The value of IOT enabled biodigesters: A choice experiment among Kenyan smallholder farmers

National Research Fund Project (Ref: NRF/R/2016/045)
"*Optimizing small-scale biogas technology for household energy and improvement of soil fertility within coffee-dairy production systems in Kiambu and Machakos Counties*"

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Outline

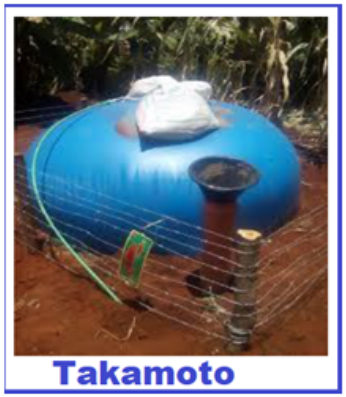
Introduction: Biodigester technology

- **Biodigesters**: What (inlet, digester, gas holder, outlet, pipeing), How (anaerobic), Why ($\Downarrow$biomass use, $\Downarrow$IAP, $\Downarrow CO_2$)
- **In numbers**: Each $1m^3$ biogas saves $\simeq 5.5kg$ firewood; 1 biodigester reduces CH_4 $\simeq 6tCO_2eq/yr$
- **Types**: Batch, Semi continuous (fixed dome [GGC2047, CARMATEC, KENBIM], floating drum [KVIC, Pragati]), Continuous (plug-flow/tubular [flexi])
- **O/M issues** Clemens et al. 2018; 23-33 % non-functional


Fixed dome


Flexi- biogas


Blue flame

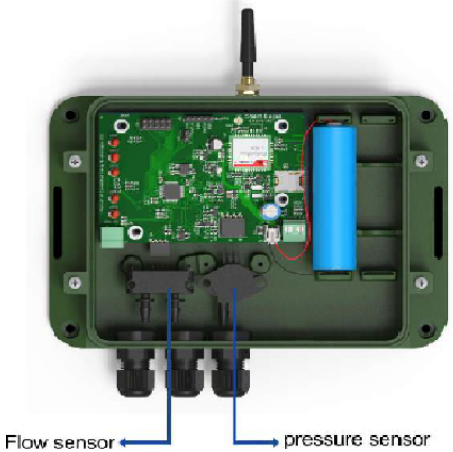

Takamoto

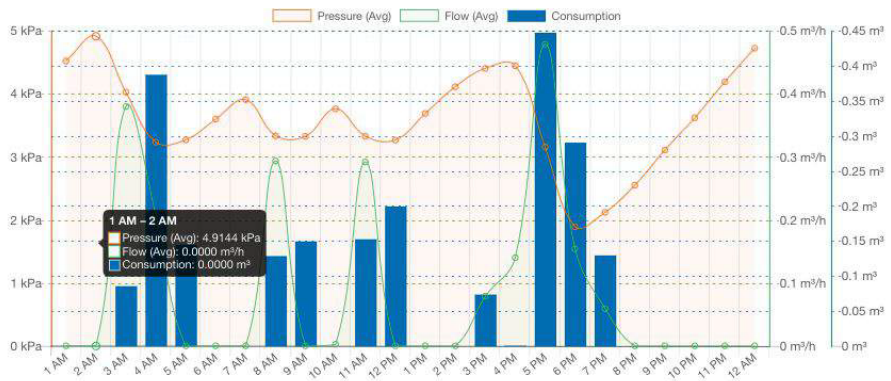

SimGas


Sistema bio

Introduction: A possible add-on (The "IOT" sensor unit)

- **The device**: Flow, pressure, temperature sensors
- **Data flow**: Data shared remotely via 4G/2G enabled SIM to server
- **Advantages**: a) Reduced repair and maintenance costs through remote diagnosis and troubleshooting b) Provide a route to more affordable carbon offset monitoringm verification and reporting (MRV)
- **Motivation** We think the possibilities of carbon crediting could benefit farmers





Literature review: various themed studies on biodigesters

Authors	Findings	Gaps/remarks
Nzila et al. 2012 [KE]	Multicriteria assessment concluded that plug-flow was most suitable	Classified economic, technical and environmental attributes but ALL carried equal weight
Kabyanga et al. 2018 [UG]; Thapa et al. 2021 [NPL]	CVM used to value plug-flow digester|GGC2047. Maximum mWTP 0.1× times|0.8× actual cost	How about other types? How about mWTP for attributes?
Talevi et al. 2022 [IN]	mWTP varies with previous experience (good/bad) with biodigesters	Biodigester owners may already have different preferences withch may have led to the malfunctions anyway

Materials & Methods

1. The investigation of choice behavior ex Lancaster 1966 → RUT & CLM McFadden 1974, → MNL McCullagh & Nelder 1983 → DCE Louviere & Woodworth, 1983, → "mixed logit (RPL)" Revelt & Train 1998, McFadden & Train 2000
2. What attributes?
   - FGDs in 2018 established no less than 22 attributes (Mailu et al. 2019, AAAE Abija)
   - PAPRIKA method used on 59 univ. students, 14 FGD participants, & 70 KALRO scientists to establish relative importance of 9 attributes [amt of gas, installation cost, durability, maintenance cost, reliability, translocation, gas pressure, gas consistency, defect identification] in that order
   - A ROL applied to data from respondents to obtain some priors (for sample size calculations etc.)
   - Some attributes: gas quantity, gas pressure, gas consistency dropped

Materials & Methods

1. The DCE with 6 attributes installation cost (65,000 Ksh/92,500 Ksh/102,000 Ksh); maintenance cost (high/moderate/low); reliability (145 days or 40% /335 days or 92%/ 345 days or 95%); Durability (2-5 years/12-15 years/15-20 years) Movability (movable/imovable); defect identification (easy/difficult)

Table 1: Attributes and levels included in the DCE

Attribute	Levels
Durability	2-5 years, 12-15 years, 15-20 years
Reliability	145 days , 335 days, 345 days
	40 percent, 92 percent, 95 percent
Maintenance cost	Low, Moderate, High
Movability	Immovable, Movable
Defect identification	Easy, Difficult
Installation cost	65,000 Ksh, 92,500 Ksh, 102,000 Ksh

Materials & Methods

1. A total of 16 choice sets each with an opt-out option yielded 48 real-valued options (in other words, "48 different biodigester types")= 64 rows; D-efficiency=2.39
2. Sets split into 2 blocks (each respondent exposed to 8 sets)
3. Tool presented in English, Kiswahili, Kikuyu, Kikamba
4. N=455 respondents (UM2-UM3) from Kiambu & Machakos coffee-dairy systems
    - Stage 1: Random selection of 6 active coffee cooperatives/county: Kiambu: 3GS, Gititu, Komothai, Ndumberi, Gitwe, Muhara; Machakos: Muthunzuuni, Kaliluni, Ithaeni, Mungala, Mwatati & Kawethei
    - Stage 2: 40 households/cooperative randomly selected (without replacement)

Example of choice set

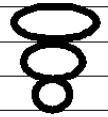
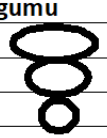
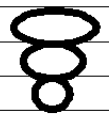
	CHAGUO LA I	CHAGUO LA J	CHAGUO LA K	Hakuna
Gharama ya kuweka	Shilingi 102,000	Shilingi 92,500	Shilingi 65,000	
Kutegemewa	Siku 345 (au 95%)	Siku 335 (au 92%)	Siku 145 (au 40%)	
Kudumu	miaka 12-15	miaka 2-5	miaka 15-20	
Gharama ya matengenezo	Juu	Chini	Wastani	
Uhamishaji	Inaweza kuhamishwa	Inaweza kuhamishwa	Haiwezi kuhamishwa	
Uwezo wa kutambua kasoro	Ni vigumu	Ni vigumu	Ni rahisi	
SWALI LA 1: Unaweza kutegua chaguo lipi?				
SWALI LA 2: Chaguo bora la pili ni lipi?				
SWALI LA 3: Ni gani wawezachagua ya mwisho?				
SWALI LA 4: Uko na uhakika kiasi gani kuhusu chaguo katika swali la 1? *Tafadhali onyesha % ya uhakika wako kwenye kipimo*	0% 10 20 30 40 50 60 70 80 90 100% |_____|_____|_____|_____|_____|_____|_____|_____|_____|_____|_____| Kiwango cha uhakika			

Figure 1: A sample of choice sets administered in experiment

Results summary stats

Table 2: Summary statistics

Variable	Unit	Min	Max	Mean	StDev
HH size	No	1	15	4.7	2.2
Age					
<40 yrs		0	1	0.18	0.38
<30 yrs		0	1	0.13	0.33
40-60 yrs		0	1	0.4	0.49
60> yrs		0	1	0.41	0.49
Education					
No educ	percent			9.7	
Primary	percent			41.6	
Secondary	percent			39.6	
Post secondary	percent			9	

Results: summary stats

Table 3: Summary statistics

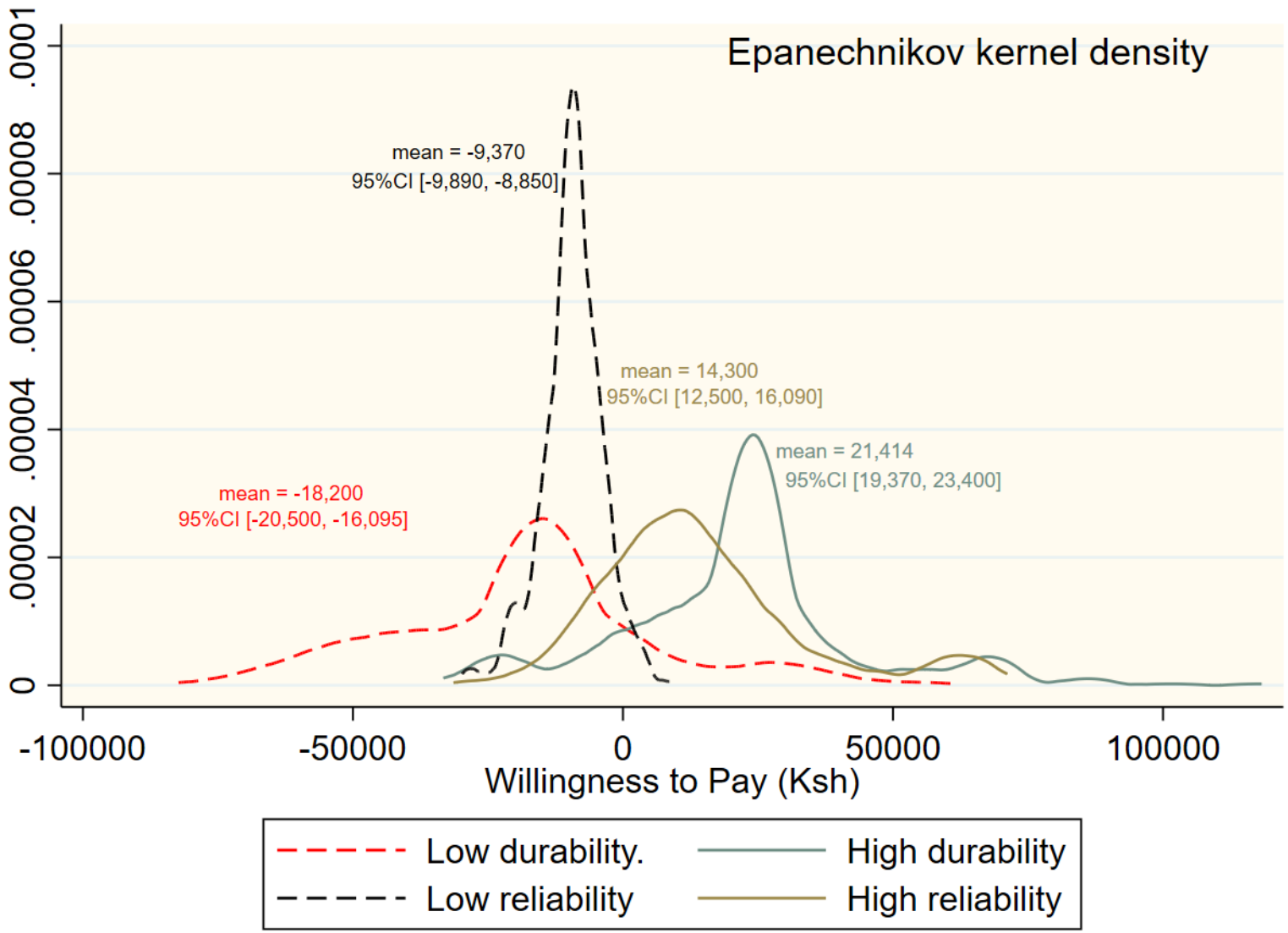
Variable	Unit	Min	Max	Mean	StDev
Fuel					
Purchase firewood	prop	0	1	0.25	0.43
Collect firewood	prop	0	1	0.49	0.50
Purchase paraffin	prop	0	1	0.36	0.48
TLU	No	0	11.8	1.28	1.48
Elevation	masl	1326	1975	1702	149
TLU own	Prop	0	1	0.67	0.47
Respondents	No			455	
Completed	No			440	
Completed tasks	No			3502	
Datapoints	No			14008	
Certainty	Percent	15	100	68	16

Results from Mixed Logit Model (regression coefficients)

	mean		std dev	
Attribute	β	Std.Err	β	Std.Err
Low Reliability	-.418***	.068	.600***	.115
High Reliability	.463***	.089	1.055***	.085
Low Druability	-.870***	.114	1.460***	.132
High Durability	.554***	.102	.984***	.101
Immovablility	-.387***	.076	.494***	.089
Defect ID	**-.403*** **	**.072**	**.376*** **	**.125**
Low Maintenance	.088	.094	.037	.107
High Maintenance	-.099	.063	.264*	.119
Installation Cost	-3.670***	.140	1.615***	.119
McFadden's pseudo R^2	.248			
No. of respondents	440			
No. of params	24			

Notes: ***p<0.001, **p<0.05, *<0.1

WTP estimates for different attributes



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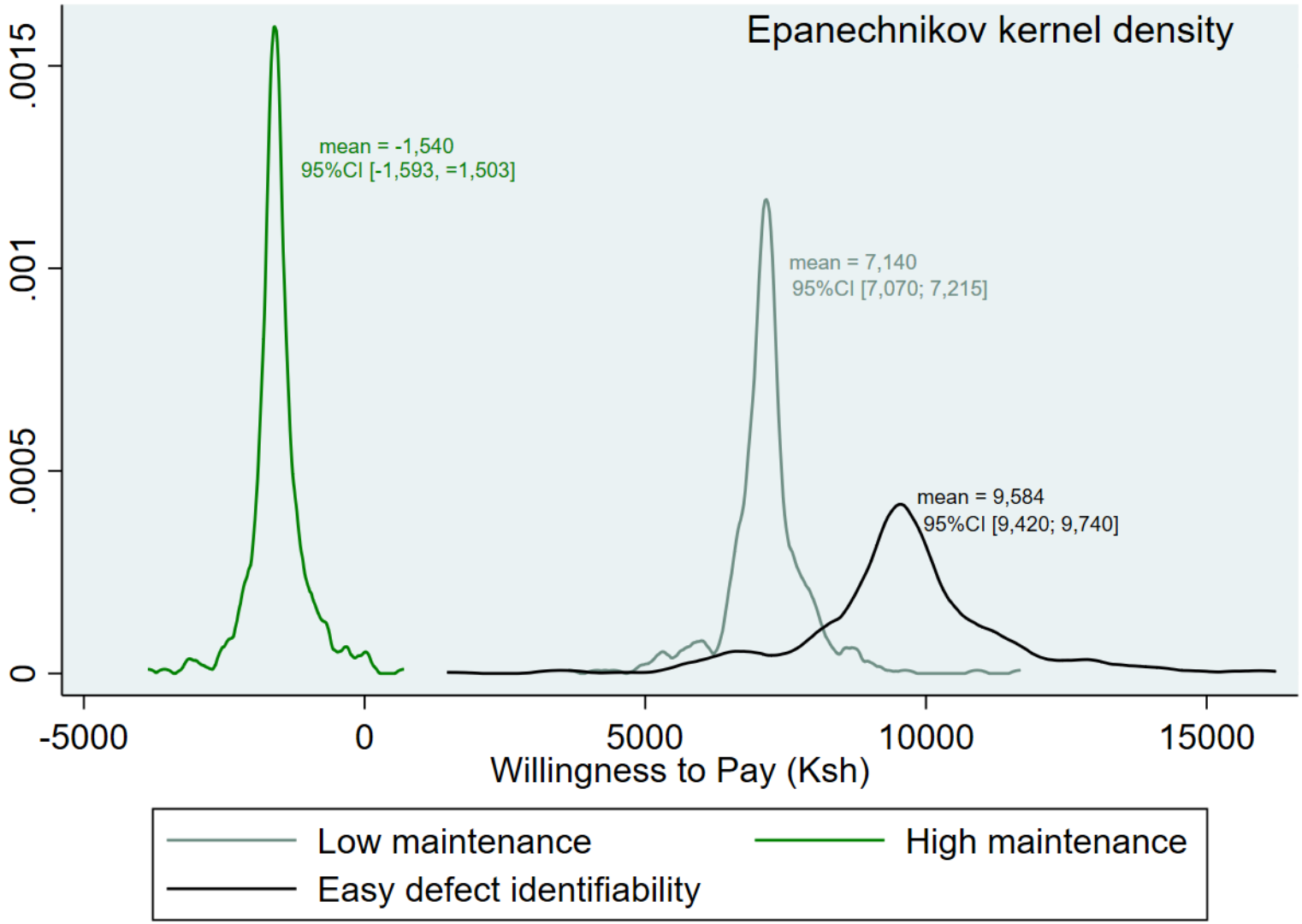

Conclusions

1. Demonstrated the usefulness of valuing important (from the user's perspective) attributes
   - Substantial coherence in the way that people trade-off different attributes
   - Results from LCM not materially different from those obtained from the RPL, althought the latter appears to be of better statistical fit.
   - Low durability is twice as important as high durability. Aligns with loss aversion in prospect theory?
   - High reliability of biodigesters is as important as high durability
   - Respondents have a liking for biodigesters that are not fixed to one spot on the ground (fixed dome, floating drum)
   - Biodigesters which present a challenge to identify defects are frowned upon. This particular result agrees with the finding in India (Talevi et al. 2022) where the mWTP was low for households that had experienced biodigester failures before.

Possible recommendations

1. What are some of the possibilities?
   - On the matter of defect identification, are there prospects of incorporating IoT technology into the technology? E.g. Borrowing from the proof of concept from Rwanda: thanks to IoT instrumentation, non-functionality of water handpumps was cut from 152 to 21 days in Rwanda Nagel et al. 2015
   - FinAct'15: "exempted plastic digesters, biogas and the lease of biogas producing equiplemt from VAT"; FinAct'21: "extended the exemptions to prefabricated biodigesters". Is this an area that can be tapped into to benefit from tax waivers?
   - Use durable materials that are light enough allowing biodigesters to be moved around (movable). Are there possibilities of incorporating polyvinyl chloride (PVC), polyethylene (PE), high-density polyethylene (HDPE) into biodigesters?

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