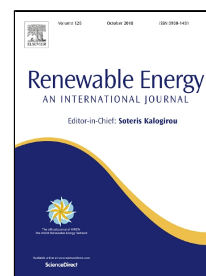# Accepted Manuscript

A risk-adjusted techno-economic analysis for renewable-based milk cooling in remote dairy farming communities in East Africa

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1 # A risk-adjusted techno-economic analysis for renewable-based milk cooling in remote dairy
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ABSTRACT

8 The dairy industry accounts for 9-14% of East Africa's agricultural gross development product. Due to lack of milk cooling facilities,
9 dairy farmers in areas without access to reliable grid electricity face problems of high milk spoilage and limited access to formal markets,
10 which limits their income and standard of living. This article examines the economic viability for a number of configurations of off-grid
11 solar, wind, biomass and biogas based milk-cooling systems serving a community in Tanzania. Key risk factors having the greatest
12 impact on system viability are identified and a stochastic approach, by means of a Monte Carlo simulation is employed to determine the
13 risk-adjusted economic performance of the project. The results indicate that biogas based systems offer the most viable option, with an
14 internal rate of return of around 25%, a net present value of around $9,000 and a projected increase in farmers' monthly income of at
15 least 78%. Despite specific risk factors, the 300-liter cooling system had an 82% probability of a positive net present value. However,
16 larger system cooling capacities have a significant likelihood of a financial loss. Consequently, risk mitigation strategies designed to
17 increase the probability of economic success are proposed.

18 *Keywords:* Renewable energy, Off-grid, Milk cooling, Economics, Monte Carlo, East Africa

Nomenclature

A	area (m²)		ICE	internal combustion engine
A_{days}	days of autonomy		IRR	internal rate of return
AC	alternating current		MC	Monte Carlo
CF	expected cash flow per period		NASA	National Aeronautics and Space Administration
C_p	specific heat (kJkg⁻¹K⁻¹)		NPV	net present value
CH_4	methane		PV	photovoltaic
d	discount rate		TDBP	Tanzania Domestic Biogas Program
DC	direct current		Tzs	Tanzanian shilling (1 USD ~ 2200 Tzs)
DF	derate factor		VaR	value-at-risk
DoD	battery depth of discharge (%)		VARS	vapor absorption refrigeration system
E	electrical energy (kWh)		VCRS	vapor compression refrigeration system
E[x]	expected value of random variable, X			
F_R	heat removal factor		*Subscripts*	
G_T	solar irradiance (kWh/m².day)		a	ambient
HRT	hydraulic retention time (days)		array	photovoltaic array
I	current (amperes)		B	boiler
LHV	low heating value (MJ/kg, MJ/m³)		batt	battery
LiBr	lithium bromide		BG	biogas
M	mass (kg)		BM	biomass
N	number		c,i	collector inlet
NH_3	ammonia		CM	cow manure
P	power (kW)		co	solar collector
Q	thermal energy (kWh)		dig	digester
q	quantity		e	evaporator
R_{CH4}	Percentage of methane in biogas		G	gasifier
Rton	refrigeration ton		gen	generator
SGC	specific gas consumption (m³/kWh)		HW	hot water
S_p	peak sun-hours		inv	inverter
t	time		oc	open circuit
T	temperature (°C)		PG	producer gas
U_L	collector heat transfer coefficient (W.m⁻². K⁻¹)		pv	photovoltaic module
UA	storage tank heat loss (kW/K)		st	storage tank
V	volume (m³)		tnk	refrigeration tank
v	wind speed (m/s)		tot	system total
VS	quantity of volatile solids per kg manure (kg)		tur	turbine
V_t	voltage (volts)			
V_B	m³ of biogas generated per kg organic fertilizer		*Greek symbols*	
x	random input variable		σ	standard deviation
ỹ	project net present value		ϒ	gas yield (m³/kg)
			η	efficiency
Acronyms			α	absorbance
BOS	balance of system		Δ, δ	change
COP	coefficient of performance		ρ	density (kg/m³, kg/l)
GDP	gross development product		τ	transmittance