Climate Informatics for the Water-Energy-Food Nexus in the Indus Basin: A Scoping Study in Modeling Dairy Farm

Report on a GCISC-LUMS Collaboration

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Background and Research Hypothesis

Climate patterns in the agricultural zones of the Indus basin are predicted to undergo undesirable change that threaten the widespread agricultural activity and associated livelihoods. In the Indus basin, most of the climate change effects are related to unpredictable changes in the hydrological cycle (e.g. intense or reduced precipitation, glacial melt, disturbance in Monsoon patterns, increased frequency of droughts and floods). While the impact of these changes have been studied on cropping patterns, cereal production and on crop losses in fruits, vegetables and horticulture, a relatively less studied area is livestock and the associated dairy sector. Livestock is a major source of greenhouse emissions thereby contributing towards climate change, but it is also a recipient of climate impacts. In the Indus basin, studies have predicted a decline in livestock by 20-30%, creating shortages in milk, meat and poultry supplies and pushing prices beyond the reach of the average Pakistani. There is an even less amount of information on the water, energy and carbon footprint of dairy operations in the basin primarily due to difficulties in data gathering. We hypothesize in this study that by introducing informatics-driven precision measurements, it is possible to:

a. Estimate water, energy and carbon footprint of farm-level dairy operations, thereby enabling accurate projections for the entire basin.
b. Study energy, water and waste fluxes to optimize the water-energy-food nexus in farm operations in order to enhance productivity, promote conservation, and introduce climate change adaptation measures.

The resulting conceptual maps, causal diagrams, system dynamical models and analytical insights can help develop economic tools that leverage the advantages of water/climate informatics driven data services and decisions under large variabilities and devise sound agricultural policy.

Water-Energy-Food Nexus in Dairy Farm Operations

Dairy farms today aspect challenges and chances driven by rapidly rising energy costs and concerns about water, energy, food and environmental impacts. Dairy farms use more energy and water than almost any other agricultural operation. Energy is used in the milking process, cooling and storing milk, heating water, pumping water, illumination and ventilation. Determining the best energy efficiency and energy management opportunities for dairy farms will help reduce energy costs, enhance environmental quality, saving water pumping cost and increase productivity and profitability. Energy efficiency is often an inexpensive, quick and simple way to save money. Our work focuses on dairy equipment, new technologies and management practices for reducing energy consumption. While power bills and energy audits can give a good overview of how energy is being in a dairy shed, the only way to drill down into exactly where and when energy is being used is to monitor. The role of agricultural sector in the world energy scenario has been emphasized because it can contribute to improve energy balance as producer of bio-energies. These energies can be change to other form of useful energies such as bio-gas, electricity and some form can be changed to natural fertilizer, which is much expensive part of the agriculture side. On the other side the energy management of agricultural activities plays a strategic role for the future of agriculture by reducing the production costs and supporting the sustainability of rural development.

Water is typically used in cultivated land, animal shed, milking shed, sterilization, biogas plant, staff residence and almost in every process in dairy farm. For cultivated land, irrigation water, some part is taken from surface water (e.g. a canal) and some part is pumped through submersible turbines from ground water. Water for animal shed, milking shed, sterilization, biogas plant and for staff residence is pumped from ground water through submersible water pumps. Meat and milk is major part of food from animal shed while fruits, wheat, rice, maze and numerous other products come from cultivated land. Energy used to take ground water on surface through submersible turbines and pumped water used to irrigate cultivated land, for animal feed, sterilization, animal shed cleaning and slurry mixing for biogas plant while slurry from animal shed is used to fed biogas plant which intern produce natural gas which is further used to generate electricity, cooking and baking purpose. Cultivated land take irrigation water and slurry residue as byproduct from biogas plant as natural fertilizer and help to grow food for staff and feed for animals. Associations among water, energy, food and land in dairy farm leads to a thorough study of the water-energy-food nexus and system dynamics modeling of water-energy-food nexus in dairy farms.

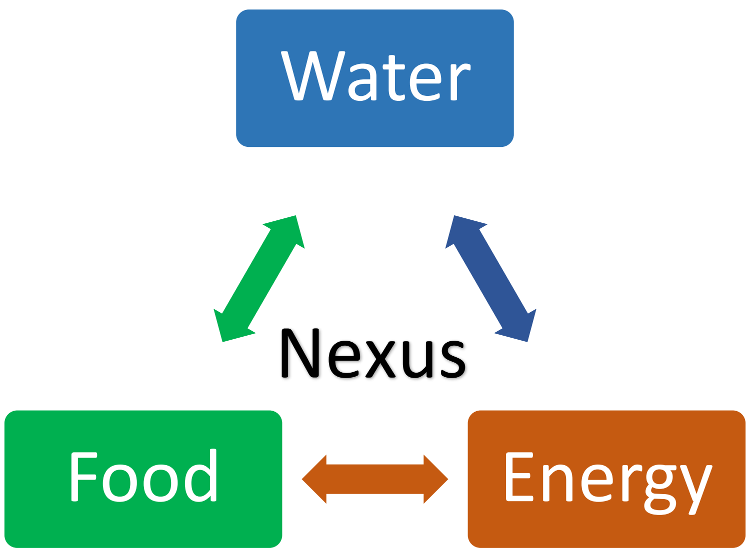


Figure 1. Water-Energy-Food Nexus

Formulation of a simulation model

Dairy farm dynamics model contains animal shed, biogas plant, power plant, staff residence and agriculture fields that represented by main blocks, rectangles, in figure.2. Resources supplied to dairy farm are surface water, ground water, fuel, electricity from power producers and animal feed that represented by circles in figure.2. Resources evolving from dairy farm are slurry (renovated into biogas, electricity and organic fertilizers), food (meat, milk), livestock, raw food and feedstuff from agriculture fields.

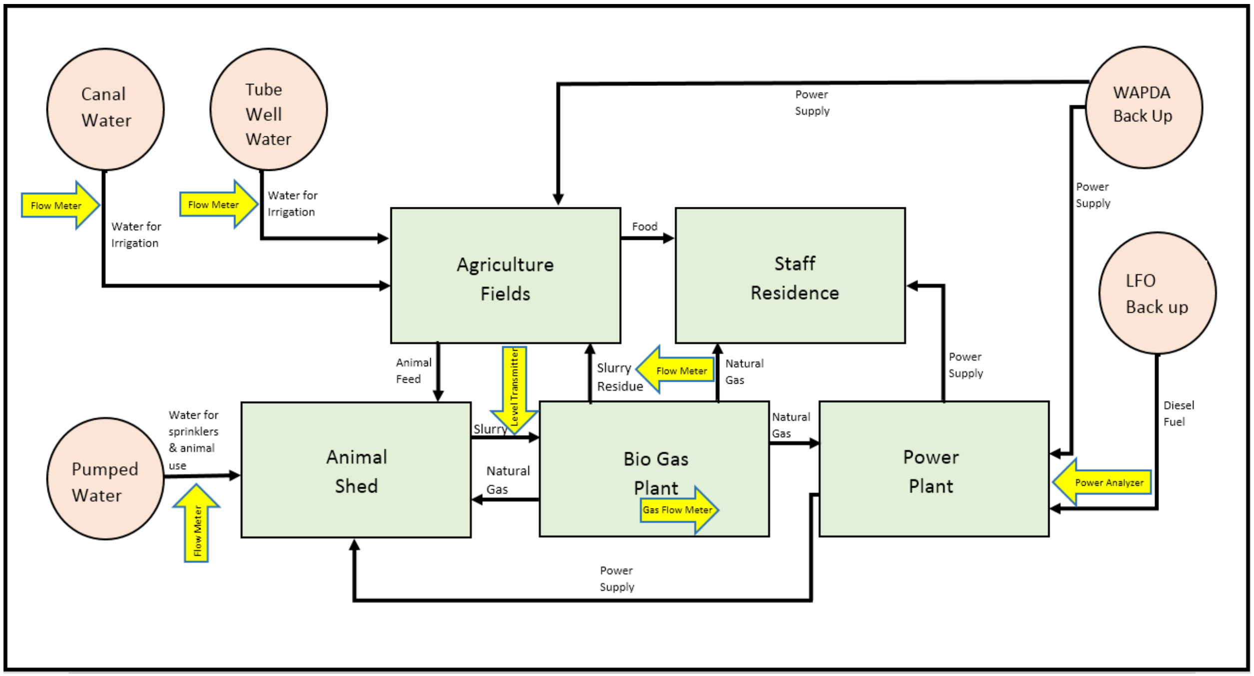


Figure 2. A Typical dairy farm in the Indus Basin (Sarsabz Dairy Farms, Nestle-Pakistan, Renala, Okara)

- *Rectangles*: main blocks in Nestle Sarsabz dairy farm
- *Circles*: resources to be monitored with the help of sensors
- *Arrowheads*: evolution and transmission of resources
- *Yellow highlighted arrowheads*: places where sensors installed

Following resources in dairy farm are being monitored with the help of sensors such as water distribution in dairy farm and cultivated land with portable electromagnetic flow meters for water monitoring at irrigation turbines, turbines for animal shed, turbines for water sprinklers, utility pumps at animal shed while ultrasonic flowmeters for irrigation water from canal through open channels. Slurry in mixer well for biogas plant, slurry storage pond, underground slurry storage tanks are being monitored with the help of ultrasonic level transmitters heaving wireless HART communicators while slurry water discharge open channels from animal shed and slurry residue discharge open channels from biogas plant are monitored with the help of thermal mass flowmeters. Total gas production at biogas plant, gas monitoring at powerhouse, gas monitoring at animal shed for sterilization water heating, and gas monitoring for utility 1 and utility 2 is being monitored with vortex type gas flowmeters. Power from WAPDA, power generation from biogas plant, power generation from HFO, demand vs. production is metered with the help of high accuracy power analyzers. Details of all resources metering and monitoring is mentioned below:

Water

- Irrigation turbines
- Irrigation water from canal through open channels
- Turbines for animal sheds
- Turbines for water sprinklers
- Utility pumps

Slurry

- Mixer well for biogas plant
- Slurry storage pond
- Underground slurry storage tank
- Slurry residue discharge channels from animal shed
- Slurry residue discharge channels from biogas plant

Biogas Plant

- Total gas production at biogas plant
- Gas monitoring at powerhouse
- Gas monitoring at animal shed for water heating
- Gas monitoring for utility 1 and utility 2

Power Plant

- Power from WAPDA
- Power generation from biogas plant
- Power generation from HFO
- Demand vs. Production

Simulation results for pumped water

Portable EM flowmeter simulation results for submersible water turbines for animal sheds.

General Parameters

Fluid	Water, potable		
State	Liquid		
Character	Clean	Atmospheric Pressure	1.0133 bar_a
Abrasivity	Not abrasive	Standard	EN/DIN/ISO
Fluid Group (PED)	Not considered for PED		
Fluid type	Newtonian		

Operating Conditions

	minimum	nominal	maximum	
Requested Flow	5	394	400	l/min
Pressure	2	4	6	bar_g
Temperature	20	30	40	°C
Density	998.3	995.83	992.49	kg/m3
Viscosity	1.00152	0.79731	0.65303	cP
Vapor Pressure	0.0234	0.0425	0.0738	bar_a
Design pressure (min/max)	2		6	bar_g
Design Temp. (min/max)	20		40	°C

Sizing and Calculated Results

	minimum	nominal	maximum	
Requested Flow	5	394	400	l/min
Velocity	0.042	3.344	3.395	m/s
Pressure loss	n.a.	n.a.	n.a.	mbar
Measurement error Volume***	2.86	0.53	0.53	%
Reynolds No.	2 650	208 854	212 035	

Fluid

Fluid name	Water, potable	State	Liquid
Chemical formula	H2O	Calculation standard	IAPWS

Fluid description

Medium character	Clean		
Conductivity	more than 50 µS/cm		
Fluid group (PED)	Not considered for PED		
Fluid type	Newtonian		
Fluid stability	Stable		
Tc (Critical temperature)	374.1 °C	Tm (Melting point)	0.04 °C
Pc (Critical pressure)	221.2 bar	Tb (Boiling point)	100 °C

Calculated results

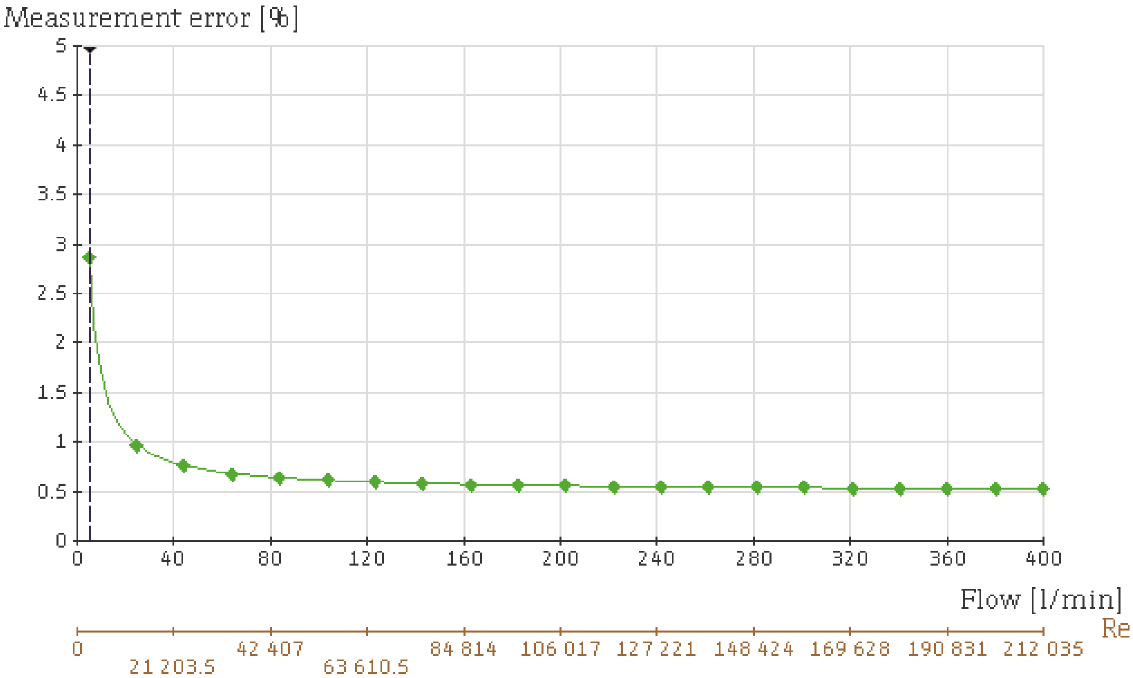
Density nom.	995.83 kg/m3	Pressure nom.	4 bar_g
Viscosity nom.	0.79731 cP	Temperature nom.	30 °C
Sound velocity nom.	1 512 m/s		
Spec. Enthalpy	0		
Vapor pressure nom.	0.0425 bar_a		

Reference values: Normal conditions (SI): Standard conditions (US):

Atmospheric pressure	1.0133 bar_a	Atmospheric pressure	1.0133 bar_a

Sizing and Calculated Results

Flow Principle		Electromagnetic		
Meter Size		DN 50		
Operating range min.		5		l/min
Operating range max.		1 100		l/min
Velocity at req. Flow min.		0.042		m/s
Velocity at req. Flow nom.		3.344		m/s
Velocity at req. Flow max.		3.395		m/s
Meas. error Vol. at req. Flow min.***		2.86		%
Meas. error Vol. at req. Flow nom.***		0.53		%
Meas. error Vol. at req. Flow max.***		0.53		%
Meas. error Spec. Vol. at req. Flow min.***		4.91		%
Meas. error Spec. Vol. at req. Flow nom.***		0.26		%
Meas. error Spec. Vol. at req. Flow max.***		0.26		%



System dynamics modeling by using causal feedback loop structure

Animal shed is vital part of the dairy farm which produce useful resource slurry to produce two major energy part products i.e. biogas and slurry residue. Another vital product is food in the form of milk and meat produced from livestock. Most part of the gas from biogas plant is fed to the power plant is to produce electricity and some part is used in staff residence and living area mostly for kitchen use. Some part of the gas is also used to heat water for sterilization and cleaning purpose. Slurry residue produced in reaction chamber after biogas production is gathered in a large

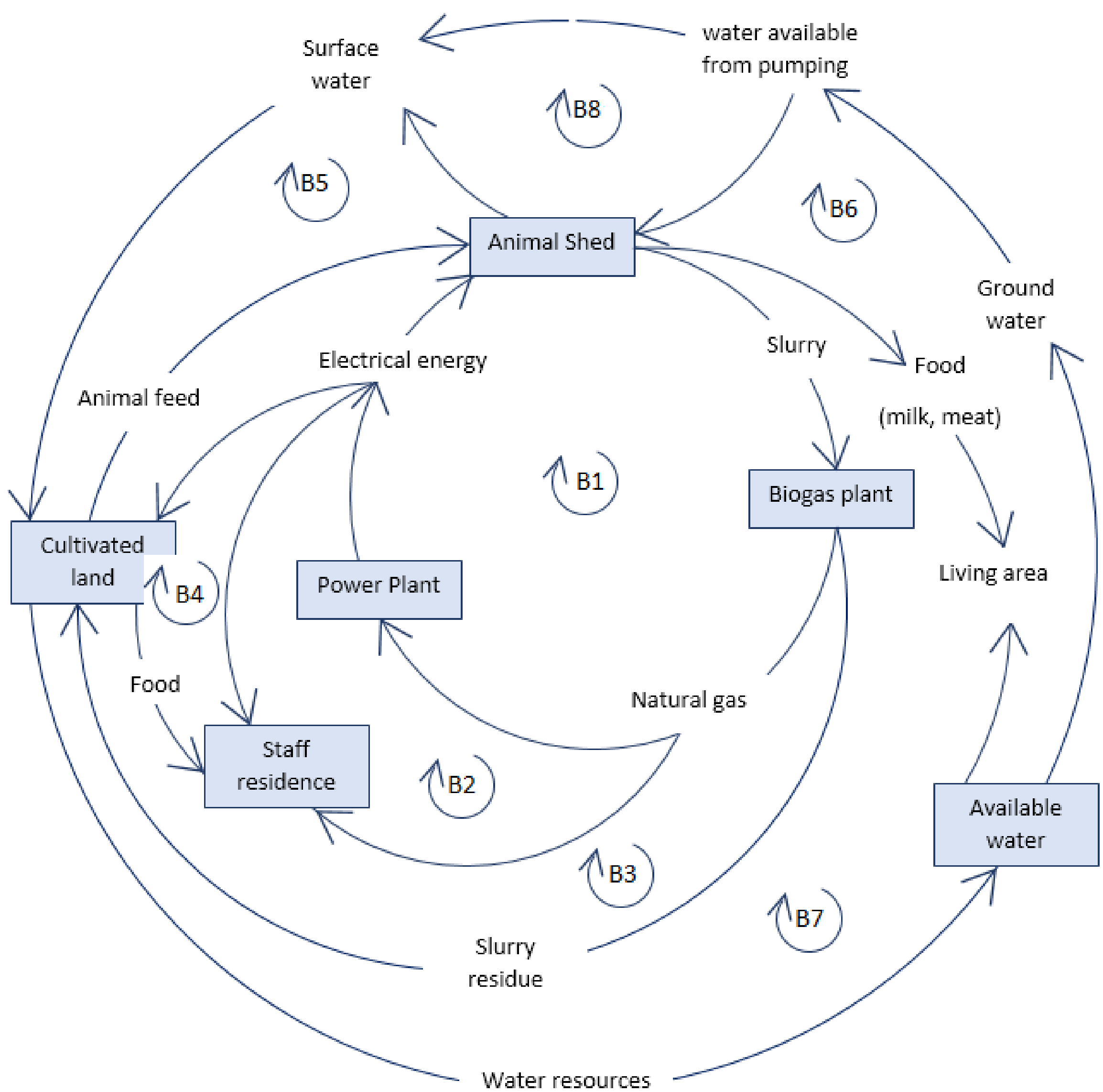


Figure 3. Feedback loop structure of dairy farm constrained by dairy farm inputs, outputs and byproducts

underground chamber. Slurry from underground chamber, slurry storage pond and slurry mixing well is led to the canal water open channel course and supplied to the cultivated land as an organic fertilizer. Some of the remaining part of slurry let dry and used as a dry fertilizer in cultivated land and some part of it use as a house hold fuel for burning purpose. Electricity produced by power plant from biogas used all over the dairy farm in animal shed, cultivated land, staff residence (figure 3, loop 2) and also supplied to nearby village or fed to the national grid to enhance revenue. Similar strategy used if some extra biogas produced. Surface water, both from canal water and pumped from ground water resources is available for irrigation purpose in cultivated land (figure 3, loop 7) however water used for animal shed cleaning, livestock drinking water (figure 3, loop 5, 8), water for sprinklers to maintain humidity & temperature and water for utility & house hold purpose of staff residence (figure 3, loop 6) is dependent on ground water. Numerous water pumps and water turbines used to take ground water from underground reservoirs to surface water stored in water tanks. Irrigation water mainly taken from canal through open channels that saves cost of electricity from water pumps and turbines to save cost of this additional media and its installation and maintenance but when canal water is not available during the summer, water turbines used to fulfill water requirements. Major problem to take water from underground water reservoirs is salinity which degrade the fertility of cultivated land. As we pump more and more water through turbines for extensive time, water table surface begins to fall. With the passage of time water table surface keep up falling and salinity in water increase which ruins the fertility of soil. After some time, fertility of soil decrease which leads to reduced yield of cultivated land.

Study of these interconnects will lead to simulation results for pumped water, biogas, power analyzers and a mathematical modeling framework from causal feedback loop structure

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Appendix: Instrumentation Survey for Sarsabz Dairy Farms, Renala

1. Water Turbine

s

2. Installed Turbine type FM

Line size 5”, 130mm

3. Irrigation Canal Water Channel

Canal water channel (Divided into 2 paths)

Water is Being Divided into 2 Fields

Channel Width 76cm, wall thickness 6cm

Channel depth 66cm

4. Submersible Water Turbine

Submersible Pumps (For Water Sprinklers)

Pipe diameter 3", Circumference 28cm

Submersible pump flow data


MONO BLOCK
ISO 9001
H.P. 2 VOLT. 440
PH. 3 RPM. 2850
AMP. 3
T.HEAD
Qyt.max. 394 lt/min
SIZE. 2" x 2"


F.EL.SOM. srl
Milano - ITALY
info@felsom.com
CE
type FP4 H055 (19 imp.) 4 Kw rpm 2850
Q=0-100-200 l/min. H=136-120-60 m
serial number: 002746
assembling date: 19/06/12
EUROPEAN PATENT
MADE IN ITALY


KOMAX
Made in UAE
Electric Submersible Motor Type KM4
KM4 055T - HP: 5,5 - KW: - RPM 2825
Volt: 380 / 50Hz - Phase : 3 - Amp : 9,8
Cosφ: 0,82 - Ax.Th.2500N - Temp:40°c - SF 1
Continous Duty - I.Cl. "F" - eff. 78 - Wt. 22Kgs

5. Slurry (Waste from animal sheds)

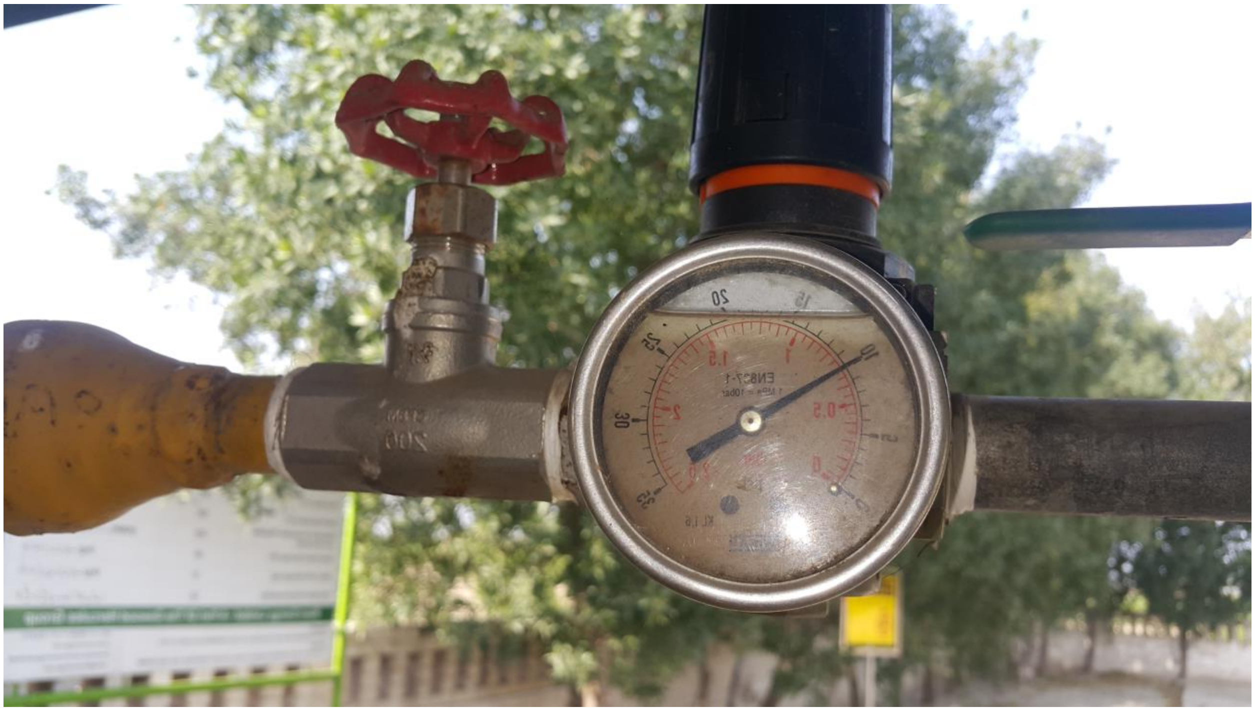
6. Slurry storage area outside the farm

Installed US level sensor

7. Slurry residue from UGBG plant slurry tank

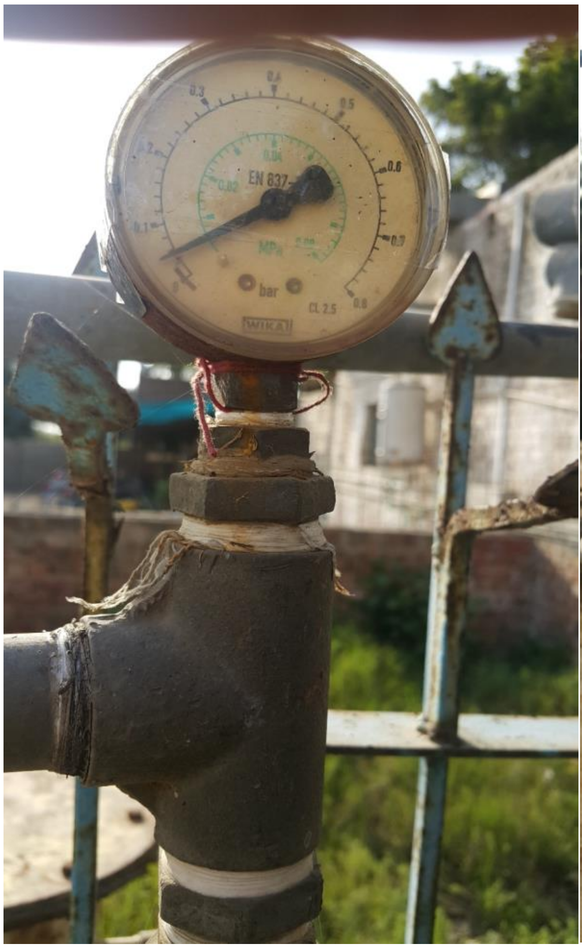
8. Slurry being mixed into water for fields

1. Header Pressure Gauge & Flow Totalizer



2. Proposed Location for BGFM

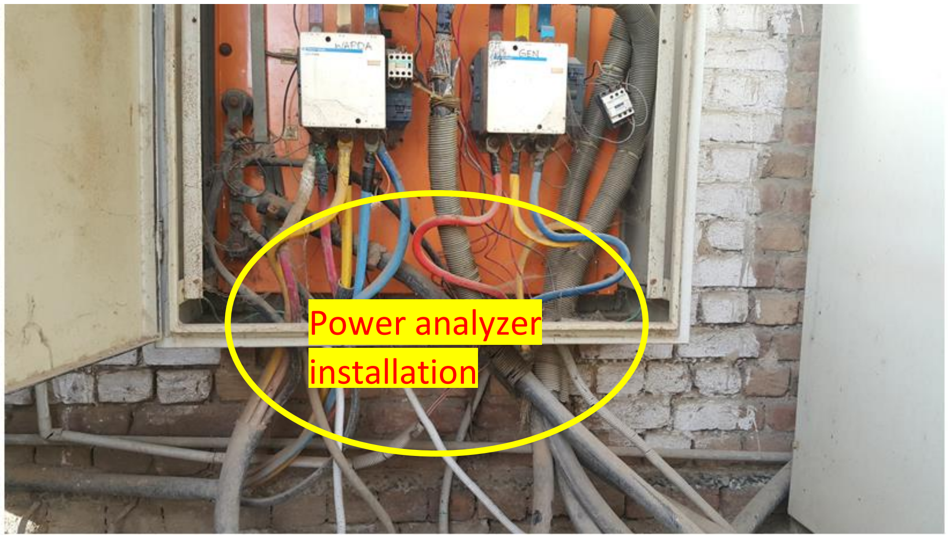
3. Power House Pressure Gauge & Flow Totalizer



4. Kitchen 1 Gas meter

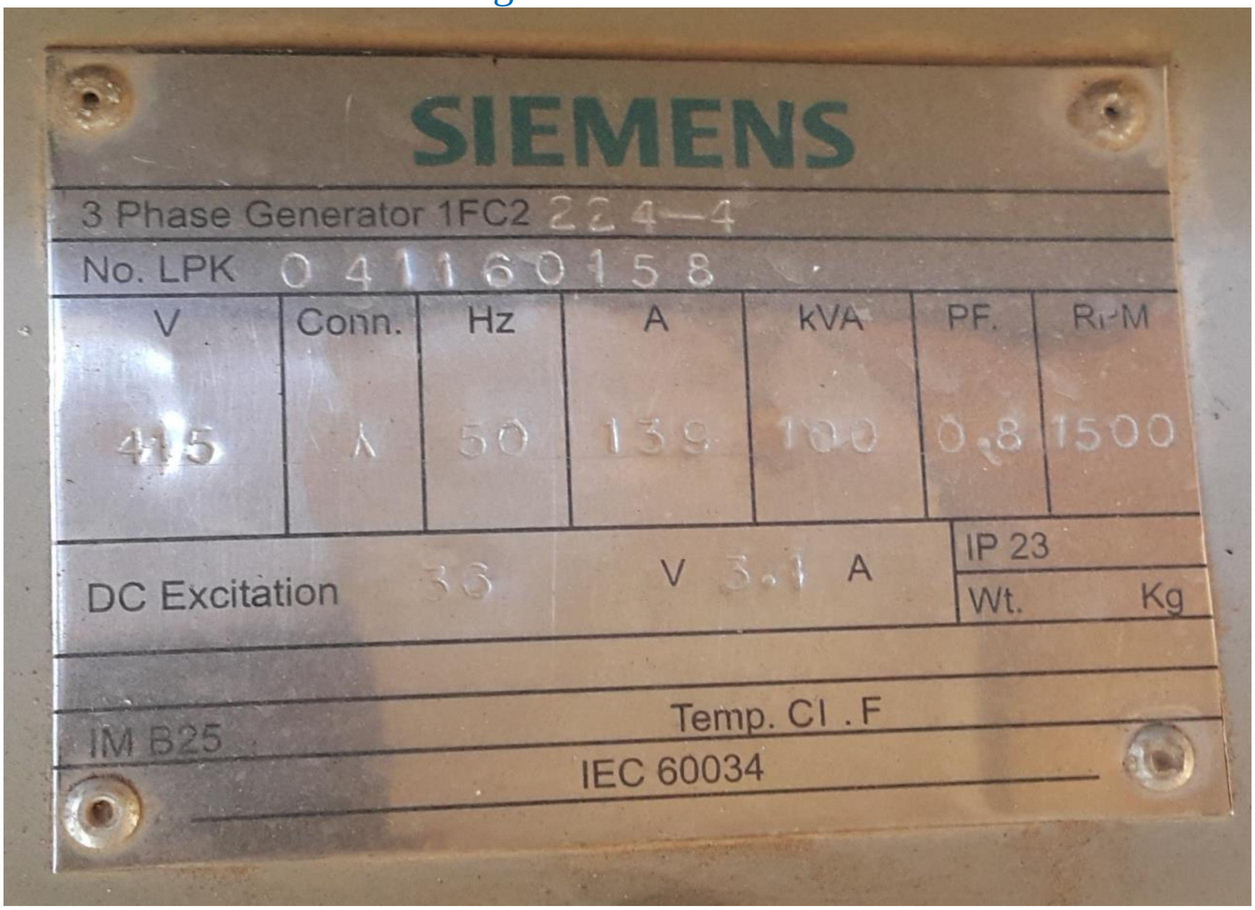
5. Kitchen 2 Gas meter

1. Distribution Panels



2. Distribution Panel Switch's for Gen & WAPDA

3. Generator Power Ratings



4. Dead PLC & Generator Hour Meter

5. WAPDA DTR (Power Rating 400KVA)

Equipment Required

1. Flow Meter/ Totalizer for submersible Pumps
   Type: Electromagnetic Flow Meter
   Fluid: Raw Water
   Size: DN50
   Output: 4-20mA
   Quantity: 2.

2. Flow Meter/ Totalizer for water turbines for irrigation
   Type: Electromagnetic Flow Meter
   Fluid: Raw Water
   Size: DN125
   Output: 4-20mA
   Quantity: 1.

3. Flow Meter for Biogas Plant
   Type: Vortex Flow Meter
   Size: DN50
   Fluid: Natural Gas
   Output: 4-20mA
   Quantity: 1.

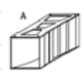
4. Flow Meter/ Totalizer for open water channels
   Type: Ultrasonic Flow Meter
   Fluid: Raw Water
   Output: 4-20mA
   Quantity: 1.

5. Ultrasonic Level Transmitter for slurry tank and slurry mixer well
   Range: 4-6m
   Output: 4-20mA
   Fluid: Slurry/ animal dung
   Qty.2

6. Power Analyzer for Biogas Power Plant
   Type: 3-Phase
   Qty.2.

7. Recorder 12 channels for Integration of all nodes
   Output: Ethernet/4-20mA/.
   Qty.1

INSTRUMENTS REQUIRED FOR NESTLE SARSABZ FARM

ITEM		DESCRIPTION	QTY	UNIT PRICE	Total PRICE
		OPTION.1. BEST INDUSTRIAL SOLUTION			
01		**Promag DN50 2"** **Electromagnetic Flow Meter** **Flow Meter/ Totalizer for submersible Pumps** **Make: Henan Dafang Dingsheng Flow Instrument Co., Ltd** 	01	$338	$338
02		**Promag DN150 6"** **Electromagnetic Flow Meter** **Flow Meter/ Totalizer for water turbines for irrigation** **Make: Henan Dafang Dingsheng Flow Instrument Co., Ltd** 	01	$487	$487
03	(3a)	**Prosonic S FMU90** **Evaluation: level/flow** **Model:FMU90-R22EA111AA1A*** 	From Zahoor Khan ultrasonic sensors		
	(3b)	**Prosonic S FDU90** **Level, ultrasonic, contactless.** **Model:FMU90-R22EA111AA1A*** 			
	(3c)	**Weather protect. cover FDU90** **Level, ultrasonic, contactless.** **Model:52025686** 			
	(3d)	**Sensor support 500mm, ST, US-sensor** **Level, ultrasonic, contactless.** **Model:919790-0000** 			
	(3e)	**Khafagiventuri QV304, Flume higher** **Level, ultrasonic, contactless.** **Model:011454-2004** **Flow Meter/ Totalizer for open water channels** **Make: Endress+Hauser (Reinach, Switzerland)** 			
04		**Prowirl DN50 2"** **Vortex Flow Meter** **Model:7F2B50-AABCCA1D2SK+AAD** **Flow Meter for Biogas Plant** **Make: Henan Dafang Dingsheng Flow Instrument Co., Ltd** 	01	$296	$296
05		**Prosonic T FMU30** **Level transmitter, Ultrasonic, contactless** **Model:FMU30-AAHEABRHF** **Ultrasonic Level Transmitter for slurry tank and slurry mixer well** **Make: Endress+Hauser (Reinach, Switzerland)** 	From Zahoor Khan ultrasonic sensors		
06		**Supply Network Analyzer** **Single-phase 230 V ~ (a.c.)** **Model:FMU30-AAHEABRHF** **Power Analyzer for Biogas Power Plant and WAPDA** **Make: Circutor (Spain)** 	02	$125	$250
06		**Installation, accessories, flanges, cables** **Mechanical work, accessories, flanges, cables, conduits etc.**	01	$1,100	$1,100
		Total Price in USD	**$2,471**		