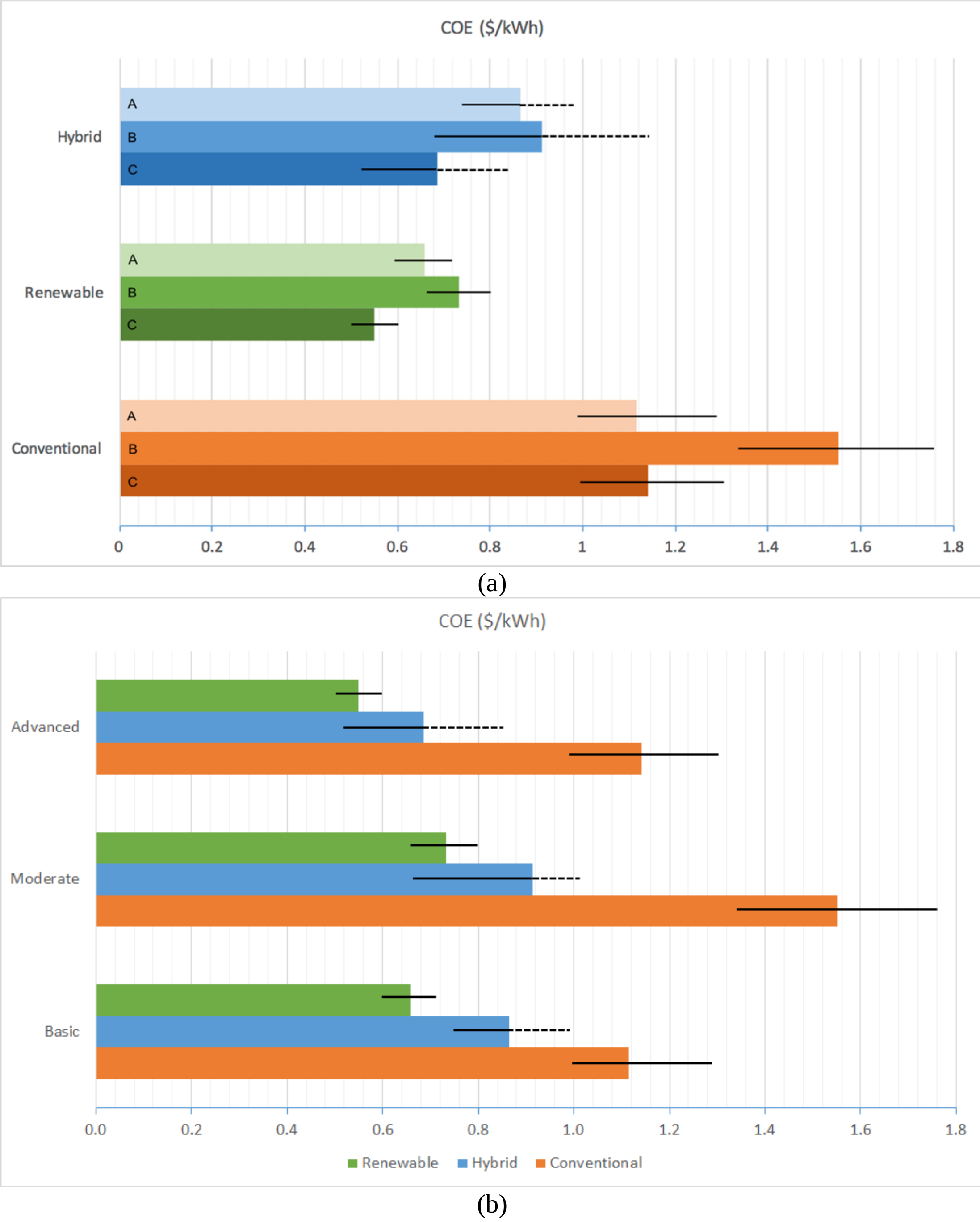

Figure 5. (a) COE for generic village grid with various system configurations; (b) COE for generic village grid with electrification scenarios.

Under the given technical and economic merits, the renewable energy system for the advanced electrification scenario comes with the lowest LCOE (ranging from 0,50 USD/kWh for the low case to 0,60 USD/kWh for the high case). It is followed by the hybrid energy system for the advanced electrification scenario which has an LCOE from 0,53 USD/kWh (the low case) to 0,84 USD/kWh (the high case estimation). Lastly, the conventional power system (driven by the diesel generator) for the moderate electrification scenario (represented by the letter B) has the highest overall LCOE from 1,34 USD/kWh (the low case) to 1,77 USD/kWh (the high case).

This study also estimated LCOE of using solar home systems (SHS) for the basic electrification scenario, as well as the conventional grid extension option for the advanced electrification scenario.

The LCOE for the basic electrification at the base case is 0,66 USD/kWh. SHS are estimated to cost around 0,71 USD/kWh. Thus, it found that for the basic electrification scenario, the proposed renewable mini-grid system is a preferable option compared to the SHS option.

For the comparison between the renewable mini-grid system versus the conventional grid extension option, the base case LCOE for each option was 0,55 USD/kWh and 0,55 USD/kWh respectively. As for the advanced electrification scenario, the proposed renewable mini-grid and the current village grid extension are equal.

Basic electrification scenario

HOMER analyzed around 533,064 simulations from each of the three different load profiles and three different system configurations with various sensitivity variables and economic constraints (i.e., discount rate, inflation rate, minimum renewable fraction, capital cost, replacement cost, O&M cost, and fuel price). The optimal system architectures for each power system are as follows:

- Conventional : Diesel generator 40 kW
- Renewable : Solar PV 50 kW, 1 kWh LA storage 250 strings, Converter 50 kW
- Hybrid : Diesel generator 25 kW, Solar PV 15 kW, 16 units wind turbine 1 kW, 1 kWh LA storage 150 strings, Converter 10 kW

Among the three recommended systems, the renewable energy system dominated other power systems with the lowest LCOE (between 0,59-0,72 USD/kWh) and the lowest NPC (between USD 145.384-176.856). The hybrid energy system comes in as the second optimized configuration with the LCOE of 0,75-0,98 USD/kWh and the NPC between USD 190.950-232.826. The last solution is the conventional energy system which has the highest LCOE (0,95-1,28 USD/kWh) and NPC (USD 233.071-314.859). The comparison of LCOE for each system is presented in Figure 5 (a) with straight lines which represent the range of results and sensitivity effects from the low and high cases.

Moderate electrification scenario

For the moderate electrification scenario, HOMER analyzed around 1.044.624 simulations from each of the three different load profiles and three different system configurations with the same sensitivity variables and economic constraints in the basic electrification scenario. The optimal system configurations for each power system are as follows:

- Conventional : Diesel generator 80 kW
- Renewable : Solar PV 300 kW, 1 unit wind turbine 1 kW, 1 kWh LA storage 300 strings, Converter 100 kW
- Hybrid : Diesel generator 60 kW, Solar PV 100 kW, 1 kWh LA storage 100 strings, Converter 25 kW

For the additional load of 76.431 kWh per annum from previous scenarios, the lowest LCOE and NPC is still achieved by the renewable energy system. The LCOE of the renewable system is increased by US$0,39 /kWh from US$0,59 /kWh (low case – basic electrification scenario) to US$0,66 /kWh (low case – moderate electrification scenario). For the same matter, the NPC of the system increased by more than double (US$240.794) from US$145.384 (low case – basic electrification scenario) to US$386.178. The hybrid energy system comes as the second optimized configuration with the LCOE of US$0,67 – 1,15 /kWh and the NPC between US$392.442 – 678.012. The highest LCOE for the scenario is generated from the conventional energy system which ranges between US$1,34 – 1,77 /kWh.

Advanced electrification scenario

The last electrification scenario analyzed the most substantial simulations. There are 1.086.690 simulations from each of the three different load profiles and three different system configurations with the same sensitivity variables and economic constraints with the previous electrification scenarios. The optimal system configurations for each power system are as follows:

- Conventional : Diesel generator 80 kW
- Renewable : Solar PV 300 kW, 8 units wind turbine 1 kW, 1 kWh LA storage 500 strings, Converter 100 kW
- Hybrid : Diesel generator 70 kW, Solar PV 100 kW, 1 kWh LA storage 100 strings, Converter 100 kW

In this scenario, the renewable energy system still has the lowest LCOE and NPC. For the additional load of 79.975 kWh from the moderate electrification scenario, the LCOE has interestingly decreased. In the low case, for instance, the LCOE is decreased by 0,18 USD/kWh. The hybrid system costs about 0,5-0,6 USD to generate one kWh of electricity. Despite the highest LCOE among other systems, the conventional system has the highest decrease of LCOE with the abatement of 0,41 USD/kWh.

5. Environmental analysis

The Government of Indonesia had voluntarily pledged to reduce the GHG emissions by 29 percent (and up to 41 percent with international supports) against the BAU scenario by 2030. To achieve the target, the GOI issued Presidential Regulation No. 61/2011 on the National and Regional Action Plan for GHG Emission Reduction in five major sectors, including the energy sector. Under Gubernatorial Regulation No. 39/2012, East Nusa Tenggara Province aimed to mitigate approximately 8,06 MtCO_2e from East Nusa Tenggara's BAU baseline scenario by 2030 (MNDP, 2017).

Based on the MNDP monitoring system, the province already claimed the GHG emission reduction of 51,88 tCO_2e from solar PV plant development. In addition to the GHG emission reduction cost, this achievement spent roughly Rp103.560.715,00 /tCO_2e. Thus, through the implementation of a renewable energy system from the advanced electrification scenario, the maximum potential GHG emission reduction of 288 tCO_2/year. The lowest GHG emission reduction potential from the basic electrification of the hybrid system with about 39 tCO_2/year. Figure 6 summarizes the overall possibility of GHG emission reduction from each electrification scenario and power system.

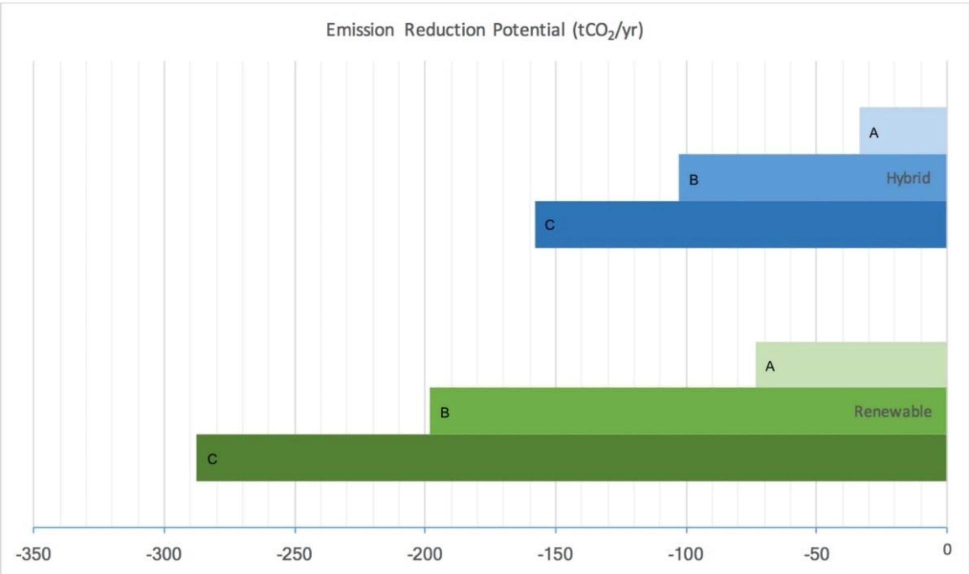

Figure 6. GHG emission reduction potential from hybrid and renewable systems

The study also considers the carbon trading option. Assuming a carbon price of US$20/t$CO_2$, the maximum potential carbon incentive from implementing the renewable energy system is about USD 5.759/year. For the same case, the hybrid energy system can mitigate up to 158 tCO_2/year (half of the renewable energy system's mitigation potential) with potential carbon incentives of US$3.160/year.

6. Summary and Conclusion

This study aimed to examine the techno-economic feasibility of renewable energy generation options to electrify rural villages in Indonesia by focusing on a case study in East Nusa Tenggara. From 2.664.378 simulations of three different load profiles and three system configurations (diesel, wind, solar and hybrid) with various sensitivity variables and economic constraints, solar PV generally has the lowest LCOE. To electrify the generic village with the lowest LCOE, the HOMER comes up with a renewable energy option for three electrification scenarios. In this study, the system's architecture for the renewable energy system mostly depends on solar PV technology to supply the electricity. Table 5 summarizes the renewable energy system components for all electrification scenarios.

Table 5. Summary of renewable energy and diesel system components for all electrification scenarios

	Unit	Basic Electrification	Moderate Electrification	Advanced Electrification
System Component				
Generic Flat Plate PV	kW	50	300	300
Generic Wind Turbine	unit	-	1	8
Generic Lead Acid Battery	strings	250	300	500
System Converter	kW	50	100	100
System Cost				
Generic Flat Plate PV	US$	34.446	206.676	206.676
Generic Wind Turbine	US$	-	2.607	20.858
Generic Lead Acid Battery	US$	109.871	187.764	255.615
System Converter	US$	16.834	33,668	33,668
Total	US$	161.151	430.716	516.817
LCOE	$SD/kWh	0,658	0,735	0,549
Energy Balance				
Production	kWh/year	88.235	530.222	535.893
Load	kWh/year	54.903	131.255	211.101
Excess/Loss	kWh/year	33.332	398.967	324.792
GHG Emission				
Emission Reduction Potential	tCO_2/year	73	198	288
Potential Carbon Incentive (USD 10/tCO_2)	US$/year	732	1,983	2,880
Diesel System Component				
Diesel Genset	kW	40	60	80
Diesel System Cost				
Diesel Genset	US$	273.272	909.651	1.076.282
LCOE	US$/kWh	1,115	1,552	1,141
Energy Balance				
Production	kWh/year	55.191	155.427	213.169
Load	kWh/year	54.933	131.364	211.339
Excess/Loss	kWh/year	258	24.063	1.830

As summarized in table 5, this study found that the LCOE of the renewable system in the advanced electrification scenario had the lowest cost per kilowatt hour (0,549 USD/kWh). In comparison with the conventional energy system – represented by the diesel-powered system – the average LCOE from all scenarios of the renewable system (0,647 USD/kWh) was almost half of the diesel-powered system (1,269 USD/kWh). From an environmental aspect, the renewable system also has the most significant emission reduction potential due to its almost zero emission system. The baseline for its emission reduction potential is from the diesel generator. Thus, the bigger the system is, the higher emission reduction potential from the renewable energy system. In this case, the maximum emission reduction potential is 288 tCO_2/year. Assuming the carbon price is US$10/$tCO_2$, this mitigation action will have a potential carbon incentive of US$2.880/year.

From this preliminary study, it could be concluded that planning the electrification of ‘a’ rural village in East Nusa Tenggara, with renewable energy is arguably compared to conventional options. The renewable energy architecture has the lowest LCOE (between US$0,549-0,735/kWh) as opposed to hybrid (US$0,686-0,913/kWh) and diesel generation (US$1,115-1,552/kWh).

This study used preliminary data, largely from literature and other assumptions for technical parameters to model the proposed systems for an ‘imaginary case’. In reality, costs, resource potential, demand and other variables will vary per situation. For a better result, future research should take into account the following considerations:

- Improved (localized) renewable energy data resources (e.g. solar GHI and wind speed) as well as local specific data parameters (e.g. fuel price and slope, emission factor) ground check and sensitivity analysis;
- In-depth techno-economic comparisons between the renewable energy mini-grid against solar home system (SHS) from the perspective of the user, an energy service company, and the government;
- Further techno-economic comparisons between the renewable energy mini-grid versus the conventional grid extension from the perspective of the user, an energy service company, and the government;
- A more comprehensive analysis of GHG abatement cost.

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Appendix A: Variables and Assumptions Power Generation System

Table A. Project's variables and assumptions.

Parameters/Variables	Unit	Case Low	Case Base	Case High	Reference
Economic					
Discount rate	%	4	6	8	Central Bank of Indonesia (2016)
Inflation rate	%	0	2	4	Statistics Indonesia (2016)
Technical					
Annual capacity shortage	%		0.05		Soeharwinto (2016)
Project lifetime	years		5		Soeharwinto (2016)
Minimum renewable fraction	%	30	50	70	Soeharwinto (2016)
Annual peak load	%		10		Soeharwinto (2016)
Diesel Generator (1 kW)					
Capital cost	US$	495	550	605	Soeharwinto (2016)
Replacement cost	US$	421.2	468	514.8	Soeharwinto (2016)
Operating & maintenance cost	US$/hr	0.18	0.2	0.22	Soeharwinto (2016)
Lifetime	hours		15,000		Soeharwinto (2016)
Diesel fuel price	US$/L	0.63	0.7	0.77	Soeharwinto (2016)
Solar PV (1 kW)					
Capital cost	US$	990	1,100	1,210	Hiendro et al. (2013)
Replacement cost	US$	594	660	726	Hiendro et al. (2013)
Operating & maintenance cost	US$/yr	4.95	5.5	6.05	Hiendro et al. (2013)
Lifetime	years		25		Hiendro et al. (2013)
Derating factor	%		80		Hiendro et al. (2013)
Wind (1 kW)					
Capital cost	US$	2,700	3,000	3,300	Hiendro et al. (2013)
Replacement cost	US$	1,350	1,500	1,650	Hiendro et al. (2013)
Operating & maintenance cost	US$/yr	108	120	132	Hiendro et al. (2013)
Lifetime	years		20		Hiendro et al. (2013)
Hub height	m		25		Soeharwinto (2016)
Converter (1 kW)					
Capital cost	US$	450	500	550	Hiendro et al. (2013)
Replacement cost	US$	405	450	495	Hiendro et al. (2013)
Operating & maintenance cost	US$/yr	4.5	5	5.5	Hiendro et al. (2013)
Lifetime	years		10		Hiendro et al. (2013)
Efficiency	%		98		Hiendro et al. (2013)
Battery (1 unit)					
Capital cost	US$	211.5	235	258.5	Hiendro et al. (2013)
Replacement cost	US$	211.5	235	258.5	Hiendro et al. (2013)
Operating & maintenance cost	US$/yr	4.23	4.7	5.17	Hiendro et al. (2013)
Lifetime	years		10		Hiendro et al. (2013)
Voltage	V		6		Hiendro et al. (2013)
Maximum Capacity	Ah		360		Hiendro et al. (2013)

Appendix B: Demand Side Assumptions

Table B. Typical electrical appliances for household sector under three scenarios.

Scenario/Sector	Electrical Appliances	Power Consumption (W)	Quantity per Consumer	Usage Duration per Day	Usage Duration per Day (h)	Total Power Consumption (Wh)
Scenario A						
Household	Light bulb (indoor)	15	2	18:00 – 00:00	6	180
	Light bulb (outdoor)	15	1	18:00 – 06:00	12	180
	TV colour 21"	70	0.2*	18:00 – 23:00	5	70
Scenario B						
Household	Light bulb (indoor)	15	3	18:00 – 00:00	6	270
	Light bulb (outdoor)	15	1	18:00 – 06:00	12	180
	Mobile phone charger	15	1	18:00 – 20:00	2	30
	Fan	40	1	13:00 – 15:00 & 21:00 – 23:00	4	160
	TV colour 21"	70	1	18:00 – 23:00	5	350
Productive Use	**Kiosk (2 per village)**					
	Light bulb	25	2	18:00 – 22:00	4	400
	Farmer (1 per village)					
	Paddy grinder	1,500	1	09:00 – 17:00	7	10,500
Social Infrastructure	**Street lighting (5 per village)**					
	Street lighting	25	5	18:00 – 06:00	12	1,500
Scenario C						
Household	Light bulb (indoor)	15	4	18:00 – 00:00	6	360
	Light bulb (outdoor)	15	1	18:00 – 06:00	12	180
	Mobile phone charger	15	1	18:00 – 20:00	2	60
	Fan	40	1	13:00 – 15:00 & 21:00 – 23:00	11	440
	TV colour 21"	70	1	07:00 – 09:00 & 19:00 – 23:00	6	420
	Refrigerator	100	0.13**	00:00 – 00:00	24	109,200

Scenario/Sector	Electrical Appliances	Power Consumption (W)	Quantity per Consumer	Usage Duration per Day	Usage Duration per Day (h)	Total Power Consumption (Wh)
Productive Use	**Kiosk (5 per village)**					
	Light bulb	25	3	18:00 – 22:00	4	1,500
	Farmer (3 per village)					
	Paddy grinder	1,500	1	09:00 – 17:00	7	31,500
	Carpenter (2 per village)					
	Drilling machine	350	1	09:00 – 17:00	7	4,900
	Dairy (2 per village)					
	Egg incubator	200	1	00:00 – 00:00	24	9,600
	Tailor (1 per village)					
	Sewing machine	120	1	09:00 – 17:00	7	840
	Restaurant (1 per village)					
	Refrigerator	100	1	00:00 – 00:00	24	2,400
	Mixer	100	1	09:00 – 17:00	7	700
	Blender	180	1	09:00 – 17:00	7	1,260
Social Infrastructure	**Street lighting (5 per village)**					
	Street lighting	25	10	18:00 – 06:00	12	3,000
	School (1 per village)					
	Indoor lights (CFL)	15	24	08:00 – 15:00	7	2,520
	Outdoor lights (CFL)	15	12	08:00 – 15:00	7	1,260
	Desktop computer	60	20	08:00 – 15:00	7	8,400
	Communication Infrastructures (3 per village)					
	Payphone	2	3	00:00 – 00:00	24	144

* 1 TV every 5 households

** 4 refrigerators every 30 households