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Waste Biomass Integration to Reduce Fuel Consumption and Levelized Cost of Electricity in Philippine Off-Grid Islands

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A techno-economic assessment was made for thirteen large off-grid islands in the Philippines using HOMER Pro (Hybrid Optimization Model for Electric Renewables Software) to determine the feasibility of integrating waste biomass into their energy systems. Sensitivity analysis on the diesel fuel prices and biomass feedstock prices was performed to determine their effects on the levelized cost of electricity (LCOE) and the renewable energy (RE) share. The results suggest that an average LCOE reduction of around 4.57 %, fuel reduction of 5.71 %, and RE share increase of 4.99 % can be realized by integrating biomass to the existing diesel system even without incorporation of other renewable energy generators such as solar photovoltaics. In cases where biomass is available in large quantities, and the energy demand is relatively low, LCOE reduction, fuel reduction, and RE share increase may even reach up to more than 20 %. This makes the integrated biomass-diesel hybrid system a viable option for reducing diesel consumption in the off-grid islands. And even with the establishment of a feedstock market, the biomass-diesel hybrid system still has a lower LCOE compared to the existing diesel-only systems. This work provides the first systematic techno-economic study on the potential of incorporating waste biomass in off-grid islands.

1. Introduction

According to the World Bank, around 1×10^9 people across the globe still lack access to the electricity supply (World bank, 2018). This is mostly evident in archipelagic countries such as the Philippines and Indonesia, where the great distances and costs required to interconnect the islands hinder their electrification (Ocon et al., 2018). The employed solution is usually off-grid systems based on diesel generators. These systems, however, pose environmental and health risks due to greenhouse gas emissions (Blum et al., 2013). Other challenges, such as the decline of fossil fuel reserves and global market trends, affect the prices of diesel fuel, which in turn, subject operating costs of these systems to high variability. Reliability issues due to the limited time of supply are also a major concern. Thus, it is imperative to find other sources of energy for these off-grid systems.

One possible solution is to integrate renewable energy (RE) sources into the diesel off-grid systems. Integration of RE resources can help improve the sustainability and reliability of off-grid island systems. Solar photovoltaics (PV), biomass, hydropower and wind energy resources can also help reduce reliance on diesel fuel and attain higher RE mix in the islands.

In the Philippines, waste biomass is abundant due to the country's vast agricultural lands. Crops, such as sugarcane, rice, corn, and coconut, are produced at high annual amounts. In 2017, the annual production reached approximately 29 Mt, 19 Mt, 14 Mt, and 2.4 Mt for sugarcane, rice, coconut, and corn, respectively (PSA, 2018). Because of these large production rates, there is also a huge potential in harnessing energy from the residues of these crops (Sevilla et al., 2015). Unlike the burning of fossil fuels, waste biomass generates zero net carbon dioxide emissions. Waste agricultural residues are also more suitable for energy generation when compared to other biomass sources because it eliminates the competition for the use of land often associated with growing energy crops over food crops (Go et al., 2019). However, biomass has some disadvantages such as supply uncertainties and varying fuel properties (e.g. moisture content, ash content, energy content) that may affect energy conversion efficiencies (San Juan et al., 2018).

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Currently, most of the installed biomass capacities in the country are supplying the main grid and uses agricultural residues as feedstock. Additionally, three sugarcane-fired power plants are expected to open within 2019 at the towns of San Carlos, La Carlota, and Manapla, Negros Occidental (Lagarde, 2018). Studies on utilizing agricultural waste for energy generation on the Philippine off-grid islands, however, remain limited. To the authors' knowledge, this is the first study to be conducted on a national scale covering multiple islands to determine their individual potential for biomass integration using a techno-economic optimization approach.
This work aims to provide techno-economic analysis of the potential of integrating agricultural waste biomass to the off-grid diesel systems. This will serve as a pre-feasibility study for developers and other stakeholders, who would like to implement biomass-diesel systems on off-grid islands. This would also help off-grid islands in the Philippines achieve the desired RE mix as mandated by the Renewable Portfolio Standards (RPS) of the Philippine Department of Energy, which requires off-grid areas to provide a portion of their electricity from RE sources.

1.1 Biomass resources

This work used geographic information system (GIS) data from the Agricultural Land-cover Map processed by the Philippines Agricultural Resources Mapping (PARMap), using Light Detection and Ranging (LiDAR) under the Phil-LiDAR 2 Project of the Philippines Department of Science and Technology. The map contains the theoretical biomass potential (t/y) and the available biomass potential (MJ/ha/y) from sugarcane, rice, coconut, and corn (Cadalin et al., 2015). Theoretical biomass potential is the sum of all agricultural residues from a certain crop in a region while the available biomass potential is the energy that can be economically and technically derived from the biomass, which can then be converted to electricity. These data were then processed, as shown in Eq(1), to determine the amount of biomass (t/y), B_e, that can be used for energy production,

$$B_e = \frac{B_v A_r}{LHV_{crop}} \tag{1}$$

Where, B_e is the amount of biomass that can be used for energy production (t/y), B_v is the available biomass potential (MJ/ha/y), A_r is the area of the region under consideration, and LHV_{crop} is the lower heating value of the crop. For this work, the LHV of rice and coconut residues used were 16.5 MJ/kg and 23.5 MJ/kg.

Seasonal variation of biomass supply

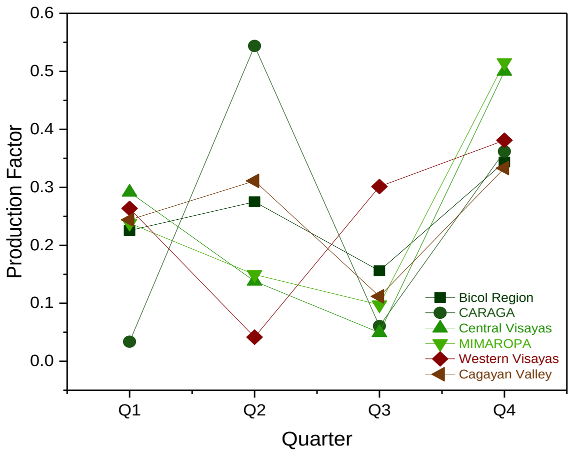

Figure 1: Average quarterly production ratio of rice for some of the regions in the Philippines (PSA,2018)

Production ratio or the ratio of the quarterly production of a specific crop to its annual production was introduced to account for the seasonal variation of the biomass supply. The average daily biomass production for each month of the year was calculated using Eq(2).

$$B_{adp,month} = \frac{B_e P_{r,Q}}{3N_{days,month}} \tag{2}$$

Where, $B_{adp,month}$ is the average daily biomass production for a specific month (t/d), $P_{r,Q}$ is the production ratio for the quarter in which the specific month belongs ((t/Q)/(t/y)), the number 3 represents the number of months per quarter (mo/Q), and $N_{days,month}$ is the number of days for the specific month (d/mo) (e.g. 31 for January).

1.2 Selection of suitable Islands

This work studied large islands under the National Power Corporation- Small Power Utilities Group's (NPC-SPUG) called as the Large NPC-SPUG areas. These islands generated a total of 942.66 GWh or 87.71 % of the gross generation and needed 173.09 MW or 82.63 % of the total peak demand in 2015 of the missionary areas under the NPC-SPUG (DoE, 2016). Their individual consumption was able to reach more than 1 GWh in 2015. Table 2 shows the list of the included islands. The listed islands are powered by diesel-only systems. Bongao Island in Tawi-Tawi and Catanduanes were not included due to the inactivity of the diesel generators and incomplete data. The primary assumption for this study is that no new diesel installations or capacity addition will occur during the project lifetime.

1.3 Energy systems modelling

The software Hybrid Optimization Model for Electric Renewables (HOMER) was used to model the energy system and to find the optimum biomass-diesel system architecture for the islands. HOMER Pro is an energy system optimization tool developed by the National Renewable Energy Laboratory (NREL), which determines the optimum system architecture from a combination of conventional and RE sources. It requires inputs such as the energy demand (e.g. electrical load), RE sources (solar irradiation, wind speeds and biomass supply), costs/technical information of the different system components, economic constraints, etc. It performs hourly simulations to determine the best possible balance between supply and demand and then ultimately, find the optimum system configuration (Bhattacharjee and Dey, 2014). Table 1 shows the technical and economic inputs used for the simulations. For this work, gasification power plants will be used to convert the biomass into electricity and the cost indicated is assumed as the average price of the technology in the Philippines. For the economic constraints, the interest rate was obtained from Bangko Sentral ng Pilipinas (BSP) and the inflation rate was obtained from the Philippine Statistics Authority (PSA).

Table 1: Technical and economic inputs for the simulations

Component	Parameter	Value	Unit	Reference
Diesel	Installation cost	0	\$/kW	Already installed
	O&M cost	0.05	\$/op. h	
	Fuel Cost	0.9	\$/L	(Ocon and Bertheau, 2019)
	Lifetime	25	y	
Gasification power plants	Installation cost	2, 000	\$/kW	(IRENA, 2018)
	O&M cost	0.16	\$/op. h	(IRENA, 2018)
	Lifetime	25	y	
Feedstock	Feedstock Cost	0	\$/t	Assumed as free
	C content (Coconut residue)	22	%	
	C content (Rice Residue)	14.4	%	
Project	Interest Rate	6.5	%	
	Inflation Rate	2.78	%	
	Lifetime	25	y	

To determine the feasibility of integrating biomass into the off-grid diesel systems, the levelized cost of electricity (LCOE), or the average cost per kWh of the electricity produced by the system was used as the main metric. HOMER calculates the LCOE using Eq(3).

$$LCOE = \frac{C_{ann,tot}}{E_{served}} \tag{3}$$

Where $C_{ann,tot}$ is the total annualized cost (\$/kWh) and E_{served} is the total electrical load served by the system (kWh).
Another metric used is the RE share, which HOMER computes as the RE fraction as shown in Eq(4).

$$f_{ren} = 1 - \frac{E_{nonren}}{E_{served}} \tag{4}$$

Where, f_{ren} is the RE fraction and E_{nonren} is the nonrenewable energy generation. RE share for this work, is f_{ren} multiplied by 100 %.

Integrating biomass into the diesel systems also affects fuel consumption and the fuel reduction was also determined using Eq(5).

$$fuel\ reduction = \frac{FC_{biomass-diesel} - FC_{diesel\ only}}{FC_{diesel\ only}} x100\ \% \quad (5)$$

Where, $FC_{biomass-diesel}$ is the fuel consumption of the biomass-diesel system (L/y) and $FC_{diesel\ only}$ is the fuel consumption of the diesel-only system (L/y). HOMER Pro calculates the fuel consumption for the systems.

1.4 Load data

A normalized load profile based from actual daily load profile and monthly load profile variation data of twenty-two island grids were used. Daily load profiles were normalized according to the peak demand during the day and yearly load profiles were normalized based on the average load during the year (Ocon and Bertheau, 2018). The peak demand and average load were obtained from the Missionary Electrification Development Plan (MEDP) of the Philippine Department of Energy (DOE).

2. Results

2.1 Islands suitable for biomass integration and their techno-economic potential

Table 2: Techno-economic potential of biomass integration for the different Large NPC-SPUG Areas

Islands	Peak Demand	Available Biomass Resource (t/d)	Diesel-only System		Biomass-Diesel System		
		(Source)	Diesel Fuel Consumption (L/y)	LCOE ($/kWh)	Diesel fuel consumption (L/y)	LCOE ($/kWh)	RE share (%)
Bantayan Island	5.51	-	8,089,739	0.2660	-	-	-
Basilan	10.46	165 (Coconut)	13,989,180	0.2422	13,271,550	0.2307	5.13
Busuanga Island	5.48	0.003 (Coconut)	7,751,023	0.2561	7,282,401	0.2428	4.76
Camotes Island	3.19	-	4,247,423	0.2411	-	-	-
Mainland	9.68	3.35 (Coconut)	12,681,730	0.2373	12,023,840	0.2265	5.54
Marinduque	9.68	24.06 (Rice)	12,681,730	0.2373	12,027,420	0.2261	5.48
Mainland	22.289	101.78 (Coconut)	28,935,020	0.2352	28,248,910	0.2300	2.41
Masbate	22.289	1.11 (Rice)	28,935,020	0.2352	28,249,330	0.2305	2.41
Occidental Mindoro	21.432	12.01 (Rice)	28,073,940	0.2373	27,380,670	0.2324	2.51
Oriental Mindoro	54.971	14.43 (Coconut)	65,298,880	0.2336	58,642,990	0.2121	10.35
	54.971	47.89 (Rice)	65,298,880	0.2336	62,791,940	0.2260	3.89
Palawan Main	48.961	30.58 (Coconut)	63,108,410	0.2335	62,436,720	0.2312	1.08
Grid	48.961	6.92 (Rice)	63,108,410	0.2335	62,425,050	0.2312	1.10
Romblon Island	2.082	237.19 (Coconut)	2,725,351	0.2372	2,069,903	0.1870	25.18
Siquijor	5.252	0	6,938,829	0.2394	-	-	-
Sulu	8.6	55.64 (Coconut)	13,387,100	0.2820	12,872,210	0.2755	0.00
Tablas Island	6.126	2.42 (Coconut)	10,494,170	0.3104	9,748,497	0.3085	0.00

Using HOMER Pro and the inputs from Table 1, the energy systems of the thirteen islands considered as Large NPC-SPUG areas were modelled to determine their respective techno-economic potential for biomass integration. Table 2 shows the results of the simulations. For the initial diesel-only systems, the average LCOE is 0.2452 $/kWh, which is close to previous studies on Philippine off-grid islands (Bertheau and Blechinger, 2018). Three out of the thirteen islands (Bantayan Island, Camotes Island, and Siquijor Island) are not suitable for biomass integration due to the low availability of the resource. Average LCOE reduction, fuel reduction, and RE share increase of 4.57 %, 5.71 %, and 4.99 %, can be observed. These low values can be due to the high energy demand in the islands and low biomass supply. One outlier is Romblon Island, which has an exceptionally high RE share increase of 25.18 %, LCOE reduction of 21.16 %, and fuel consumption reduction of 24.05 %. This is almost four times the average LCOE for the islands included in the analysis. This may be attributed to the high availability of the biomass resource coupled with the relatively low energy demand. On the other hand, Palawan main grid showed that low biomass availability and high energy demand can result to lower

LCOE reduction and RE share increase, thus lower integration potential. In Tablas Island and Sulu Island, implementing biomass-diesel systems would result to lower LCOE reduction and no significant increase in the RE share due to the smaller size of the gasifier power plants that can be installed compared to the sizes of the existing diesel generators. In some islands, it is possible to replace one of the existing diesel generators with gasification power plants to supply the energy demand, such as in Busuanga Island, Marinduque Mainand, Oriental Mindoro, and Palawan Main Grid.

2.2 Effect of changes in diesel fuel prices in the LCOE and RE share

To determine the effect of the variability in diesel fuel prices to the LCOE and RE-share of the integrated biomass-diesel systems, a sensitivity analysis was performed by varying the diesel price to -50 %, +50 %, +100 %, +200 %, and +300 % from the base price of 0.9 \$/L. As shown in Figure 2, the average LCOE for all the islands considered increases as the diesel fuel prices increases. A 50 % decrease in the base diesel fuel price will make integration of biomass into the diesel-only systems less attractive. The average RE share remained constant despite changes in the fuel price. This may be because of the availability of the biomass supply for the islands. The island grids will be compelled to use the diesel generators even with high prices while the supply from the gasification power plants remains the same due to the limited availability of the biomass resource.

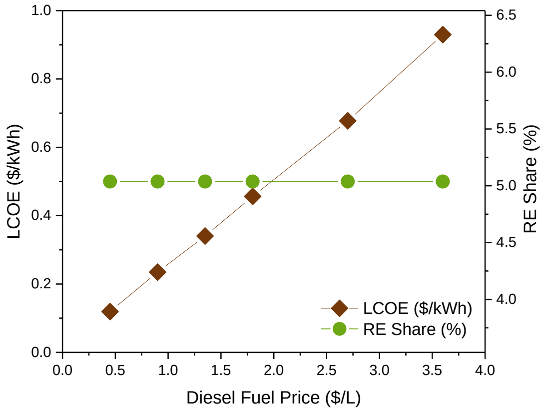

Figure 2: Sensitivity analysis on the effect of the diesel fuel price to the average LCOE and average RE share of the integrated biomass-diesel systems.

2.3 Effect of the establishment of feedstock market

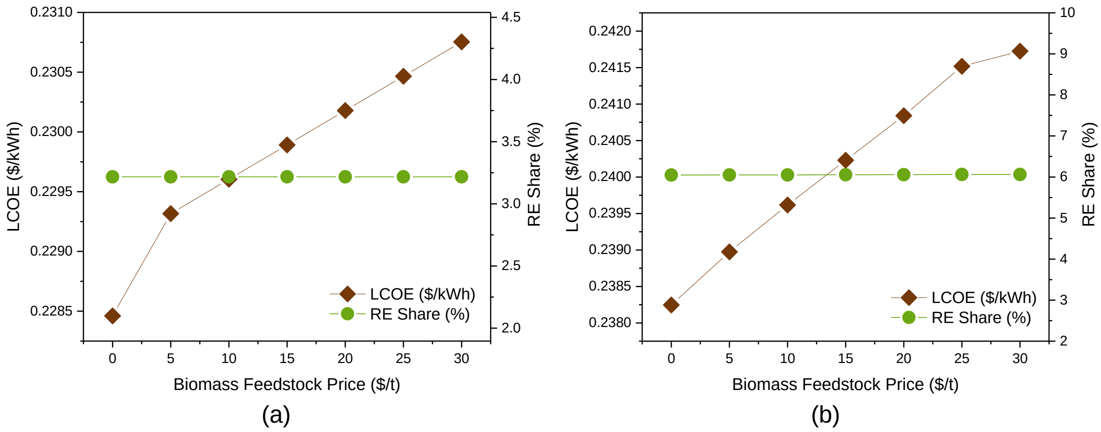

Figure 3: (a) Sensitivity analysis on the effect of rice residue prices (\$/t), and (b) coconut residue prices (\$/t) to the average LCOE and average RE share of the integrated biomass-diesel system.

The initial case was done using the assumption that the biomass feedstock can be obtained for free. However, this is not the real case because of the premiums paid to farmers, and the collection and transport cost for the feedstock (IRENA, 2012). We then determined the effect of establishing a feedstock market as shown in Figure 3. Even if the feedstock prices reach 30 \$/t, there is 1 % average increase in the LCOE if the feedstock is from rice residues, while 1.46 % average increase if coconut residues were used, both of which does not exceed the LCOE for the diesel-only systems. Varying the feedstock prices have no observable effect on the RE share.

3. Conclusions

This work has shown the techno-economic potential of integrating biomass into the off-grid diesel systems in the Philippines. Based on the techno-economic assessment of the thirteen islands under the Large NPC-SPUG Areas, the average LCOE reduction can reach up to 4.57 %, and in cases where biomass availability is high and energy demand is low, this can reach up to 25 % and possibly resulting to lower electricity cost for the consumers and lower missionary electrification subsidies. The average fuel reduction of 4.99 % and RE share increase of 5.71 % also mean that there would be a decrease in the greenhouse gas emission. Establishing a feedstock market has minimal effects on the RE share, and even if the feedstock prices reach up to 30 $/t, the LCOE for biomass-diesel systems remains lower than the diesel-only systems. If properly implemented, integrating biomass into the off-grid diesel systems in the Philippines can be a viable option especially for islands with high resource availability and low energy demand. Future work on the use of agricultural waste biomass in non-electricity applications such as biofuels production should also be considered.

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