Food and Agriculture Organization
of the United Nations

Feasibility Study – Appendix 9:

Potential Contribution of Short Rotation Plantations for Energy Use to the Low Emission Development Strategy

For the GCF-FAO Project "Forest Landscape Restoration for Climate Benefits and Resilience (Fiji FLR)"

Abstract/Summary

Fiji's Low Emission Development Strategy 2018-2050 (LEDS) has 4 scenarios where the "Very High Ambition" scenario targets to achieve net zero emissions by 2050 by aggregating the emissions from all sectors of the economy. Various electricity generation sources are planned in the future in LEDS and one of them is biomass power plants. Table S1 shows the generation capacity for different scenarios of LEDS.

Table S1 Biomass power plant generation capacity in Fiji's LEDS

	Business as usual unconditional scenario	Business as usual conditional scenario	High Ambition Scenario	Very High Ambition Scenario
LEDS – biomass power plants generation (GWh)	115.9	646.9	601.1	846.8
Biomass power plant capacity (MW)	22	136*	166*	256
Agri + forestry + SRP electricity generation potential (GWh)	450	450	450	450
% contribution to LEDS	More than enough	70%	75%	53%
Deficit (GWh)		197	151	397
Additional land area needed for SRP to meet LEDS targets (Ha)		12,900	9,900	26,000

* The MW and GWh generation from biomass power plant (BPP) are obtained from Fiji LEDS model. Please note that the generation in high ambition scenario is less than the generation in business as usual conditional scenario despite high ambition scenario having more BPP capacity compared to business as usual conditional scenario. This is because, these values were part of a bigger model that had other renewable energy sources of generation and merit order dispatch rule was used for BPP but for new solar and wind generators, full capacity dispatch rule was applied. In high ambition scenario, there were new solar and wind capacity additions and these were dispatched whenever it was produced to meet the hourly demand curve resulting in low generation (GWh) from BPPs.

This report considered agricultural (crop residues and livestock manure), forestry (logging and milling residues) and short rotation plantations (SRPs) on degrading shrubland, cropland and grassland.

Table S2 summarises the generation capacity for different divisions in Fiji from different sources. ***Table S2 reveals that the potential generation from forest and agricultural residues and SRPs on degrading shrubland, cropland and grassland is not sufficient to meet the generation capacity of biomass power plants in three of the scenarios shown in Table S1.*** The maximum biomass energy generation potential needed in LEDS is 847 GWh from the Very High Ambition scenario but as seen from Table S2, the maximum generation from all possible residues and SRPs is estimated to be 450 GWh which can cover almost 53% of the LEDS biomass generation capacity. This gives a deficit of 397 GWh which corresponds to approximately 26000 Ha of additional land area needed for SRP.

Table S2 Electricity generation potential from various biomass feedstock.

	Central		**Eastern**		**Northern**		**Western**	
	EP (GWh)	PP (MW)	EP (GWh)	PP (MW)	EP (GWh)	PP (MW)	EP (GWh)	PP (MW)
Forestry Residue								

Forest logging residue	41.7	7			30.9	5.0	82	13
Sawmill residue	4.4	0.7			3.43	0.6	18.7	3
Veneer Mill residue					1.6	0.3		
	46.1				35.9		100.7	
Agriculture residue								
Temporary crops residue	11.9	1.9	2.4	0.4	24	3.9	12.5	2.0
Permanent crops residue	7.5	1.2	14.5	2.4	40	6.5	23.6	3.8
Livestock manure	20.7	3.4	3.0	0.5	14.9	2.4	38.8	6.3
	40.1		19.9		78.9		74.9	
SRPs								
Degrading shrubland, cropland, grassland for SRPS	3.22	0.5	0.239	0.04	22.0	3.8	27.7	5.0
Total	89.4	14.7	20.14	3.34	136.8	22.5	203.3	33.1
TOTAL	450	74						

Considering other organic waste (from municipal solid waste, wastewater treatment plants and non-hazardous industrial wastewater) electricity generation potential is estimated to be 64.5 GWh with 10.5 MW power plant capacity. This reduces the land area for other SRPs requirement by 4200 Ha.

Where can the additional 22800 Ha (26000-4200) land area come from?

The total area of degrading shrubland, cropland and grassland is not much (3750 Ha) for overall Fiji but data shows that degrading forest land area is approximately 20000 from Vanua Levu and 40000 from Viti Levu. Hence, additional SRPs to meet the deficit LEDS requirement would require just 36% of the degrading forest land area. If degrading forest land areas are not used for additional SRPs than other resources need to considered for electricity generation.

Nomenclature/Abbreviations

A	Area of the SRP
BAU_{cond}	Business-as-usual conditional scenario
BAU_{uncond}	Business-as-usual unconditional scenario
BPP	Biomass power plant
BY_i	Biogas yield per year
CF	Capacity factor of power plant
CHP	Combined heat and power
ConF	Conversion factor (1.5 MWh/tonne of dry biomass)
CP	Annual crop production
EC_B	Energy content of biogas taken as 5 kWh/m^3 of biogas
EFL	Energy Fiji Limited
$E_{in\ feedstock}$	Energy in feedstock
$E_{out\ of\ BPP}$	Energy out of biomass power plant
EP	Electricity generation potential
FSC	Fiji Sugar Corporation
GWh	Gigawatt hours
HA	High Ambition Scenario
Ha	Hectares
HFO	Heavy Fuel Oil
HHV	Higher heating value
i	Type of crop
IDO	Industrial Diesel Oil
IPP	Independent power producer
IRENA	International Renewable Energy Agency
LEDS	Low Emission Development Strategy
MC	Moisture content wet basis for i crop
Mr	Mass of dry residue
MW	Megawatt
NGEL	Nabou Green Energy Limited
P_R	Maximum capacity of power plant
PP	Power plant capacity
PV	Photovoltaic
Q_i	Total quantity of manure produced per year
R	Recovery rate of residue generated at mill
r	Rate of feedstock production from SRP
r_B	Biogas production rate
Rlog	Recovery rate of residue from logging
r_m	Rate of manure production per day

RPR	Residue to crop production ratio
SAF	Surplus availability factor
SRP	Short rotation plantations
TBP	Theoretical biomass potential
TWIL	Tropik Woods Industries Limited
VHA	Very High Ambition Scenario
Vlog	Volume of log production
Vr log	Volume of residue from logging
Vr mill	volume of residue generated at sawmill or veneer mill
W2E	Waste to Energy
η_{f+b}	Efficiency of boiler and furnace
η_g	Efficiency of generator
η_s	Efficiency of steam turbine

Table of Contents

List of Figures

List of Tables

1.0 Introduction

Energy Fiji Limited, EFL, is the sole power utility in Fiji responsible for planning, generating, and distributing grid electricity to four islands in Fiji: Viti Levu, Vanua Levu, Levuka, and Taveuni. In 2022, 1,081 GWh of electricity was generated and supplied to the EFL grid. 598 GWh was from hydropower plants, 410 GWh from thermal power stations that use industrial diesel oil and heavy fuel oil, 0.093 GWh from wind and the remaining 73.5 GWh is from independent power producers (EFL, 2023). Solar Photovoltaics also contributes to grid electricity but this production is from the consumer end is not captured in the utility annual report. Independent Power Producers (IPPs) produce electricity from biomass resources and export surplus to the grid, while EFL generates all the other forms of grid electricity. These IPPs are Fiji Sugar Corporation (FSC), Tropik Woods Industries Limited (TWIL), and Nabou Green Energy Limited (NGEL).

FSC and TWIL have combined heat and power (CHP) plants where the heat is used for the mills' drying process. FSC sells power to the grid from its mills in Lautoka, Ba, and Labasa. Lautoka, Labasa, and Ba mills have cogeneration plants of 5MW, 24 MW, and 9 MW respectively. These IPPs sell electricity to EFL only during the sugarcane crushing season from June to November (EFL, 2019). FSC uses its electricity internally first and sells any excess energy to the grid. TWIL is a sawmill that produces electricity from its 9 MW power plant using pine residue and sells surplus electricity to the grid. NGEL, commissioned in 2017, uses woodchips to power its 12 MW biomass power plant.

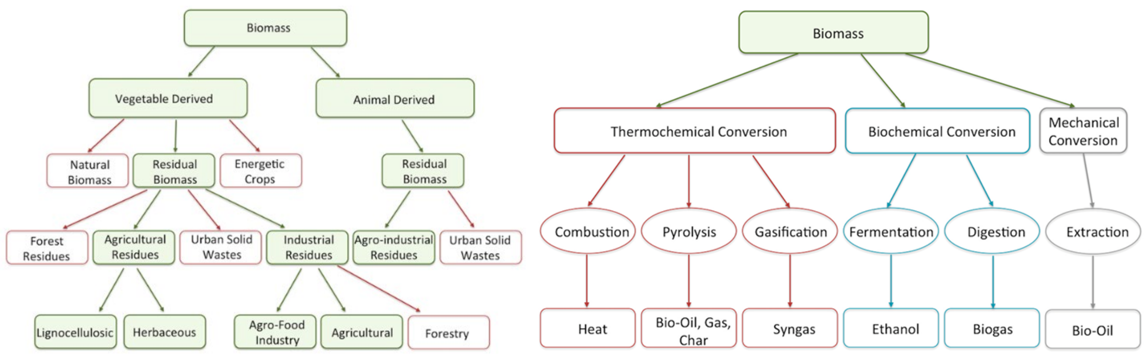
Fiji's Low Emission Development Strategy 2018-2050 envisions deep decarbonization of the economy including all modes of transport, electricity generation, and energy demand. Specifically, four scenarios are studied in the LEDS (GoF, 2018):

i. A "Business-as-Usual (BAU) Unconditional scenario – (BAU_{uncond})," reflects the implementation of existing and official policies, targets, and technologies that are unconditional in the sense that Fiji would implement and finance them without reliance on external or international financing.
ii. A "BAU Conditional scenario – (BAU_{cond})," which reflects the implementation of existing and official policies, targets, and technologies that are conditional in the sense that Fiji would rely on external or international financing to implement mitigation actions, thus this scenario would have higher ambition than "BAU Unconditional."
iii. A "High Ambition scenario – (HA)" projects ambitions beyond those already specified in policies, relying on the adoption of new, more ambitious policies and technologies and availability of additional financing to implement mitigation actions, and achieves significant emission reductions by 2050 compared with the business-as-usual scenarios.
iv. A "Very High Ambition scenario - (VHA)" projects ambitions well beyond those already specified in policies, thus relying on the adoption of new, significantly more ambitious policies and availability of new technologies and additional financing to implement mitigation actions, and in which most sectors achieve net zero or negative emissions, by 2050.

A range of energy sources and technologies are considered in LEDS as seen from Table 1. One renewable energy source considered in the report is bioenergy which encompasses but is not limited to landfill gases, bioenergy from wastewater treatment plants, biogas digesters, and biomass power plants (BPP). The sources of feedstock used in biomass power plants could be agricultural residues, forest and sawmill residues, and others as shown in Fig. 1(a). In addition, there are various technologies as shown in Fig. 1(b) that could be used for bioenergy generation, some include direct combustion, pyrolysis and gasification (Sugathapala, 2022). For BPP, crucial is the assessment of resources and supply of resources. This document attempts to analyse the resources available for BPP operation based on the data that is already published or in the public domain. It is to be noted that the supply chain of biomass feedstock from the point of generation to the biomass power plants needs to be strategically planned where potential suppliers, landowners, and truckers, are part of the planning and consultation process and aware of the specific fuel (in terms of quality and quantity) needed by BPP.

Table 1 Total installed capacity for different scenarios for on-grid generation. Source: (GoF, 2018)

	Capacity additions (MW) for different scenarios			
	VHA	HA	BAU_{cond}	BAU_{uncond}
New Biogas Plant Vuda	1	1	1	0
New Biomass Plant	256	166	136	22
New W2E Plant	10	10	10	0
New Solar PV	522.8	322.8	272.8	222.8
New Hydro	434.7	284.7	234.7	0.7
New FSC	90	90	18	0
New Geothermal	350	150	52	0
New Wind	350	200	150	0
New HFO	0	0	105	105
New IDO	2	2	107	142
Total	2016.5	1226.5	1086.5	492.5
Total Biomass-based	267	177	147	22
% of biomass capacity	13.2	14.4	13.5	4.5



(a) (b)

Fig. 1(a) Biomass classification based on feedstock and (b) Scheme of main conversion processes for energy exploitation from biomass. Source: (Algieri et al., 2019).

The assignment aims to elaborate scenarios for a sustainable supply of bioenergy to cover the added bioenergy power in the country, in particular, related to Short Rotation Plantations for Energy purposes. Specifically, the assignment will:

i. analyse available domestic sources for bioenergy from forestry and agricultural resources that could contribute to the sustainable feedstock supply chain of the bioenergy projects foreseen in the BAU conditional, high ambition and very high ambition scenario of the LEDS;
ii. estimate quantity (e.g. in m3 dry matter of feedstock for forestry and agricultural resources) and corresponding energy outputs (in kWh per year) currently available from sustainable domestic bioenergy sources;
iii. estimate of the amount (in ha) of Short Rotation Plantations (SRP) necessary to provide additional sustainable bioenergy feedstock supply in all scenarios of the LEDS in point (i);
iv. indicate the type of SRPs that could be utilized to cover for additional bioenergy supply, mindful that it is essential to utilize non-invasive species;
v. identify preliminary sites where bioenergy plants could be implemented in all four scenarios of the LEDS, with corresponding capacities (in MW) and description of corresponding sustainable feedstock supply chains;
vi. identify the quantities necessary of the feedstock (e.g. m^3 of wood residues, m^3 from SRP etc.) and their origin for the sustainable feedstock supply of the bioenergy plants mentioned above;
vii. identify the areas on which the necessary SRPs indicated in iii. and iv. above could be planted, taking in consideration: the existing powerplants, the expected construction of new ones and the areas with higher energy demand. This analysis should also consider sustainable transport distances of feedstock to existing and potential future power plants.

2.0 Targets of Fiji LEDS

From studying the biomass capacity addition in power generation in future years of the LEDS report, it is seen that in BAU_{uncond} – 22 MW of biomass power plant is present, in BAU_{cond} = 136 MW, HA = 166 MW ad VHA = 256 MW. However, all these are not introduced in one year but are spread over the planning period from 2018 to 2050.

To achieve net zero emissions (VHA scenario), the next BPP must be operational by 2025 as seen in Table 2, which gives us almost 2 years to get the plant ready. However, supplying it with short rotation plantations (SRP) may prove to be challenging as it will take land, planting time and maturing for cutting, finances, stakeholders buy-in, investors, and many other crucial aspects (Prasad and Raturi, 2021). Hence, proper planning and buy-in from key stakeholders (landowners, truckers, investors, government, etc.) need to be established. For the high ambition (HA) scenario and BAU_{uncond} scenarios, the next BPP must be operational by 2033 and 2034 respectively which gives authorities and stakeholders another approximately 10 years to get resources and get the first 30 MW plant ready.

Table 2 New Generic Biomass Power Plants capacity addition in LEDS. Data Source: (GoF, 2018)

Year	**Capacity added (MW)**	**Generation in 2050 from LEDS analysis (GWh)**
BAU_{uncond}		
2017	10	
2018	12	
	22 MW	116
BAU_{cond}		
2017	10	
2018	12	
2025	24[1]	
2034	30	
2041	30	
2047	30	
	136 MW	647
High Ambition Scenario		
2017	10	
2018	12	
2025	24	
2033	30	
2039	30	
2044	30	
2049	30	
	166 MW	601
Very High Ambition		
2017	10	
2018	12	
2025	24	
2029	30	
2032	30	
2036	30	
2039	30	
2042	30	
2044	30	
2048	30	
	256 MW	847

Apart from the generic new biomass power plants being considered in Fiji's LEDS there are other biomass-based generation capacities that are considered in Fiji's LEDS which are given in Table 3.

Table 3 Other biomass-based power plants

Other power plants using biomass resources	**Capacity and year added**		
	Conditional	**HA**	**VHA**
		Has conditional scenario additions	Has HA scenario additions
New W2E Plant Suva	10 MW in 2025		
New FSC_labasa_Ltk	18 MW in 2025	42 MW in 2035 and 30 MW in 2045	
New Biogas plant Vuda	1 MW in 2020 (please note, this has not eventuated at the moment.		

[1] New wood pellet biomass

3.0 Theoretical Framework

3.1 Formula for electricity generation potential from biomass power plant

For energy generation potential from BPP, direct combustion of feedstock is taken and not other possible processes, pyrolysis, gasification, etc. To calculate energy generation potential, two important aspects have to be considered; (i) biomass feedstock (tonnes/year), (ii) higher heating value of the feedstock, (iii) the efficiency of the different blocks in the power plant, Fig. 2. The efficiency of power plant varies between 25-36% and the net average electrical efficiency is around 30% (IRENA, 2014).

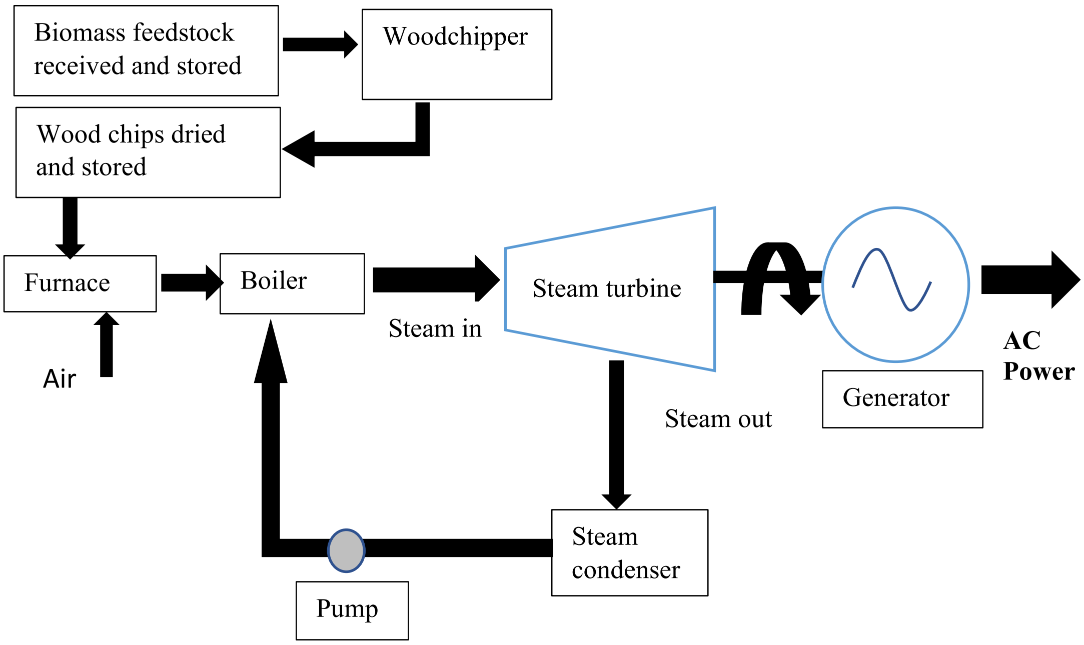


Fig. 2. Block diagram for typical biomass power plant.

There are a number of authors who have studied the dry biomass yield from short-rotation plantations. (Christersson and Verma, 2006) report that short-rotation plantations are trees grown either as single stems or as coppice systems, with a rotation period of fewer than 30 years and with an annual woody production of at least 10 tonnes of dry matter or 25 m^3 per hectare. (Sabatti et al., 2014) found from their study in Italy on poplar SRPs that the mean annual dry biomass matter was 21.7, 19.5 and 19.3 tonnes $Ha^{-1}year^{-1}$ for different genotypes and the higher heating value ranging from 18.96 to 19.56 MJ/kg. (Senelwa and Sims, 1999) also studied the fuel properties of 12 different species of short rotation plantations in New Zealand and found that the HHV ranges from 19.6-20.5 MJ/kg for wood.

To calculate the energy yield from the woody biomass feedstock, Eqs. (1-3) are used.

$$E_{in\ feedstock} = r \times A \times HHV \times 1000\ kg/tonne \quad \text{Eq. 1}$$

$$E_{out\ of\ BPP} = \frac{E_{in\ feedstock}}{\eta_{f+b} \times \eta_s \times \eta_g \times 3600\ MJ/MWh} \quad \text{Eq. 2}$$

$$P_R = \frac{E_{out\ of\ BPP}}{8760 \times CF}$$ Eq. 3

Where

$E_{in\ feedstock}$ – is the energy in feedstock (MJ)

r – is the rate of feedstock production from SRP (taken as 10 tonnes/Ha)

A - is the area of the SRP in the field (Ha)

HHV – is the higher heating value of feedstock (taken as 19.5 MJ/kg)

η_{f+b} – is the efficiency of boiler and furnace (taken as 85%)

η_s – is the efficiency of steam turbine (taken as 35%)

η_g – is the efficiency of generator (taken as 95%)

$E_{out\ of\ BPP}$ – is the energy out of biomass power plant (MWh)

P_R – is the maximum capacity of the power plant (MW)

CF – is the capacity factor (taken as a range 0.5-0.95 and average taken as 70%)

IRENA reports that technically the capacity factor, CF (Eq. 3) of a biomass power plant can go as high as 85-95% given that there is continuous feedstock supply to the power plant. For wood-fired biomass power plants the capacity factor mostly is around 75% but it can go as low as 50% (IRENA, 2014) which is greatly affected by the availability of the feedstock and the downtime of the powerplant due to scheduled maintenance.

For this exercise, the overall efficiency of the power plant is taken as 28%, the higher heating value of feedstock is taken as 19.5 MJ/kg, the dry matter feedstock from the short rotation plantation is 10 tonnes/ha and the capacity factor of the power plant is taken as 70%.

Using Eqs. (1-3), the power rating of BPP was estimated for a 1 ha area of SRP being harvested annually and getting 10 tonnes of dry matter. Fig. 3 shows how the power rating BPP could vary depending on the capacity factor of BPP and it is seen that as the capacity factor increases for the power plant. Further, for a capacity factor of 0.70, the installed capacity of the BPP would be 2.5 kW for a 1 Ha SRP.

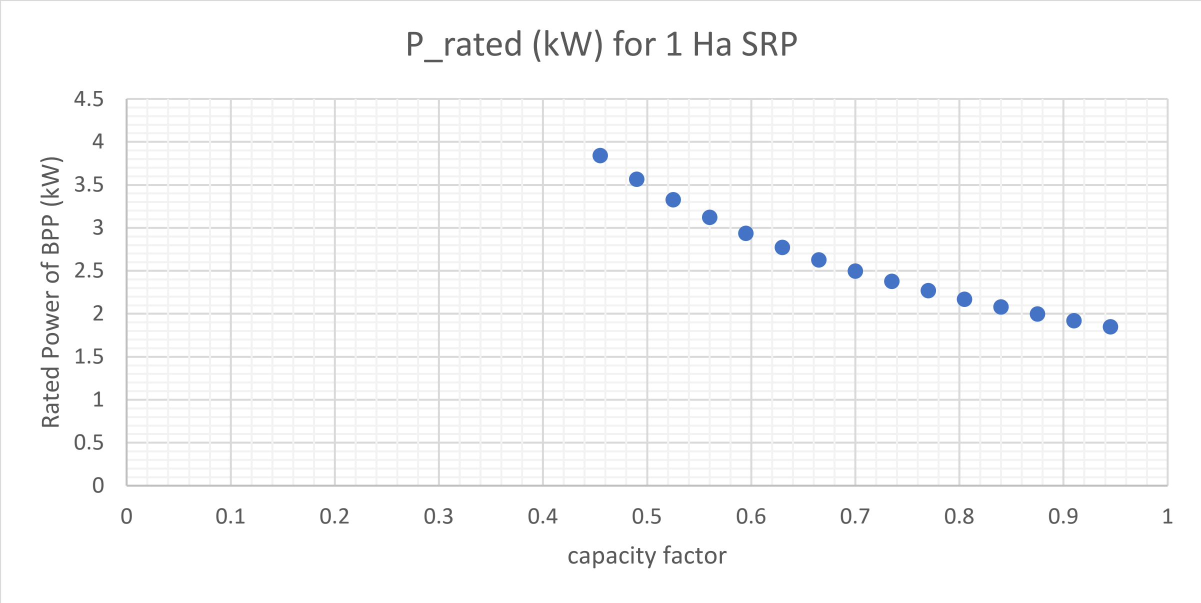


Fig. 3. Rated power of the BPP based on 1 Ha SRP feedstock.

3.2 How much SRP would be needed in LEDS to meet all of 256 MW in VHA scenario?

From Table 1, it is seen that to achieve net zero goal for Fiji, 256 MW of bioenergy-based power plant would be needed. If all this capacity were to be supplied with SRPs, then theoretically total land area needed would be around 103,000 Ha using a capacity factor of 0.7 and the values and assumptions stated in the previous section. However, because the capacity factor depends on feedstock availability, the capacity was varied in steps of 5% ranging from 0.455 to 0.945, as seen in Fig. 4. When CF = 0.455, the land area needed is close to 67,000 Ha which almost doubles to 138,000 Ha as the capacity factor reaches 0.945. Hence, as the capacity factor is increased, and area increases, the energy output from the BPP increases and reaches almost 2120 GWh when capacity is 0.945 from 1020 GWh when capacity factor is 0.455 as seen in Fig. 5.

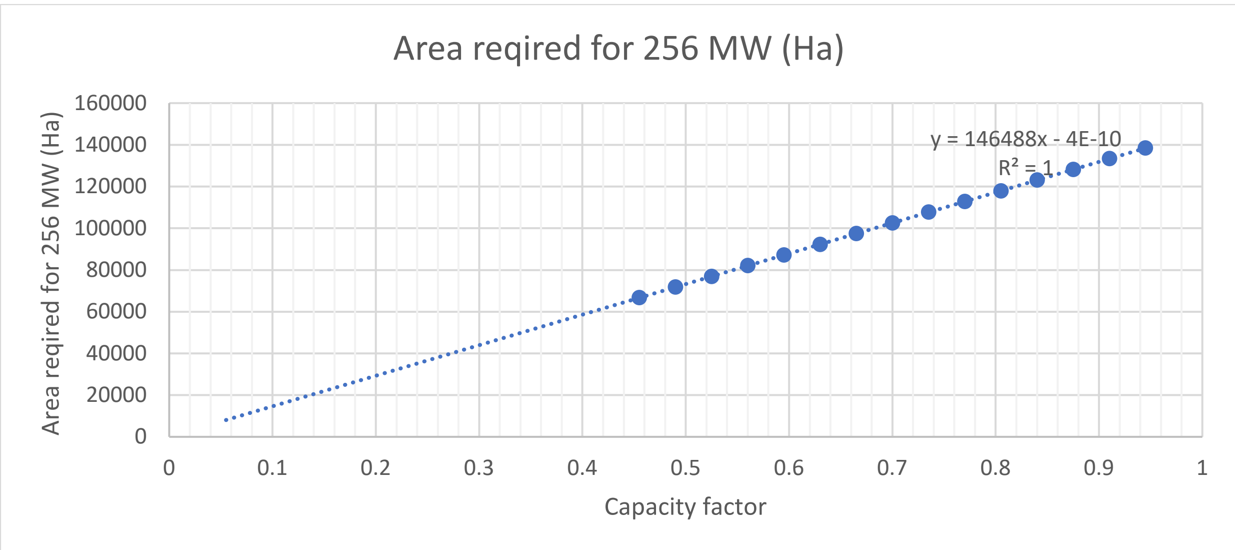


Fig. 4. Total land area needed for 256 MW capacity of BPP under the "Very High Ambition" scenario of LEDS.

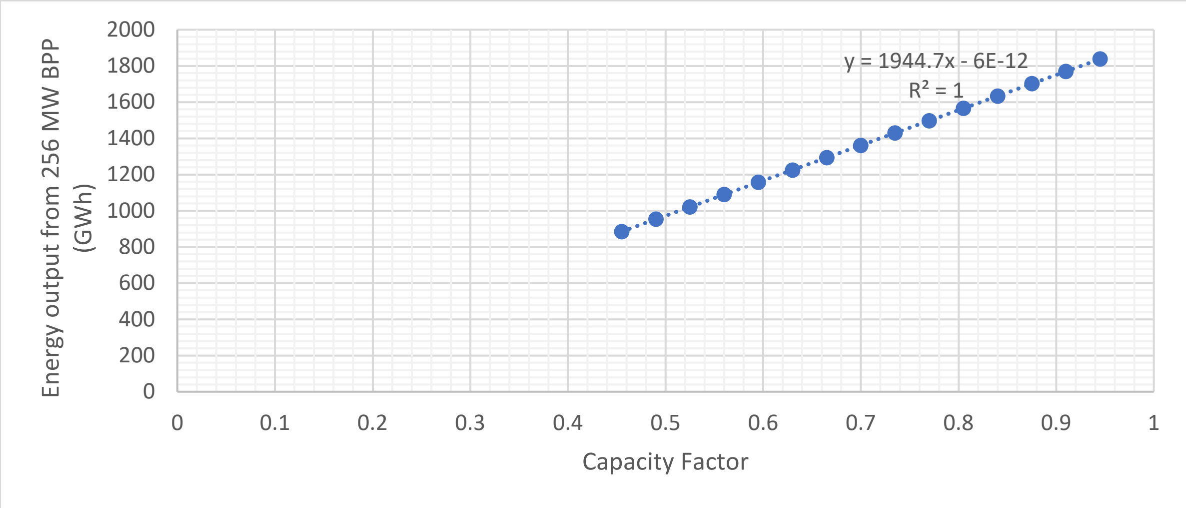


Fig. 5. Energy output from 256 MW BPP.

Fiji has 1.8 million ha of land area out of which 1.01 million ha are covered in forests where 95% are privately owned and 5% are owned by the government. However, 89% of the total forest cover is native forest which does not get logged often and logging only happens after approval from the Ministry of Forestry as they are protected under various programmes. The remaining forest cover is from planted forests which consist of mainly softwood (pine) and hardwood (mahogany).

So the question then arises, how do we supply for the 256 MW biomass-based power plants? Section 4.1 and 4.2 discusses the electricity generation potential from agricultural and forest residues. Another option is to look at short rotation plantations which is discussed in section 5.

4.0 Potential for available forest and agricultural resources for bioenergy production

4.1 Agricultural resources

4.1.1 Agricultural crops

According to the 2020 Agricultural Census, the total area of farmland in the country is 194768.6 Ha and the recorded total volume of crop production in the country is 399 056.7 metric tonnes for 2020. Of this farmland area, 45.8% is permanent crops while the rest is temporary crops.

There are two types of crops in Fiji; Permanent and temporary. Permanent crops are crops that do not have to be re-planted for several years. Eg. coconut, avocado, papaya, yaqona (kava), pineapple, banana, vanilla, passion fruit, sugarcane etc. Temporary crops are crops with less than one year of growing cycle, eg. vegetables and root crops. In this category area under vanilla, passion fruit, sugarcane and similar crops is not included, as these are classified as permanent crops (MoA, 2021). The planting, harvesting and processing of crops produce residues which can be used for bioenergy generation.

(Lal, 2005), (Koopmans and Koppejan, 1997), (Odoi-Yorke et al., 2022) present the residue-to-crop production ratio (RPR) for various agricultural products and also note that the residue depends on, among other factors, the local weather conditions, soil type and crop management.

To estimate the theoretical biomass potential for energy generation from agricultural residues, (Shane et al., 2016) and (Tumen Ozdil and Caliskan, 2022) methodology was used.

The total theoretical biomass potential (TBP) in tonnes was estimated using Eq. 4.

$$TBP = \sum_i CP_i \times RPR_i \times SAF_i \times \frac{100 - MC_i}{100} \quad \text{Eq. 4}$$

Where

i – is the type of crop

CP – is the annual crop production in tonnes

RPR – is the residue to crop production ratio

SAF[2] – is the surplus availability factor

MC – is the moisture content wet basis for i crop.

To estimate the electricity generation potential from agricultural residue, Eq. 5 is used.

$$EP = \sum_i TBP_i \times ConF \quad \text{Eq. 5}$$

Where

$ConF$ – is the conversion factor.

$ConF$ is taken as an average value of 1.5 MWh per tonne of dry biomass feedstock with the efficiency of the power plant ranging between 20-40% (FDoE and UNDP, 2014a).

The capacity of the power plant is estimated using Eq. 3 and taking the capacity factor of the power plant as 70%.

Table 4 Parameters taken for the estimated bioenergy potential from crops

	Type of residue	**RPR**		**SAF**		**MC_{wb}**	
		Value	Ref: FDoE and UNDP, 2014b) under otherwise stated	Value	Ref (Shane et al., 2016) unless otherwise stated	Value (%)	Ref: FDoE and UNDP, 2014b) unless otherwise stated
Temporary crops							
Cassava	stalk	0.06		0.8		15	(FDoE and UNDP, 2014b)
	peeling	0.25	(Shane et al., 2016)	0.2		15	assumed

[2] The surplus availability factor, also called the recoverability factor of the crop residues, is ratio of the residues available for bioenergy production after part of it is used for other purposes to the total residue production.

Dalo	stalk	0.06		0.8	assumed	15	
Yaqona	stalk	0.06		0.8	assumed	15	
Okra	stalk	0.06		0.8	assumed	15	assumed
Ginger	stalk and leaves	0.06		0.8	assumed	15	assumed
Kumala	leaves and peels	0.4	(Shane et al., 2016)	0.8		15	assumed
Rice	straw	0.45		0.684	(Jekayinfa et al., 2020)	12.71	
	husk	0.27		1	assumed	12.37	
Watermelon	peel	0.2[3]	assumed	0.8	assumed	80	assumed
Cowpeas	peels and leaves	2.9	(Koopmans and Koppejan, 1997)	0.8	assumed	15	(Koopmans and Koppejan, 1997)
Yam	Peels	0.06	(Jekayinfa et al., 2020)	0.8	assumed	15	assumed
Pumpkin	stalk and peels and waste pumpkin that are not harvested	0.2	(FFW, n.d.)	0.8	assumed	80	assumed
Eggplant	stalk	0.06		0.8	assumed	80	assumed
Chinese cabbage	leaves	0.3	(Choi et al., 2002)	0.8	assumed	15	assumed
Maize	stalk	1	(Koopmans and Koppejan, 1997)	0.8		22	(Koopmans and Koppejan, 1997)
	husk	0.2	(Koopmans and Koppejan, 1997)	1		11	(Koopmans and Koppejan, 1997)
	cob	0.273	(Koopmans and Koppejan, 1997)	1		7.53	(Koopmans and Koppejan, 1997)
English cabbage	leaves	0.2		0.8	assumed	15	assumed
Permanent crops							
Coconut	husk	0.42		0.884	(Aslam et al., 2021)	10	
	shell	0.7		0.75	(Aslam et al., 2021)	13	
	fronds	2.4 dry tonnes/ha/yr		0.8	assumed	n/A	
Pineapple	Leaves	80 tonnes/ha/yr		0.7	assumed from (Shane et al., 2016)	80	
Banana	Peels	0.25		0.8	(Tumen Ozdil and Caliskan, 2022)	15	
	Stem/Leaves	89 dry tonnes/ha/year		0.8	(Tumen Ozdil and Caliskan, 2022)	n/a	
Pawpaw	Peels	0.25		0.8	assumed	15	
	Stem/Leaves	89 dry tonnes/ha/year		0.8	assumed	n/a	

Some values of assumed because of the limited published literature

Using Eqs. 4 and 5 and values given in Table 4, the estimated electricity generation potential from agricultural crops is given in Table 5. In addition, the potential was estimated using around

[3] 20% of waste is not utilised in field due to imperfection or over ripening, etc. Source: Shane, A., Gheewala, S.H., Fungtammasan, B., Silalertruksa, T., Bonnet, S., Phiri, S., 2016. Bioenergy resource assessment for Zambia. Renewable and Sustainable Energy Reviews 53, 93-104..

95% of total crop production values from different divisions in Fiji. The missing values in Table 5 for temporary crops in different divisions mean that certain crops are in the low 5% of the total production in that area. Considering national data, the top 10 temporary crop production are (in the order of decreasing magnitude): cassava, dalo, yaqona, okra, ginger, cowpeas, pumpkin, kumala, watermelon and rice. For the Eastern division, root crops are the dominating temporary crops while ginger is one of the dominant temporary crops in the Central division. Rice and cowpeas are also at the top list of dominant temporary crops in the Northern division while okra is seen to be one of the dominant temporary crops in the Western division. It is estimated that 34.4 thousand tonnes of dry temporary crop residue is available while 57 thousand tonnes of dry permanent crop residue is available.

The total annual electricity generation potential from temporary crops is 51.7 GWh with power plant capacity of approximately 8.4 MW. This potential is distributed around the different divisions and from Fig. 6, it is seen that Northern division has the greatest electricity with approximately 4 MW power plant capacity.

For permanent crop production, 4 crops are the most dominating; Coconuts, pineapple, banana and pawpaw. The annual electricity generation potential from permanent crops for overall Fiji is 85.5 GWh where the Northern division is seen, from Fig. 6, to have the largest share corresponding to 5.9 MW power plant capacity.

Hence, the overall annual electricity generation potential from available agricultural crops is 137.2 GWh with 22.4 MW of power plant capacity.

Table 5 Crop Production, theoretical biomass potential and electricity generation potential from agricultural crops.

		Fiji			Central			Eastern			Northern			Western		
	Type of residue	**CP**	**TBP**	**EP**	**CP**	**TBP**	**EP**	**CP**	**TBP**	**EP**	**CP**	**TBP**	**EP**	**CP**	**TBP**	**EP**
		tonnes	tonnes (dry basis)	MWh		tonnes (dry basis)	MWh		tonnes (dry basis)	MWh		tonnes (dry basis)	MWh		tonnes (dry basis)	MWh
Temporary crops																
Cassava	stalk	117561	4796	7195	45244	1846	2769	12812	523	784	12204	498	747	47300	1930	2895
	peeling		4996	7495		1923	2884		545	817		519	778		2010	3015
Dalo	stalk	102324	4175	6262	67898	2770	4155	11304	461	692	18786	766	1150	4337	177	265
Yaqona	stalk	24610	1004	1506	5415	221	331	1013	41	62	15908	649	974	2274	93	139
Okra	stalk	11481	468	703										10803	441	661
Ginger	stalk and leaves	10157	414	622	9910	404	606									
Kumala	leaves and peels	5749	1564	2346	2229	606	909							3344	910	1364
Rice	straw	3360	903	1354							3178	854	1281			
	husk		795	1192								752	1128			
watermelon	peel	4552	146	218							2791	89	134	1298	42	62
Cowpeas	peels and leaves	6745	13300	19950							6017	11865	17797	671	1324	1985
Yam	Peels	1166	48	71				694	28	42						
Pumpkin	stalk and peels	6153	197	295	5441	174	261							662	21	32
Eggplant	stalk	2815	27	41										1958	19	28
Chinese cabbage	leaves	1770	361	542										1204	246	368
Maize	stalk	1057	659	989										983	614	920
	husk		188	282											175	263

	cob		267	400											248	372
English cabbage		938	128	191										710	97	145
Total		300438	34436	51654	136137	7945	11917	25824	1598	2397	58884	15992	23988	75543	8344	12516
Power Plant Capacity (MW)		306035		8.424			1.943			0.391			3.912			2.041
Permanent crops																
Coconut	husk	35479	11855	17783	809	270	406	9471	3165	4747	24759	8273	12410	439	147	220
	shell		16205	24307		370	555		4326	6489		11309	16963		201	301
	fronds		6812	10218		155	233		1818	2728		4754	7131		84	126
Pineapple	Leaves	28629	8016	12024	2071	580	870	76	21	32	1473	412	619	25009	7003	10504
Banana	Peels	3945	671	1006	1418	241	362	123	21	31	381	65	97	2024	344	516
	Stem or Leaves		9364	14046		3366	5050		291	437		904	1356		4802	7204
Pawpaw	Peels	3877	659	989	14	2	4	5	1	1	909	154	232	2949	501	752
	Stem or leaves		3450	5176		13	19		4	6		809	1213		2624	3937
Total		71930	57033	85549	4312	4998	7497	9675	9647	14471	27522	26681	40021	30421	15706	23560
Power Plant Capacity (MW)				13.951			1.223			2.360			6.527			3.842
Total agricultural crops																
Total		**372368**	**91468**	**137203**	**140449**	**12942**	**19416**	**35499**	**11245**	**16868**	**86406**	**42672**	**64009**	**105964**	**24050**	**36076**
PP capacity (MW)				**22.375**			**3.166**			**2.751**			**10.439**			**5.883**

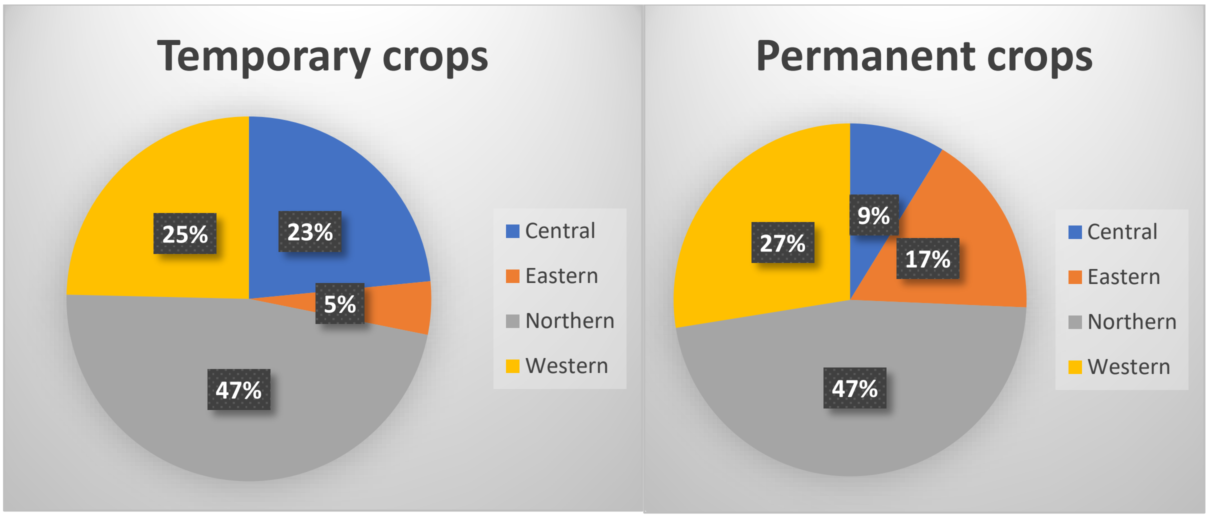


Fig. 6. Energy generation potential from agricultural crops in different divisions in Fiji.

4.1.2 Agricultural Livestock

Livestock farming in Fiji comprises beef cattle, dairy cattle, pig, goat, sheep, poultry and apiculture. The total number of livestock in Fiji is shown in Table 6. There are two types of cattle raised in Fiji; dairy for milk production while beef cattle for meat production. Overall it is seen that livestock numbers are high in the Central, Northern and Western division as the Eastern division is composed of small maritime islands where population numbers are significantly low compared to other divisions. Goat and sheep tend to be mostly concentrated in the Northern and Western division while the majority of poultry stock are in the Central and Western division.

Table 6 Livestock population in Fiji. Source: (FAO and MoA, 2021)

	Fiji	Central	Eastern	Northern	Western
Beef cattle	70041	12924	1608	15265	40244
Dairy cattle	49650	20093	503	6744	22310
Pig	58420	25577	10262	7170	15411
Goat	143853	4691	719	45288	93155
Sheep	37435	1022	706	17868	17839
Poultry	1449857	452014	5088	94361	898394
Apiculture (hives)	13162	357	98	4458	8249

Quality and quantity of produced livestock manure are variable according to type of feed and livestock living conditions (Noorollahi et al., 2015) and Table 7 provides daily manure production from different livestock from different articles.

The calorific value of biogas used by (Milbrandt, 2009) is 6 kWh/m^3 of biogas for estimation of bioenergy potential in Liberia while (FDoE and UNDP, 2014a) used 5 kWh/m^3 of biogas. For this work, 1m^3 of biogas is assumed to have an electricity generation potential of 5 kWh.

Table 7 Parameters for livestock

Livestock	Manure production (kg/day)				Biogas yield (m^3/kg)
	(Amare, 2015)	(Noorollahi et al., 2015)	(FDoE and UNDP, 2014b)	Value Used in this report	(Milbrandt, 2009)
Cattle	10-15	1.3-6.1	10	6	0.04
Sheep	0.75 – 1	0.64	2	0.64	0.05
Goats	0.75 – 1		2	0.64	0.05
Poultry	0.06 – 0.2	0.02-0.03	0.1	0.02	0.06
Pig		1.54	1.5	1.5	0.07

To estimate the electricity generation potential Eqs. 6 - 8 are used.

$$Q_i = \frac{N_i \times r_{m_i} \times 365}{1000} \quad \text{Eq. 6}$$

$$BY_i = Q_i \times r_{B_i} \quad \text{Eq. 7}$$

$$EP_i = BY_i \times EC_B \quad \text{Eq. 8}$$

Where

Q_i – is the total quantity of manure produced per year (tonnes)

BY_i – is the biogas yield per year (m^3)

EP_i – is the electricity generation

EC_B – is the energy content of biogas taken as 5 kWh/m^3 of biogas

i – is the type of livestock

N – is the number of livestock

r_m – is the rate of manure production per day

r_B – is the biogas production rate (m3/tonne)

Considering Table 8, the total theoretical electricity generation potential from different livestock in Fiji is 77.4 GWh with a total power capacity of around 13 MW. For different divisions, the Western division has 38.8 GWh of annual electricity generation potential, followed by Central (20.8 GWh), Northern (14.9 GWh) and then Eastern division having 3 GWh annual electricity generation potential. Cattle, pig, goat, sheep and poultry have 52.4, 11.2, 8.4, 2.2, and 3.2 GWh per year respectively,

In terms of the livestock that has the most potential is cattle as its numbers are relatively high. From Fig. 7, it is seen that all divisions have cattle as the highest electricity generation potential except Eastern which is comprised of small maritime islands.

To put projects on the ground, it would be useful to explore poultry for electricity generation as we have commercial companies raising poultry livestock and the stock is at one particular place where it will be relatively easy to collect manure and feed it to digester for methane production from where it can be used for electricity generation using an appropriate technology as shown in Fig. 1.

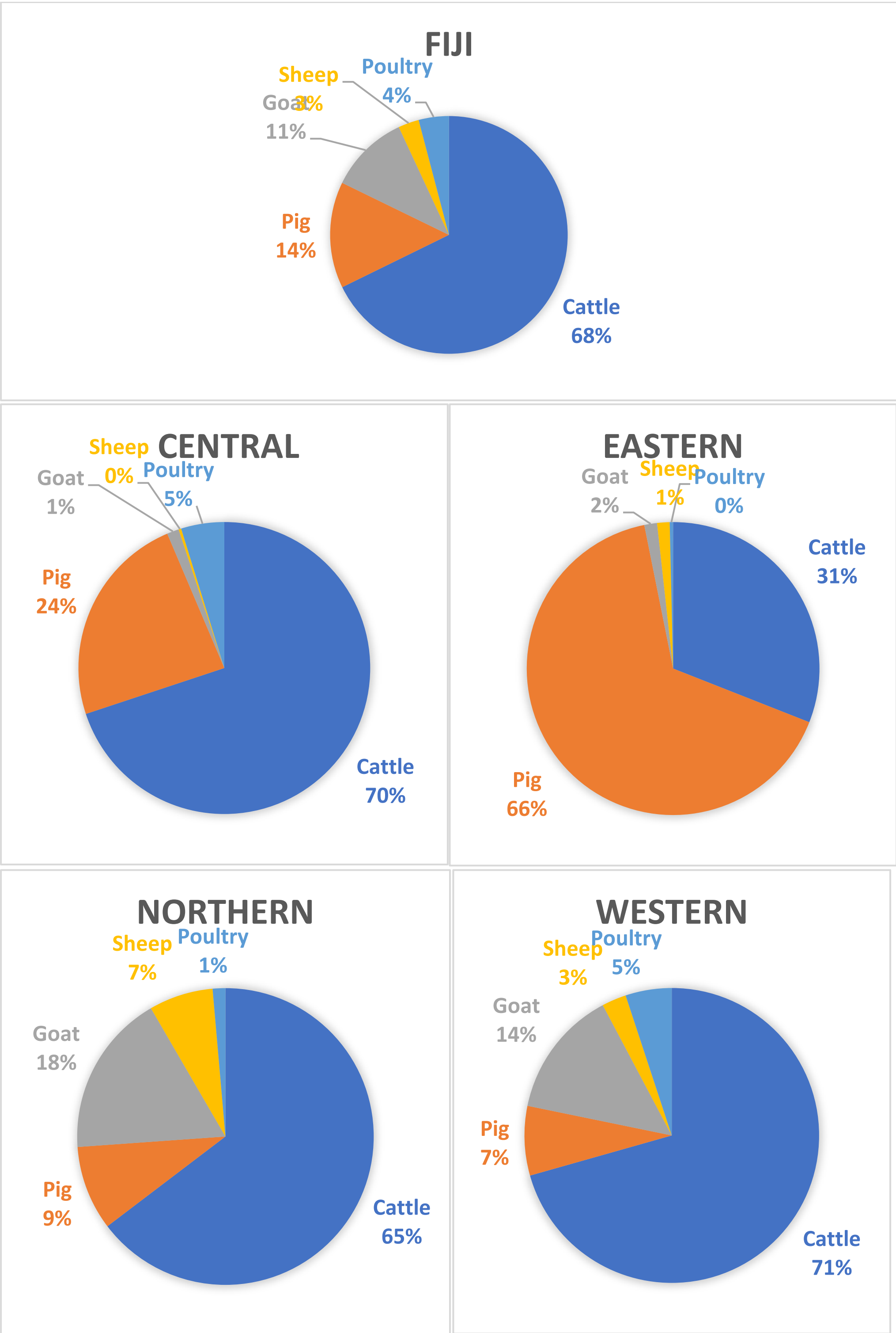


Fig. 7. Electricity generation potential share from different livestock around Fiji.

Table 8 Annual electricity generation potential from livestock

		Cattle	Pig	Goat	Sheep	Poultry	Total
	r_m (kg/day)	6	1.5	0.64	0.64	0.02	
	r_B (m3/kg)	0.04	0.07	0.05	0.05	0.06	
Fiji	*N*	119691	58420	143853	37435	1449857	
	Q (tonnes/yr)	262123	31985	33604	8745	10584	347041
	BY (m^3/yr)	10484932	2238947	1680203	437241	635037	15476359
	EP (MWh/yr)	52425	11195	8401	2186	3175	77382
	PP (MW)	9	2	1	0	1	13
Central	*N*	33017	25577	4691	1022	452014	
	Q (tonnes/yr)	72307.2	14003.4	1095.8	238.7	3299.7	90944.9
	BY (m^3/yr)	2892289.2	980238.5	54790.9	11937.0	197982.1	4137237.7
	EP (MWh/yr)	14461.4	4901.2	274.0	59.7	989.9	20686.2
	PP (MW)	2.4	0.8	0.0	0.0	0.2	3.4
Eastern	*N*	2111	10262	719	706	5088	
	Q (tonnes/yr)	4623.1	5618.4	168.0	164.9	37.1	10611.6
	BY (m^3/yr)	184923.6	393291.2	8397.9	8246.1	2228.5	597087.3
	EP (MWh/yr)	924.6	1966.5	42.0	41.2	11.1	2985.4
	PP (MW)	0.2	0.3	0.0	0.0	0.0	0.5
Northern	*N*	22009	7170	45288	17868	94361	
	Q (tonnes/yr)	48199.7	3925.6	10579.3	4174.0	688.8	67567.4
	BY (m^3/yr)	1927988.4	274790.3	528963.8	208698.2	41330.1	2981770.8
	EP (MWh/yr)	9639.9	1374.0	2644.8	1043.5	206.7	14908.9
	PP (MW)	1.6	0.2	0.4	0.2	0.0	2.4
Western	*N*	62554	15411	93155	17839	898394	
	Q (tonnes/yr)	136993.3	8437.5	21761.0	4167.2	6558.3	177917.3
	BY (m^3/yr)	5479730.4	590626.6	1088050.4	208359.5	393496.6	7760263.5
	EP (MWh/yr)	27398.7	2953.1	5440.3	1041.8	1967.5	38801.3
	PP (MW)	4.5	0.5	0.9	0.2	0.3	6.3

4.1.3 Future biomass power plants using agricultural residues

Using the estimated theoretical electricity generation potential from section 4.1.1 (agricultural crop residues) future power plants can have capacity of 3.2 MW, 2.8 MW, 10.4 MW and 5.9 MW at Central, Eastern, Northern and Western division respectively. In addition, from section 4.1.2, livestock manure can have estimated power plant capacity of 3.4 MW, 0.5 MW, 2.4 MW and 6.3 MW at Central, Eastern, Northern and Western division respectively. Please note that this generation potential does not take into account the sustainable transport distances of manure as the power plant site would first need to be determined (Ramos-Suárez et al., 2019). Apart from the manure transport, issues related to farmers being incentivized to collect manure and transport animal manure using appropriate technology and the safety issues of handling animal manure need to be considered (Hoyos-Sebá et al., 2024).

4.2 Forestry and Mill resources

Sixty percent of Fiji's area, or 1.1 million hectares (ha), is covered by forests. Of the 1.1 million hectares of forest cover, 82.2% are made up of natural forests, with the remaining 7.4% coming from hardwood plantations, 6.2% from softwood plantations, and 4.1% coming from mangrove forests (MoF, 2023).

From the latest annual report of the Fiji Ministry of Forest, the production of logs and different mills is shown in Table 9. In 2022, the total log volume produced was 545,208 m^3, a decrease of 215,609 m^3 (28.3%) from the previous fiscal year. Pine makes up 85.4% of the 545,208 cubic meters of total volume, followed by mahogany at 8.3% and native species at 6.3%.

Forest residues can be further classified as wood processing residues, which are produced during sawmilling and plywood processing, and logging residues, which are produced during the harvesting of timber. Stumps, roots, and branches are examples of logging residues; sawdust, offcuts, abandoned logs, and barks are examples of wood processing wastes.

To estimate the theoretical energy potential of the forest residue, the simple approach used by (FDoE and UNDP, 2014a, b; Shane et al., 2016) was adopted shown in Eqs. 9-11.

$$V_{r_{log}} = V_{log} \times R_{log} \quad \text{Eq. 9}$$

$$V_{r_{mill}} = V_{\log process\ in\ mill} \times R \quad \text{Eq. 10}$$

Where

$V_{r_{log}}$ – is the volume of residue from logging in m^3

V_{log} – is the volume of log production in m^3

R_{log} – is the recovery rate of residue from logging

$V_{r_{mill}}$ – is the volume of residue generated at a sawmill or veneer mill in m^3

R – is the recovery rate of residue generated at mill

$$M_r = \frac{V_{r_{log}} \times density \times (100 - MC)/100}{1000} \quad \text{Eq. 11}$$

Where

M_r – is the mass of dry residue in tonnes

To convert the volume of residue from m^3 to mass of residue in tonnes, an average density of 792 kg/m^3 for logging residues and 300 kg/m^3 for wood waste and saw-milling residues with a moisture content of 20%.

To estimate the electricity generation potential Eq. 5 is used. It is seen from Table 9 that the annual electricity generation potential from forest logging is 154.5 GWh (25 MW power plant capacity) based on the 2022 annual report of the Ministry of Forestry. There was no data in the report regarding the annual logged volume from different divisions in Fiji. (Prasad and Raturi,

2021) informs that on average 53% , 27% and 20% of log produced are from Western, Central and Northern divisions. Using these percentage shares, around 82 GWh (13 MW) of electricity can be generated Western division from forest logging while Central and Northern are 41.7 GWh and 30.9 GWh with power plant capacity of 7 MW and 5 MW respectively.

The annual electricity generation potential from residue generated at sawmill is 26.4 GWh (4.3 MW power plant capacity). Sawmills are operated in different divisions and (MoF, 2023) reports 97792.1 m^3, 17953.9 m^3 and 22742.5 m^3 of logs are processed at sawmills in Western, Northern and Central/Eastern divisions respectively. Based on the volume of logs processed at different sawmills, it is estimated that the electricity generation potential is 18.7 GWh, 3.43 GWh and 4.4 GWh at the Western, Northern and Central/Eastern divisions respectively. The power plant capacity for different divisions from sawmill residue is 3.043 MW, 0.559 MW and 0.708 MW from Western, Northern and Central/Eastern divisions respectively.

Veneer mills are only operated in the Northern division and as seen in Table 9, the electricity generation potential from veneer mill residue generation is estimated to be 1.6 GWh. The power plant capacity is 0.261 MW.

Table 9 Theoretical bioenergy potential from forest residues

	Annual Quantity (m3) (MoF, 2023)	**Recovery rate (%)**	**Logging residue (m3)**	**Estimated tonnes of waste**[4]	**Electricity generation Potential energy (MWh/year)**[5]	**PP (MW)**
Total Fiji log production	545208	30[6]	163562.4	103633.1	155450	23.4
Saw logs	138488.67	53[7]	73398.995	17615.8	26424	4.31
Veneer sheet	8904.04	50[8]	4452.02	1068.5	1602.7	0.261

4.3 Share contribution of agriculture residue and forestry residue to LEDS scenarios

Under the BAU unconditional scenario, plant capacity addition is 22 MW where the agricultural and forest residue can meet the generation capacity and there is excess. However, BAU conditional, high ambition and very high ambition scenarios have 136, 166 and 256 MW capacity and correspond to 647, 601 and 847 GWh of electricity generation from biomass power plants. Agriculture and forest residue potential are not able to meet this generation.

---

[4] conversion of volume to mass is based on average density of 792 kg/m^3 for logging residues and 300 kg/m^3 for wood waste and saw-milling residues with a moisture content of 20%

[5] Based on assumption that a tonne of dry biomass generates on average 1.5 MWh with the efficiency in the range of 20 – 40%

[6] Average value using Native, pine and mahogany logging data presented in FREPP report (FDoE 2014b).
[7] 53% is assumed based on the input and output of sawmill. Total recovery is 47% so the waste generated must be 53%.
[8] Average recovery factor based on (FDOE,2014b) data

Fiji LEDS have 847 GWh of electricity generation from biomass power plants under the very high ambition scenario where net zero emissions in Fiji is achieved. From the analysis and in Table 10 it is seen that agricultural crop residue can contribute to 16.2% of the generation capacity while agricultural livestock contributes a further 9.1% to the VHA biomass electricity generation. So overall, agricultural resources provide 214.5 GWh of electricity generation potential that has an overall 25.3% share in LEDS biomass electricity generation. Please note, that the baggase potential is not considered in this analysis as it is used by FSC for its current production, and it also has plans to expand its electricity generation capacity as stated in LEDS in Table 2.

Forest residue contributes 21.7% share (183.5 GWh) in electricity generation from biomass in the LEDS VHA scenario. Altogether, agriculture and forest residues contribute 398 GWh of electricity generation to the LEDS VHA scenario (the most ambitious scenario).

449 GWh of electricity generation needs to come from other biomass resources which can come from SRP and other organic waste in Fiji.

Table 10 Share of electricity generation potential from Agriculture and forestry residue

		Forestry residue				
Scenarios	LEDS (GWh)	Logging residue	Sawmill residue	Veneer residue	Total	% share
BAU_uncond	115.9	155.5	26.4	1.6	183.5	158
BAU_cond	646.9	155.5	26.4	1.6	183.5	28.4
HA	601.1	155.5	26.4	1.6	183.5	30.5
VHA	846.8	155.5	26.4	1.6	183.5	21.7
	LEDS (MW)	Logging residue	Sawmill residue	Veneer residue	Total	% share
BAU_uncond	22	25.4	4.31	0.261	30	118
BAU_cond	136	25.4	4.31	0.261	30	22
HA	166	25.4	4.31	0.261	30	18.1
VHA	256	25.4	4.31	0.261	30	11.7
		Agricultural residue				
	LEDS (GWh)	Temporary crops	Permanent crops	Livestock	Total	% Share
BAU_uncond	115.9	51.6	85.5	77.4	214.5	186
BAU_cond	646.9	51.6	85.5	77.4	214.5	33.2
HA	601.1	51.6	85.5	77.4	214.5	35.7
VHA	846.8	51.6	85.5	77.4	214.5	25.3
	LEDS (MW)	Temporary crops	Permanent crops	Livestock	Total	% Share
BAU_uncond	22	8	14	13	35	159
BAU_cond	136	8	14	13	35	25.7
HA	166	8	14	13	35	21.1
VHA	256	8	14	13	35	13.7

5.0 SRP on degraded land as feedstock for BPP

5.1 Area of SRP needed for providing the deficit from Agriculture and Forest residue to support LEDS bioenergy

From Table 11 it is seen that to provide the additional electricity generation to meet the LEDS generation capacity after agricultural and forest residues EP is taken account, altogether approximately 29,300 Ha of SRP plantation is needed to achieve the Very High Ambition (VHA) of LEDS that achieve net zero emissions by 2050. Lower area of SRP will be needed for BAU and High Ambition scenario; 13000 to 16000 Ha.

Table 11 Electricity generation and area of SRP need to meet LEDS targets.

	BAU_uncond	BAU_cond	HA	VHA
LEDS (GWh)	115.9	646.9*	601.1*	846.8
Agriculture and Forestry residue EP (GWh)	398 - Able to meet and there is surplus	398	398	398
% contribution of Agri and forest residue EP to LEDS		61.5%	66.2%	47.0%
Deficit to meet LEDS (GWh)		248.9	203.1	448.8
PP capacity needed from SRP (MW)		40.6	33.1	73.2
Area of SRP needed (Ha)		16300**	13300**	29300

* the MW and GWh generation from biomass power plant (BPP) are obtained from Fiji LEDS model. Please note that the generation in high ambition scenario is less than the generation in business as usual conditional scenario despite high ambition scenario having more BPP capacity compared to business as usual conditional scenario. This is because, these values were part of a bigger model that had other renewable energy sources of generation and merit order dispatch rule was used for BPP but for new solar and wind generators, full capacity dispatch rule was applied. In high ambition scenario, there were new solar and wind capacity additions and these were dispatched whenever it was produced to meet the hourly demand curve resulting in low generation (GWh) from BPPs.

** Because the BPP generation potential is less for HA compared to BAU_cond, the power plant capacity for SRP to meet the deficit in LEDS (GWh) after considering agricultural and forestry residue is less for HA compared to BAU_cond. Hence, the area of SRP is also less for HA compared to BAU_cond.

5.2 How much SRP is possible from degraded land?

(UNDRR, n.d.) has a number of definitions on land degradation from different organisation and it reports that FAO defines land degradation as “a reduction in the capability of the land to produce benefits from a particular land use under a specified form of land management”. Degraded land can be from several different sources of landcover; mangroves, cropland, grassland, shrubland and forest land.

5.2.1 Potential generation from degrading forest landcover for SRP

From the area of degradation land data, the energy potential for these areas was calculated which is shown in Table 12. Restoring land is defined as land area that is being now being restored to be productively used while stable land areas are land where historical usage is being continued at present. The estimations used in sections 5.2 uses degrading land areas and not the restoring or stable land areas. It is seen that in Vanua Levu, there is 21,262 Ha of forest land area that is degrading which has a total electricity generation potential of 325.9 GWh while on

Viti Levu, there is 42,476 Ha of forest degrading land area which has a total electricity generation potential of 651 GWh from SRP. These areas of degraded forest land are more than enough to meet the electricity generation requirement for 3 scenarios of Fiji LEDS considering Tables 11 and 12. However, utilizing degrading forest land for SRPs for energy could negatively impact forest conservation or meeting the "30 million trees in 15 years" target.

5.2.2 Potential of degrading shrubland, cropland and grassland for electricity generation with populated areas

So, if we consider other landcover types (cropland, grassland and shrubland) from Table 12; in Vanua Levu there is 13,200 Ha of degrading land area from these landcover types that have a potential of 202.3 GWh of electricity generation potential. For Viti Levu, degrading land area from cropland, grassland and shrubland have 31,728 Ha with 486.4 GWh of electricity generation potential. Combining these the potential means that utilizing shrubland, cropland and grassland can meet LEDS VHA. However, some of these sites are near populated areas.

Table 12 SRP potential on degradation land in Viti Levu and Vanua Levu.

Island	**Landcover**	**Landcover ID**	**Degradation trend**	**Area (in ha)**	**Energy Production MWh**	**GWh**	**MW**
Vanua Levu	Mangrove	2	Degrading	513	7865.7	7.9	1.3
Vanua Levu	Cropland	5	Degrading	7,152	109639.6	109.6	17.9
Vanua Levu	Grassland	6	Degrading	4,825	73962.1	74.0	12.1
Vanua Levu	Shrubland	7	Degrading	1,222	18739.4	18.7	3.1
Vanua Levu	Forest	8	Degrading	21,262	325925.9	325.9	53.2
Viti Levu	Mangrove	2	Degrading	2,223	34072.0	34.1	5.6
Viti Levu	Cropland	5	Degrading	15,824	242573.6	242.6	39.6
Viti Levu	Grassland	6	Degrading	11,931	182885.7	182.9	29.8
Viti Levu	Shrubland	7	Degrading	3,974	60911.9	60.9	9.9
Viti Levu	Forest	8	Degrading	42,476	651123.1	651.1	106.2
Vanua Levu	Mangrove	2	Restoring	3,823	*58598.6*	*58.6*	*9.6*
Vanua Levu	Cropland	5	Restoring	26,104	*400159.7*	*400.2*	*65.3*
Vanua Levu	Grassland	6	Restoring	13,198	*202321.2*	*202.3*	*33.0*
Vanua Levu	Shrubland	7	Restoring	3,376	*51755.8*	*51.8*	*8.4*
Vanua Levu	Forest	8	Restoring	84,956	*1302306.1*	*1302.3*	*212.4*
Viti Levu	Mangrove	2	Restoring	2,941	*45084.8*	*45.1*	*7.4*
Viti Levu	Cropland	5	Restoring	34,447	*528048.2*	*528.0*	*86.1*
Viti Levu	Grassland	6	Restoring	38,725	*593619.9*	*593.6*	*96.8*
Viti Levu	Shrubland	7	Restoring	13,045	*199974.5*	*200.0*	*32.6*
Viti Levu	Forest	8	Restoring	175,485	*2690044.6*	*2690.0*	*438.7*
Vanua Levu	Mangrove	2	Stable	4,657	*71390.6*	*71.4*	*11.6*
Vanua Levu	Cropland	5	Stable	26,888	*412178.1*	*412.2*	*67.2*
Vanua Levu	Grassland	6	Stable	11,259	*172585.6*	*172.6*	*28.1*
Vanua Levu	Shrubland	7	Stable	2,783	*42660.6*	*42.7*	*7.0*
Vanua Levu	Forest	8	Stable	134,617	*2063570.6*	*2063.6*	*336.5*
Viti Levu	Mangrove	2	Stable	9,973	*152878.2*	*152.9*	*24.9*

Viti Levu	Cropland	5	Stable	71,857	*1101500.8*	*1101.5*	*179.6*
Viti Levu	Grassland	6	Stable	45,533	*697976.9*	*698.0*	*113.8*
Viti Levu	Shrubland	7	Stable	10,368	*158925.5*	*158.9*	*25.9*
Viti Levu	Forest	8	Stable	247,940	*3800713.0*	*3800.7*	*619.8*

Degrading forest land areas are not considered for energy generation as this may be in conflict with other national targets such as the “30 million trees in 15 years”. The highlighted degrading land areas from cropland, grassland and shrubland (highlighted in Table 12) can be further analysed for energy generation potential which is done in the following sub-section.

5.2.3 Potential of degrading shrubland, cropland and grassland for electricity generation without populated areas

The possible degrading areas for shrubland, cropland and grassland are calculated using the following filters and it is shown in Fig. 8:

- Outside current and planned protected areas.
- On area with a slope lower than 45°.
- Outside urban center (population higher than 300 hab/km^2)

From Fig. 8 it is seen that 3750 Ha is the available degrading land area for possible SRPs where 59% is on Viti Levu while the remaining is on Vanua Levu. This acreage would generate 37,500 tonnes of dry biomass from SRP. The electricity generation potential from SRPs on these lands for overall Fiji, as seen from Table 13, corresponds to a total of 57.5 GWh where 59% is from degrading grassland on the two main islands, followed by 25.2% for shrubland and the remaining from degrading grassland. When comparing Tables 11 and 13, **the area of degrading land for SRP is insufficient to meet the electricity generation capacity of Fiji’s LEDS and so other alternatives need to be explored.**

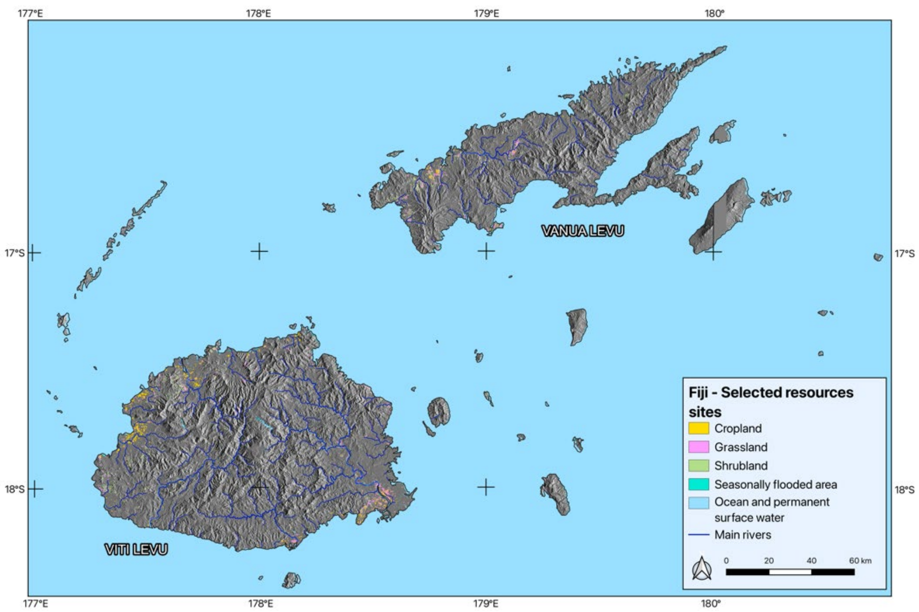


Fig. 8. Locations for degrading shrubland, grassland and cropland

Table 13 Electricity generation potential from degrading cropland, grassland and shrubland after using filters.

Island	Landcover	Degradation trend	area (in ha)	Electricity generation potential (MWh)	GWh	MW
Viti Levu	Cropland	Degrading	110	1682.6	1.68	0.274
Vanua Levu	Cropland	Degrading	484	7417.0	7.42	1.210
Viti Levu	Grassland	Degrading	1434	21982.7	21.98	3.585
Vanua Levu	Grassland	Degrading	776	11895.6	11.90	1.940
Viti Levu	Shrubland	Degrading	672	10298.5	10.30	1.679
Vanua Levu	Shrubland	Degrading	273	4190.4	4.19	0.683
Viti Levu	Cropland	Stable	489	*7492.1*	*7.49*	*1.222*
Vanua Levu	Cropland	Stable	906	*13893.4*	*13.89*	*2.266*
Viti Levu	Grassland	Stable	10146	*155532.5*	*155.53*	*25.36*
Vanua Levu	Grassland	Stable	1544	*23671.4*	*23.67*	*3.860*
Viti Levu	Shrubland	Stable	3078	*47176.5*	*47.18*	*7.693*
Vanua Levu	Shrubland	Stable	1051	*16105.0*	*16.11*	*2.626*
Viti Levu	Cropland	Restoring	295	*4529.1*	*4.53*	*0.739*
Vanua Levu	Cropland	Restoring	885	*13572.1*	*13.57*	*2.213*
Viti Levu	Grassland	Restoring	8971	*137514.0*	*137.51*	*22.43*
Vanua Levu	Grassland	Restoring	870	*13337.0*	*13.34*	*2.175*
Viti Levu	Shrubland	Restoring	3254	*49874.3*	*49.87*	*8.133*
Vanua Levu	Shrubland	Restoring	464	*7108.1*	*7.11*	*1.159*

5.2.4 Biomass raw material collection distance from power plant site

(Ma et al., 2022) recommend that 40 km be used as the biomass raw material collection distance threshold (BCDT) when carrying out uniform planning for biomass raw materials. This BCDT can achieve a utilization capacity of biomass energy of 75% that can achieve a high degree of energy self-sufficiency and ensure its economic competitiveness.

From the degrading land from shrubland, grassland and cropland cover, it is recommended to place biomass power plants that are within a radius of 30 km from the power plant site. This will ensure feedstock to be transported easily and at a lower cost. The distance to resource sites is shown in Fig. 9 which is calculated based on the access to roads using GIS.

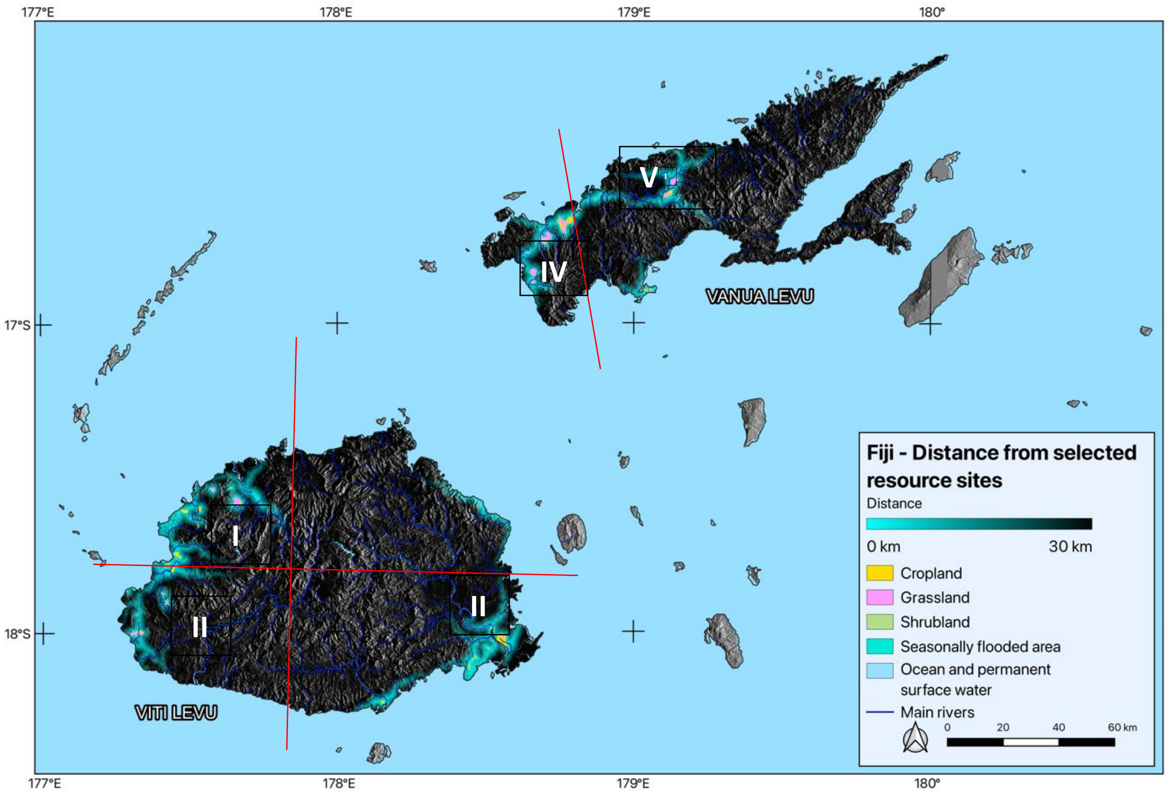


Fig. 9. Distance to resource sites with potential regions where BBP can be sited.

Future biomass power plants for SRP can be situated in the four regions shown in Fig.9.

Disaggregated data of degrading cropland, shrubland and grassland for different provinces is given in Table 14. There are different provinces in Fiji as shown in Fig. 10 which are distributed in the four divisions in Fiji. The Central division has Naitasiri, Namosi, Rewa, Serua, and Tailevu provinces while the Eastern division has Kadavu, Lau, Lomaiviti and Rotuma. The Western division has Ba, Nadroga/Navosa and Ra provinces while the Northern division has Bua, Cakaudrove and Macuata provinces.

Comparing Figs. 9 and 10 and Table 14, the region marked I on Fig. 9 corresponds to Ba province which has a total energy generation potential of 15.3 GWh with an estimated power plant capacity of 2.5 MW from degrading shrubland, cropland and grassland.

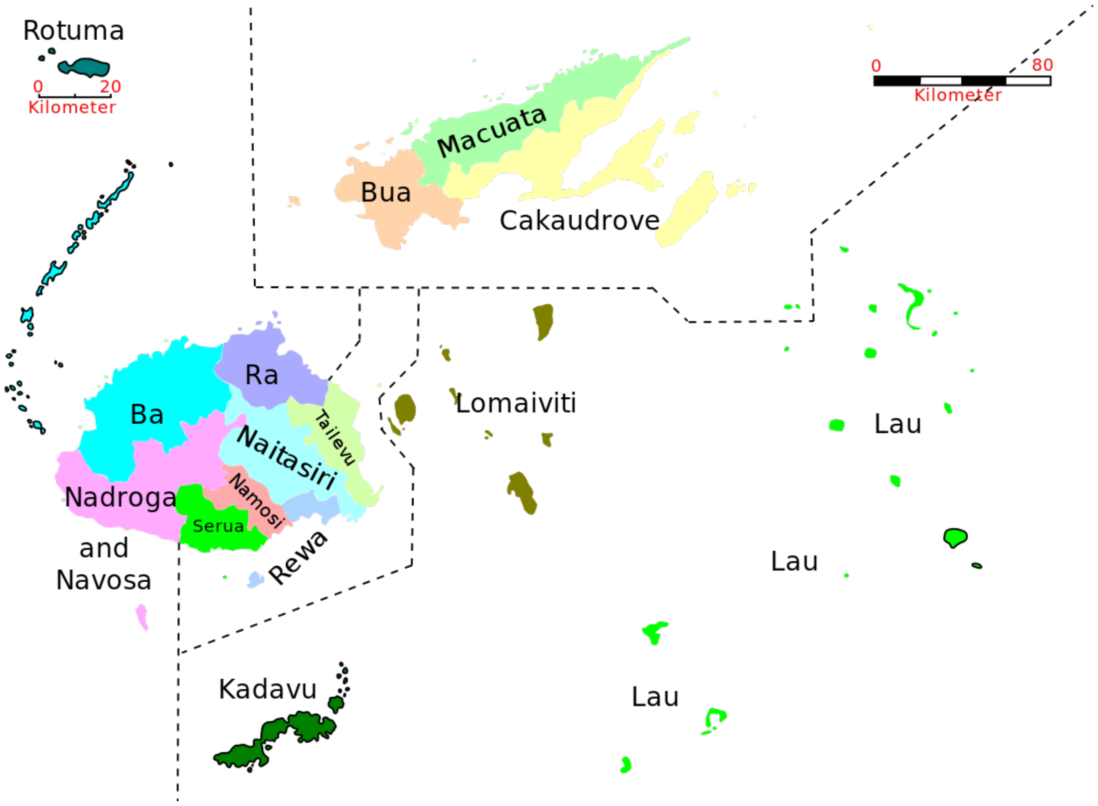


Fig. 10. Map of different provinces in Fiji. Source: (Wikipedia, 2023).

The region marked II in Fig. 9 corresponds to Nadroga and Navosa province which has energy generation potential of 12 GWh with a power plant capacity of 2 MW. Region I and II falls in the Western division of Fiji.

The region marked III in Fig. 9 has a lot of provinces falling in that region which corresponds to the Central division and from Table 14 it is seen that the total energy generation potential for this region is 3.2 GWh with a power plant capacity of 0.5 MW.

The region marked IV in Fig. 9 corresponds to Bua province which has energy generation potential of 21.3 GWh with a power plant capacity of 3.5 MW.

The region marked V in Fig. 8 has mostly Macuata province with a little bit of resource coming from Cakoudrove province. The total energy generation potential of these two regions is 2.2 GWh with a power plant capacity of 0.4 MW.

Overall, it is seen that the Western division and Northern division have the largest energy generation potential from SRPs.

Table 14 Energy generation potential of SRPs on degrading cropland, grassland and shrubland in different divisions

	Division	Central					Eastern				Northern			Western			Total
	Province	Naitasiri	Namosi	Rewa	Serua	Tailevu	Kadavu	Lau	Lomaiviti	Rotuma	Bua	Cakaudrove	Macuata	Ba	Nadroga & Navosa	Ra	
	Area (Ha)	0.26	9.41	0.39	6.39	17.59	0.00	0.00	0.81	0.00	475.66	4.29	3.91	26.93	48.47	0.35	594
	EP (MWh)	3.92	144.20	5.94	97.96	269.63	0.00	0.00	12.37	0.00	7291.53	65.72	59.92	412.75	743.01	5.38	9112
Cropland	PP (kW)	0.64	23.52	0.97	15.97	43.97	0.00	0.00	2.02	0.00	1189.09	10.72	9.77	67.31	121.17	0.88	1486
	Area (Ha)	18.64	11.22	9.15	47.90	7.69	0.00	0.00	0.51	0.00	676.30	15.63	84.08	733.41	444.66	161.77	2211
	EP (MWh)	285.68	172.04	140.30	734.32	117.84	0.00	0.00	7.86	0.00	10367.07	239.59	1288.89	11242.50	6816.26	2479.81	33892
Grassland	PP (kW)	46.59	28.06	22.88	119.75	19.22	0.00	0.00	1.28	0.00	1690.65	39.07	210.19	1833.41	1111.59	404.41	5527
	Area (Ha)	10.34	4.19	11.23	53.02	2.73	0.00	0.00	0.24	0.00	236.79	8.87	27.74	235.67	292.19	62.85	946
	EP (MWh)	158.54	64.21	172.19	812.75	41.79	0.00	0.00	3.64	0.00	3629.75	135.96	425.28	3612.57	4479.02	963.50	14499
Shrubland	PP (kW)	25.85	10.47	28.08	132.54	6.82	0.00	0.00	0.59	0.00	591.94	22.17	69.35	589.13	730.43	157.13	2365
	Total area (Ha)	29.23	24.82	20.77	107.31	28.00	0.00	0.00	1.56	0.00	1388.75	28.79	115.73	996.00	785.32	224.98	3751
	Total EP (MWh)	448.14	380.45	318.43	1645.03	429.26	0.00	0.00	23.87	0.00	21288.35	441.27	1774.08	15267.82	12038.29	3448.70	57504
	Total PP (kW)	73.08	62.04	51.93	268.27	70.00	0.00	0.00	3.89	0.00	3471.68	71.96	289.32	2489.86	1963.19	562.41	9378
Total EP (GWh)						**3.22**				**0.239**			**22.0**			**27.7**	**57.5**
Total PP (MW)						**0.525**				**0.0039**			**3.83**			**5.02**	**9.4**

5.3 Types of SRP to be considered for Fiji

Short rotation plantations, or SRPs, are fast-growing tree plantations that are harvested in two to twenty years and provide large volumes of woody biomass efficiently and quickly (Lindegaard et al., 2016). Examples of these plantations include willow (Salix spp.), poplar (Populus spp.), and eucalyptus which are common in Europe (Lindegaard et al., 2016) while (ForestResearch, 2023) also mention Sycamore, Nothofagus (southern beech) and Ash as some other species that can be planted as SRP in Europe. Oceania (New Zealand), has a long history of managing planted forests. It provides ideal growing conditions for several quickly growing species, including Cupressus spp., Eucalyptus spp., Pinus radiata (Monterey Pine), and Pseudotsuga menziesii (Douglas-fir) (Brundu and Richardson, 2015). In addition, the use of carefully managed short-rotation alien species, including Tectona grandis, P. taeda, P. elliottii, and Eucalyptus spp., is being promoted in South America (Brundu and Richardson, 2015). Gliricidia Sepium and Acacia Mangium are the primary species currently being planted for Nabou biomass power plant in Fiji between Sigatoka and Nadi corridor. It is reported that the operators have secured 5,000 Ha for the 12 MW Nabou biomass power plant (Gimco, n.d.).

In their study, (Lindegaard et al., 2016) have assumed that the positive impacts (SRP as biofuel use and reduced emissions with economic development) outweigh the negative impact. (Lindegaard et al., 2016) recommend that to increase the penetration of SRP for energy production in Europe there needs to be (i) increase awareness programmes through workshops and similar events, (ii) conduct evidence-based review of SRP including cost-benefit analysis, (iii) access to finance to kick-start the industry, (iv) provide subsidies in areas where SRP can grow, (v) establish pilot projects that connect growers with the product user, (vi) increase R&D in SRP

On the flip side, (Bose et al., 2023) informs that plots continuously replanted with the same tree species have a high chance of accumulating detrimental microorganisms and losing good microbes. They recommend more research to gain a better understanding of the build-up of hazardous soil bacteria in short-rotation plantation forestry, and advise crop rotation and intercropping measures to prevent this disease in the future (Bose et al., 2023). In addition, in a landscape where agriculture predominates, the introduction of well-managed SRPs can enhance biodiversity; but, in a landscape with significant wooded areas, the introduction of SRCs is likely to have the opposite impact (Vanbeveren and Ceulemans, 2019). However, experimental results show that if plantations are managed according to recognised scientific principles, productivity can be sustained and improved and the properties of the soil (Nambiar and Harwood, 2014).

To use SRP as a renewable energy resource, (Eufrade Junior et al., 2016) recommend that the design and management of very high-density forests should focus not only on the energy and biomass yield, but also on the nutrients export. So, preferably, SRP must be a used species or clones of rapid growth, with high performance and high efficiency in the use of nutrients (Eufrade Junior et al., 2016).

Invasive trees are plants classified as exotic which are brought into a country for a specific purpose but then later (after some years) it poses a real threat to the natural ecosystem (taking over the native forest and using soil nutrients that would otherwise go to native trees) and even to the land occupied by agriculture. Black locust (Robinia pseudoacacia L.) is a fast-growing tree species native to temperate North America, and widely diffused and naturalized in Europe.

(Crosti et al., 2016) reports that advise against planting Black locust trees in regions where it has proven invasive have been issued by several international reports. Other fast-growing plantations are reported to be invasive but it is not a universal problem. For instance, acacia planted in large areas in Vietnam and Indonesia have not reported it to be invasive but South Africa report invasiveness of some planted acacias (Nambiar, 2021). Pinus Prosopis and Acacia species have been reported to be invasive (Kiptoo and Kiyiapi, 2023) and these authors report that the main lessons learned are that the management of exotic plantation trees must be thought out at the landscape level and must combine a variety of actions targeted at different stages of the invasion process such as (Hess et al., 2019) recommends reducing propagule sources among many other actions. Hence, strategies such as stakeholder awareness, knowledge on how to detect invasive plants and planning ways of managing and reducing the risk of exotic plants becoming invasive must be developed and followed.

Fiji is a tropical island nation and it has on average 1676-3573 mm of rainfall per year (Kumar et al., 2014). Although the rainfall and sunshine hours varies for different divisions. (Moya et al., 2019) informs about 50 species of plants that are used as short rotation woody crops in Latin America which has tropical climate conditions (average annual rainfall ranges between 591 – 3240 mm (IndexMundi, n.d.)) that could possibly explain the diversity of the SRWC. Hence for Fiji, more research would need to taken to identify which particular species could be a high contender for SRP in Fiji where its yield, threat to being invasive, nutrient requirement, etc. has to be considered. It is possible to learn from the SRPs in Latin America.

5.4 Potential for other feedstock for possible bioenergy generation

From sections 4 and 5, we see that agricultural and forestry residues and SRPs on limited degrading land are insufficient to meet the generation requirement in 3 scenarios of Fiji LEDS. So, it is vital to identify other sources of electricity from organic waste.

This sub-section mostly summarises the data presented in (FDoE and UNDP, 2014a, b) that utilizes waste from (i) Municipal solid waste (MSW), (ii) Sewerage and Sludge and (iii) Non-hazardous industrial waste.

The theoretical potential for electricity generation from MSW in Fiji through the thermo-chemical path is estimated to be 38 GWh per year using 69000 tonnes of organic waste annually at different landfill sites or dumps (FDoE and UNDP, 2014a) as seen from Table 15.

Table 15 Electricity generation potential in Fiji from MSW through thermochemical conversion. Source: (FDoE and UNDP, 2014a)

Location of landfill/dump	**Estimated annual organic MSW received (tonnes)**	**Estimated annual electricity generation potential (MWh) - thermochemical conversion**
Naboro landfill	42344	23290
Lautoka dump	16220	8921
Ba dump	1950	1072
Sigatoka dump	4745	2610
Rakiraki dump	975	536
Savusavu dump	650	358
Labasa dump	1625	894
Levuka dump	845	465

Sewerage sludge could also be another source for electricity generation. (FDoE and UNDP, 2014a) reports that the theoretical potential for electricity generation from sewage sludge in Fiji is estimated to be 12.33 GWh per year as seen in Table 16.

Table 16 Estimated electricity generation potential at major sewerage treatment plants in Fiji. Source: (FDoE and UNDP, 2014a).

Centre	**Volume of sewage treated (m3/day)**	**Average TSS in raw effluent (mg/l)**	**Estimated methane generation potential (m3/day)**	**Estimated electricity generation potential (MWh/yr)**
Suva	24500	300	4630	8450
Nausori	600	220	83	152
Pacific Harbour	691	170	74	135
Lautoka	6750	275	1170	2134
Nadi	3000	249	470	858
Sigatoka	600	195	73	134
Ba	975	138	85	155
Labasa	900	165	93	170
Adi Cakobau School	150	285	27	49
Wailada	150	180	17	31
Naboro	300	190	36	65

Regarding non-hazardous industrial wastewater, there are various sources; Fiji Dairy, FSC, Meat industry. Fiji Meat Industry Board (FMIB) is the main abattoir in Fiji. The waste generated includes bones, organs, hooves, and other inedible animal parts leftover after all the edible parts of the animal have been removed. It is estimated that on average 15 liters water wasted in each slaughtering (FDoE and UNDP, 2014a). Due to the high organic nature of waste, there is a good potential to generated biogas and in turn electricity. A total of 122928 MJ of energy can be generated per day from slaughtering animals. Using 1 MJ = 0.27778 kWh, the energy potential from FMIB is 34.15 MWh/day which corresponds to 12.5 GWh as seen from table 17.

Table 17 Theoretical potential for electricity generation from FMIB Waste. Source: (FDoE and UNDP, 2014a).

Animals Slaughtered	**No. of animals slaughtered per day**	**Average weight of animals (kg)**	**Average quantity of waste generation (kg/day)**	**Estimated energy generation potential (MJ/day)**
Cattle	50	225	5625	87750
Pigs	120	55	1980	30888
Sheep	10	25	125	1950
Goat	10	30	150	2340

Distillaries in Fiji can also be source for organic waste. Fiji has Paradise Beverages and South Pacific Distillaries are two companies that are making alcohol based deverages. (FDoE and UNDP, 2014a) reports 1.64 GWh of electricity generation potential per year.

Hence, from the 3 categories of 64.47 GWh can be generated per year.

6.0 Electricity Demand and Supply in Fiji

Grid electricity is supplied by Energy Fiji Limited (EFL) and EFL supplied approximately 93% of the total grid electricity generation (1081 GWh) from its hydro, IDO and HFO and wind power plants in 2022. The remaining grid electricity generation in 2022 was supplied by IPPs using biomass feedstock (bagasse and woodchips). Some of the current generation power plants are shown in Table 18. Four island in Fiji are being supplied with grid electricity; Viti Levu, Vanua Levu, Ovalau and Taveuni where each island have their own grid network and electricity is not supplied between islands. Viti Levu has the largest electricity grid network because of this population numbers on this island where central and western division have the highest electricity demand because of more business centers in this region. Vanua Levu is the 2nd largest electricity network followed by Ovalau and then Taveuni.

Table 18 Current power plants for grid electricity supply

name	owner	longitude	latitude	capacity (in MW)	commissioning date	fuel	GPPD ID num.
Wailoa	Fiji Electricity Authority	178.05	-17.76	80	1983	Hydro	WRI1061469
Levuka Power Station	Fiji Electricity Authority	178.84	-17.68	2.98	?	Oil	WRI1061473
Kinoya	Fiji Electricity Authority	178.48	-18.11	48	2015	Oil	WRI1061458
Butoni	Fiji Electricity Authority	177.51	-18.11	10.1	2008	Wind	WRI1061467
Nadarivatu	Fiji Electricity Authority	177.94	-17.67	40	2012	Hydro	WRI1061476
Tropik Woods IPP (Viti Levu)	Tropik Woods	177.54	-17.59	9.3	?	Biomass	WRI1061475
Waiyevo	Fiji Electricity Authority	-179.98	-16.78	3	?	Oil	WRI1061477
Vaturu	Fiji Electricity Authority	177.55	-17.74	3	2005	Hydro	WRI1061465
Rarawai Mill	Fiji Sugar Corporation	177.68	-17.54	5	?	Biomass	WRI1061478
Wainikasaou	Fiji Electricity Authority	178.03	-17.83	6	2004	Hydro	WRI1061468
Labasa Sugar Mill	Fiji Sugar Corporation	179.39	-16.43	10	2015	Biomass	WRI1061474
Vuda	Fiji Electricity Authority	177.43	-17.68	20	1999	Oil	WRI1061457

Nabou biomass power plant	GIMCO	177.32	-18.00	12	2018	Biomass	?
lautoka FSC mill	Fiji Sugar Corporation	177.44	-17.61	5	?	Biomass	?

? – data is not available

With the high demand in Viti Levu, future power plants needs to have bigger capacity of power plants.

From the analysis in section 4 and 5, Table 19 summarises the generation potential from the different divisions in Fiji, where the central and western divisions fall in Viti Levu and northern division is on Vanua Levu while Eastern division are smaller islands. From Table 19, it is estimated that Viti Levu grid can have additional 48 MW of power plant coming onboard from various feedstock supply – agricultural crop residue, livestock manure, forestry residue and short rotation plantation on degrading shrubland, cropland and grassland. Vanua Levu has a potential of 22.5 MW of power plant based on biomass resources.

Table 19 Summary of estimated electricity generation potential from various biomass energy sources.

	Central		**Eastern**		**Northern**		**Western**		**Fiji**	
	EP (GWh)	PP (MW)	EP (GWh)	PP (MW)	EP (GWh)	PP (MW)	EP (GWh)	PP (MW)	EP (GWh)	PP (MW)
Forestry Residue										
Forest logging residue	41.7	7			30.9	5	82	13	154.6	25
Sawmill residue	4.4	0.7			3.43	0.6	18.7	3	26.5	4.3
Veneer Mill residue					1.6	0.3			1.6	0.3
	46.1	7.7	0.0	0.0	35.9	5.9	100.7	16.0	183	30
Agriculture residue										
Temporary crops residue	11.9	1.9	2.4	0.4	24.0	3.9	12.5	2.0	50.8	8.3
Permanent crops residue	7.5	1.2	14.5	2.4	40	6.5	23.6	3.8	85.6	13.9
Livestock manure	20.7	3.4	3	0.5	14.9	2.4	38.8	6.3	77.4	12.6
	40.1	6.5	19.9	3.3	78.9	12.8	74.9	12.1	214	35
SRPs									0	0

Degrading shrubland, cropland, grassland for SRPS	3.22	0.5	0.239	0.04	22	3.8	27.7	5	53	9
Total	89.4	14.7	20.14	3.34	136.8	22.5	203.3	33.1	450	74
Possible other organic waste									64.5	
Overall deficit for VHA									333	

Further Table 20 informs us that using the agricultural sector residues, forestry sector residues, livestock manure and SRPs on degrading shrubland, cropland and grassland are not sufficient to meet the generation targets of Fiji's LEDS for bioenergy generation. This excludes other organic waste generation potential. Other sources and resources have to be considered.

Table 20 Deficit from current available bioenergy resources EP toward LEDS

	BAU_uncond	BAU_cond	HA	VHA
LEDS (GWh)	115.9	646.9*	601.1*	846.8
Agri+forestry+SRP (GWh)	450 - Able to meet and there is surplus	450	450	450
% contribution of available bioenergy resources EP to LEDS		70%	75%	53%
Deficit (GWh)		197	151	397
Additional land area needed for SRP to meet LEDS targets (Ha)		12,900	9,900	26,000

* the MW and GWh generation from biomass power plant (BPP) are obtained from Fiji LEDS model. Please note that the generation in high ambition scenario is less than the generation in business as usual conditional scenario despite high ambition scenario having more BPP capacity compared to business as usual conditional scenario. This is because, these values were part of a bigger model that had other renewable energy sources of generation and merit order dispatch rule was used for BPP but for new solar and wind generators, full capacity dispatch rule was applied. In high ambition scenario, there were new solar and wind capacity additions and these were dispatched whenever it was produced to meet the hourly demand curve resulting in low generation (GWh) from BPPs.

7.0 Conclusions

Biomass electricity generation is a relatively proven technology, but the main issue is sustainable feedstock supply. Before the implementation of any BPP, it is imperative to get all key stakeholders on board (from landowners, truckers, and power plant operators to policymakers) and discuss the key items for ensuring the success of the BPP. BPP need to be sited in areas where there is a reliable feedstock supply.

This study shows significant potential from agricultural and forest residue. However, the degrading land areas for shrubland, cropland and grassland are not sufficient to supply the remaining deficit EP to meet the LEDS generation target for biomass power plants as seen in Table 19. Overall, the Central, Eastern, Northern and Western divisions have estimated power plant capacity of 15 MW, 3 MW, 23 MW and 33 MW respectively using the available resources shown in Table 19.

The deficit generation could come from degrading forest areas but not all 100% of the degrading forest areas will have to be used. The total estimated degrading forest land area is 63,700 ha of which 22,000-26,000 ha will be needed for additional SRPs to supply bioenergy to meet LEDS VHA scenario generation target. Alternatively, other resources will have to be considered to meet the LEDS electricity generation targets from bioenergy.

References

Algieri, A., Andiloro, S., Tamburino, V., Zema, D.A., 2019. The potential of agricultural residues for energy production in Calabria (Southern Italy). Renewable and Sustainable Energy Reviews 104, 1-14.

Amare, Z.Y., 2015. The benefits of the use of biogas energy in rural areas in Ethiopia: A case study from the Amhara National Regional State, Fogera District. African Journal of Environmental Science and Technology 9, 332-345.

Aslam, Z., Li, H., Hammerton, J., Andrews, G., Ross, A., Lovett, J.C., 2021. Increasing access to electricity: An assessment of the energy and power generation potential from biomass waste residues in Tanzania. Energies 14, 1793.

Bose, T., Hammerbacher, A., Slippers, B., Roux, J., Wingfield, M.J., 2023. Continuous Replanting Could Degrade Soil Health in Short-Rotation Plantation Forestry. Current Forestry Reports 9, 230-250.

Brundu, G., Richardson, D., 2015. Code of conduct on plantation forestry and invasive alien trees—First draft—T-PVS/Inf (2015) 1. Council of Europe, Strasbourg.

Choi, M.H., Ji, G.E., Koh, K.H., Ryu, Y.W., Jo, D.H., Park, Y.H., 2002. Use of waste Chinese cabbage as a substrate for yeast biomass production. Bioresource Technology 83, 251-253.

Christersson, L., Verma, K., 2006. Short-rotation forestry-a complement to" conventional" forestry. Unasylva (English ed.) 57, 34-39.

Crosti, R., Agrillo, E., Ciccarese, L., Guarino, R., Paris, P., Testi, A., 2016. Assessing escapes from short rotation plantations of the invasive tree species Robinia pseudoacacia L. in Mediterranean ecosystems: a study in central Italy. iForest - Biogeosciences and Forestry 9, 822-828.

EFL, 2019. 2019 Annual Report. Energy Fiji Limited, Fiji.

EFL, 2023. 2022 Annual Report. Energy Fiji Limited, Fiji.

Eufrade Junior, H.J., Melo, R.X.d., Sartori, M.M.P., Guerra, S.P.S., Ballarin, A.W., 2016. Sustainable use of eucalypt biomass grown on short rotation coppice for bioenergy. Biomass and Bioenergy 90, 15-21.

FAO, MoA, 2021. 2020 Fiji Agriculture Census - Volume I: General Table & Descriptive Analysis Report. Food and Agriculture Organisation of the United Nations and Fiji Ministry of Agriculture, Partiamentary Paper No. 59/2021, Suva, Fiji.

FDoE, UNDP, 2014a. Report on Feasibility of Resources and Sites For Waste-to-Energy Power Generation in Fiji. Fiji Department of Energy and UNDP

FDoE, UNDP, 2014b. Report on Quantification and Assessment on the Amount and Types of Resources for Waste-to-Energy Power Generation in Fiji. Fiji Department of Energy and United Nations Development Program, Suva, Fiji.

FFW, n.d. SME Solutions centre - value adding to underutilised/waste pumpkin produce. Fight Food Waste CRC, https://fightfoodwastecrc.com.au/project/sme-solutions-centre-value-adding-to-underutilised-waste-pumpkin-produce/ (accessed on 29 Nov 2023).

ForestResearch, 2023. Tools and Resources: Short Rotation Forestry. Forest Researh https://www.forestresearch.gov.uk/tools-and-resources/fthr/biomass-energy-resources/fuel/energy-crops-3/short-rotation-forestry/ (accessed on 4 Dec 2023).
Gimco, n.d. BIOMASS ENERGY for Climate Change Mitigation & Adaptation in South Pacific, https://www.sprep.org/attachments/bem/Biomass_Energy_CAPP_COP23.pdf (accessed on 4 Dec 2023).
GoF, 2018. FIji Low Emission Development Strategy 2018-2050. Ministry of Economy, Government of the Republic of Fiji, Fiji.
Hess, M.C., Mesléard, F., Buisson, E., 2019. Priority effects: Emerging principles for invasive plant species management. Ecological Engineering 127, 48-57.
Hoyos-Sebá, J.J., Arias, N.P., Salcedo-Mendoza, J., Aristizábal-Marulanda, V., 2024. Animal manure in the context of renewable energy and value-added products: A review. Chemical Engineering and Processing - Process Intensification 196, 109660.
IndexMundi, n.d., https://www.indexmundi.com/facts/indicators/AG.LND.PRCP.MM/rankings/south-america (accessed on 7 Dec 2023).
IRENA, 2014. Renewable energy power cost: Chapter 8 - Biomass power generation. International Renewable Energy Agency, Abu Dhabi.
Jekayinfa, S.O., Orisaleye, J.I., Pecenka, R., 2020. An assessment of potential resources for biomass energy in Nigeria. Resources 9, 92.
Kiptoo, T.K., Kiyiapi, J.L.O., 2023. Impacts of Invasive Species on Commercial Forest Plantations in Africa-A Review. Journal of Aquatic Terrestrial Ecosystems 1, 56-65.
Koopmans, A., Koppejan, J., 1997. Agricultural and forest residues-generation, utilization and availability. Regional consultation on modern applications of biomass energy 6, 10.
Kumar, R., Stephens, M., Weir, T., 2014. Rainfall trends in Fiji. International Journal of Climatology 34, 1501-1510.
Lal, R., 2005. World crop residues production and implications of its use as a biofuel. Environment International 31, 575-584.
Lindegaard, K.N., Adams, P.W., Holley, M., Lamley, A., Henriksson, A., Larsson, S., von Engelbrechten, H.G., Esteban Lopez, G., Pisarek, M., 2016. Short rotation plantations policy history in Europe: lessons from the past and recommendations for the future. Food Energy Secur 5, 125-152.
Ma, C., Zhang, Y., Ma, K., 2022. The effect of biomass raw material collection distance on energy surplus factor. Journal of Environmental Management 317, 115461.
Milbrandt, A., 2009. Assessment of Biomass Resources in Liberia NREL, Colorado.
MoA, 2021. 2020 Fiji Agriculture Census Report, https://www.agriculture.gov.fj/censusrep.php (accessed on 24 November 2023).
MoF, 2023. 2021-2022 Annual Report. Ministry of Foresty, Parliamentary Paper No. 71 of 2023, Suva, Fiji.
Moya, R., Tenorio, C., Oporto, G., 2019. Short Rotation Wood Crops in Latin American: A Review on Status and Potential Uses as Biofuel. Energies 12, 705.
Nambiar, E.K.S., 2021. Small forest growers in tropical landscapes should be embraced as partners for Green-growth: Increase wood supply, restore land, reduce poverty, and mitigate climate change. Trees, Forests and People 6, 100154.
Nambiar, E.K.S., Harwood, C.E., 2014. Productivity of acacia and eucalypt plantations in Southeast Asia. 1. Bio-physical determinants of production: opportunities and challenges. The International Forestry Review 16, 225-248.
Noorollahi, Y., Kheirrouz, M., Asl, H.F., Yousefi, H., Hajinezhad, A., 2015. Biogas production potential from livestock manure in Iran. Renewable and Sustainable Energy Reviews 50, 748-754.
Odoi-Yorke, F., Osei, L.K., Gyamfi, E., Adaramola, M.S., 2022. Assessment of crop residues for off-grid rural electrification options in Ghana. Scientific African 18, e01435.
Prasad, R.D., Raturi, A., 2021. Prospects of Sustainable Biomass-Based Power Generation in a Small Island Country. Journal of Cleaner Production 318, 128519.

Ramos-Suárez, J.L., Ritter, A., Mata González, J., Camacho Pérez, A., 2019. Biogas from animal manure: A sustainable energy opportunity in the Canary Islands. Renewable and Sustainable Energy Reviews 104, 137-150.
Sabatti, M., Fabbrini, F., Harfouche, A., Beritognolo, I., Mareschi, L., Carlini, M., Paris, P., Scarascia-Mugnozza, G., 2014. Evaluation of biomass production potential and heating value of hybrid poplar genotypes in a short-rotation culture in Italy. Industrial Crops and Products 61, 62-73.
Senelwa, K., Sims, R.E.H., 1999. Fuel characteristics of short rotation forest biomass. Biomass and Bioenergy 17, 127-140.
Shane, A., Gheewala, S.H., Fungtammasan, B., Silalertruksa, T., Bonnet, S., Phiri, S., 2016. Bioenergy resource assessment for Zambia. Renewable and Sustainable Energy Reviews 53, 93-104.
Sugathapala, A.G.T., 2022. Feasibility of small scale biomass power plants in Sri Lanka. United Nations Development Programme (UNDP), Sri Lanka.
Tumen Ozdil, N.F., Caliskan, M., 2022. Energy potential from biomass from agricultural crops: Development prospects of the Turkish bioeconomy. Energy 249, 123770.
UNDRR, n.d. Land Degradation. United Nations Office for Disaster Risk Reduction, https://www.undrr.org/understanding-disaster-risk/terminology/hips/en0004#:~:text=Land%20degradation%20means%20reduction%20or,combination%20of%20processes%2C%20including%20processes (accessed on 6 Dec 2023).
Vanbeveren, S.P.P., Ceulemans, R., 2019. Biodiversity in short-rotation coppice. Renewable and Sustainable Energy Reviews 111, 34-43.
Wikipedia, 2023. Provinces of Fiji, https://en.wikipedia.org/wiki/Provinces_of_Fiji (accessed on 11 Dec 2023).