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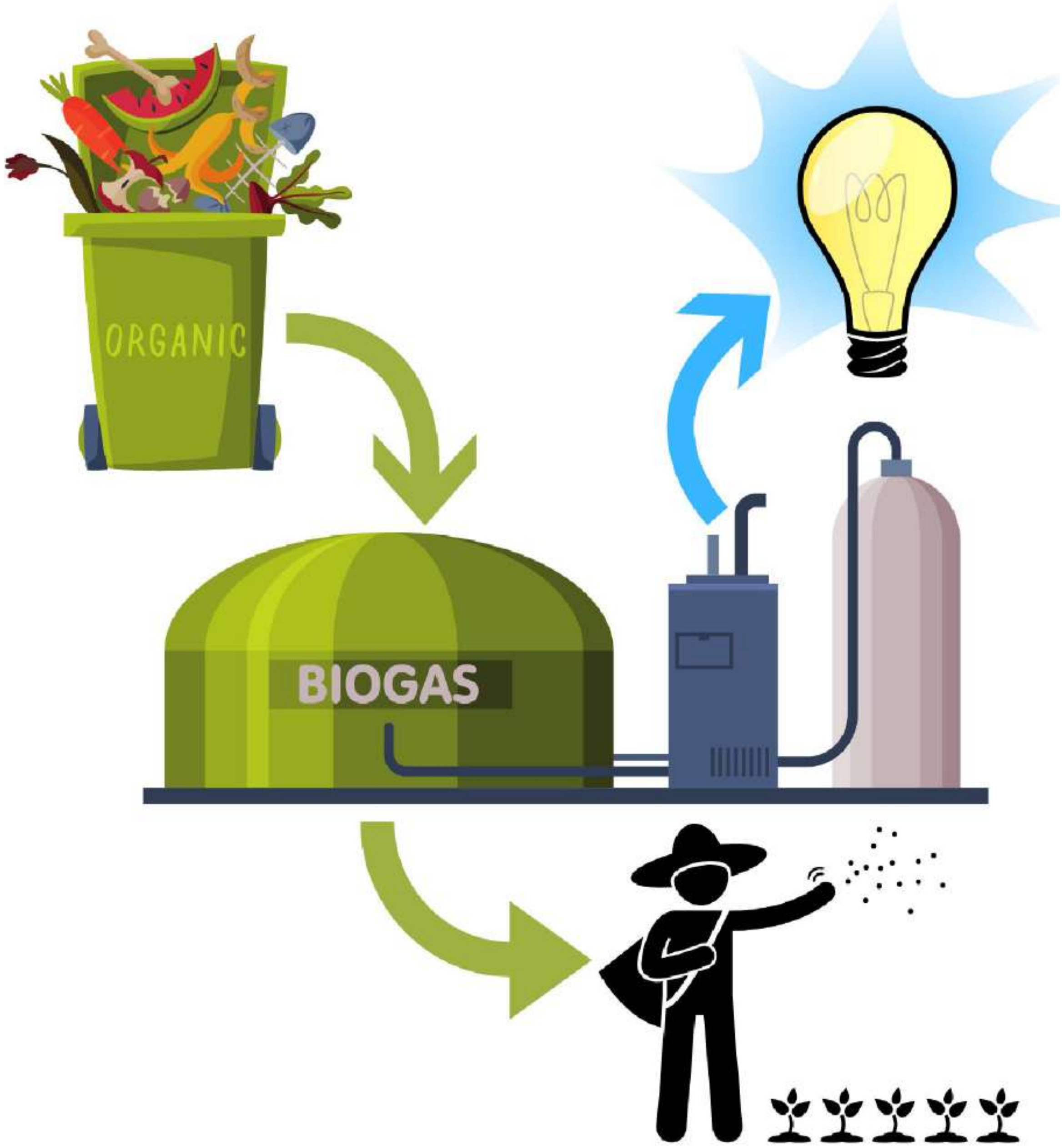
BIOMASS WASTE TO ENERGY IN CAMEROON: AN ANALYSIS OF ITS POTENTIAL

18th Asia Pacific Conference

Panel Session	Climate Change & Resources
Presenter	Nkweauseh Reginald Longfor



OUTLINE

INTRODUCTION
- Background
- WtE Potential
- Case of Cameroon

METHODS
- Analytical framework
- Research Strategy

FINDINGS

Theoretical, technical and Economic WtE Potentials in Cameroon

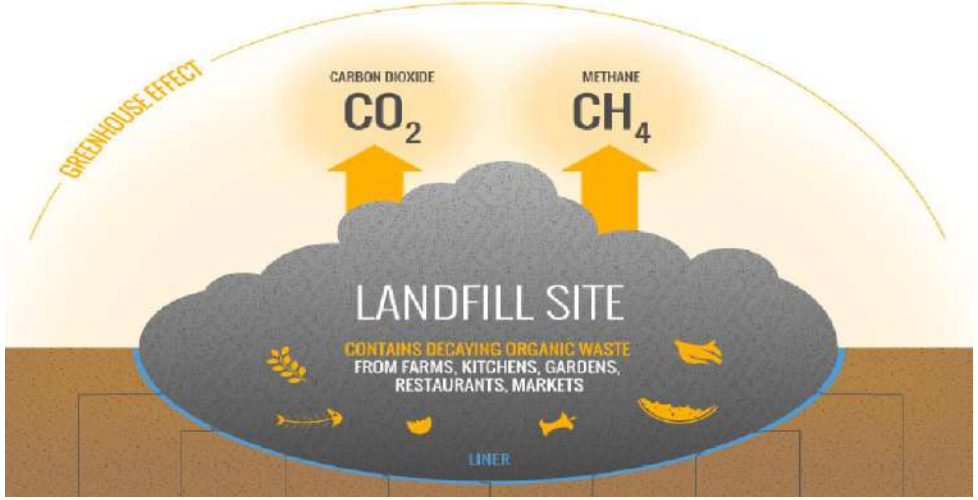
DISCUSSION
- Implications based on observable WtE potentials.

- Policy Implications

CONCLUSION

Summary and Limitations of Study

BACKGROUND

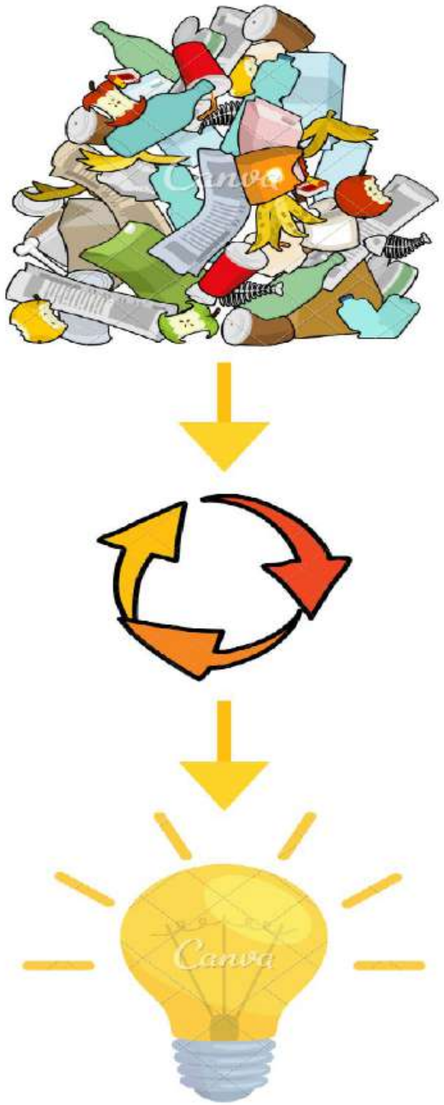


Source: http://gazasia.com/biogas-source/landfill-sites-2/

The environment threatened by increasing waste generation rates across the world.

- In 2016, major cities generated 2,01 billion tonnes of solid waste equivalent to a waste generation per capita of 0,74kg/per.day. (WorldBank, 2019).
- Current levels of Waste generation is influenced by urbanization, industrialization, population growth, economic development etc.(Hoornweg & Bhada-Tata, 2012; Zhang, Tan, & Gerberg, 2010)
- By 2050, annual waste generated is expected to increase by 70% equivalent to 3,40 billion tonnes. (WorldBank(1), 2019),

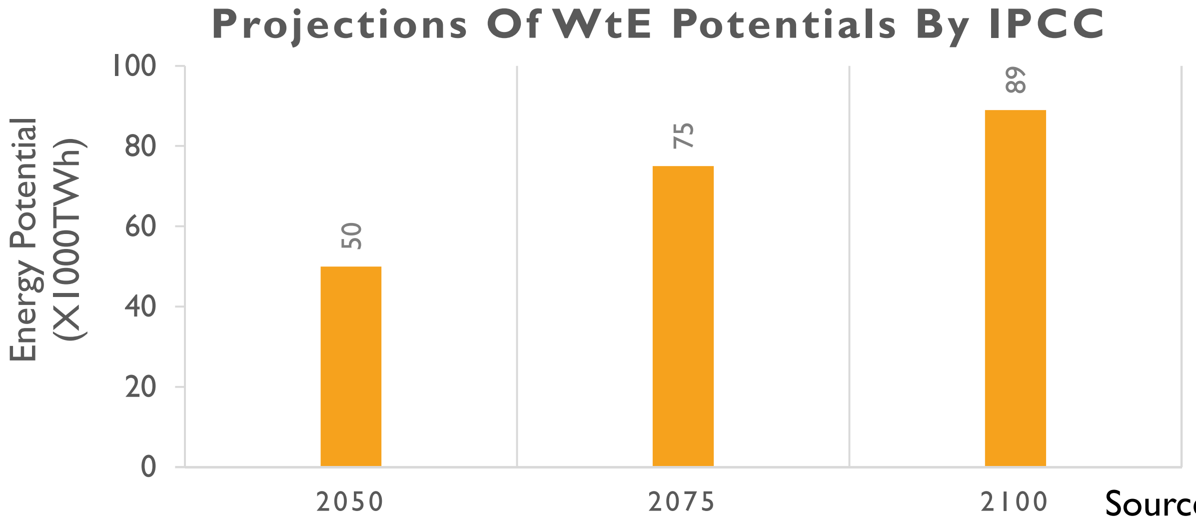
BACKGROUND



Recently, there have been considerable Research Efforts on recycling organic wastes as a renewable source to:

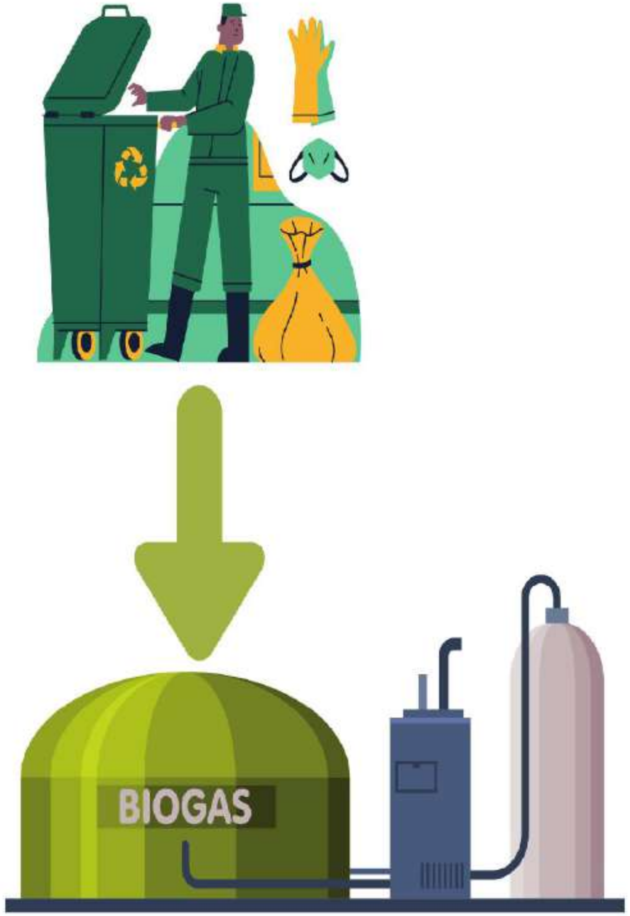
- Meet energy targets as well as lessen dependency on fossil fuels.
- Reduce Anthropogenic GHG emissions. (Milbrandt et *al,* 2018; Hoornweg & Bhada-Tata, 2012).

- Organic waste-to-Energy (WtE) has huge potential to contend fossil fuels on large scale (S.O. Negro et *al,* 2007)
- Current WtE potential can meet 20% of the World's gas demands as well as reduce GHG emissions (IEA, 2020).



Source: (after) Divya et al.,2015

BACKGROUND



- Aside meeting energy targets, WtE utilization reduces stress environment by;
  - Diverting wastes disposed of at landfill sites
  - Improve waste Management practices (REN21, 2019)

Anaerobic Digestion (AD) is a promising WtE technology for recycling organic waste at low costs(Milbrandt et *al*, 2018; Divya et *al*., 2015; Aghbashlo *et al*., 2019).

AD enables energy production from organic wastes as well as recovery of nutrients as fertilizers (Istrate et *al*., 2020).

In **AD**, organic wastes are processed in the absence of oxygen under bacterial activity to produce biogas whose main components are CH_4, CO_2, H_2S, NH_3, and other gases (Aghbashlo *et al*., 2019).

Constant biogas production depends on constant supply of (Wet) Organic wastes and favorable conditions (such as pH, temperature, hydraulic retention time (Silva dos Santos et al, 2018; Achinas & Euverink, 2016).

Waste-to-biogas production via AD process is both renewable and 'carbon neutral' because carbon contained in organic wastes is trapped in a relatively short period from atmospheric CO2 (Silva dos Santos et al, 2018; Awe et al, 2017)

POTENTIAL FOR TRANSFORMING BIOMASS WASTE TO ENERGY

Country	Year	Feedstock	WtE Potential	Reference
Indonesia	**2014**	Agricultural wastes	50GW, yet only 2GW is currently utilised	Kuvarakul et al,2014;
Malaysia	**2016**	Farm animal wastes	8.27TWh/yr	Abdeshadian et al. (2016)
Uruguay	**2016**	Agricultural wastes Manure Agroindustrial solid wastes Slaughterhouse & dairy wastewater Vinase	162GWh/yr - 263GWh/yr	Moreda (2016)
Mexico	**2016**	Organic solid wastes, Municipal and Industrial wastewater Livestock manure	6.4TWh/yr - 167.9TWh/yr	Rios & Kaltschmitt (2016)
Brazil	**2018**	MSW Wastewater Sludge Vinase Livestock manure	4.5GW - 6.9GW	I.F Silva dos Santos et al. (2018)

POTENTIAL FOR TRANSFORMING BIOMASS WASTE TO ENERGY

Operational Analysis[a] of Biomass projects

Life Cycle Analysis[b]

Cradle-to-grave environmental stress (Impacts of resource use, human wellness, global climate change) caused by WtE Project.

Exergy Analysis[c]

Quantitative & Qualitative energy/material flows, thus providing insights on energy/material use efficiency and renewability of WtE project

Exergoenvironmental analysis[d]

Links both the sustainability aspect of the LCA method and the irreversibility feature of the exergy approach providing great insights on environmental constraints caused by WtE systems

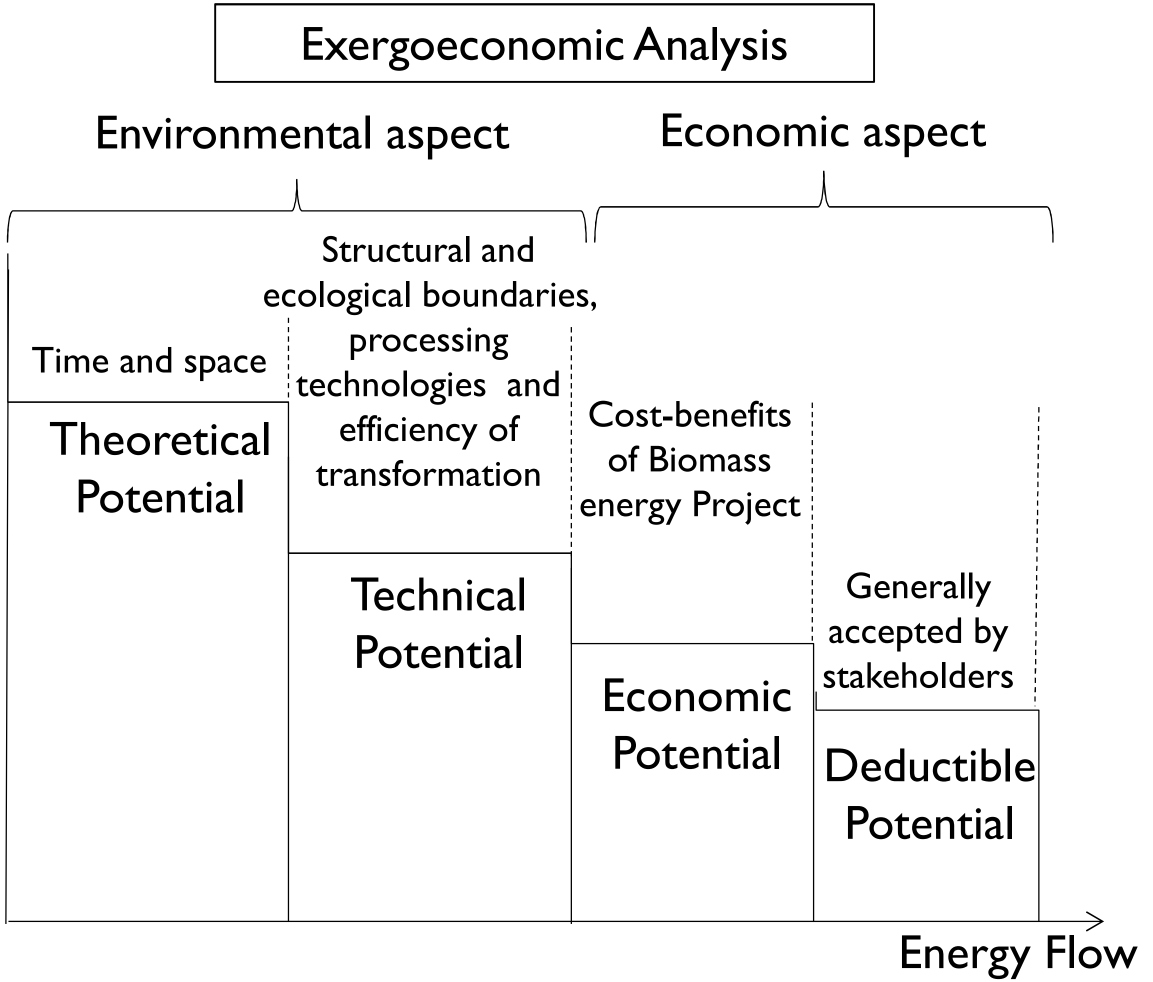
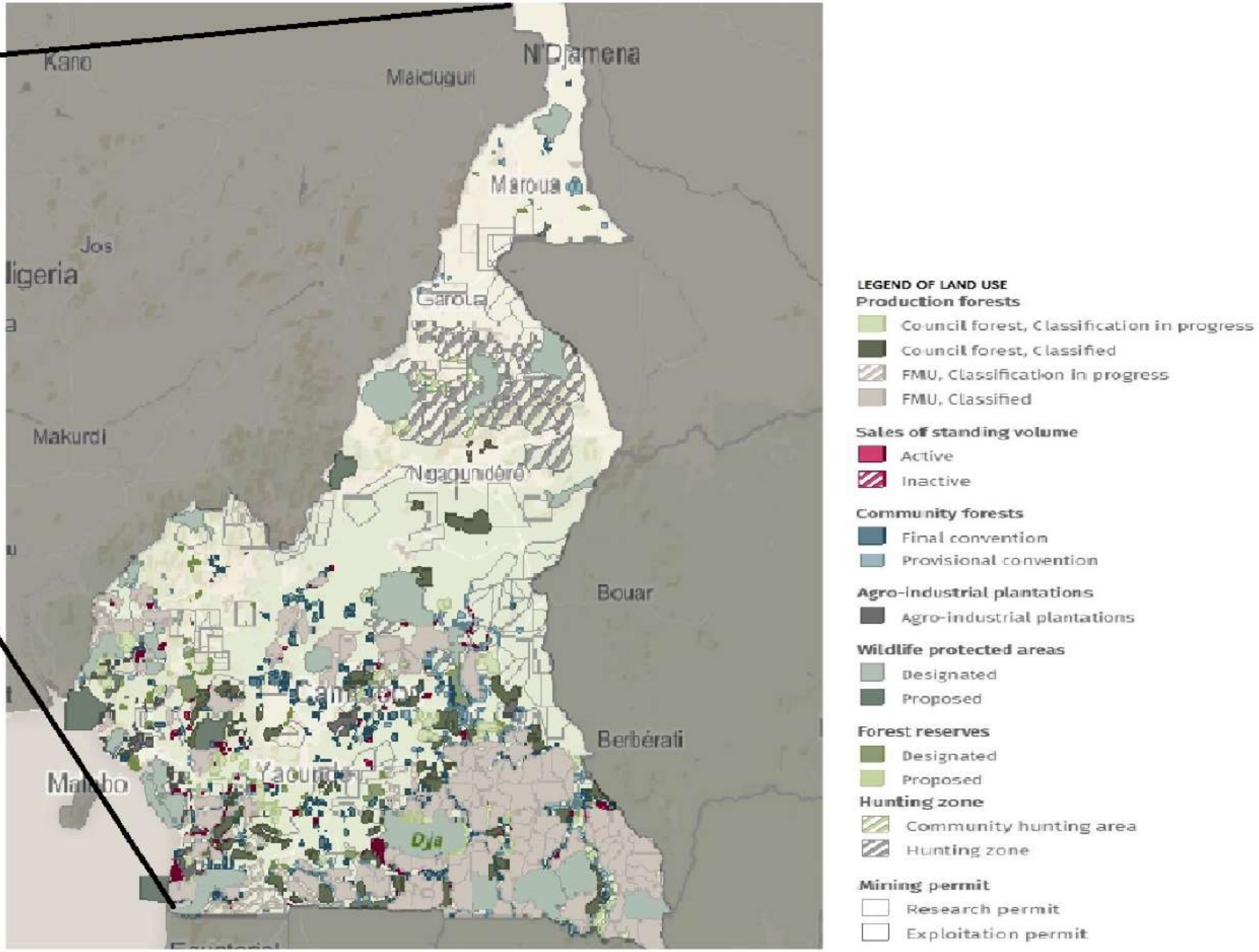


Figure 6: Likelihood Evaluation: theoretical to Acceptable Potential *(Source: Author)*

[a] *Roder et al, 2015; Singlitico et al, 2019; Baldineli et al, 2017; Wang, Chai et al, 2021*
[b] *Gao, et al., 2019; Zhu et al, 2019; Fernandez & Liu, 2017; Perez-Camacho et al, 2018*
[c] *Genc et al, 2017; Aghbashlo et al, 2018; Aghbashlo & Rosen, 2018*
[d] *Meyer et al. (2009)*

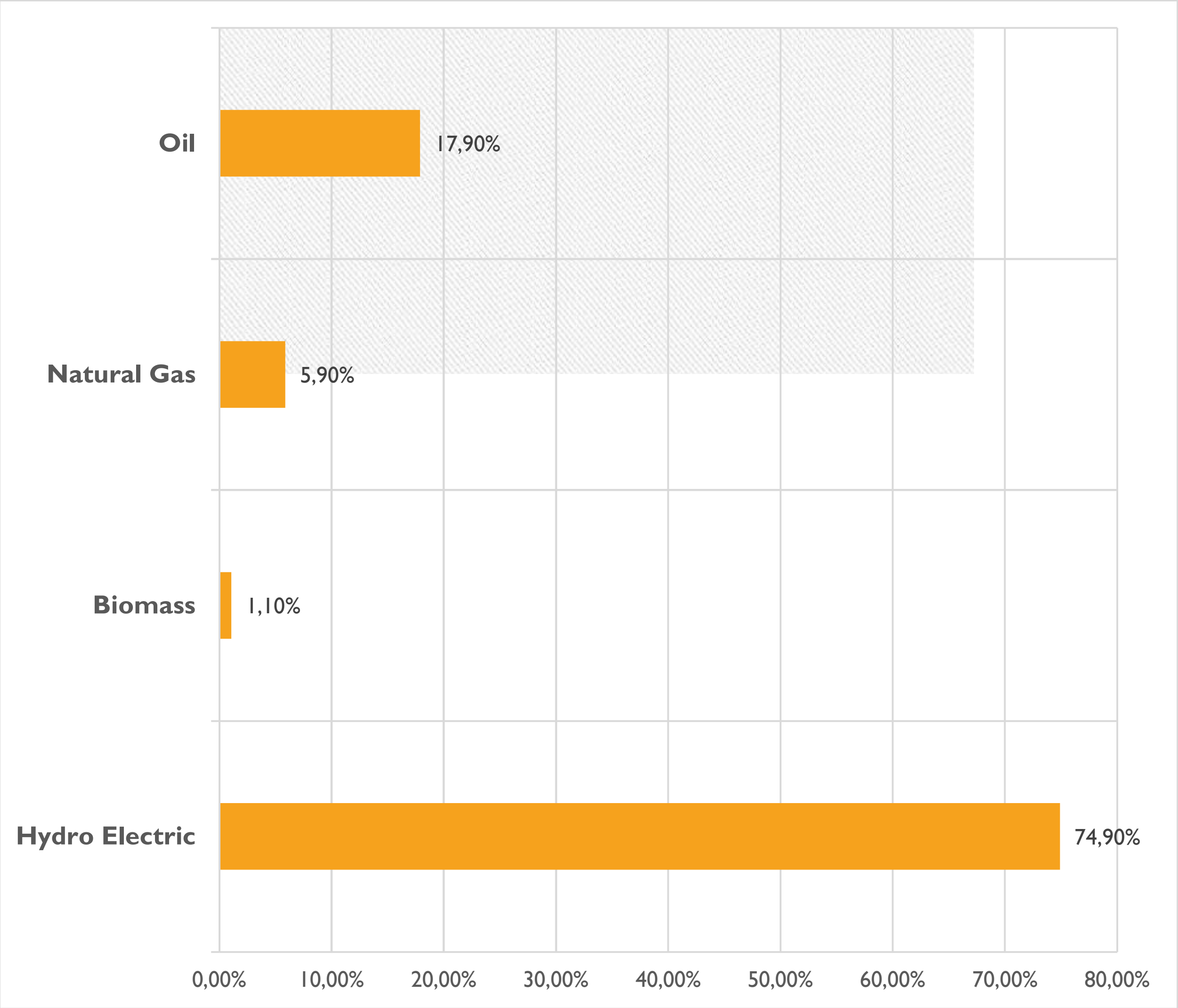
RESEARCH BACKGROUND: OVERVIEW



Location of Cameroon on Gulf og Guinea
Source: ForestAtlas, 2019; OHO, 2018)

- **Area**: 475, 440sq Km
- **Population**: 25,196,480 inhabitants(growth rate: 2.57%)
- **Urbanization Rate**: 3.4%
- **%Population In Urban areas**: 56.4%
- **Economic growth rate**: 3.2%
- Agriculture accounts for 14.37% of Total GDP with over 70% of population employed in this area (AfDB, 2019; Statista,2019)

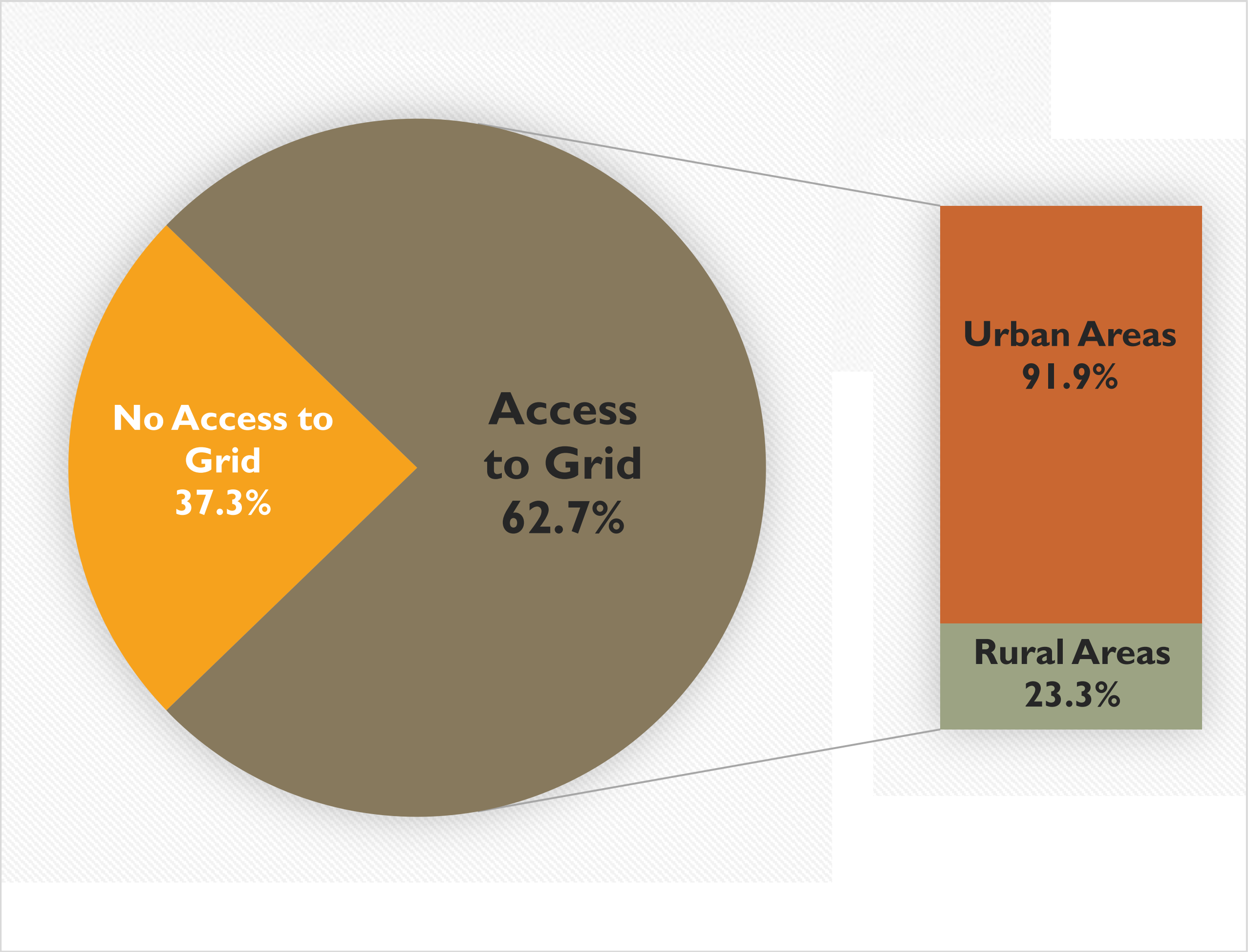
BACKGROUND: ELECTRICITY GENERATION



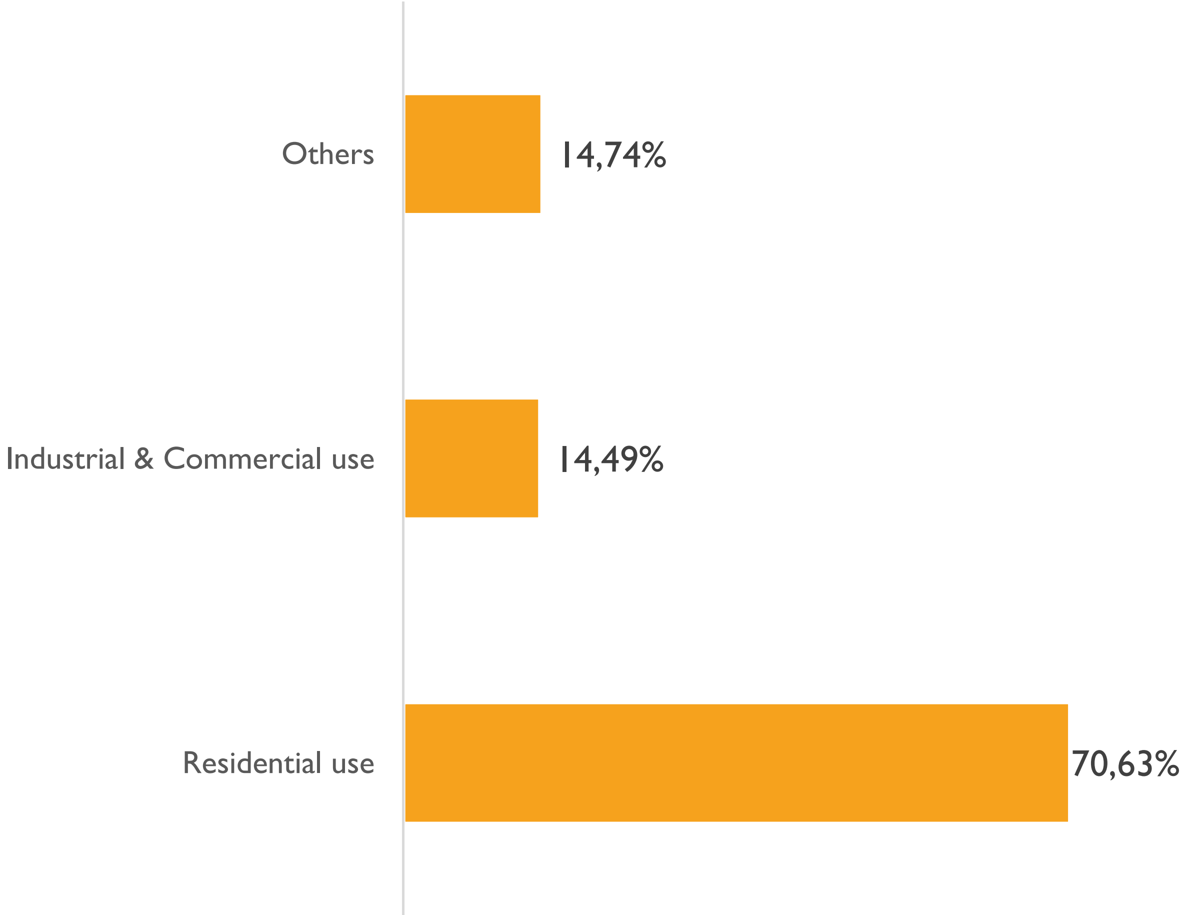
Electricity Generation by energy sources in Cameroon
(Source: (edited by Author) Asan V.W.,2014; CIA,2018)

- Four major Sources of energy exist: Hydropower, Petroleum, Coal and Biomass (Asan V.W., 2014; Djouedjom T.F., 2018)
- Over 90% of Population utilize firewood for domestic purposes (cooking, heating and lighting) (Djouedjom T.F., 2018)

BACKGROUND: ELECTRICITY DISTRIBUTION



Distribution of Total Population Access to National Grid
(Source: (edited by author) WorldBank, 2018)



Distribution of Electricity consumption
(Source: (edited by author) Asan V.W, 2014)

BACKGROUND: CURRENT SITUATION

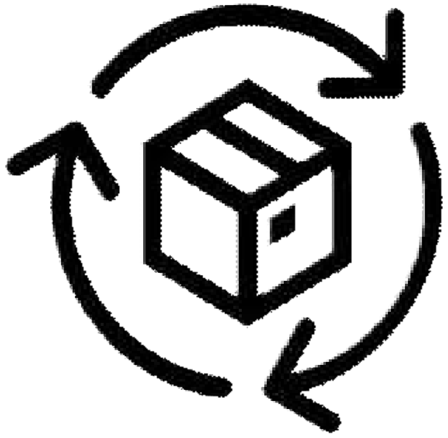
In order to respond to the rising electricity demand the government aims at;

- **Revitalizing** the energy sector by **promoting renewable energy** and renovating the energy supply network
- Attaining **3000MW** and **5600MW** total installed capacity by 2020 and 2030 respectively.

RESEARCH QUESTION

1. **What is the Potential of Biomass waste to energy in Cameroon.**
2. **How can biomass waste to energy be utilized in Cameroon?**

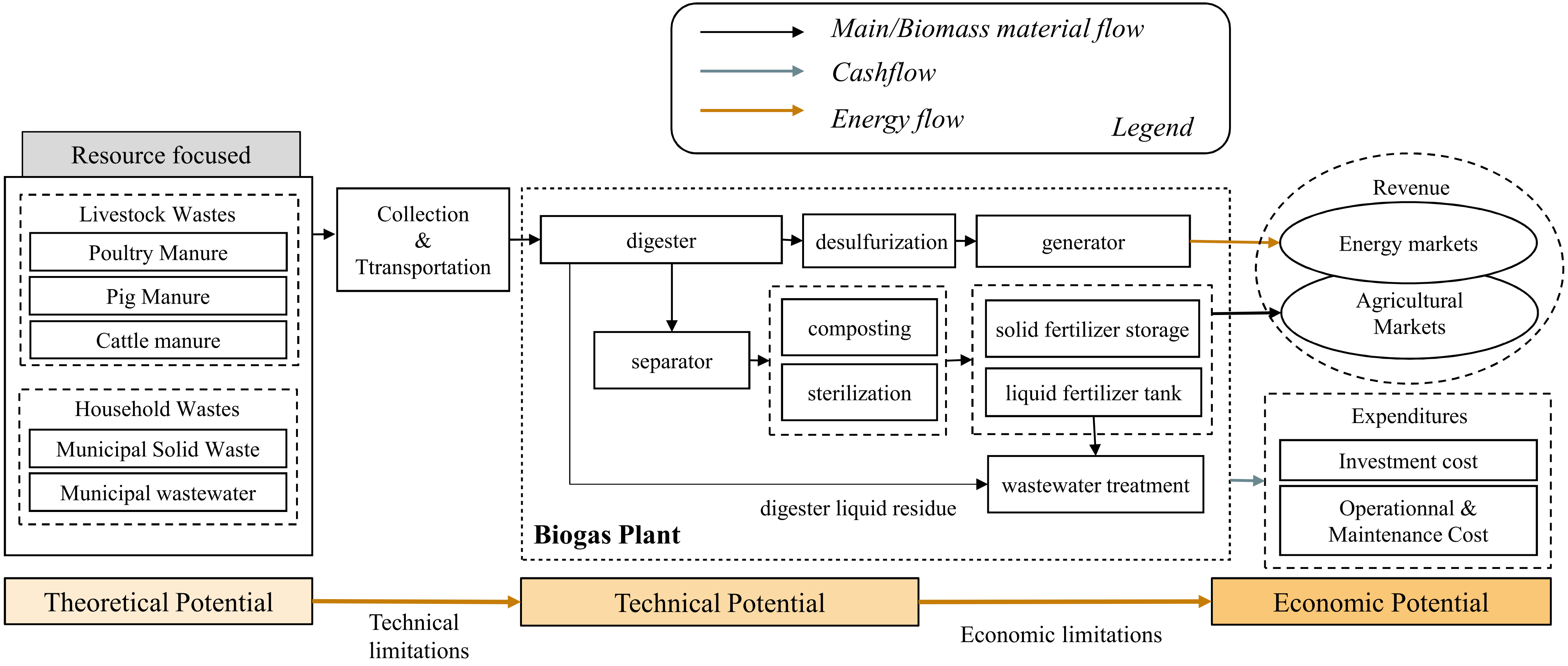
METHODOLOGY



Analytical Framework

Research Strategy

ANALYTICAL FRAMEWORK



MUNICIPAL WASTES

THEORETICAL POTENTIAL

$$\text{ThPE}_{\text{mun}} = \sum_{mun} \boldsymbol{W_{mun}} \cdot \varphi_{org} \cdot \partial_{CH4} \cdot F_{gas} \cdot P_{MSW,Landfill} \cdot \theta_{HHV} \cdot \eta_e$$

$$\boldsymbol{W_{mun}} = I_{SW} \cdot Pop_{mun} \cdot \beta_{MSW} \cdot 365$$

TECHNICAL POTENTIAL

$$\text{TPE}_{\text{mun}} = \sum_{mun} \boldsymbol{SW_{mun}} \cdot \varphi_{org} \cdot \partial_{CH4} \cdot F_{gas} \cdot P_{MSW,Landfill} \cdot \boldsymbol{\varepsilon_{biogas}} \cdot \boldsymbol{OP} \cdot \boldsymbol{\theta_{LHV}} \cdot \eta_e$$

$$\boldsymbol{SW_{mun}} = I_{SW} \cdot Pop_{mun} \cdot \boldsymbol{Pop_{MSW}} \cdot \beta_{MSW} \cdot 365$$

- $\boldsymbol{ThPE_{mun}}$ = Theoretical Potential of Electricity generated from Methane gas in biogas from municipalities (mun) (TWh/a).
- $\boldsymbol{\partial_{CH4}}$= Methane content in biogas in landfill (%) (40-60%) (Lars Waldheim, 2001)
- $\boldsymbol{W_{mun}}$ = Amount of wastes generated by municipality(mun) per annum(a) (Mg MSW/a).
- $\boldsymbol{\varphi_{org}}$ = Percentage organic content of the wastes generated by Municipalities (%)
- $\boldsymbol{Pop_{MSW}}$ **(%)** = Fraction of Population Associated with MSW collection service.
- $\boldsymbol{F_{gas}}$ = Biogas Production Factor (m^3/Mg)
- $\boldsymbol{\theta_{HHV/LHV}}$ = Upper/Lower heating value of biogas generated from waste (MJ/m^3)
- $\boldsymbol{\eta_e}$ = Electrical conversion efficiency from biogas (%)
- $\boldsymbol{P_{MSW,Landfill}}$ = Percentage (%) of MSW sent to Landfill sites.
- $\boldsymbol{I_{SW}}$= Per capita Solid waste Generation Index (kg/inh.day)
- $\boldsymbol{\beta_{MSW}}$= MSW Collection efficiency (%)
- $\boldsymbol{Pop_{mun}}$ = Demographic Population of municipality (inh)
- **OP** = Annual Operation of Power Plant

MUNICIPAL WASTEWATER

THEORETICAL POTENTIAL

$$Th.PE_{ww} = \sum_{mun} \boldsymbol{BY_{mun}} \cdot \theta_{HHV} \cdot \eta_e$$

TECHNICAL POTENTIAL

$$T.PE_{ww} = \sum_{mun} \boldsymbol{BY_{mun}} \cdot \boldsymbol{\theta_{LHV}} \cdot \boldsymbol{OP} \cdot \eta_e$$

$$\boldsymbol{BY_{mun}} = WW_{total} \cdot \frac{|WW_{in}(1-S) - WW_{out}|}{f(T) \cdot C_{CH4}} \cdot (1 - I_i) \longleftarrow \text{(Chenicharo, 2007)}$$

$$f(T) = \frac{P \cdot K}{R \cdot T}$$

$$WW_{total} = Pop_{mun} \cdot \boldsymbol{Pop_{WW}} \cdot I_{ww} \cdot \beta_{WW} \cdot 365$$

- **TPE_{ind} (TWh/a)** = Technical Potential of Electricity generated from Methane gas in biogas by industrial source (ind) in different municipalities (mun)
- **$\theta_{UHV/LHV}$ (MJ/m³)** = Upper/Lower heating value of biogas generated from waste, 24.0 MJ/m³.
- **η_e(%)** = Electrical conversion efficiency from biogas, ranges from 33% to 90%.
- **BY_{mun}(m³/yr)** = Biogas yielded per municipality in anaerobic digesters.
- **WW_{total}(m³/yr)** = Total flow of wastewater affluent into anaerobic reactors per municipality.
- **Pop_{mun} (inh)** = Demographic Population of municipality, (See Table 5)
- **Pop_{WW} (%)** = Fraction of Population Associated with Wastewater treatment range from 40% to 80%. Author estimated values.
- **I_{ww} (m³/inh.day)** = Wastewater Generation per capita, range from 0.135-0.165m³/inh.day. (values estimated by author and (I.F. Silva Dos Santos et al, & Filho, 2018)
- **β_{WW}(%)** = Wastewater collection efficiency range from 45% to 100%, Values estimated by the author.
- **WW_{in}(kg/m³)** = Chemical Oxygen Demand (COD) concentration of affluent by reactor, ranges from 0.6-0.8kg/m³.
- **WW_{out}(kg/m³)** = COD concentration of effluent.
- **S** (kg COD_{sludge}/kg COD_{in}) = Solid production yield, 0.17 kg COD_{sludge}/kg COD_{in}.
- **I_i (%)** = Loss index of gas in reactor resulting from leakages or distribution of gas in liquid effluent, 40%
- **C_{CH4}(%)** = Methane concentration in biogas, ranges from 40% to 60%.
- **365** = Number of days in a year.
- ***f*(T)** = Volumetric correction factor due to temperature.

AGRICULTURAL WASTES

THEORETICAL POTENTIAL

$$Th.PE_{agr} = \sum_{mun} \sum_{a} SW_{a} \cdot \varphi_{DM} \cdot \varphi_{Org,a} \cdot F_{gas,a} \cdot \partial_{CH4} \cdot \theta_{HHV} \cdot \eta_{e}$$

$$SW_{a} = N_{a} \cdot R_{waste,a} \cdot 365$$

TECHNICAL POTENTIAL

$$T.PE_{agr} = \sum_{mun} \sum_{a} SW_{a} \cdot \varphi_{DM} \cdot \varphi_{Org,a} \cdot F_{biogas,a} \cdot \varepsilon_{biogas} \cdot \partial_{CH4} \cdot \theta_{LHV} \cdot OP \cdot \eta_{e}$$

$$SW_{a} = N_{a} \cdot R_{waste,a} \cdot \beta_{SW,a} \cdot 365$$

- $T.PE_{arg}$ = Theoretical Potential of Electricity generated from Methane gas in biogas by different animal types (a) in different municipalities(mun) (TWh/a).
- N_{a} = Number of heads of animal type (a), based on the most recent available livestock census.
- SW_{a} = Maximum waste generated per animal type (a) per year (Mg/a)
- β_{SW}(%) = Manure collection efficiency range from 45% to 100%, Values estimated by the author.
- OP= Annual operation of power plant
- φ_{DM} (%) = Dry matter (DM) in manure produced per animal type (a), see Table 10.
- φ_{org}(%) = Organic content of the manure generated per animal type (a), see Table 10.
- F_{gas} (m^3/Mg) = Biogas Production Factor per animal type, see Table 10.
- ∂_{CH4}(%) = Methane Content in biogas generated, ranges from 40 to 60%.
- ε_{biogas}(%) = Collection efficiency of biogas from digester.
- θ_{LHV} = Lower heating value of biogas generated from waste (MJ/m^3). The LHV ranges between 17.9 to 25.1MJ/m3 (Ronald L. Droste, 1997)
- $R_{waste,a}$ = Rate of manure generation of the animal herd (kg/day.unit)
- η_{e} = Electrical conversion efficiency from biogas (%)

ECONOMIC POTENTIAL

$$NPV_{mun,w} = \sum_{y=1}^{n} \frac{C_{mun,w,y}}{(1+r)^{y}} - C_{o}$$

$$IRR = NPV = 0$$

Total Cash Inflow, $C_{in} = I_{energy} + I_{fertiliser}$

Total Cash Outflow, $C_{out} = E_{periodicinvestment} + E_{maintenance} + E_{other}$

Net Cash flow, $C_{n} = (C_{in} - C_{out})$

SECTOR A: MUNICIPAL

$$EPE_{mun} = \sum_{mun} TPE_{mun} \,; when\ NPV_{mun} > 0$$

SECTOR B: INDUSTRIAL

$$EPE_{ww} = \sum_{mun} TPE_{ww,mun} \,; when\ NPV_{mun} > 0$$

SECTOR A: AGRICULTURAL

$$EPE_{agr} = \sum_{mun} TPE_{agr,mun} \,; when\ NPV_{mun} > 0$$

- $NPV_{mun,w}$ = Net Present Value of each biogas project by municipality(mun), for each source of organic waste
- IRR = Internal Rate of Return of Biogas Project
- $C_{mun,w,y}$= Net cash inflow from electricity generated by municipality (mun), for organic waste source (w), within the year (y).
- C_{o} = Total initial cost of investment for the biogas project. r = The interest rate by year (y)
- n = Economic project lifetime.

Framework of Sensitivity Analysis

Output scenario: Fertilizer and Electricity Sales

A. Baseline – Waste to Fertilizer (%)
- Own electricity Consumed (%)

Process scenario: Fertilizer and Electricity Sales

a. Baseline – Investment cost + Overall costs + Benefits

b. Increase in Investment Cost by 10%

c. Increase in Overall Cost by 10%

d. Decline in Benefits by 10%

e. 1year lag in Benefits

f. 10% overall cost increase + Benefit decrease by 10%

Input scenario: Feedstock

X. Baseline fee(MSW, Agr. Ind) - Free

Scenario Combinations

AaX **AbX** **AcX** **AdX** **AeX** **AfX**

Three Biogas plant Types

- **LBP = 10,000m^3**
- **MBP = 2,000m^3**
- **SBP = 500m^3**

Screenshots of Simulation System

Municipal Wastes		
Municipal Solid Waste (MSW) Generation Per Capita (kg/inh,day)[1]	1,49	-10%
	1,65	
	1,89	10%
Population associated with MSW collection (%)	40%	Minimum
	60%	
	90%	Maximum
MSW collection Efficiency (%) [9]	45%	Minimum
	55,5%	Average
	65%	Maximum
Biogas Production factor (m3/tonne) (Moderately degradable waste)	140	Minimum
	170	Average
	200	Maximum
Organic fraction of MSW (%)	69%	
Methane content in Biogas (%) [8]	40%	Minimum
	50%	Average
	60%	Maximum
MSW sent to Landfill (%) [9]	58%	
Lower Heating Value, HHV (MJ/m3) [8]	24,0	

	Adamaoua	Center	East	Extreme North	Littoral	North	North-West	West	South	South-West	Total
Population [5]	1 166 246	4 038 347	830 039	3 897 577	3 264 328	2 378 489	1 933 358	1 892 545	740 671	1 515 888	21 657 488,00
Waste by Municipality, Wmun (tonne) | 10% decrease	**114 167,32**	**395 325,90**	**81 255,01**	**381 545,51**	**319 554,86**	**232 837,42**	**189 262,21**	**185 266,91**	**72 506,51**	**148 394,82**	**2 120 116,47**
Waste by Municipality, Wmun (tonne) | 10% Increase	**339 915,95**	**1 177 023,18**	**241 924,52**	**1 135 994,13**	**951 426,34**	**693 238,27**	**563 499,66**	**551 604,24**	**215 877,17**	**441 823,18**	**6 312 326,65**
Biogas Potential Potential (m3) | Minimum	**2 566 042,94**	**8 885 408,25**	**1 826 300,56**	**8 575 677,82**	**7 182 366,18**	**5 233 291,19**	**4 253 887,82**	**4 164 088,66**	**1 629 667,83**	**3 335 345,81**	**47 652 077,06**
Biogas Potential Potential (m3)| Maximum	**16 371 440,09**	**56 689 202,77**	**11 651 858,84**	**54 713 112,29**	**45 823 737,26**	**33 388 573,40**	**27 139 947,04**	**26 567 025,38**	**10 397 335,47**	**21 279 618,17**	**304 021 850,71**
Energy Potential Potential (MJ)|Minimum	**16 258 448,09**	**56 297 946,64**	**11 571 440,33**	**54 335 494,69**	**45 507 472,13**	**33 158 132,97**	**26 952 633,22**	**26 383 665,75**	**10 325 575,40**	**21 132 751,03**	**301 923 560,26**
Energy Potential Potential (MJ) | Maximum	**282 898 484,77**	**979 589 423,89**	**201 344 120,71**	**945 442 580,35**	**791 834 179,91**	**576 954 548,30**	**468 978 284,78**	**459 078 198,64**	**179 665 956,93**	**367 711 802,03**	**5 253 497 580,30**
Electricity Potential (TWh/a) | Minimum	**0,0045**	**0,0156**	**0,0032**	**0,0151**	**0,0126**	**0,0092**	**0,0075**	**0,0073**	**0,0029**	**0,0059**	**0,08**
Electricity Potential (TWh/a) | Maximum	**0,0786**	**0,2721**	**0,0559**	**0,2626**	**0,2200**	**0,1603**	**0,1303**	**0,1275**	**0,0499**	**0,1021**	**1,46**

Screenshots of Simulation System

Fraction of electricity consumed by facility on site[15]	40%	Japan
Fraction of waste turned to organic fertiliser for sale	40,0%	Municipal
	0,6%	Agricultural
	25%	Industrial
Unit cost of Electricity(US$/kWh)[13]	$0,08	Residential
Unit cost of Fertiliser (US$/tonne)[14]	$ 260	
Initial investment of one Biogas digester plant($) [15]	######	
Operating, repairs and maintenance % of capital [15][16]	15%	

Min

Economic analysis of Biogas plants with Municipal Solid Wastes - 10,000m3 capacity

	Cash Outflow				Cash Inflow				
Year	Investment ($	Investment ($ million)	nce & Operation (million	Total Co	Electricity sales (Million US$)	Fertilizer (Million US$)	Benefits (million US$)	Cashflow (Million US$)	Cumulative Cash flow
0	110,84	0,00	0,00	110,84	0,00	0,00	0,00	-110,84	-110,84
1		0,00	16,63	16,63	4,18	30,28	34,45	17,83	-93,01
2		0,00	16,63	16,63	4,18	30,28	34,45	17,83	-75,18
3		0,00	16,63	16,63	4,18	30,28	34,45	17,83	-57,36
4		0,00	16,63	16,63	4,18	30,28	34,45	17,83	-39,53
5		0,00	16,63	16,63	4,18	30,28	34,45	17,83	-21,70
6		0,00	16,63	16,63	4,18	30,28	34,45	17,82	-3,88
7		0,03	16,63	16,65	4,18	30,28	34,45	17,80	13,92
8		0,04	16,63	16,66	4,18	30,28	34,45	17,79	31,71
9		0,05	16,63	16,67	4,18	30,28	34,45	17,78	49,49
10		0,05	16,63	16,67	4,18	30,28	34,45	17,78	67,27
11		0,04	16,63	16,66	4,18	30,28	34,45	17,79	85,06
12		0,03	16,63	16,65	4,18	30,28	34,45	17,80	102,86
13		0,04	16,63	16,66	4,18	30,28	34,45	17,79	120,65
14		0,47	16,63	17,10	4,18	30,28	34,45	17,36	138,00
15		0,05	16,63	16,67	4,18	30,28	34,45	17,78	155,78
16		0,05	16,63	16,67	4,18	30,28	34,45	17,78	173,56
17		0,04	16,63	16,66	4,18	30,28	34,45	17,79	191,35
18		0,03	16,63	16,65	4,18	30,28	34,45	17,80	209,15
19		0,04	16,63	16,66	4,18	30,28	34,45	17,79	226,94
20		0,04	16,63	16,66	4,18	30,28	34,45	17,79	244,73
	110,84	0,96	332,51	444,31	83,53	605,51	689,04	244,73	
							NPV	22,10	
							IRR	15,10%	

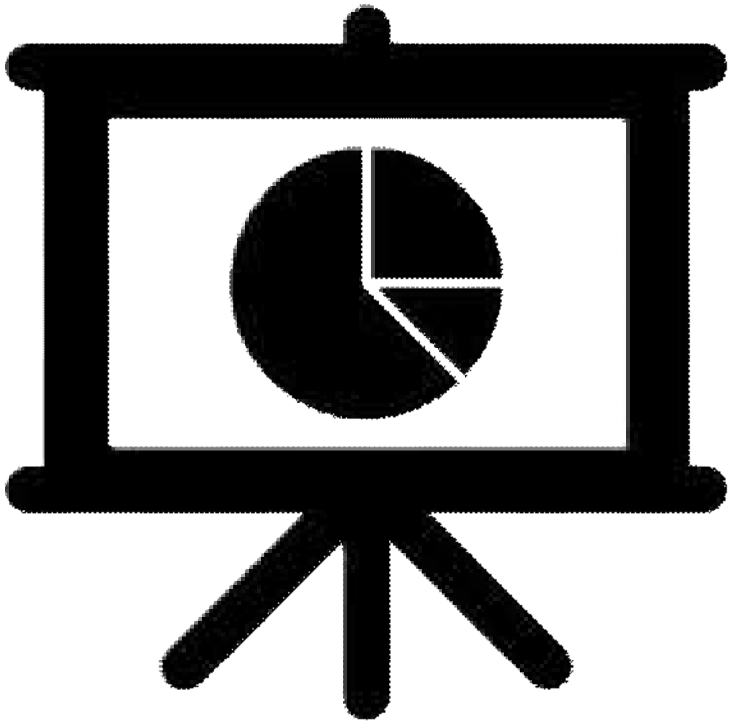
Average

Economic analysis of Biogas plants with Municipal Solid Wastes - 10,000m3 capacity

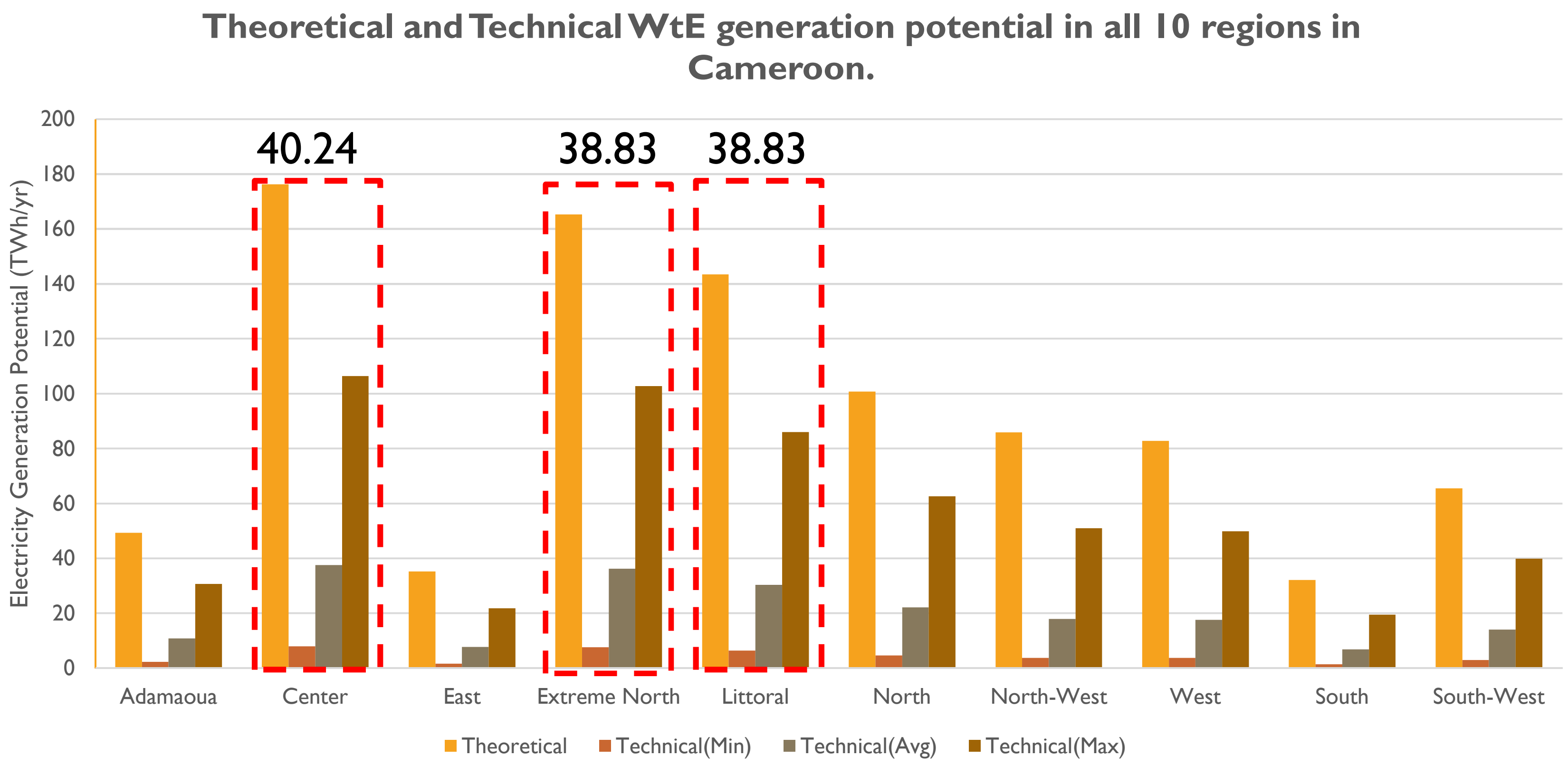
	Cash Outflow				Cash Inflow				
Year	Investment ($	Investment ($	ance & Operation	Total Co:	ty sales (Million	Fertilizer (Million US$)	Benefits (million US$)	Cashflow (Million	Cumulative Cash flow
0	110,84	0,00	0,00	110,84	0,00	0,00	0,00	-110,84	-110,84
1		0,00	0,00	0,00	23,61	114,37	137,99	137,99	27,15
2		0,00	16,63	16,63	23,61	114,37	137,99	121,36	148,51
3		0,00	16,63	16,63	23,61	114,37	137,99	121,36	269,87
4		0,00	16,63	16,63	23,61	114,37	137,99	121,36	391,24
5		0,00	16,63	16,63	23,61	114,37	137,99	121,36	512,60
6		0,00	16,63	16,63	23,61	114,37	137,99	121,36	633,96
7		0,03	16,63	16,65	23,61	114,37	137,99	121,34	755,30
8		0,04	16,63	16,66	23,61	114,37	137,99	121,33	876,62
9		0,05	16,63	16,67	23,61	114,37	137,99	121,32	997,94
10		0,05	16,63	16,67	23,61	114,37	137,99	121,31	1 119,25
11		0,04	16,63	16,66	23,61	114,37	137,99	121,33	1 240,58
12		0,03	16,63	16,65	23,61	114,37	137,99	121,34	1 361,91
13		0,04	16,63	16,66	23,61	114,37	137,99	121,33	1 483,24
14		0,47	16,63	17,10	23,61	114,37	137,99	120,89	1 604,13
15		0,05	16,63	16,67	23,61	114,37	137,99	121,31	1 725,44
16		0,05	16,63	16,67	23,61	114,37	137,99	121,32	1 846,76
17		0,04	16,63	16,66	23,61	114,37	137,99	121,33	1 968,09
18		0,03	16,63	16,65	23,61	114,37	137,99	121,34	2 089,42
19		0,04	16,63	16,66	23,61	114,37	137,99	121,33	2 210,75
20		0,04	16,63	16,66	23,61	114,37	137,99	121,33	2 332,07
	110,84	0,96	315,89	427,68	472,27	2 287,49	2 759,76	2 332,07	
							NPV	2 332,07	
							IRR	117,60%	

RESULTS

BIOMASS WASTE TO ENERGY POTENTIAL IN CAMEROON



RESULTS



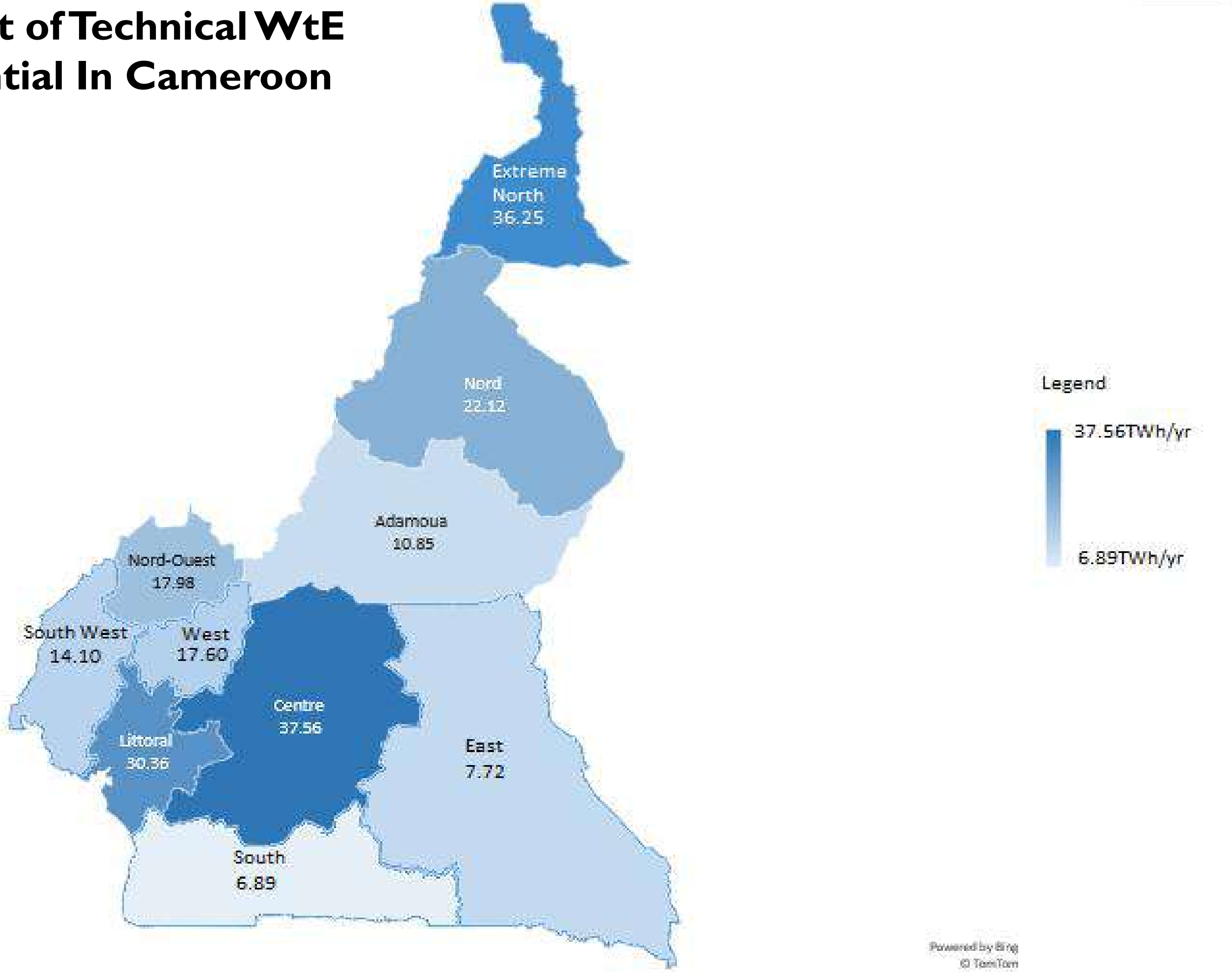
- All 10 Regions have theoretical and technical conditions of WtE production

- T.PE = 18% Th.PE

- Highest WtE Potential in most populated regions of the country.

RESULTS

Graphical Abstract of Technical WtE Production Potential In Cameroon



RESULTS

Waste Type	Potential	Amount of Waste (thousand Tonnes/yr)	Biogas ($10^3 m^3/yr$)	Electricity (GWh/yr)
Municipal Solid waste	Theoritical	13 043,22	939 581,55	6 820,32
	Technical | Minimum	291,11	47 652,08	83,87
	Technical | Average	1 099,75	148 177,46	474,17
	Technical | Maximum	2 458,27	304 021,85	1,46
Waste Water	Theoritical	939 581,55	24 553 145,08	1 126 230,61
	Technical | Minimum	47 652,08	301 923,56	38 288,28
	Technical | Average	148 177,46	1 707 004,31	215 296,24
	Technical | Maximum	304 021,85	5 253 497,58	632 301,13
Cattle Wastes	Theoritical	24 553 145,08	0,00682	162,29
	Technical | Minimum	301 923,56	0,00008	0,15
	Technical | Average	1 707 004,31	0,00047	2,23
	Technical | Maximum	5 253 497,58	0,00146	13,76
Pig wastes	Theoritical	0,0068	1 725,10	7 765,62
	Technical | Minimum	0,0001	291,11	0,02
	Technical | Average	0,0005	1 099,75	0,38
	Technical | Maximum	0,0015	2 458,27	2,82
Poultry Wastes	Theoritical	1 725,10	22 357,34	15 697,84
	Technical | Minimum	291,11	88,03	0,97
	Technical | Average	1 099,75	695,94	14,53
	Technical | Maximum	2 458,27	2 867,33	90,54

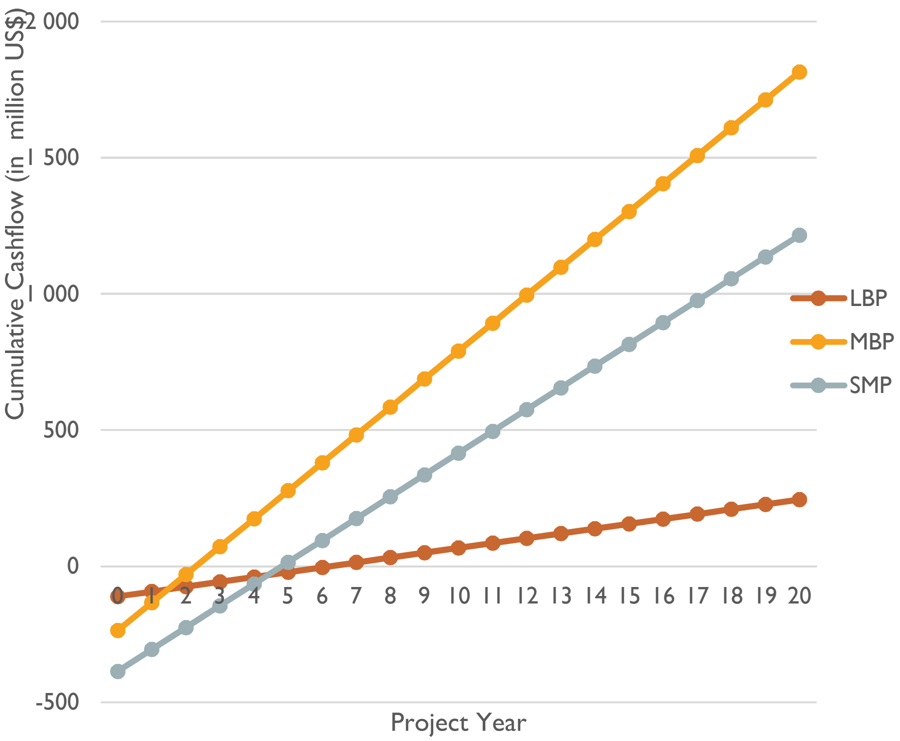
Second WtE potential

Highest WtE potential

Highest livestock WtE potential

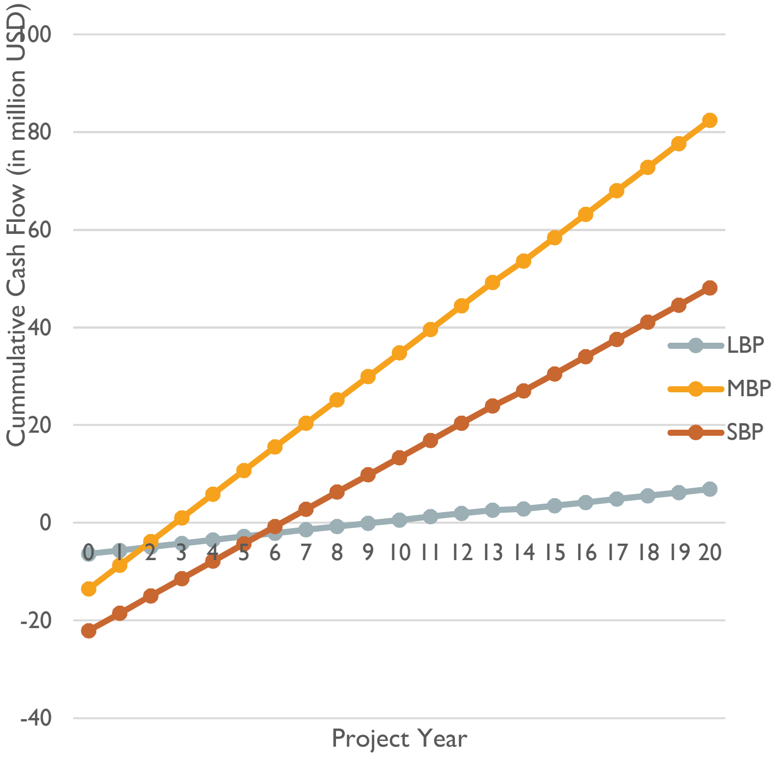
RESULTS

Net Present Value (NPV) of Biogas Plants with MSW



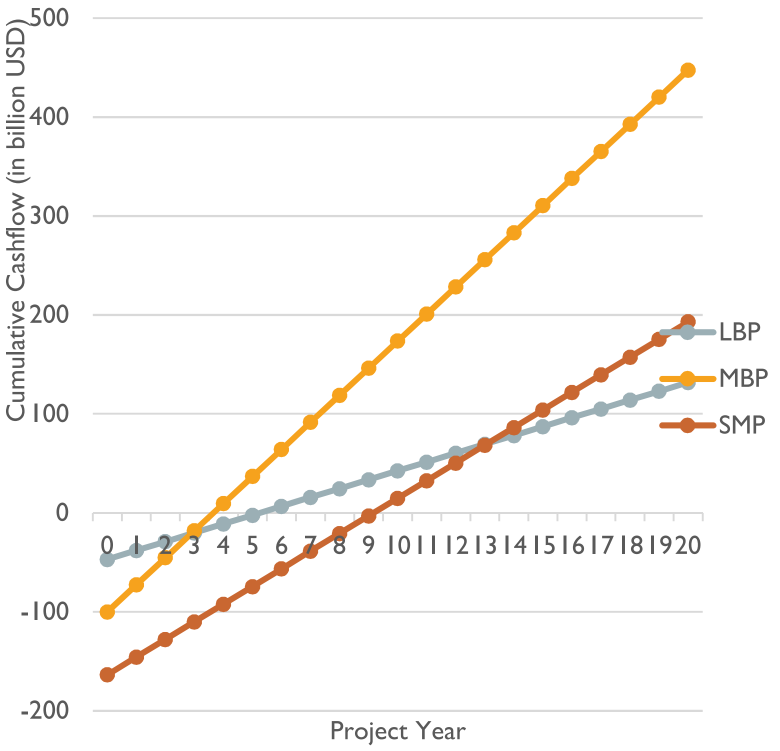
E.PE = 0.47TWh/yr

Net Present Value (NPV) of Biogas Plants with Livestock Manure



E.PE = 0.02TWh/yr

Net Present Value (NPV) of Biogas plants with Municipal Wastewater



E.PE = 200.43TWh/yr

Framework of Scenario Analysis

Table: Sensitivity Analysis of Economic Potential of Electricity Production Assessment

	MSW (%)			Livestock manure (%)			Municipal wastewater (%)		
	LBP	MBP	SBP	LBP	MBP	SBP	LBP	MBP	SBP
- Base	15.10	43.46	20.24	8.63	35.77	15.04	18.38	27.15	8.93
- Increase in investment costs by 10%	11.82	38.12	16.71	5.34	31.07	11.74	14.95	23.16	5.76
- Increase in overall costs by 10%	11.81	38.12	16.71	5.26	31.07	11.73	14.95	23.16	5.76
- Decline in benefits by 10%	11.42	37.58	16.34	4.89	30.59	11.38	14.60	22.75	4.42
- 1-year lag in benefits	10.90	29.82	14.83	5.67	25.17	10.91	13.45	19.66	6.06
- Increase in overall costs by 10% and decrease in benefits by 10%	8.28	32.74	13.02	1.31	26.31	8.16	11.35	19.07	2.13

Least sensitive parameter

SBP=Small Biogas Plants, MBP = Medium Biogas Plants, LBP = Large Biogas Plants

Most sensitive parameter

DISCUSSION AND POLICY IMPLICATIONS

Economic Policy

Regulatory Policy

DISCUSSION



- Total WtE generation potential range from 42.6TWh to 570.67TWh
- There is a need to respond to the rising energy demands of the population via WtE utilization.
- Full implementation of MSW and livestock manure energetic Potential could increase the current share of Biomass (1.1%) to the energy Mix to about 6.6%.
- Cameroon being actively engaged in the agricultural sector(70%) has other potential sources for WtE production such as agricultural residues from cultivated farmlands.
- Over 80% of livestock WtE production was from poultry wastes this due to the high level of poultry rearing in Cameroon, with over 59million herds (NIS, 2015)
- Large scale implementation of this potential may be difficult due to lack of logistics to technically collect all Livestock manure across the country.

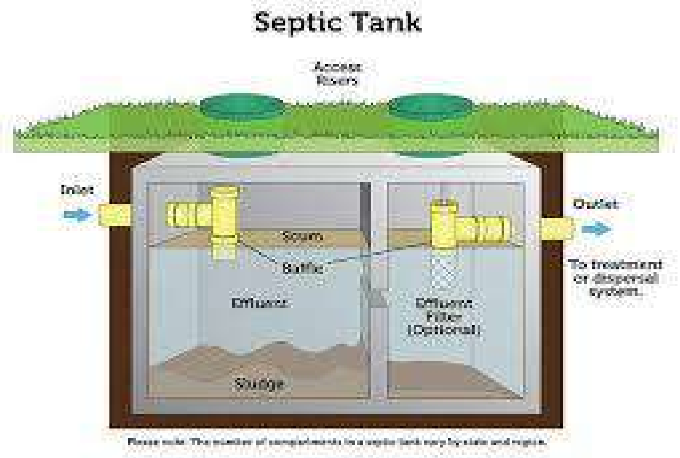
Source: google.com/images. (2020);Accessed 11.Nov.2020

DISCUSSION

Source: google.com/images. (2020);Accessed 11.Nov.2020

- Wastewater treatment accounts for the greatest WtE generation potential in Cameroon.
- Development of wastewater treatment plant makes the city economically attractive and eco-friendly.
- Biogas from Wastewater treatment plants is economically viable for cities with population size > 300,000 inhabitants and has ability to supply over 0.25% of residential fuels (I.F. Santos et al., 2016)
- The smallest region in Cameroon (South Region) has a population of about 740,671 inhabitants (NIS, 2015), making development of wastewater treatment plants a plausible option for WtE utilization in Cameroon.

DISCUSSION



- Wastewater collection is still done in Septic tanks and most are built not following standard norms.
- The structure/design of the septic tanks make it difficult to capture biogas (reason it was excluded in this study).
- However, there exist no conventional system for municipal wastewater treatment in Cameroon
- This study reveals that wastewater treatment for energy generation could be an alternative for revenue generation as well as proper sanitation development in Cameroon.
- Furthermore, most waste management projects are unsuccessful due to lack of material, financial and skilled manpower.
- This study reveal that development of biogas plants could require investments worth **$110.84 million USD** (MSW), **6.34 million USD** (livestock manure) equivalent to **0.32%, 0.01%** of Cameroonian GDP in 2017.

Source: google.com/images.(2019);Accessed 11.Nov.2020

DISCUSSION

- Investments on biogas projects require large infrastructures such as pipelines, waste treatment sites.
- Need for policies to promote sustainable development of Biogas projects.
- Need for new energy markets where entrepreneurs can exploit this source.
- WtE utilization involves several actors(entrepreneurs, institutions), most importantly policy makers to elimate barriers- and promote WtE utilization.
- The limited use WtE in Cameroon indicates the limited knowledge about the costs, financial circumstances and trade agreements related to biogas plant development.
- Policies would guarantee
  - Market access for renewable energy generation,
  - Improve the price reductions for grid connected renewable energy systems
  - Promoting advances in technology

Source: google.com/images.(2019);Accessed 11.Nov.2020

Policy Implications

P1 — P2 — P3

Economic Policy (Tax incentives, reduction in sales, VAT etc…)	Regulatory Policy (Net Metering System)	Regulatory Policy (Feed-In Tariff)

- Current Policy Measure in Cameroon.
- It applies to direct taxes (including Income/corporate tax)
- Provides exemption on import of renewable energy equipment(especially at the early phase of market development).
- Applicable to both small scale-residential installations and large scale commercial renewable energy generation projects
- In Cameroon, can be applicable to biogas projects where households benefit from some credits for installing small scale biogas plants that converts both wastewater and solid wastes to Electricity.

Policy Implications

P1 — P2 — P3

Economic Policy (Tax incentive, VAT etc)	Regulatory Policy (Net Metering System)	Regulatory Policy (Feed-in Tariff)

- Currently exist in 66 countries across the world (REN21, 2019).
- It offers cash compensation, payout at avoidable costs enabling energy suppliers to generate revenue with costs of energy above market price, thus enabling financial competitiveness of the project (Silva dos Santos et al, 2018).
- Electricity generated at landfill sites can allow residential/commercial energy suppliers to earn money from selling electricity to the grid.
- Corresponding credits of energy stored on grid can be traded to other regions with high energy demand.
- It adopts or eliminates fees charged by utilities for connecting to the electricity grid, thus giving access to residential, commercial and industrial power generation.

Policy Implications

P1 P2 P3

Economic Policy (Tax incentive, VAT etc)	Regulatory Policy (Net metering System)	Regulatory Policy (Feed-in Tariff)

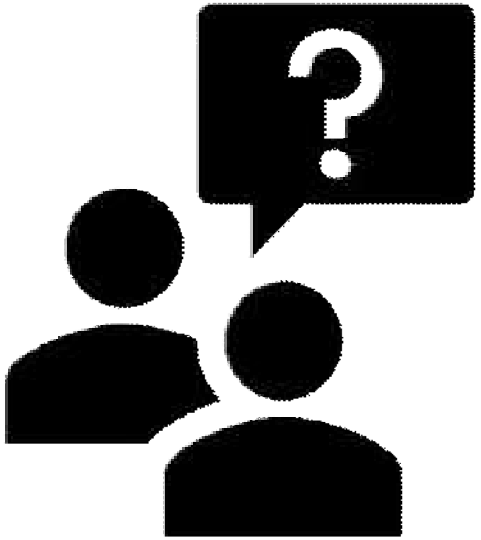
- Many energy suppliers seek assurance that energy produced will be purchased, there reducing risks of their income(I.F. Silva dos santos et al., 2018).
- Currently applicable in over 111 countries across the world.
- Appropriate for less established projects with comparatively high project development costs (REN21, 2019).
- Provides high levels of investment security which enables new actors to enter the energy market (Competition).
- Improves the attractiveness of Biogas projects for investors who seek greater returns.
- This act greatly influenced and accelerated the deployment of Solar PV in Japan by a factor of 12.5 times the installed capacity for the past 5 years (Kimura, 2017).

CONCLUSION

- This study demonstrated that there is there is a great potential of electricity from recycling organic wastes generated and disposed by different cities in Cameroon.
- There is need for policy makers to develop policies that will promote development and diffusion of WtE technologies in Cameroon.
- Cameroon's current Economic policy is inadequate to promote energy production from this source. Regulatory policies seem promising for the development of renewable energy as seen in several countries developing biogas projects.
- Further research is required to assess the potential of integrating other potential biomass wastes sources such as Agricultural residues from cultivated farmlands, solid wastes from commercial sites, industrial wastewater etc.
- This research focused on Anaerobic mono digestion biomass wastes, further research can assess the exergoeconomic potential of using other mainstream technologies such as Bioaugmentation, Anaerobic co-digestion (AcoD) and integrated biogas production for energy production.

THANK YOU

Any Questions?



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