DELIVERABLE II

BASELINE AND RESOURCE ASSESSMENT TO SUPPORT INDUSTRY SCALE BIOGAS PLANT IN TONGA

Part I: Report on resource availability and sustainability

Client:

United Nations Industrial Development Organization (UNIDO)
Project: Tonga Circular Economy Project- Biogas Feasibility Study

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Abbreviations

AAP	Australia's Aid Programme	l/(pig x d)	Litre per pig and day
ADB	Asian Development Bank	l/(cattle x d)	Litre per cattle and day
l	Litre	m³/d	Cubic metre per day
a	annum	m³/a	Cubic metre per year
ERM	Energy Road Map	MAFF	Ministry of Agriculture, Forestry, Food & Fisheries
FAO	Food and Agriculture Organization	PIC	Pacific island Country
GDP	gross domestic product	RE	renewable energy
GHG	Green House Gas	t	tons
ha	Hectares	TPL	Tonga Power Limited
HTG	Hybrid Tropical Grass	UNFCCC	United Nations Framework Convention on Climate Change
kg	Kilogram	WAL	Waste Authority Limited

1 Objective of this report

This assessment will provide detailed outlook on the availability of raw fuel resources from various potential sources, based on latest information available to generate biogas in Tonga.

It will also assess the options for sustainable supply of the resources to operate these plants throughout their technical lifetime using circular economy approach applied along the bio economy value chain in Tonga.

While studying the availability of raw fuel resources, their sustainability will also be assessed through their potential impacts on land, energy and water usage over baseline, competing use and food conflicts etc., if suggested to use for biogas production.

1.1 Deliverables

1.Status quo analysis of the current situation

2. Material flow analysis and understand available resources, waste streams for the industrial scale biogas plant

3. Identify waste management system (collection, transport and separation)

2 Status Quo Analysis of the current Tongan Scenario

2.1 Project Background

Kingdom of Tonga started to be concerned and take actions against climate change occurred after the ratification of the UNFCCC on July 20th 1998. Awareness on climate change and sea-level rise topics began to be discussed with the implementation of the preparation of its initial national communication under the UNFCCC between 1999 and 2005 (Global Climate Change Alliance, 2013). The groundwork provided the direction for discussing climate change problems and also looked upon capacity development and awareness creation on climate changes in Tonga and its future effects.

Kingdom of Tonga has been experiencing two major challenges in in two different perspectives. One perspective is substantial dependency on fossil fuel to generate electricity and price fluctuations in fossil fuels in world market resulting Tongan economy and Tongan

population heavily exposed to volatility of electricity prices. Tonga Power Limited (TPL) and the government has been striving hard to keep the electricity prices constant using non fuel components of electricity tariff and subsidies. Giving subsidies has created a financial burden for the government and also using fossil fuels create environmental damage like oil spills, air pollution and ground water contamination.

The second perspective is: Forecasts for all emissions circumstances due to fossil fuel combustion indicated that, due the CO_2 emissions and overall climate change effect, the annual average surface air temperature and sea-surface temperature will increase in future in Tonga (Table 1). More very hot days and warm nights are expected as a result. The predictions for future tendencies in rainfall are not exactly identified, yet expects a decrease in dry season rainfall and an increase in wet season rainfall with an increase in extreme rainfall days. Tropical cyclones will be more powerful but less frequent, while sea-level rise and ocean acidification will continue which will have serious impacts for Tonga. Table 1 clearly states that, if global warming continues there is a tendency that some of the islands in Tonga will be lost forever as a result of rise in sea levels.

Climate Variable	Expected change	Projected Change by 2030	Projected Change by 2050	Confidence Level
Annual surface temperature	Average air temperature will increase	+0.3 C to +1.1 C	+1.0 C to + 1.8 C	Moderate
Maximum temperature (1 in every 20-year event)	More very hot days	N/A	+0.8 C to +2.0 C	Low
Minimum temperature (1 in every 20-year event)	Fewer cool nights	N/A	-0.3 C to +3.1 C	Low
Annual total rainfall (%)	Increase in annual rainfall	-10% to +16%	-7 % to +17%	Low
Wet season rainfall (%)	Increase in wet season rainfall	-10% to +20%	-6% to +24%	Moderate
Dry season rainfall (%)	Increase in Dry season rainfall	-12% to +14%	-15% to +17%	Low
Sea surface temperature (C)	Increase in sea surface increase	+0.3 C to +1.1 C	+0.9 C to + 1.7 C	Moderate
Annual maximum acidification (aragonite saturation)	Increase in Ocean acidification	+3.3 to +3.5	+2.9 to +3.1	Moderate
Mean Sea level (cm)	Rise in sea level	+7 cm to +27 cm	+11 cm to + 51 cm	Moderate

Table 1 - Climate change projections for Tonga for 2030 and 2055 under the high emissions scenario (Source -Global Climate Change Alliance, 2013)

The Tongan Government has looked upon answers to above mentioned major challenges of reducing the Tongan contribution to global Green House Gas (GHG) emissions and same time improving national energy security by approving a policy to supply 50% of electricity generation through renewable resources by 2020.

Tongan government passed the Renewable Energy Bill of 2008, becoming the first Pacific island Country (PIC) to have key instruments for promoting renewable energy (RE) Sources. Tonga has developed an Energy Road Map (ERM) with the target of covering 70% of energy demand by renewable energy by 2030. Since energy generated from solar and wind power are already been added to the national grid, Tonga would like to further enhance its renewable energy portfolio by approaching biogas as a renewable energy.

Energy targets of Tonga are given in below. (Tonga Nationally Determined Contributions Review Report, 2018)

- 50% of electricity generated from renewable sources by 2020
- 70% of electricity generated from renewable sources by 2030
- 100% of electricity generated from renewable sources by 2035

2.2 Necessity of Planning

Tonga is searching for a technology that would instantly reduce the costs of power generation and have significant direct reduction of tariff passed on to consumers, a power source which is also sustainable in the long term where circular economy can play a major role. Since agriculture remains to be the major economic activity in Tonga, it might have very high potential of biomass which can be used for energy production, which will help to diversify its energy portfolio.

If the existing biomass resources can be successfully quantified and effectively analysed and utilized, it could bring positive impacts for the country in terms of less dependency on fossil fuel fired power, reduction of carbon emissions and less environmental pollution but also in income increase for already existing biomass producers and rural households who are involved in biomass supply chain (providing agricultural residuals and selling energy crops).

2.3 Scope of the Project

This study is carried out only to analyse the potential biomass availability in Tongatapu island. Tongatapu is considered as the largest island in Kingdom of Tonga and according to Tonga Statistics Department 2016, 74.16% of the total population of Tonga is living in Tongatapu. Tonga Agricultural census main report published in 2015 states that the number of households engaged in crop cultivations, animal husbandry, fishing activities are highest in Tongatapu

island when considered with other islands of Kingdom of Tonga. Hence biomass availability in Tongatapu island will be higher than other islands.

2.4 Limitations of the report

This report is compiled based on secondary data available through various reports since primary data collection was not possible due to COVID 19 pandemic situation and lack of support from Tongan stakeholders.

Figures and calculations are based on theoretical potential and practical scenario might be different due to many conditions (waste separation, transportation, machineries used, human labor involvement, etc).

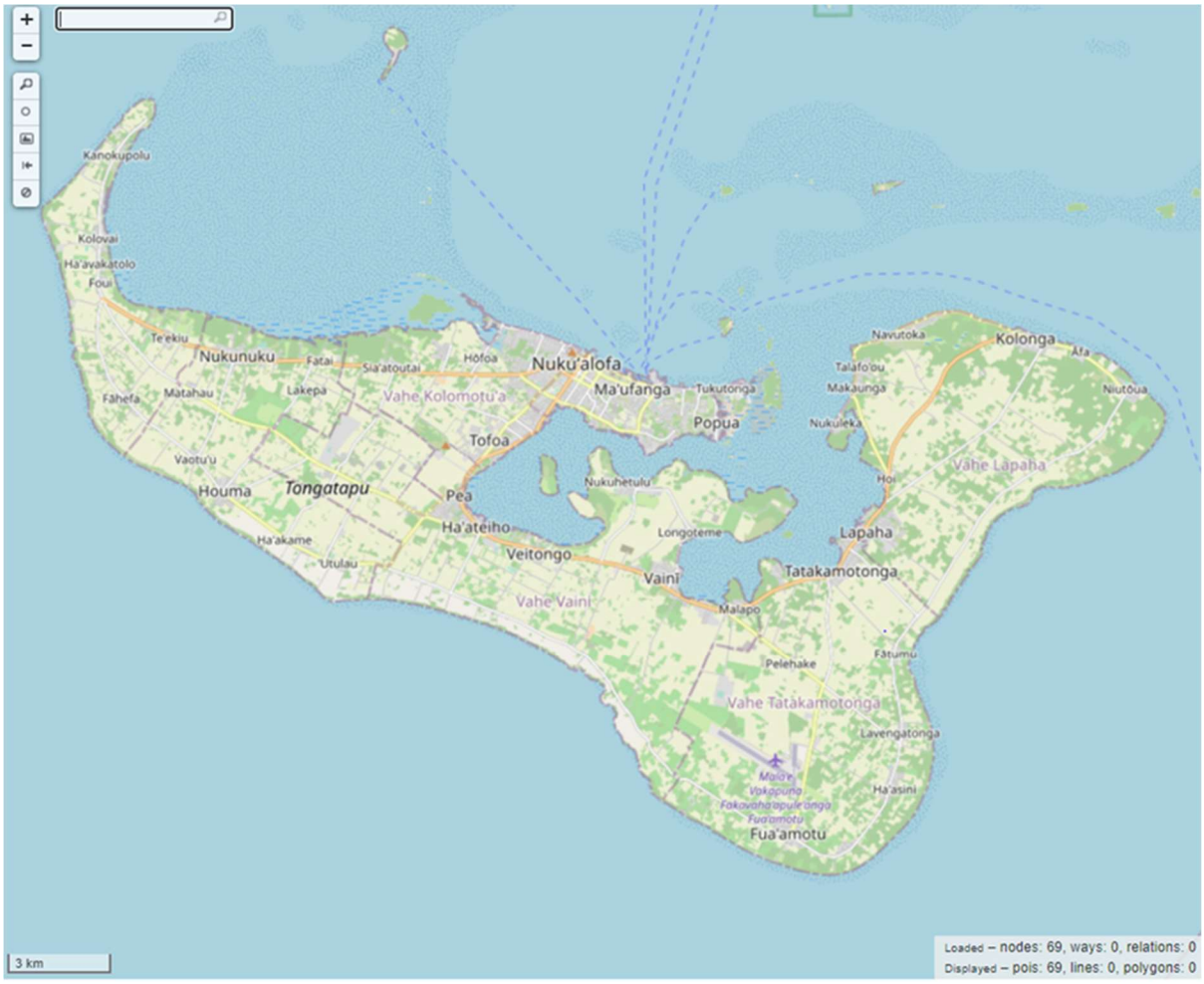

Figure 1 - Geographical map of Tongatapu
Source – Created with Overpass turbo software

Figure 1 gives a geographical map of Tongatapu Island which is the is biggest Island of Kingdom of Tonga which has a land area of 26,050 ha where potential analysis of Biomass is done.

3 Material Flow Analysis and understanding available resources, waste streams for industrial scale biogas plant.

There are numerous sources that can be utilized as substrates to produce biogas. Most commonly used biomass is Animal waste (Manure) from animal husbandry, Food waste, Agricultural crop residues, Municipal waste, industrial waste and waste water which can be used to generate biogas. This section focusses on identifying available biomass sources in Tongatapu Island.

3.1 Agricultural Sector and Crop Residues

Agriculture endures to be the predominant economic activity in Tonga, although its relative importance is getting less dominant over the years. The Agricultural sector's contribution to GDP has declined from 26% in 2004/5 to 19% in 2009/10; and has further declined to 18% by 2013/14. However, waste produced by agricultural crop cultivation can be a possible source of biomass for biogas production. Crops cultivated in the island are for two purposes which are; export purpose and domestic usage and crop cultivations aimed at domestic consumption dominates the sector. (National Agricultural census main report, 2015)

According to National Agricultural census main report of Tonga published in 2015, Tongtapu is having the highest number of households that are actively participated in crop cultivations. Main Crops cultivated in Tongatapu can be categorized as follows in Table 2.

Annual Crops	Perennial Crops	Other Crops
Cassava or manioc	Kava	watermelon
Yam (ufi tokamu'a and ufi tokamui)	Paper mulberry (hiapo)	Head cabbage
Yautia (talo futuna)	Vanilla	tobacco
Sweet potato (kumala)	Pineapple (faina	Capsicum
Swamp taro (talo Tonga)	Pandanus (louakau)	Tomato

Table 2 - Agricultural crop cultivation in Tonga

Tongatapu is having a total area of 26,050 ha out of which 15,885 ha are cultivated land area which accounts to approximately 61% of total available land area. Land usage and production yield data for each type of crop in Tongatapu island is given in Table 3.

Type of Crop	Area in Tongatapu [acres]	Area in Tongatapu [ha]	Annual Yield in Tonga [t/acre]
Cassava or manioc	8,160	3,264	6388
Yam (ufi tokamu'a and ufi tokamui)	4,248	1,699.2	no data
Yautia (talo futuna)	1,956	782.4	no data
Sweet potato (kumala)	1,408	563.2	6639
Swamp taro (talo Tonga)	1,216	486.4	4,297.5
Kava	141	56.4	no data
Paper mulberry (hiapo)	587	234.8	no data
Vanilla	159	63.6	186
Pineapple (faina)	208	83.2	no data
Pandanus (louakau)	9	3.6	no data
watermelon	416	166.4	473
headcabbage	22	8.8	no data
tobacco	37	14.8	no data
Kapsicum	24	9.6	no data
Tomatos	111	44.4	no data
Papaya	28	11.2	no data

Table 3 - Annual crop yields and land use for agriculture in Tongatapu

Annual yield data was not found in literature for many of the crops and hence, when considering the available biomass potentials, crops with yield figures are only considered.

Peelings from Cassava, sweet potato, swamp taro is considered as crop residual and assumed 3 tons per day is expected as waste. Annual waste from crop residuals will be 900 tons per annum. Further, 3 tons of pineapple leaves per day can be expected as residues from pineapple cultivations and per annum expecting 900 tons of pineapple leaves as waste.

3.2 Biomass from Fish Industry

Fishing is one of the most important economic activities in the Kingdom since it is surrounded by about 200 square kilometers of bodies of water and 980 households are engaged in fishing in Tongatapu. Main purpose of Fishing is subsistence fishing (for day-to-day consumption) which is 54%. 42% of 980 households engaged in semi- subsistence which was mainly for consumption and some for sale. Only 4% out of 980 households in Tongatapu are engaged in commercial fishing.

Year	Fish Production [t]
2010	2,075
2011	1,976
2012	1,943
2013	1,713
2014	1,833
2015	1,742
2016	1,617
2017	1,400
2018	1,242

Table 4 - Fish production in Tonga per year
Source - Food and Agriculture Organization (FAO) of the United Nations

Table 4 explains the fish production of Tonga from year 2010 to 2018 in tons. As per the data given in Table 4, Fish production in Tonga has decreased over the years. In year 2010, where it has been 2,075 tons and by the year 2018 it has decreased up to 1,242 tons. According to FAO statistics, until the early 1960s, domestic demand for fish was fully met through catches from the country's reefs and lagoons. Later, however, with the increases in population and

due to growth of the cash economy tonga was led to do overfishing in many inshore areas. As a result of overfishing, Tonga later had to face insufficient production from coastal fisheries and led to import of some Fish species for domestic consumption while commercial fishing continues. The notion of "fishing communities" has limited applicability to Tonga. Almost all households in coastal villages are involved in coastal fishing activities and it could therefore be stated that all coastal villages in Tonga are "fishing communities".

Domestic fish markets can be found in urban areas like any other country. Fish markets are kept as roadside sales occurring from semi-subsistence fish capture and since primary objective of fish capture is consumption, it is expected that fish waste will be demonstrated in kitchen waste fraction of municipal solid waste in Tongan households. Several small fishing companies distribute fish to restaurants and there is no data about fish waste being created from commercial fish capture done for export purpose.

Tonga do not have large freshwater bodies and as a result, freshwater catches are extremely small. According to FAO, with limited factual basis, Gillett (2016) states that Tonga's inland fishery production in 2014 was just one ton, and there is no management or strategies to uplift inland fishery sub-sector.

Considering all above facts, it is arrived at the conclusion that fish subsector do not create a significant amount of biomass to be considered for biogas production.

3.3 Waste from Livestock Farming

In Kingdom of Tonga, livestock is reared mainly for the purpose of subsistence purpose. A total of 12,859 household have been engaged in livestock rearing and out of 12,859 households, 3,443 households do subsistence animal husbandry, 9,257 households engage in semi subsistence animal husbandry, and only 159 households engaged in commercial purpose animal husbandry. Below Table 5 shows type of animals kept per household in Tonga and average number of livestock being reared in Tongatapu (Tonga National Agricultural census main report, 2015).

Type of Livestock	Average number of livestock kept in a household
Cattle	7
Pigs	11
Horses	2
Sheep	8
Goats	4
Chicken	19
Ducks	8

Table 5 - Average number of livestock kept per house in Tonga
Source - Tonga National Agricultural census main report, 2015

In going forward, manure from horses and sheep are not considered in the report.

Type of Livestock	2001 year	2015 year	Increase / decrease percentage
Horses	3,255	1,942	(-)40%
Sheep	0	1,240	100%

Table 6 - Horses and Sheep livestock numbers
Source - Tonga National Agricultural census main report, 2015

As Table 6 above mentions, there were 1,942 horses in total in Tonga for the year 2015 and in year 2001 there has been 3,255 horses in Tonga. This is a 40% decrease in number when compared to the year 2001.

The report does not specifically mention data about the number of horses reared in Tongatapu. As given in Table 5 average number of horses being reared per household is 2. It is assumed that horses are reared for tourist entertaining purposes and since number of horses being reared is significantly small it is not considered in this study. Further, because of the decreasing trend of the horse numbers, a continuous manure supply can not be expected from horses for biogas production.

Sheep is a new livestock category in Tonga where there were no sheep at all in 2001, but 1,250 sheep altogether in Tonga by the year 2015 as given in Table 6. 53% of total sheep is reared in Tongatapu which is 653 sheep (Tonga National Agricultural census main report, 2015). Sheep shows an increasing trend in the numbers yet being reared in households and

allowed to roam freely in household where it would lead to practical difficulty in collecting manure from sheep just like the case of chicken. Hence manure from sheep is not considered for this report as a potential biomass source.

Tonga National Agricultural census main report, 2015 does not specifically states the number of Chicken being reared in Tongatapu. Instead gives Total number of Chicken and duck being reared in Tonga is 92,071 for the year 2015 and it is assumed that 50% of total chicken are reared in Tongatapu which is 46,036. Chicken is freely roaming in households and hence collection of manure would be practically difficult and amount of manure generated for the whole year is only 911 tons and hence negligible. For manure availability going forward, chicken manure is not added up.

3.3.1 Available Biomass from animal husbandry

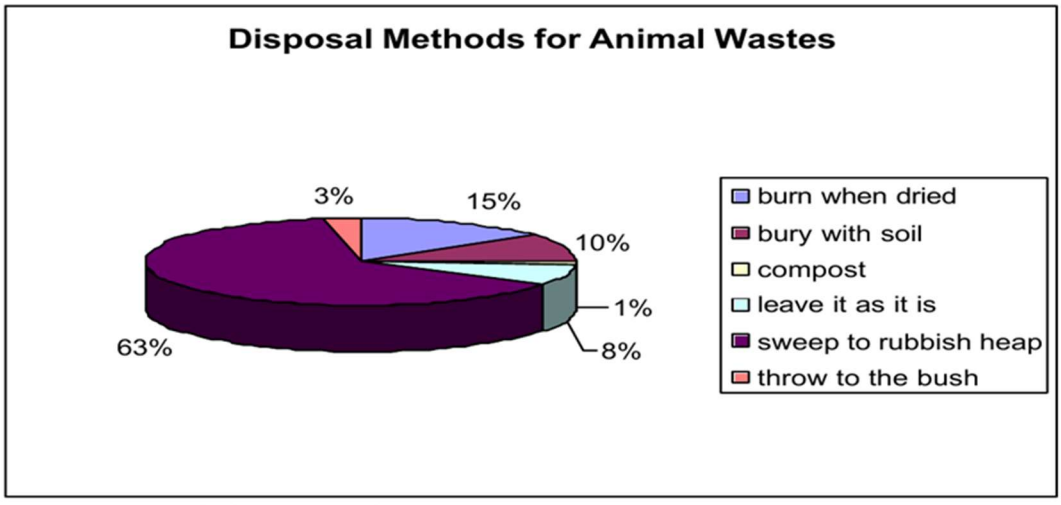

Figure 2 - Disposal methods of Animal waste
Source - Household Economic Survey, June 2005 as cited by P.Lal, Lilieta Takau,2006

As Figure 2 shows above, 15% of households burn the manure when dried and 10% of households burry the manure with soil. 1% of households practice manure being added to compost bins and 8% of households leave manure as it is in household gardens. Majority, which is 63% of households practice sweeping the manure to a rubbish heap, and 3% of households throw the manure to a bush. Because of this scenario that it can be stated that it is practically difficult in collecting manure from households except animals are reared as small or medium sized groups.

3.3.2 Availability of Pig Manure

According to P.Lal, Lilieta Takau , 2006 even though there is a law enforced by the government that pigs should not be allowed to roam free, this law is rarely enforced and pigs are often seen roaming freely which makes collection of pig manure difficult in practical scenario. For the purpose of this study, below calculations indicated in Table 8 are done to figure out pig manure quantities assuming that pig manure can be collected from households who rear more than 20 pigs.

Total number of pigs in Tonga for the year 2015 is 110,616 out of which 54% of total pigs are reared in households in Tongatapu which is 60,061 pigs. Total number of households who rear pigs in Tonga are 10,038 houses. It can be calculated that 60,061 pigs are reared in 5,450 households in Tongatapu. As Table 7 explains, 33% of these households kept less than 5 pigs, 25% kept 5-9 pigs; 26% kept 10-19 pigs; 14% kept 20- 49 pigs and about 2% kept more than 50 pigs (Tonga National Agricultural census main report, 2015).

Number of Animals	Percentage of households who keep respective pig groups[1]	Number of households who keep respective pig groups in Tongatapu	Average number of pigs per group	Total number of pigs in each group
Less than 5	33%	1,789 households	2	3,578
5 -9 pigs	25%	1,363 households	6	8,178
10 – 19 pigs	26%	1,417 households	13	18,421
20-49 pigs	14%	763 households	31	23,653
More than 50 pigs	2%	109 households	55	5,995

Table 7 - Availability of Number of Pigs in Households of Tongatapu

According to Table 7, 1,789 households in Tongatapu rear pigs less than 5. Assuming an average of 2 pigs per household, 3,578 pigs are reared in groups of 2 pigs. 1,363 households in Tongatapu rear groups of 5 – 9 pigs. Assuming an average of 6 pigs per household, 8,178 pigs are reared in groups of 5 – 9 pigs. 1,417 households rear 10 – 19 pigs. Assuming an average of 13 pigs per household, 18,421 pigs being reared as groups in 10 – 19 pigs.

[1] Tonga National Agricultural census main report, 2015

2 pigs per household, 6 pigs per household and 13 pigs of household is considered as small-scale animal rearing for subsistence purpose. And pigs being allowed to roam freely makes it practically difficult to collect manure. Hence manure from those households is not considered as possible biomass quantities.

763 households in Tongatapu rear pigs in groups of 20 – 49 pigs. Assuming an average of 31 pigs for the group, 23,653 pigs are reared in groups of 20 – 49 pigs. 109 households in Tongatapu rear pigs in groups more than 50. Assuming an average of 55 pigs per group, 5,995 pigs are reared in groups of more than 50 pigs. Households with an average of 31 pigs and 55 pigs are considered as small-scale pig farms and manure collection is practically possible to some extent.

Average number of pigs per group	Total number of pigs	Manure production [l/(pig x d)]	Total Manure [m^3/d]	Manure availability	Total availability [m^3/d]
31	23,653	3	71	30%	21.3
55	5,995	3	18	50%	9.0
Total pig manure availability [m^3/d]					30.3
Total pig manure availability [m^3/a]					11,053

Table 8 - Total Pig manure availability per year

It is assumed that each pig produces 3 litres of manure each day. 23,653 pigs would produce 70,959 litres of manure per day or approximately 71 m^3 of manure per day as explained in Table 8 above. 5,995 pigs would produce 18 m^3 of manure per day.

Since Tongatapu do not have organized waste collection systems covering the whole island and due to practical difficulties of collection manure, it is estimated that 30% of total manure from households who rear pigs in groups of 20 - 49 can be collected which will be a total of 21.3 m^3/ day. Assuming 50% of manure can be collected from households who rear pigs in groups more than 50, it would produce 9 m^3 of manure per day. Per day 30.3 m^3 of pig manure can be collected and per annum 11,053 m^3.

3.3.3 Availability of Cattle Manure

During the year 2015, a total of 18,803 cattle were kept in the Kingdom of Tonga in 3,310 households. Out of 18,803 of total cattle 16,768 were beef cattle (89% of total cattle) and 2,035 were dairy cattle (11% of total cattle) as given in agricultural census main report of Tonga, 2015. Tongatapu had 8,854 beef cattle and 1,061 dairy cattle in 2015 (Tonga agricultural census main report, 2015).

Number of Animals	Number of households in Tonga who rear cattle [2]	Number of households who keep respective cattle groups in Tongatapu	Average number of cattle per group	Total number of cattle in each group in Tongatapu
1 or less than 5 cattle	2,029	1,070	1.4	1,498
5 -9 cattle	782	412	7	2,886
10 – 19 cattle	376	198	15	2,974
20-49 cattle	109	57	35	2,012
More than 50 cattle	14	7	75	554

Table 9 - Cattle numbers in Tongatapu

As Table 9 explains, 2,029 households in Tonga rear cattle in groups of 1-5 or less than 5. 782 households in Tonga rear cattle in groups of 5 – 9. 376 households rear 10 – 19 cattle and 109 households rear cattle in groups of 20 – 49. Only 14 households in Tonga rear cattle in groups of more than 50.

Since 52.7% of all cattle reared in the Kingdom of Tonga are reared in Tongatapu, it can be calculated that 1,070 households in Tongatapu rear cattle in groups of 1 – 5, 412 households in Tongatapu rear cattle in groups of 5 – 9, 198 households in Tongatapu rear cattle in groups of 10 – 19, 57 households in Tongatapu rear 20 - 49 cattle and 7 households in Tongatapu rear cattle groups in more than 50.

Assuming an average of 1.4 cattle per household, 1,498 cattle are reared in Tongatapu in 1 – 5 cattle group. Assuming an average of 7 cattle per household who rear cattle in groups of 5

[2] Tonga Agricultural Census Main report, 2015

– 9, 2,886 cattle are reared in Tongatapu. 2,974 cattle are reared in Tongatapu in groups of 10 – 19 assuming an average of 15 cattle per household. 2,012 cattle are reared in Tongatapu in groups of 20 – 49 assuming an average of 35 cattle per household. 554 cattle are reared in Tongatapu in groups of more than 50 assuming an average of 75 cattle per household. Due to practical difficulty in collecting manure from households who rear cattle in groups of 1-5, 5 -9 and 10 – 19, going forward, they are not considered.

Total number of cattle	Manure production [l/cattle x d]	Total Manure [m^3/d]	Manure availability	Total availability [m^3/d]
2,012	10	20	20%	4.0
554	10	6	30%	1.7
Total cattle manure availability [m^3/d]				5.7 m^3/d
Total cattle manure availability [m^3/a]				2,075 m^3/a

Table 10 - Total Cattle manure availability per year

As given in Table 10, there are 2,012 cattle available from households who rear cattle in groups of 20-49 and 554 cattle available from households who rear cattle in groups of more than 50 in Tongatapu. Each cattle are assumed to produce 10 Liters of manure per day. Total manure produced from 2,012 cattle would be 20m^3/d and 554 cattle would produce manure of 6m^3/d. Because of the manure collection and transportation difficulties, it is estimated that 20% of manure from households who rear cattle in groups of 20 – 49 can be collected which amounts to 4m^3/d of manure (Table 10). From households who rear more than 50 cattle, it is estimated that 30% can be collected from total manure produced which is amounting to 1.7 m^3/d.

A total of 5.7m^3 of cattle manure can be expected per day and per annum 2,075 m^3.

3.4 Municipal Solid waste (MSW)

It is surveyed that total average annual waste generation per Tongan is 1 ton (P.Lal, Lilieta Takau, 2006). Out of which 65% are kitchen waste and garden waste which are possible biogas substrates. Average weekly garden waste generation per household 8.4 kg and Organic kitchen waste is 2.2 kg (P.Lal, Lilieta Takau, 2006). In Tongatapu, there are 13,096 households (Census of population and Housing, Tonga 2016) and total population in Tongatapu by the year 2016 is 74,611 (Census of population and Housing, Tonga 2016). Per household there

are 6 people and annual garden and kitchen waste generation is calculated as follows in Table 11.

Table 11 explains, in 2016, there were 74,611 population in Tongatapu and 13,096 households. Per household weekly kitchen waste generation is 2.2 kg. Annual kitchen waste generation per household is 114.7 kg. Since there are 6 people in a household, it can be calculated that per person annual kitchen waste generation is approximately 20 kg. Annual kitchen waste generation by the whole population in Tongatapu would amount to 1,502,268 kg.

Description	Calculation
No. of households in 2016 in tongatapu	13,096
no. of population in Tongatapu in 2016	74,611
people per household	6
Weekly kitchen waste generation per household [kg/week]	2.2
Annual kitchen waste generation per household [kg/a]	115
Annual kitchen waste generation per person [kg/a]	20.1
Annual kitchen waste generation for population [kg/a]	1,502,268

Table 11 - Annual kitchen waste generation in Tongatapu

Annual kitchen waste generation as per above calculation is 1,502 tons which is significantly small. Due to majority of kitchen waste being fed into animals reared in households and being added to compost bins also due to unavailability of proper waste collection systems covering whole Tongatapu, total collectable biomass from Kitchen waste from households are negligible and not considered as possible biogas substrate.

However, Tonga being a tourist destination, kitchen waste produced from hotels and restaurants can be considered as a possible biomass source. Assuming organic kitchen waste produced from hotels and restaurants as 3 tons per day, 1,095 tons per annum can be expected.

Table 12 shows the amount of garden waste available annually as a biogas substrate. Per household weekly garden waste generation is 8.4 Kgs and per household annual garden waste

generation is 438.7 Kgs. Since there are 6 people per household in the year 2016, per person annual garden waste generation would amount to 5,745,530 kgs or 5,745 tons.

Description	Calculation
Weekly garden waste generation per household [kg/week]	8.4
Annual garden waste generation per household [kg/a]	438.7
Annual garden waste generation per person [kg/a]	77
Annual garden waste generation for population [kg/a]	5,745,530

Table 12 - Annual Garden waste generation in Tongatapu

Annual garden waste generation from households as per above calculation is 5,745 tons which is significantly small and practically difficult to collect as proper waste collection system is not available. Hence cannot be considered as a possible biogas substrate.

3.5 Human waste

Tonga does not have a centrally managed human waste system and thus relies on household-based human waste management. 83% the households use septic tanks for human excreta disposal (P.Lal, Lilieta Takau , 2006). A further 10% use flush pits, and only 7% of households use traditional pit toilets. While the emptying of septic tanks is suggested at least once every five years, over 41% of households never empty their septic tanks as shown in Figure 3 (P.Lal, Lilieta Takau, 2006).

As Figure 3 explains, only 15% of households empty their septic tanks once over in every 7 years (P.Lal, Lilieta Takau , 2006). Only 1% of households empty their septic tanks, hence going forward human waste availability is not considered.

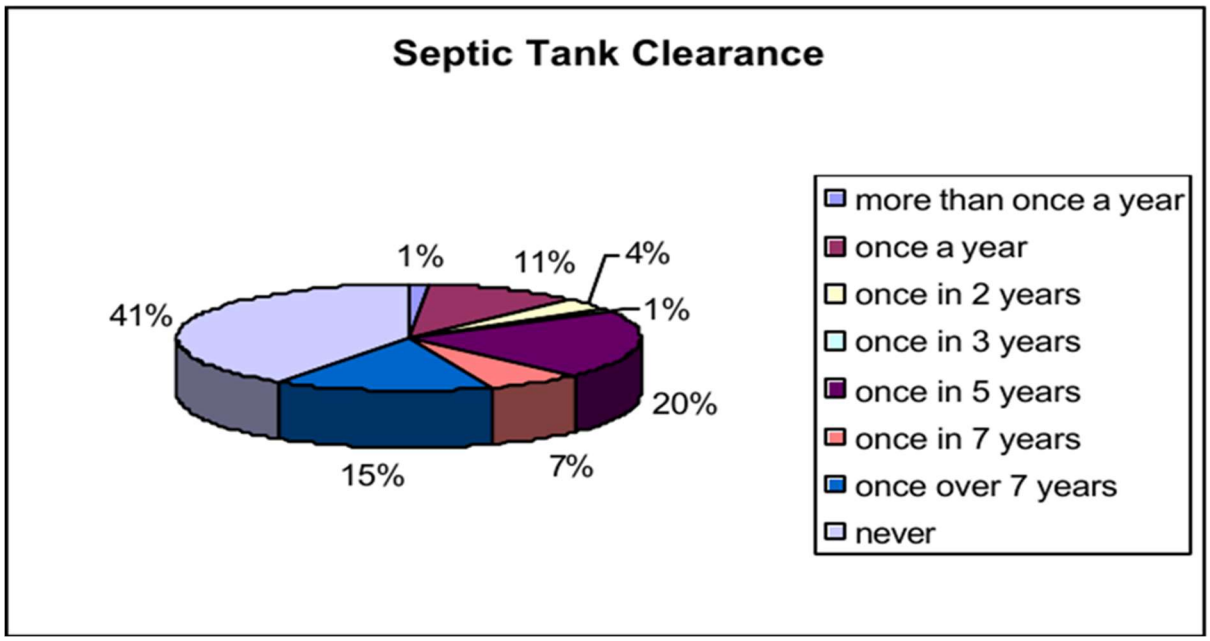

Figure 3 - Septic tank clearance of Households in Tongatapu
Source - P.Lal, Lilieta Takau , 2006

3.6 Grass from Landscape Management

According to Tonga National Agricultural Census 2015 main report total available cultivable land in Tongatapu is 39,253 acres out of which 16,988 acres of land is cultivated with annual crops, 1,104 acres of perennial crops and 638 acres of other crops. Total land area cultivated is 18,730 acres and the left land of 20,523 acres is considered as grassland. It is estimated that 5 tons of grass cutting on average per day can be expected from this total grassland and per annum 1,825 tons.

3.7 Total Availability of Biomass

Potential biomass source	tons per annum
Agricultural Crop residues	1,800
Fish Industry	0
Pig manure	11,053
Cattle manure	2,075
Kitchen waste from hotels and restaurants	1,095
Human waste	0
Grass Cuttings from Landscape Management	1,825
Total available biomass	17,848

Table 13 - Total quantity of possible biomass substrates

Table 13 is a summary of all the biomass substrates that can be considered for the biogas plant in Tongatapu. A total quantity of 17,848 tons of biomass can be expected per annum.

4 Identify waste management system (collection, transport and separation)

4.1 Solid waste from Households (Urban areas)

Solid waste management is mostly done by individual households, although there are few local governments and private companies who would provide service in collecting waste from households. Frequently used household waste disposal method is burning where 75% of the households' practice claiming it as the easiest and cheapest way. 7% of households burry the garbage in their backyards, another 7% taking the waste to open dump areas, 6% taking to bush allotments, 1% do indiscriminate dumping and 4% households' handover the waste to regular waste collection operators (Household Economic Survey, June 2005).

Government of Tonga has provided a waste collection service for its citizens to manage solid waste. According to P.Lal, Lilieta Takau , 2006, these are not regularly used by the residents. In fact, it is stated that, during the first half of the year 2005, only about 12% urban households have used this service offered by the government. This is lower than those reported in 2003, when it was estimated that 25% of households used services provided by the government (Sinclair, 2000).

Waste collection service is offered by the government is managed by Ministry of Health where it owns and operates only one collection truck, which is frequently subjected to breakdowns (P.Lal, Lilieta Takau, 2006).

With the aid of The Asian Development Bank (ADB), Australia's Aid Programme (AAP), Ministry of Finance and National Planning, Pacific Engineering Consultant Group and Egis Eau consultancy firm based on France, Tongan government has come up with Waste Authority Limited (WAL) which has been able to upgrade the MSW collection service from residents, municipal functions and some commercial and industrial premises via a fleet of six collection vehicles. Waste collected by WAL is filled into Tapuhia Landfill (Waste Authority limited, Tonga, 2018).

Tonga also has private contractors who collects waste. On Tongatapu, Waste Managment Ltd is such a private operator who provides regular collection services for residential and business premises, using an open-deck collection truck. It had nearly 200 registered customers and charges a fee of $8 per bin per collection. This fee is much higher than the fee charged by the Ministry of Health, which is $5 per week (P.Lal, Lilieta Takau , 2006).

Figure 4 and Figure 5 shows images of Tukutonga landfill by the year 2006 and Figure 6 gives the geographical locations of Tukutonga landfill and Tapuhia Landfill.

Figure 4 - Tukutonga Landfill
Source - (P.Lal, Lilieta Takau , 2006)

Figure 5- Tukutonga Landfill
Source - (P.Lal, Lilieta Takau , 2006)

According to Tongans, the private company, provides a more flexible collection system, with the collection service. They also sort waste into glass and other recyclable materials which are

reused or recycled, PET plastic bottles are incinerated and organic matter is composted. The rest of the waste is disposed of at the Tukutonga dump (P.Lal, Lilieta Takau , 2006). Landfill gas collection and treatment are not done at the moment and Tongatapu's waste is extremely dry due to the segregation of much organic food materials by households for chickens, pigs, and dogs (ADB, 2014).

Figure 6 - Tukutonga and Tapuhia Landfill cites geographical Location

Source – Created with Overpass turbo software

4.2 Solid waste from Households (Rural areas)

There are no regular operated collection services as mentioned in literature. Garbage collections at the village level, where they exist, are organized by the village council (P.Lal, Lilieta Takau, 2006) and probably being ended up as landfills.

5 Sustainability of Available sources of Biomass and Future Outlook

At present tonga is practicing a liner approach of using resources where they produce the resources / import resources, consume and whatever the leftover is thrown away. Making use of the available biomass to produce biogas is a circular economic approach for Tonga to reduce the amount of waste that is thrown into a landfill, reduce green house gas emissions and achieve its energy targets of having 70% of renewable energy by the year 2030 as discussed in Topic 2 of this report while making maximum use of the resources.

In order to diversify Tonga´s energy portfolio by introducing an industrial scale biogas plant of min. 0.5 MW, a continuous supply of biomass from possible sources should be ensured. As discussed under Topic 3 of this report, even though there are many biomass sources and considerable amount of biomass quantities are being produced, lack of an organized waste separation and collection system and current practices of Tongas hinders the potential of using the total quantity of biomass for the biogas plant. As discussed in Table 13, only 17,848 tons of biomass can be expected per annum which is not sufficient to operate 0.5 MW biogas plant. It is expected that around 200 kW of energy can be produced with the available biomass quantity. The continuous supply of available biomass for future is questionable because it may change with population demographics of Tonga, climatic conditions of Tonga, Land availability, Agricultural practices and changing food habits of Tongans and due to many other factors.

In order to achieve the energy targets of having 70% renewable energy by 2030 and by diversifying energy portfolio by introducing a biogas plant of 0.5 MW; a continuous supply of biomass should be ensured. Since Tonga is having a lot of fallow land and grass land (depending on the source applied, 39% to 45% of the agricultural land in Tonga is not used for agricultural purposes) which are not currently being used for agricultural crop cultivations, cultivating energy crops such as Hybrid Tropical Grass (HTG) could be a possibility.

HTG is a C4, sterile, non-invasive hybrid of Pennisetum purpureum x Pennisetum americanum which can only be propagated from canes. HTG is also known as Hybrid Napier Grass, Super Napier Grass, and Napier Pakchong 1.

HTG was originally developed by the Thai Department of Agriculture in support of their evolving dairy industry. As a general rule, any biomasses that are readily digestible by cows are also digestible within the digesters of a biogas plant.

Viewed strategically, HTG was specifically developed by the Thai Department of Agriculture to leverage off Thailand's prolific and inexhaustible photosynthesis resources. This makes HTG and excellent foundation crop on which to initiate Tonga's biogas sector. HTG supports a high yielding and relatively low input perennial cropping system (Figure 7) able to deliver yields of over 500 Metric Tons (tons) of fresh matter/ha/a through multiple harvests throughout the year.

Figure 7 - HTG Energy Crop

In cooperation with Malaysian based HTG experts, BSW Energy Malaysia (BSW), an initial desktop analysis has been undertaken to determine the extent of land on the main Island of Tongatapu that could support HTG. This desktop analysis considered land use maps supplied

by MAFF along with climate and related agricultural information sourced from the 'Tonga Climate Service for Agriculture' (ToCSA).

Tongatapu is having a total area of 26,050 ha, thus 40% fallow land corresponds to more than 10,000 ha of land theoretically available for cultivation of energy crops. To increase the estimated biogas potential (around 200 kW) based on the substrates available to the envisaged capacity of 500 kW 30 ha of HTG cultivation would be more than sufficient (assuming a conservative yield of 300 t HTG/ha/a). That means that a small portion of the available fallow land would be sufficient to produce all the electrical energy for Tongatapu.

To push this technical solution, it should be clarified whether the fallow land is available from a legal point of view resp. what the ownership situation is. In addition, it should be evaluated whether the technical requirements for cultivation, harvesting and storage of HTG are given respectively what is necessary to establish the preconditions. In parallel, practical organizational structures (e.g., private farmers, biogas plant owner/operator) should be identified on how to organize cultivation, harvesting and storage of HTG.

A step-by-step approach where a multi-substrate biogas plant grows with the amount of available substrate appears to be an adapted solution under the given circumstances. Thus, at the beginning, all available substrates could be treated, and a lower amount of energy (around 200 kW) could be produced. Once the first HTG or even more grass cuttings are available, the biogas plant can be expanded to an electrical output of 500 kW and beyond to much higher electrical outputs.

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