Wind and Solar Desalination for Small Scale Agriculture and Potable Water

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Presented by

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1st Annual WIN Workshop

Brackish Groundwater National Desalination Research Facility (BGNDRF)

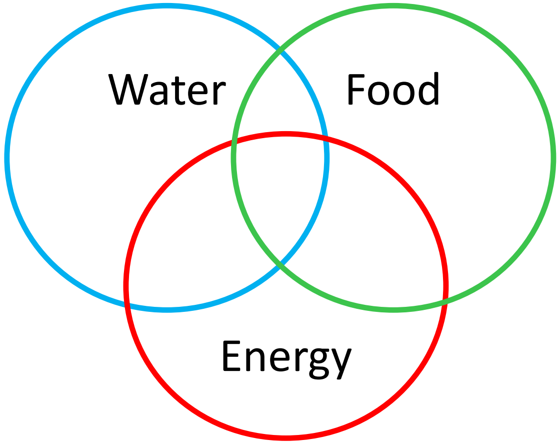
GreenDesal

Outline

- Motivation: Food-Energy-Water Nexus
- Renewable power system
- Wind and solar resources at BGNDRF
- Desalination system overview
- Prior efforts and P2P project
- Summary and final remarks

Motivation: Food-Energy-Water Nexus

- Brackish groundwater requires desalination for irrigation and drinking usage
- Desalination increases energy demand which will lead to greenhouse gas emissions if powered by carbon-based fuels
- Concentrate treatment can minimize environmental issues related to disposal converting to valuable fertilizers
- Fertilizer production from concentrate reduces consumption of energy and resources



Renewable Power System: Hybrid

Why hybrid? For off-grid applications, it offers flexibility, adaptation to site conditions, and complementary

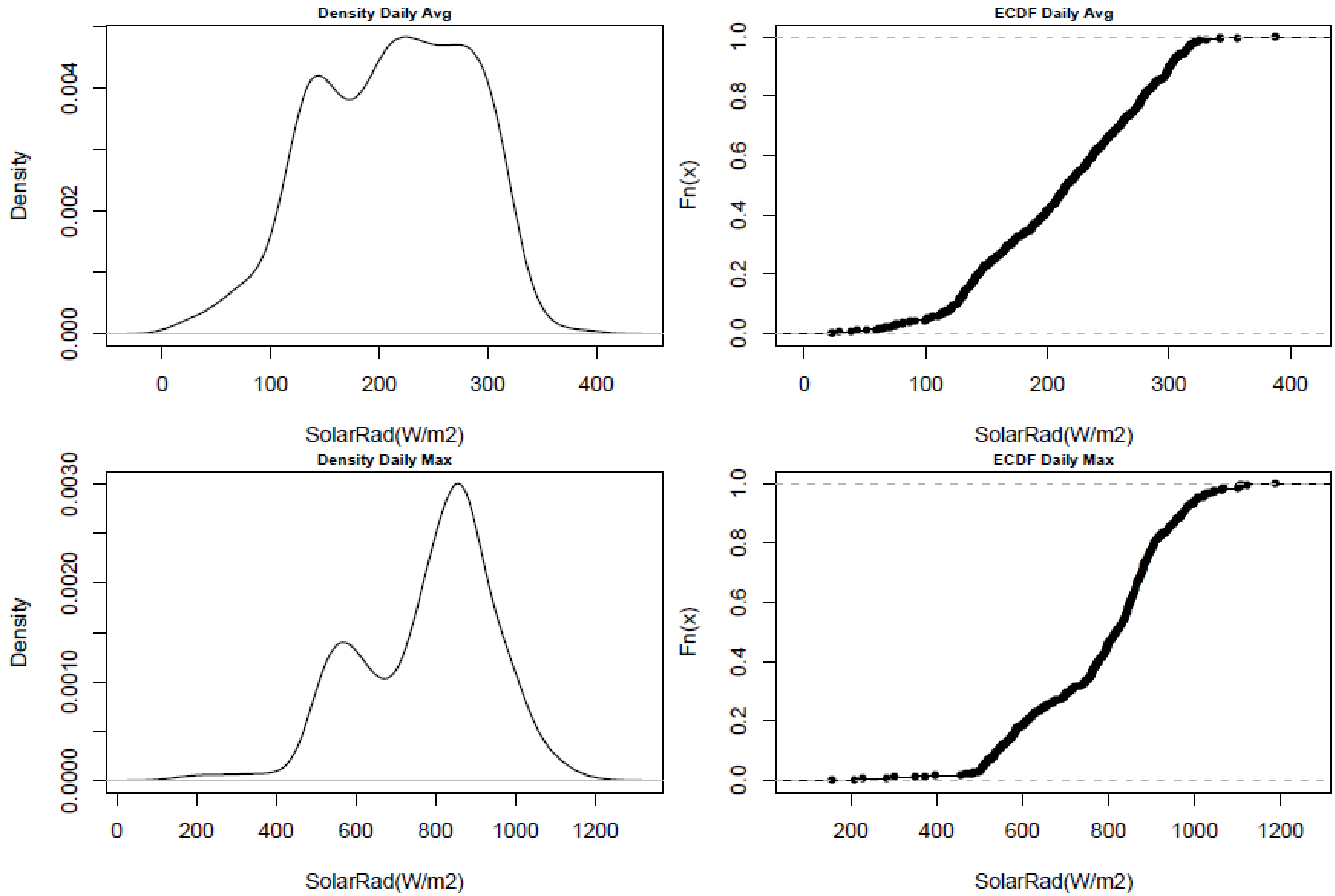
- Solar: low output in winter months or inclement weather; no production at night

- Wind: increased output in winter and inclement weather; possible production at night

Solar and wind resources at BGNDRF

- Collecting meteorological data at BGNDRF since May 2017
- Real-time samples, processed and stored every 5 min
- 5-min average, maximum, minimum, sd
- Currently 135,679 observations
- Wind speed measured at two heights
- Solar radiation
- Goal: characterize solar and wind resources for electricity production

Solar radiation: statistics



Effect of height on wind power

Two classic models: power and logarithmic

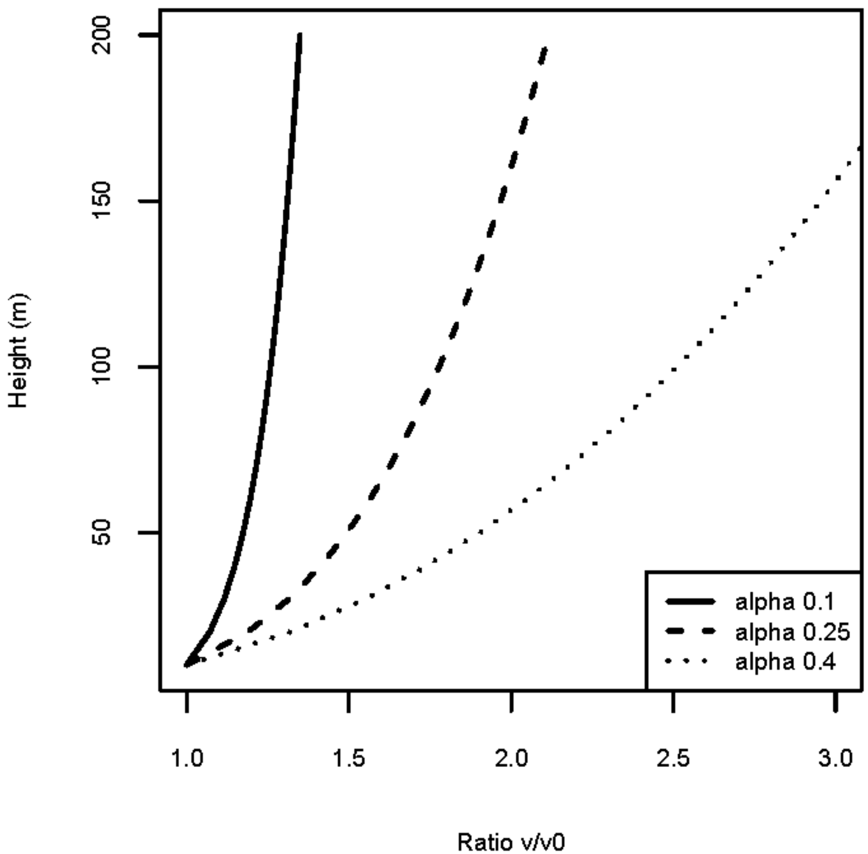
$$\frac{v}{v_0} = \left(\frac{H}{H_0} \right)^{\alpha} \qquad \frac{v}{v_0} = \frac{\ln(H / l)}{\ln(H_0 / l)}$$

Where H_0 is a reference height, v is wind speed at height H, v_0 is wind speed at the reference height, α is a friction coefficient, and l is roughness length, that characterizes the terrain conditions

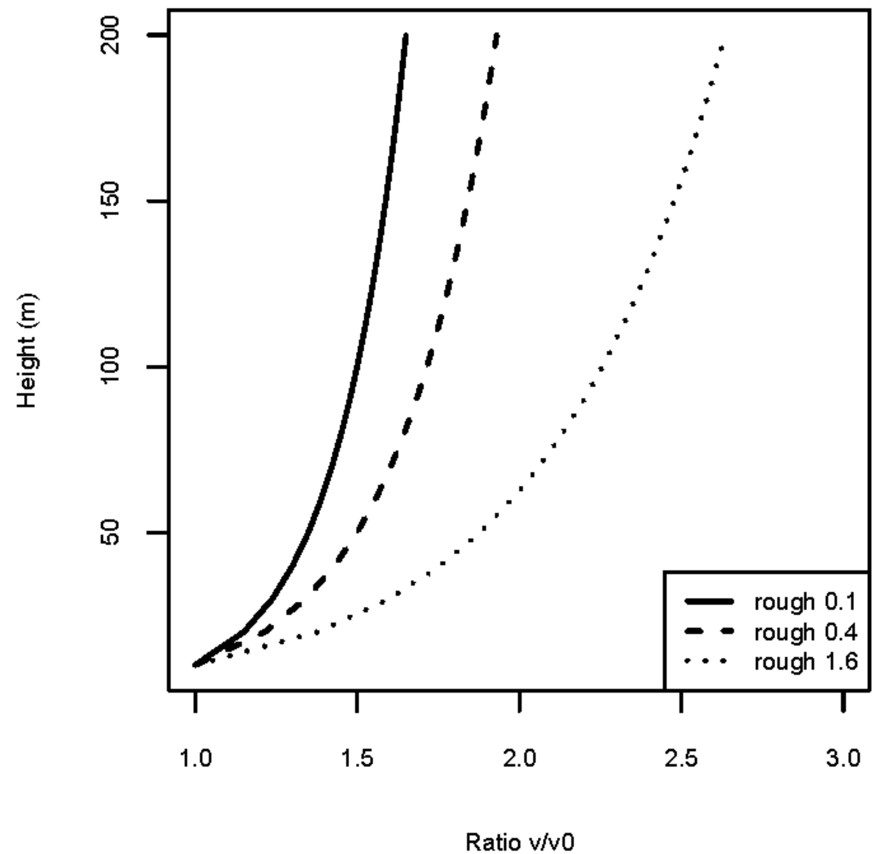
Since power increases as the cube of wind speed, assuming equal air density, the ratio of specific power goes as the cube of speed ratio

$$\frac{P}{P_0} = \left(\frac{v}{v_0} \right)^3$$

Height



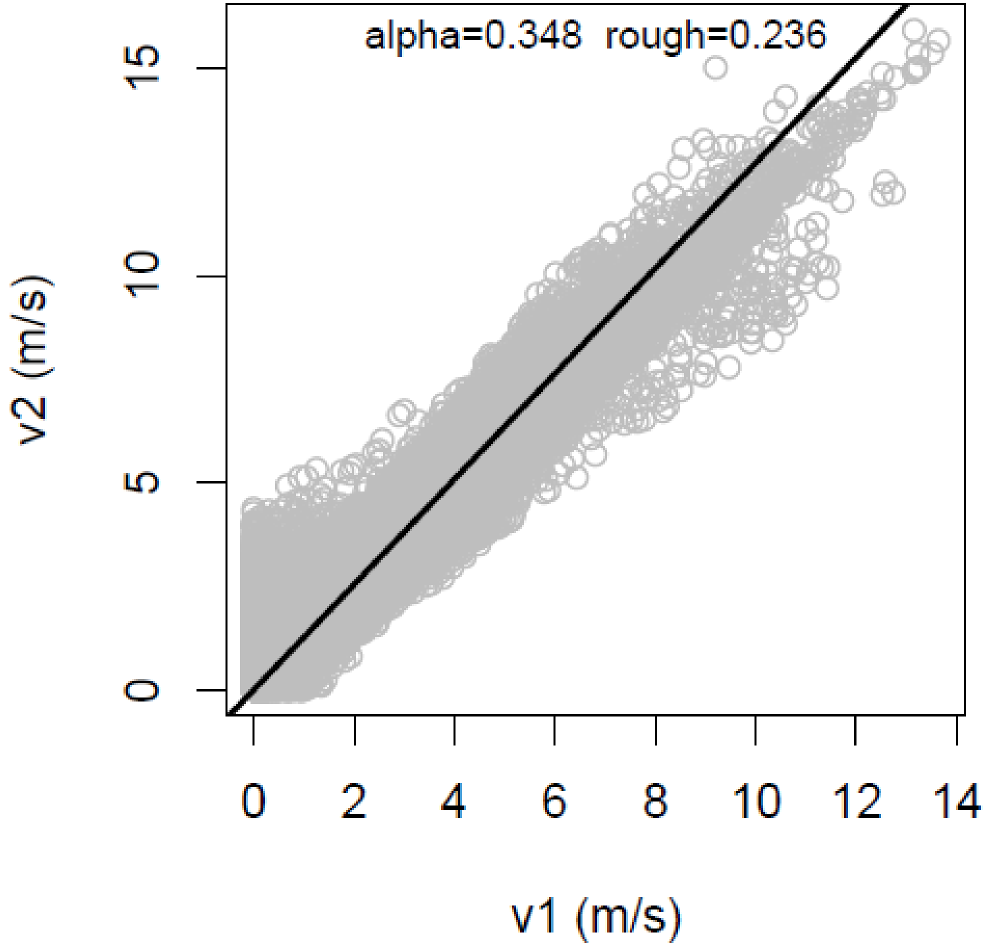
Height (m)
200
150
100
50
1.0
1.5
2.0
2.5
3.0
Ratio v/v0
alpha 0.1
alpha 0.25
alpha 0.4



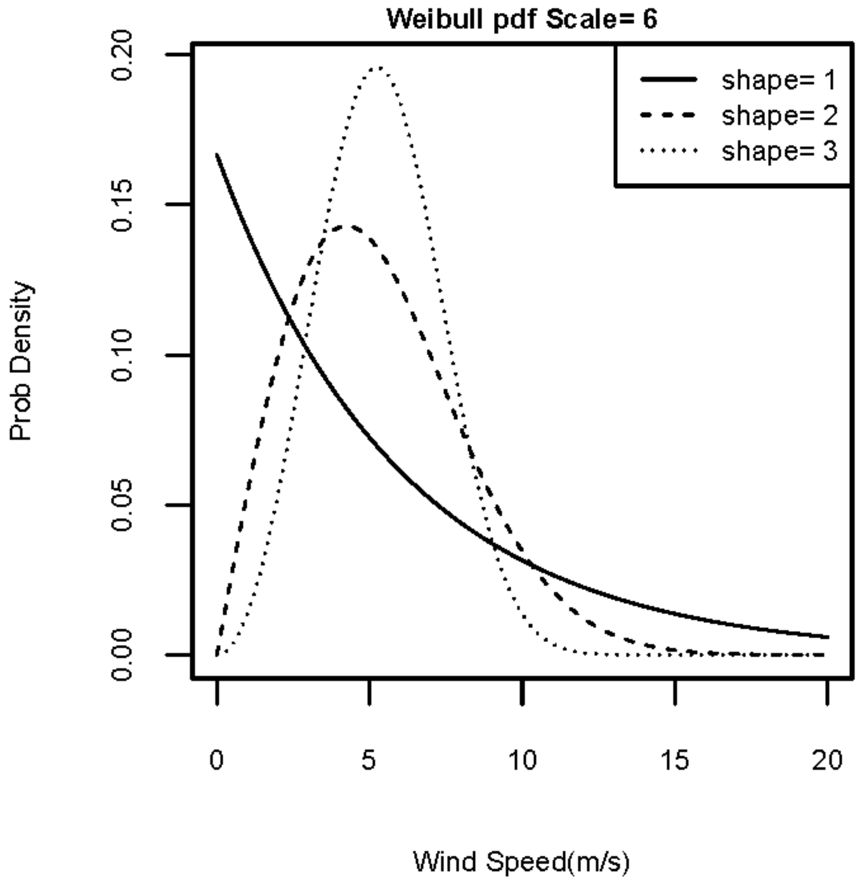
Height (m)
200
150
100
50
1.0
1.5
2.0
2.5
3.0
Ratio v/v0
rough 0.1
rough 0.4
rough 1.6

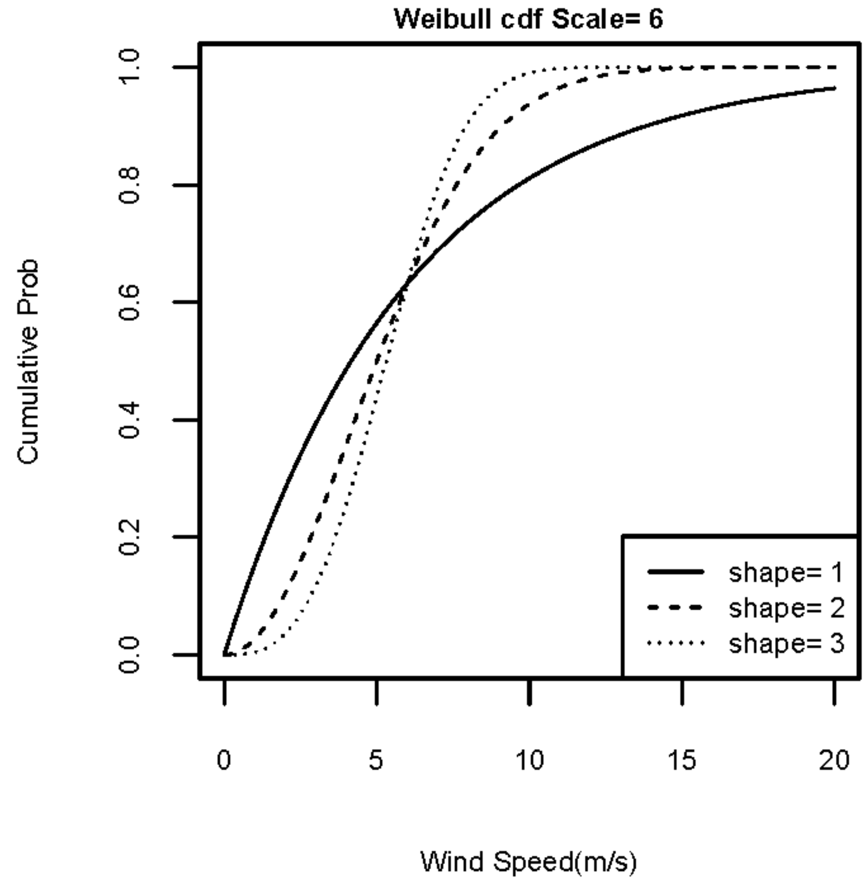
Two anemometer calibration

Using renpow package of R cal.vH(x)

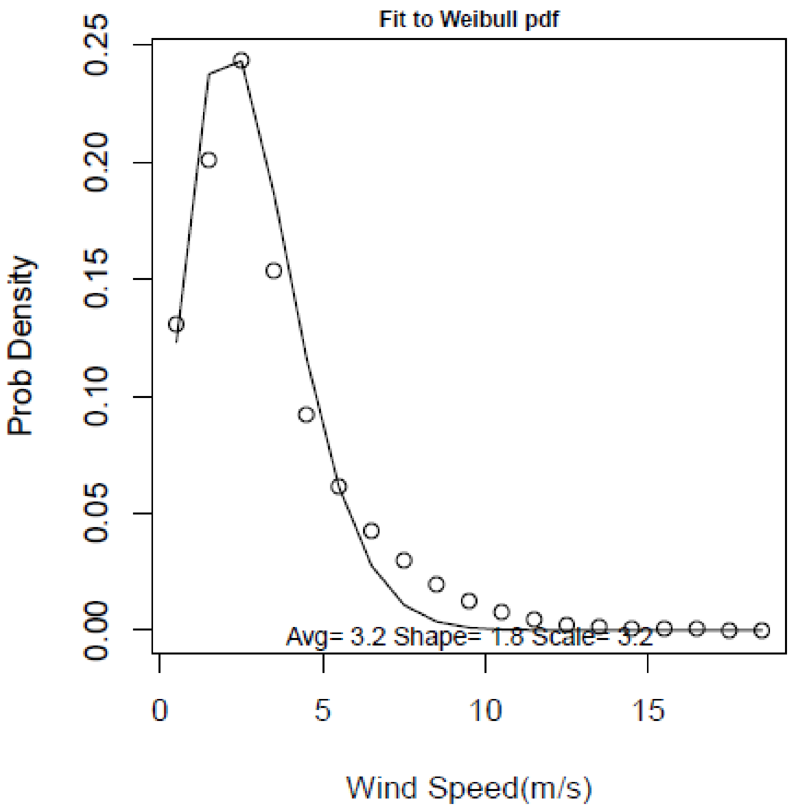


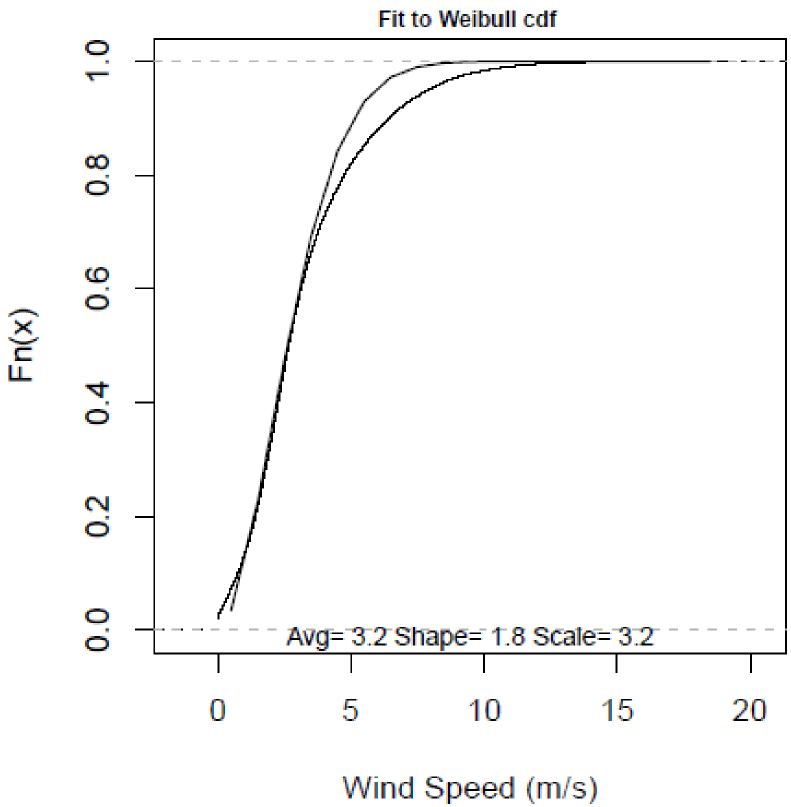
Wind speed statistics



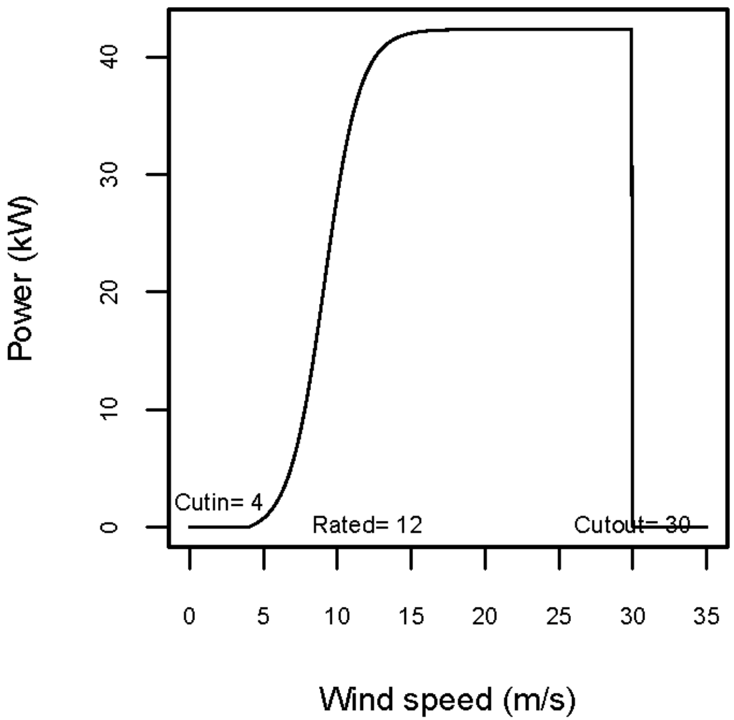


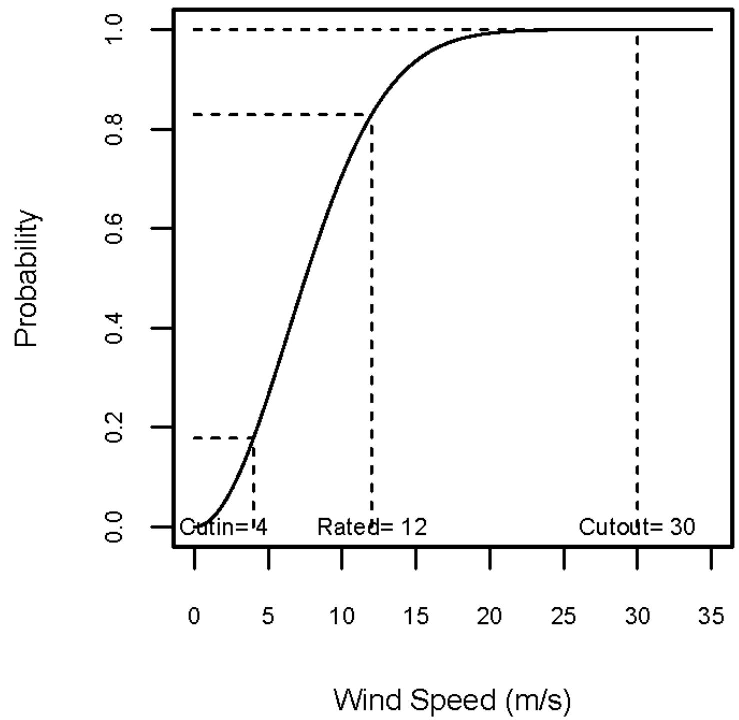
Do we have Rayleigh winds at BGNDRF?



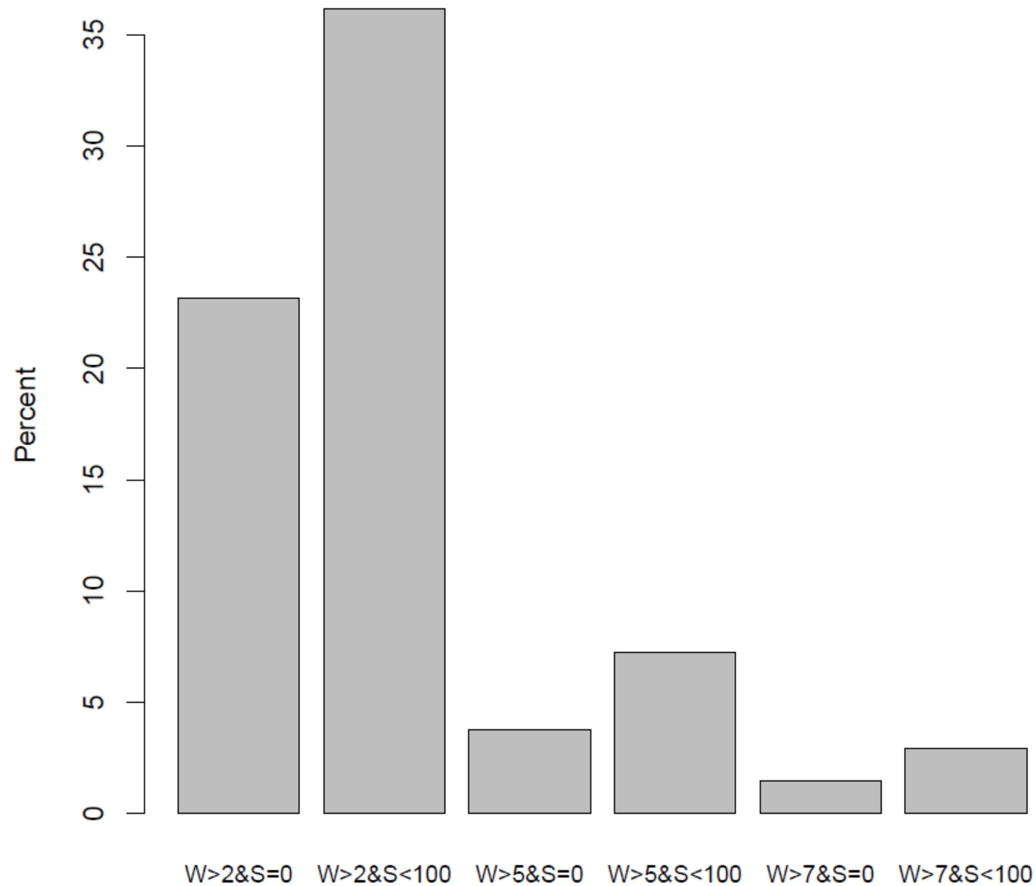


Power vs wind and probability



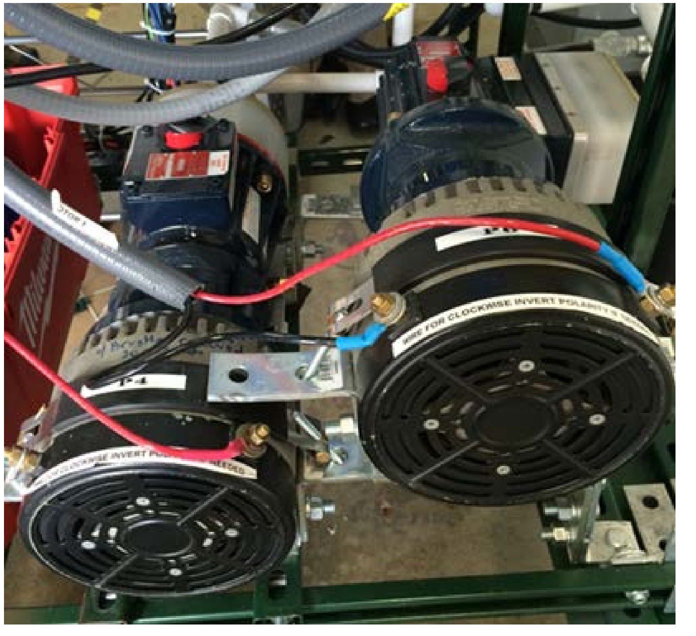


What is the wind potential when solar radiation is lacking?



Electrical Efficiency

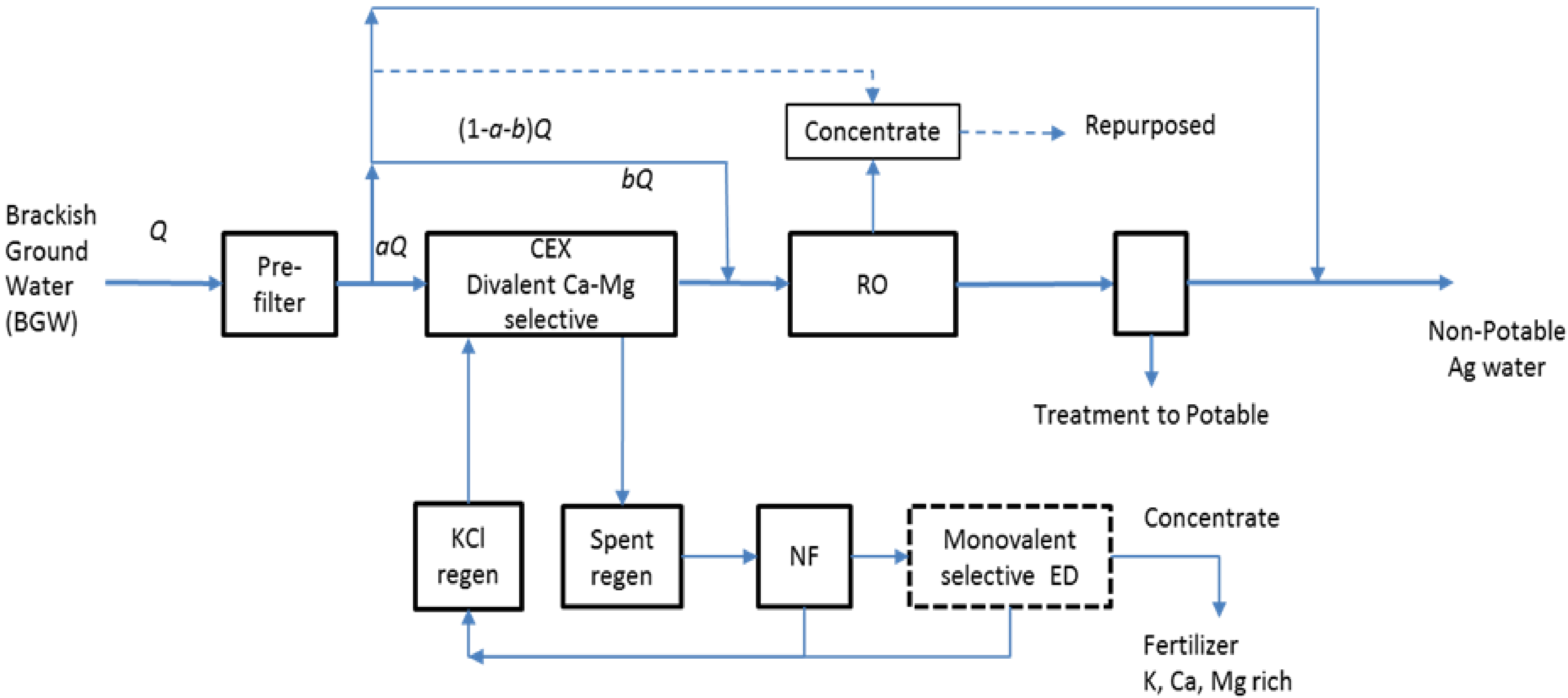
- Motors: off the shelf, DC (avoids inverter), high efficiency, easy to work with, can remove and install brushes
- Motor controllers: off the shelf, used in electrical vehicle industry
- Pumps: piston, high efficiency



Intermittent resource: storing energy

- Battery bank 24 V
  - Electrical to electrochemical
  - e.g., 4 strings of two 150Ah = 600Ah
- Using diversion loads for heating water or complement heating of working fluid for solar thermal
  - Electrical to thermal (kWh to J of heat)
  - e.g., 240 W for 4 h/day, ~ 1kWh per day, or 3.6 MJ per day
- Water produced and stored is proxy for energy storage
  - Electrical to volume (kWh to m^3)
  - e.g., 16 kWh to 10 m^3 per day
  - Discount demand for pumping needed

Desalination System Overview



Designed to process 11.1 m^3 water at ~75% recovery to yield 8.0 m^3 for irrigation and 0.27 m^3 for drinking water in 24 hours

Generates 2.7 m^3 RO concentrate along with 0.13 m^3 NF concentrate in one day.

Why use CEX and NF?

- Due to the elevated hardness of the BGNDRF groundwater, CEX resins are used to soften the water so that RO can operate at high water recovery
- Potassium chloride is used to regenerate the saturated CEX. The spent regenerant is recycled by NF, thus minimizing the amount of KCl needed to run the system
- The NF concentrate rich in potassium, calcium and magnesium could also be concentrated by monovalent permselective electrodialysis (ED) but it is directly usable as fertilizer

Prior Efforts

Prototype received third place finalist winning an honorable mention in the Desal Prize of USAID

Tested at BGNDRF during the competition using groundwater from well #3 with TDS ~ 3300-4200

Collaboration of UNT with Technion Israel Institute of Technology, and institutions in Nepal, Brazil, and Jordan

Preliminary tests

Water quality analysis of GreenDesal prototype Spring 2016 (analysis conducted by Dr. Pei Xu's team at NMSU laboratories)

	Ground water	Pre-treated to RO	RO Permeate	RO Concentrate	Spent Regen	Recycled Regen	NF Concentrate
TDS (mg/L)	**3224**	**3927**	**172**	**16940**	**22660**	**13398**	**22532**
Conductivity, mS/cm	4.1	5.3	0.5	20	33	20	33
Sodium, mg/L	359	604	32	2261	397	409	437
Potassium, mg/L	3.7	849	51	4731	4560	6080	4778
Magnesium, mg/L	187	46	0.2	260	1466	53	1447
Calcium, mg/L	301	43	n.a.	316	2147	219	2056
Chloride, mg/L	661	668	81	2714	12959	6562	12553
Sulfate, mg/L	1513	1516	8	6656	1129	74	1259
Nitrate, mg/L	0.2	0.3	0.07	0.8	2.3	1.6	2.7
Fluoride, mg/L	0.2	0.3	0.01	0.4	0.1	n.a.	n.a.
Phosphate,mg/L	n.a.	1.1	n.a.	n.a.	n.a.	n.a.	n.a.

Current efforts

Pilot Evaluation of a Sustainable Autonomous Brackish Groundwater Desalination System

Pitch to Pilot (P2P)

Cooperative Agreement R17AC00035

Bureau of Reclamation

Dr. Miguel Acevedo, University of North Texas
Dr. Pei Xu, New Mexico State University

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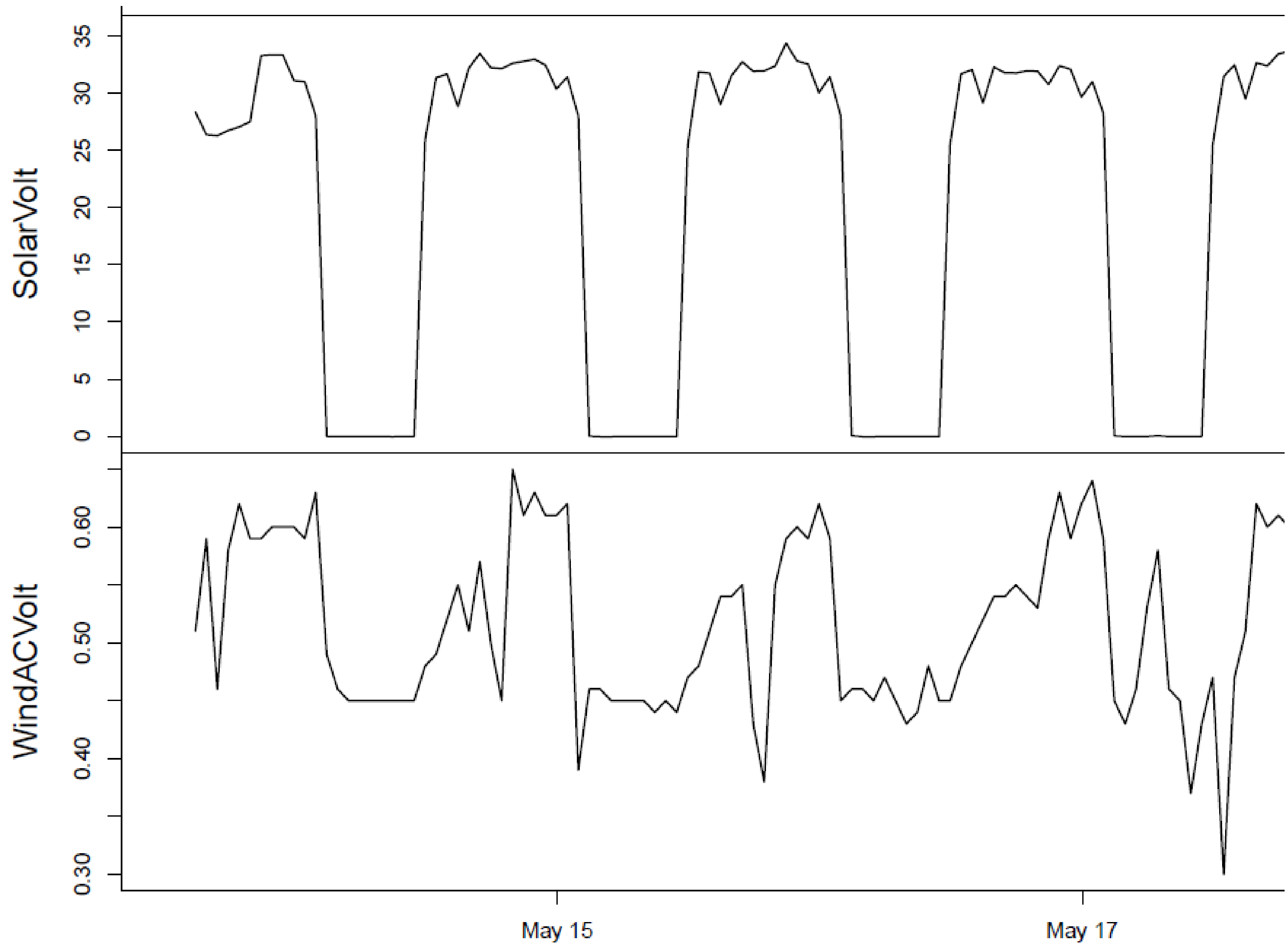
Objectives for the P2P Project

- Expansion and improvement
- Systematic experimentation and sampling
- Continuous long-term operation and monitoring
- Performance evaluation
- Practical evaluation
- Economic evaluation

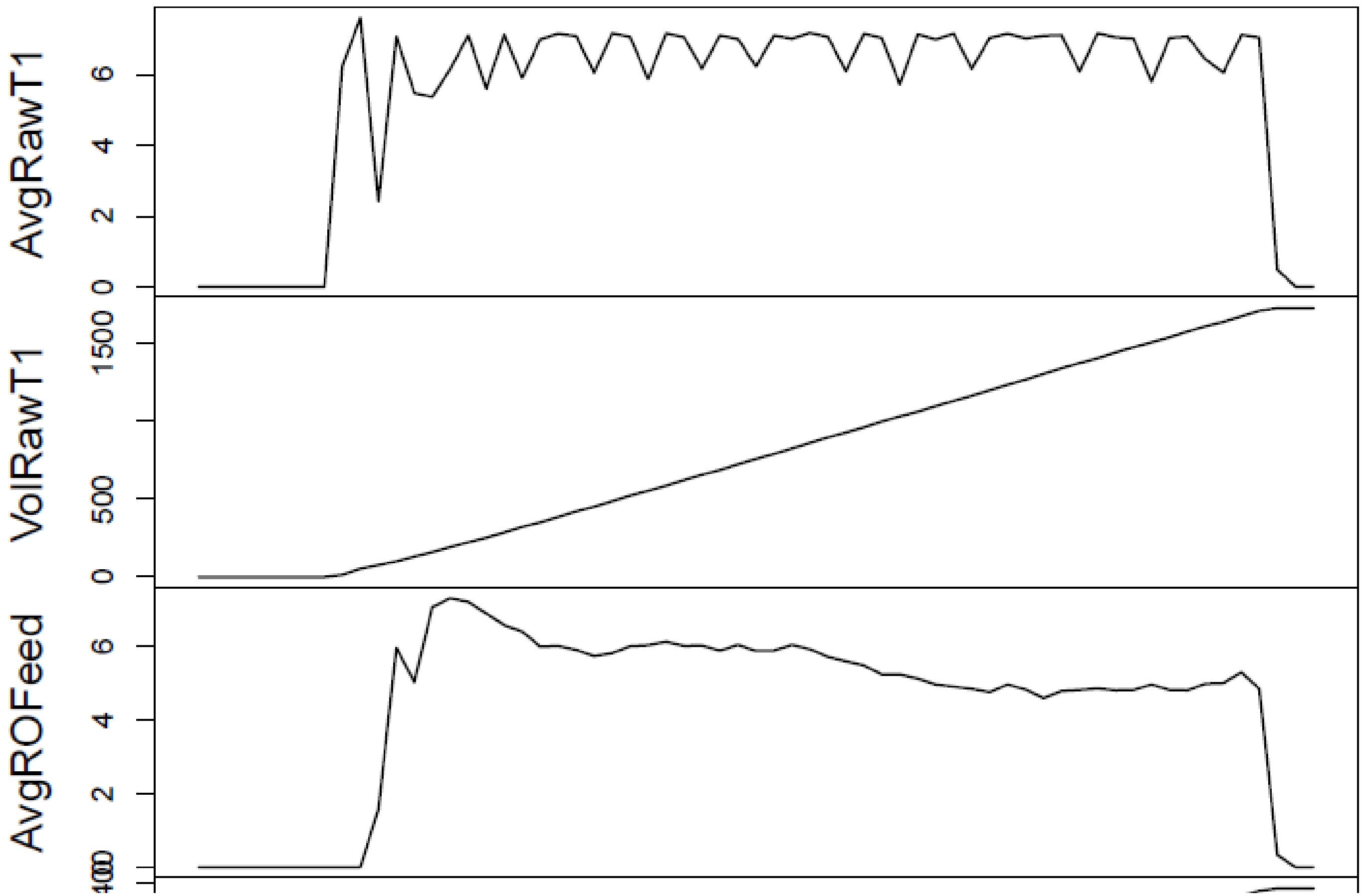
Current efforts at BGNDRF

- Power system with installed capacity of 3 kW: wind turbine (1.6 kW) and solar PV panels (4×320W=1.3kW)
- With estimated CF=0.7 it produces 50kWh per day and thus cover energy consumption
- Prototype under improvement and testing with water from wells #3, #1, and #4
- Water flow rate of 2 gpm
- Currently increasing to 4 gpm

Power monitoring: example



Monitoring flow and volume: example



Results using well #1: example

Samples	EC	Li	Na	K	Mg	Ca	Cl	SO_4
	µS/cm				mg/L			
Feed water	1693	0.05	336	6.96	23.6	112	44	510
Mixing tank (T1)	1779	0.04	313	5.00	18.9	67.0	149	491
Irrigation (T4)	772	0.02	123	2.41	12.4	18.0	25.2	199
RO perm (T6)	117	nd	13.1	0.3	0.8	0.20	15.6	2.2
RO Brine	8790	0.31	1990	49	169	663	627	2333

Summary

- Motivated by Food-Water-Energy nexus
- Powered by hybrid renewable technology
- Wind and solar resources characterization at BGNDRF
- Known and proven water treatment technologies
- Blending water to meet needs of agricultural and potable water
- Brines repurposed for alternative food production or further concentrated into fertilizers.
- Systematic data collection and interpretation