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MICRO ENERGY INTERNATIONAL

International Scientific Conference

[MES 2015] Micro Perspectives for Decentralized Energy Supply

April 23 – April 25, 2015

Bangalore, India

Techno-Economic Feasibility of PV Irrigation in Egypt

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Agriculture in Egypt

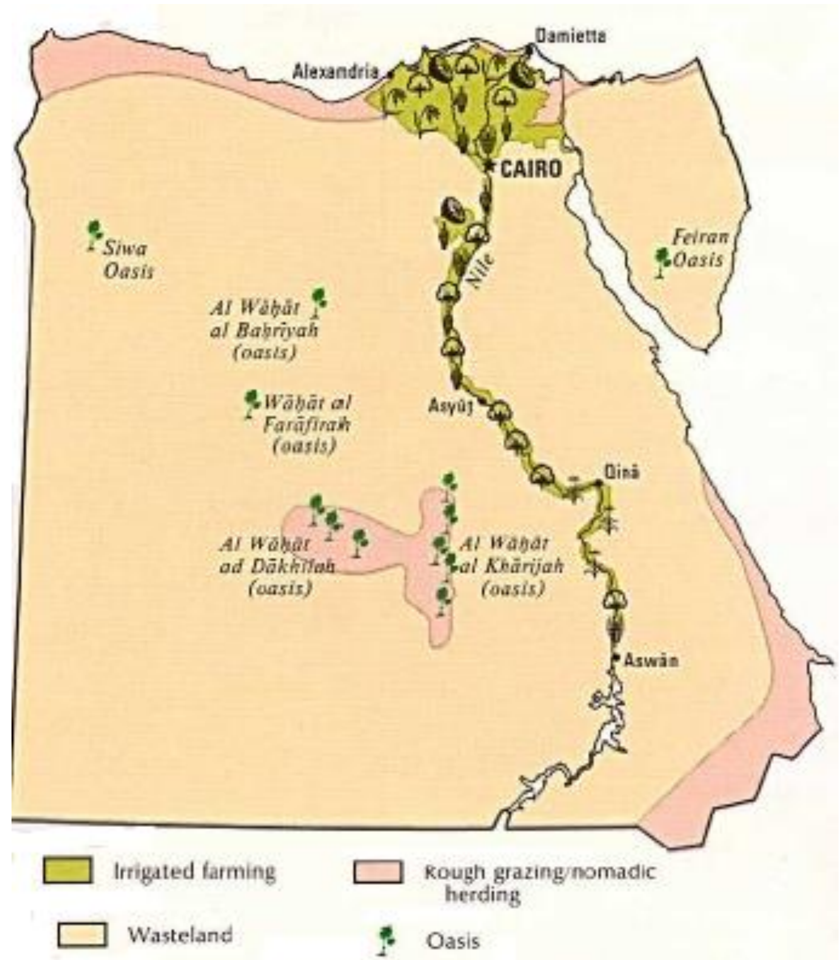
Highest employment rate; 55% indirectly & 30% directly, 17% of the GDP & 20% of all foreign exchange earnings. [1]

- Takes place in 2 lands :

1. “Old lands” (65%) [2]: Nile Delta & Valley with plot sizes from 1 to 3 acres.
2. “New Lands”: plot sizes from 2 to thousands of acres. [3]

- 99% of the population residing to only 4% of the total land mass.[2][4]

- 1 m sea level rise; flood 34% of the Delta; jeopardizing 12% of Egypt’s agricultural land. [5]



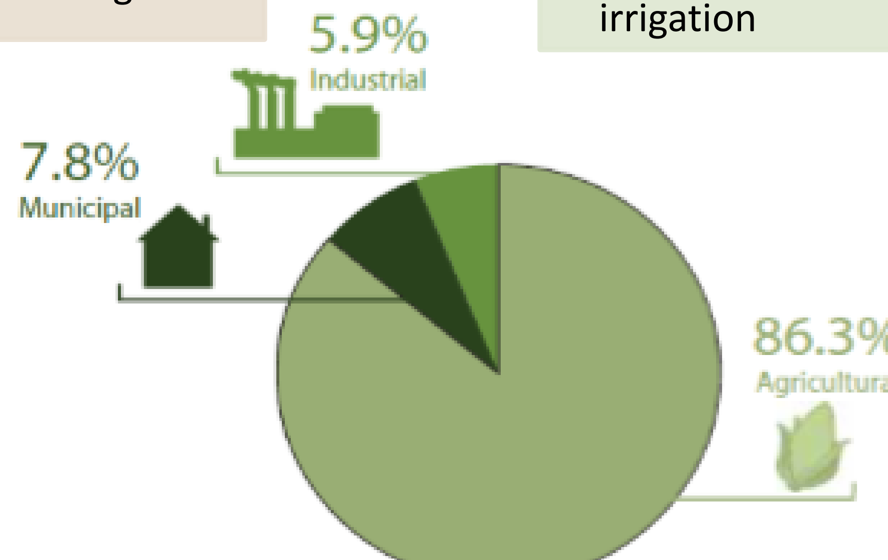
Source: FAO 2011, Egypt Country Pasture/Forage Resource Profiles

Water resources for irrigation

Egypt reached water poverty limit.

- by 2050, Population increase to 130 million and Egypt would require twice the current share of the Nile water. [17][4]
- Another climate change scenario projects 0.75 Nile discharge decrease if CO_2 emissions are doubled. [4]

Nile River	Underground water + treated water
77% of available water resources	28% of available water resources
Old Lands/New Lands	New Lands
Flood irrigation	Drip or trickle irrigation



Source: UNEP. (2010). “Africa Water Atlas”. Division of Early Warning and Assessment (DEWA)

Powering irrigation

US department of trade reported the Egyptian water pump market among the largest in the world with the dominance of diesel powered pumps over grid electric and PV ones. [3]

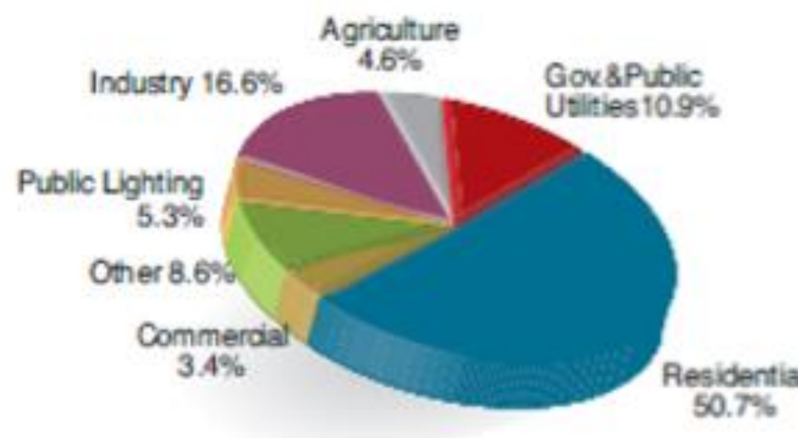
- "Diesel pump domination over the electric grid seems unjustified!"

Delta is connected to the national grid and at the most subsidized electricity to agriculture at 31.7%;circa 0.015 US$/Kwh. [6]

- Diesel domination is attributed to [3]:

1- Unreliable grid with frequent cuts.

2- Old Lands are small plots with a low average power requirement not of interest to electrification authority.

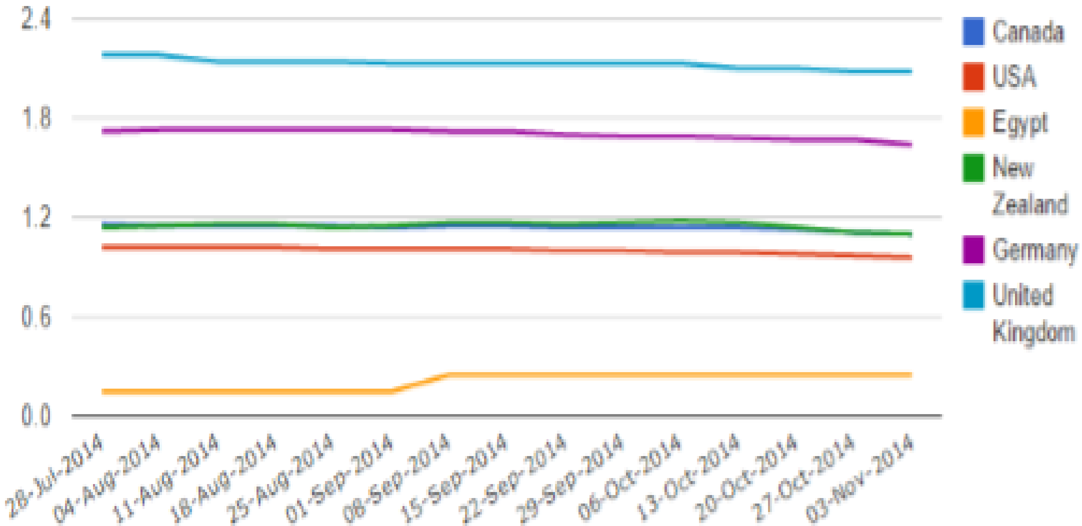


Source: Egyptian Electricity Company Annual Report. 2013

Powering irrigation (Subsidies)

Dominance of diesel pumps over PV ones was justifiable.

- Farmers tend to purchase systems with higher recurrent costs rather high capital ones. [7]
- 71% of total subsidies is allocated to energy subsidy. [8]
- Diesel prices subsidized at 65% reaching 0.15 US$/liter in early 2014. [9]



Source: Siemens, Making sense of it all

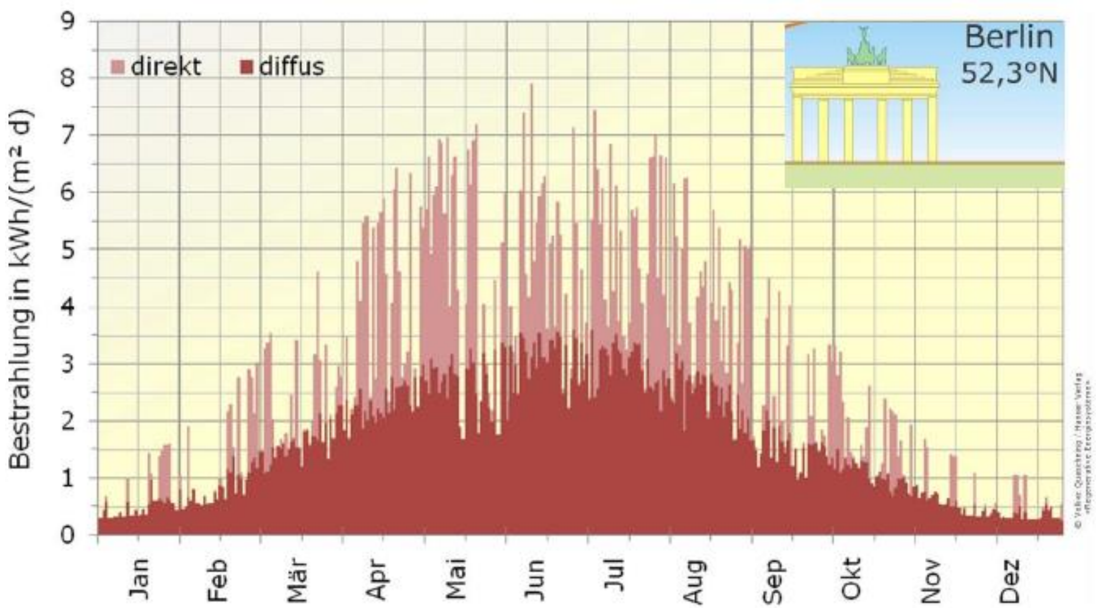
Source: Global Petrol prices.com

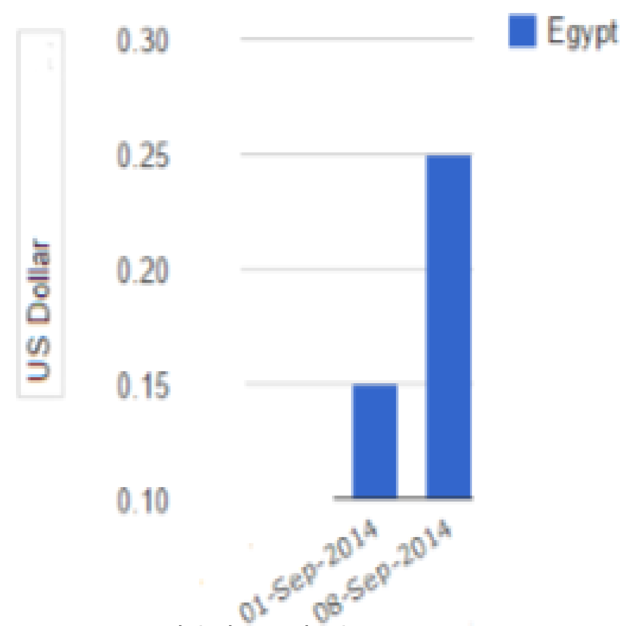
Shift towards the PV driven pumping

PV learning curves are declining, fuel costs are ever increasing and diesel is among the highest CO_2 emitting fuels (1.050 kg of CO_2 /KWh). [12]

The government reclaimed More than 3 million acres and considering;

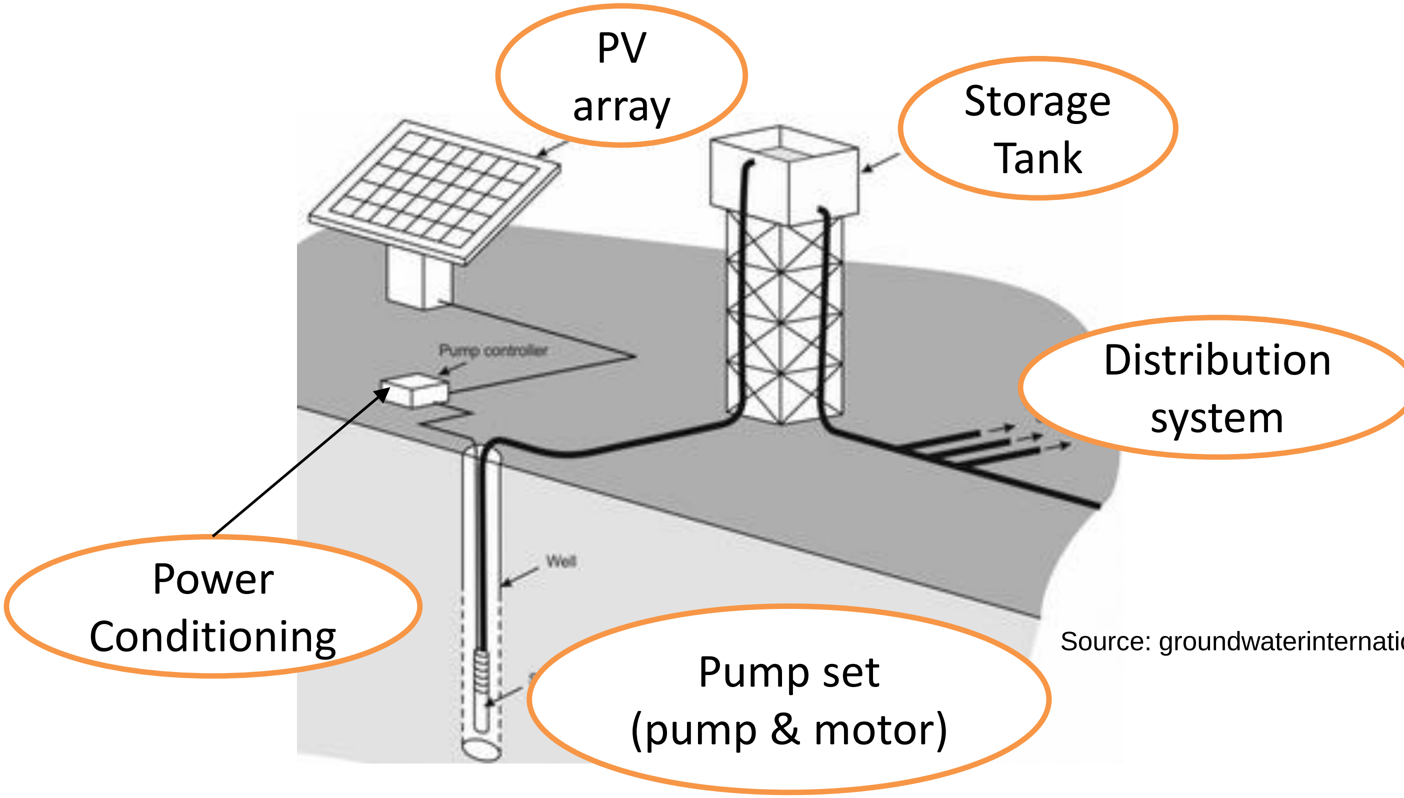
- underground water for irrigation. [3]
- Egypt’s favorable solar conditions of 3900 sunshine hours and above 2600 KWh/m^2 in the south to power the irrigation. [4]





Source: Global Petrol prices.com

Common components of PV Pumping



Source: groundwaterinternational

Power conditioning

- Controller: An Electronic device matches the PV power to the motor and controls the operation of the PV pump; start and stop.

Source: Lorentz

- Inverter: convert DC electricity to AC (Alternating Current) to run AC pumps sets,

Source: SMA.

Pump set (Motor & Pump)

Brushless DC Motors	AC Motors
More efficient, low maintenance	Cheaper but require relatively expensive inverters
Less complex power conditioning	Large variety over larger loads

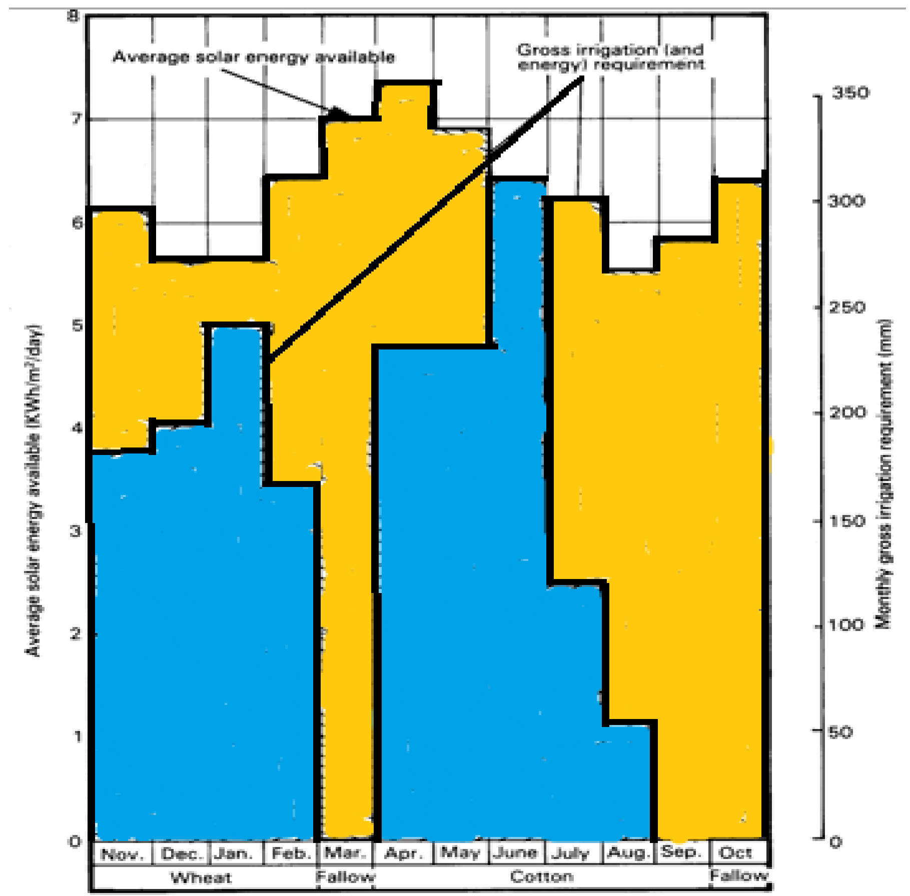
Submersible Pump	Surface Pump
High heads (compared to 6.5 m limitation)	Cheaper
No cavitation problems	Push water to longer distances

Centrifugal Pump	Positive Displacement Pump
Efficiency drop away from design speed	Efficiency drop at lower heads.
Low starting torque	Higher depths of head

Storage

Storage is not as severe in PV pumping as in other applications.

- Store water in gravity feed storage tanks and avoid higher investment and O&M costs of batteries. [14]
- Unlike the storage capacity of 2 to 5 days for a village water supply, a proportional relation between the crops evapotranspiration and the solar insolation. [14]
- 2 to 3 days of storage available at the root zone of the plant. [16]



Source: FAO, 1986

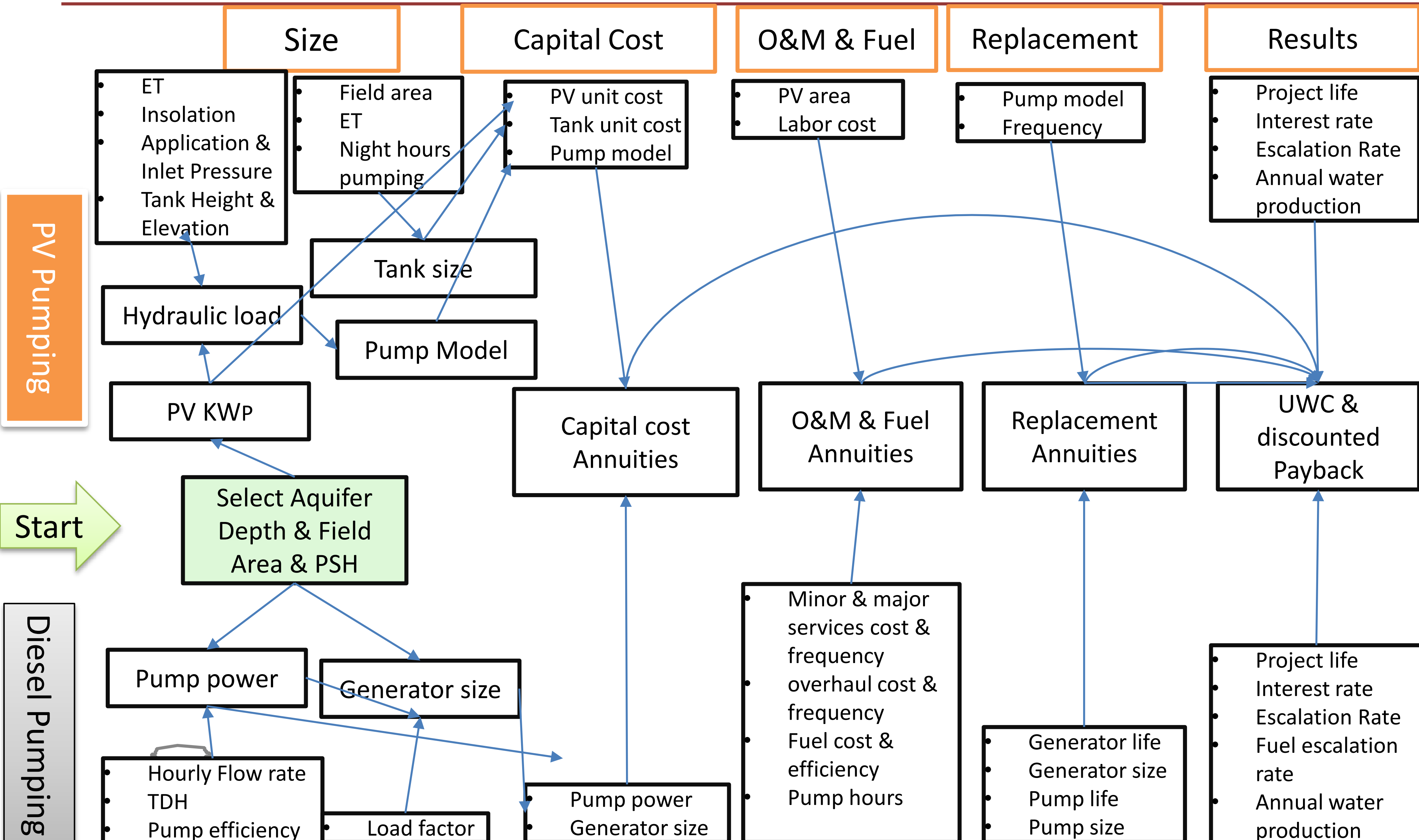
Distribution System

In the PV pumping context, **application efficiency** and the **application heads** are the factors determining the compatibility of the application.

Application	Efficiency (%)	Head (m)	Suitable (Yes/No)	Remarks
Channel	40-60	Very low	Sometimes	
Drip	90	Low	Yes	
Hose and Basin	90	Low	Yes	Labor intensive
Sprinkler	70	High	No	
Flood	40- 50	Very Low	No	

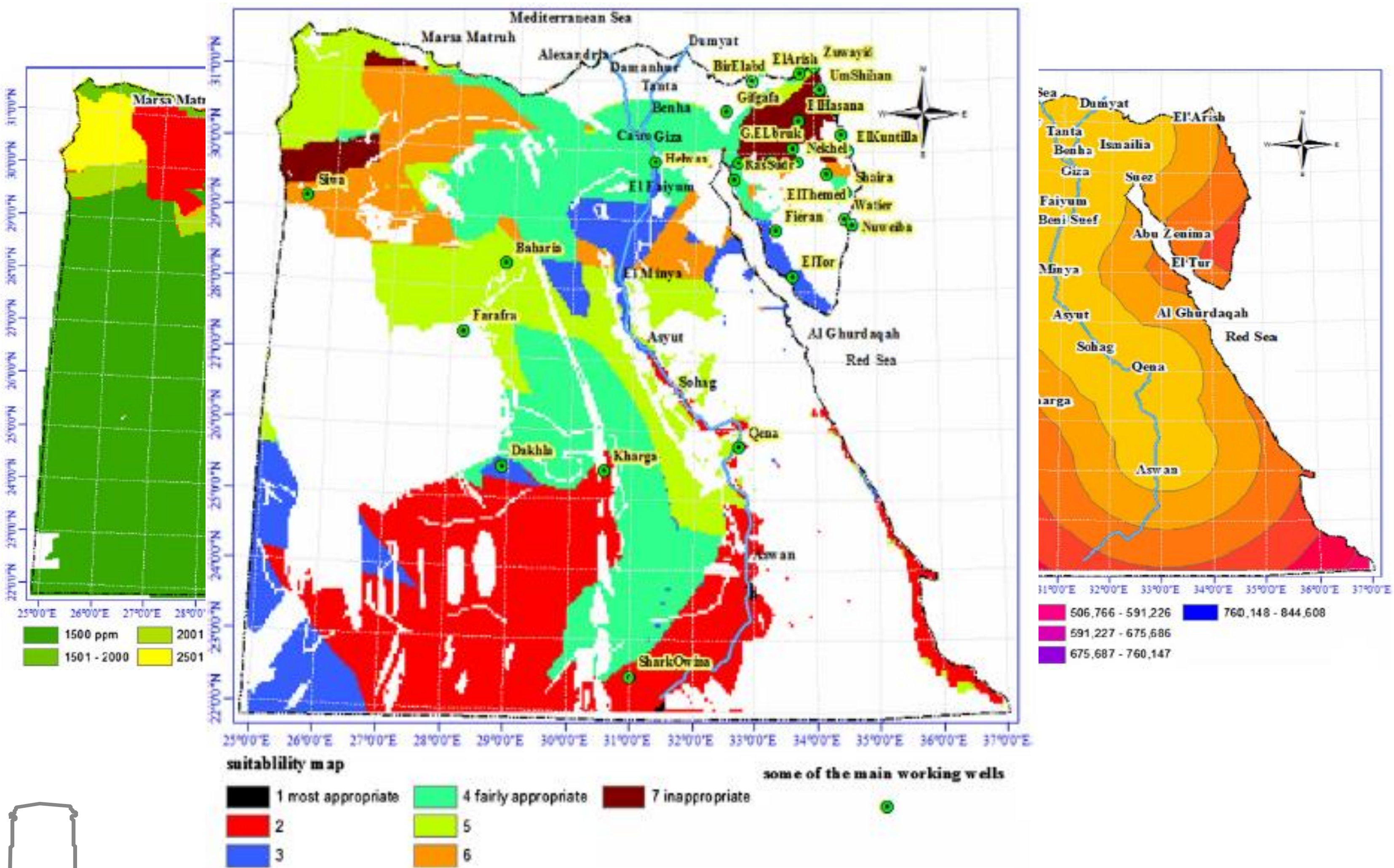
Source: An Introduction and Update on the Technology, Performance, Costs, and Economics. UNDP

Model flowchart



site selection

Source: Environment and Climate changes Research Institute (ECRI), National Water Research Center (NWRC), Egypt. Mariam G. Salim

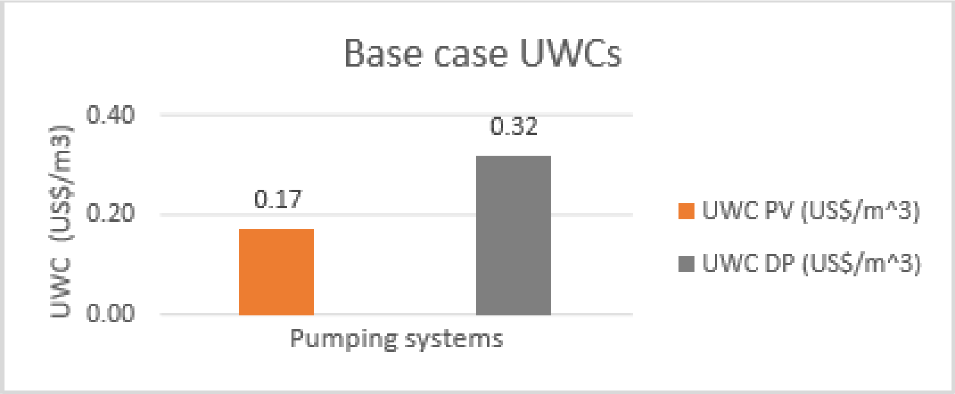


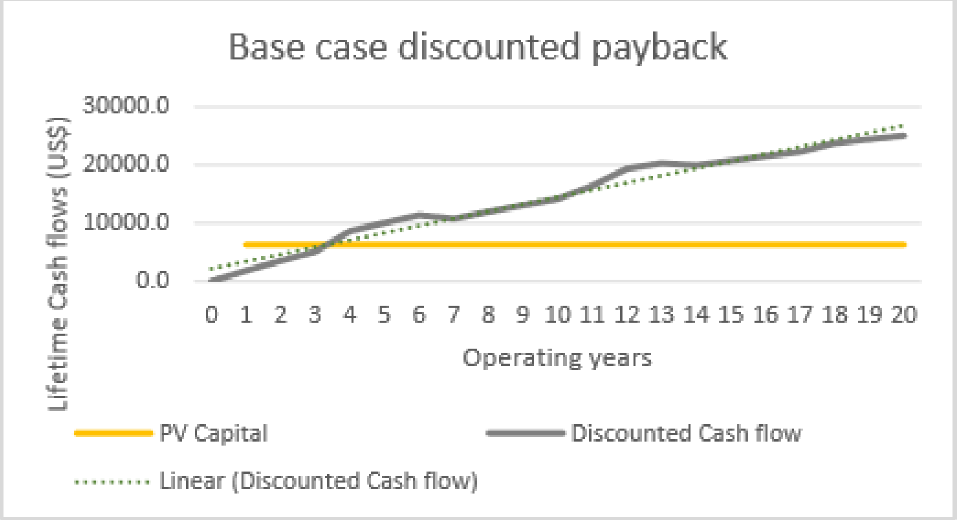
Base case results

Technical diesel pumping inputs	Value
η_P, Pump Efficiency (%)	0.6
L_F, Load Factor	0.7
$Specific_{fc}$, Specific diesel consumption (liter/KWh)	0.3

Technical PV pumping inputs	Value
Solar Insolation (KWh/m^2)	6.8
A_f, Area of Field (m^2)	6,000
Drip System (Drip/Channel)	Drip
Night Pumping Hours (hr)	0
Hours Of storage (hr)	1
Aquifer Depth (m)	60
η_{sub}, Subsystem Efficiency	0.6
η_{PV}, module, PV Module Efficiency at STC (%)	0.14

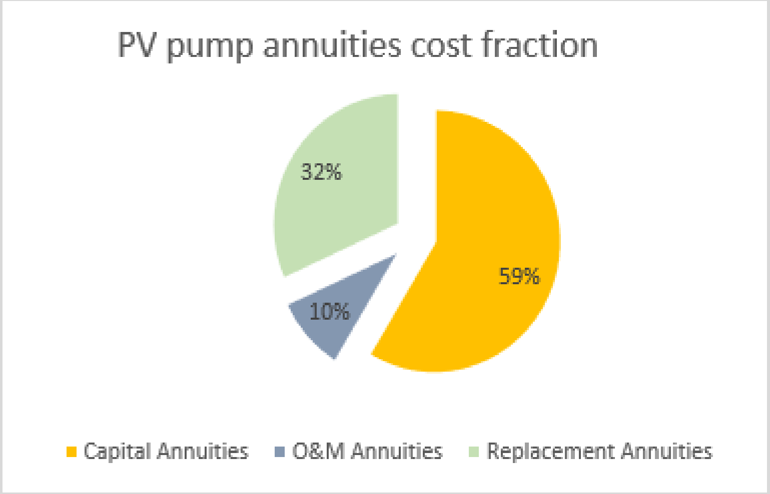
Economic inputs	Value
n, Project lifetime (years)	20
i, Interest rate (%)	10
r_n, escalation rate (%)	3





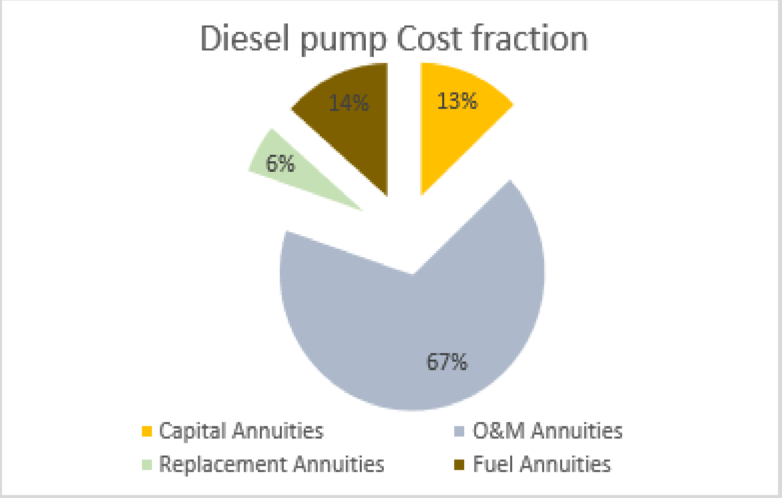
Cost Fractions

- PV pumping is capital intensive
- O&M is neglected



- Fuel costs should dominate the diesel pumping annuities cost fraction.

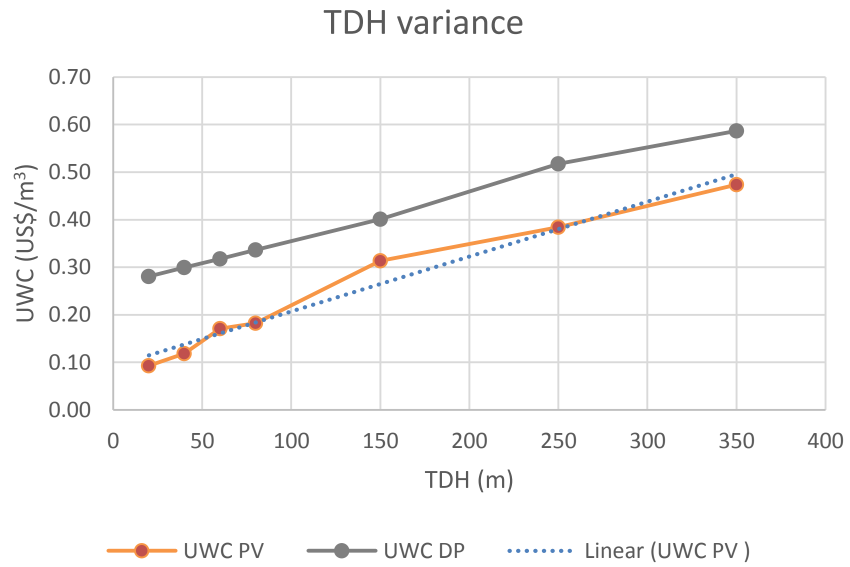
low hydraulic load, subsidized diesel, O&M dominate (economies of scale).



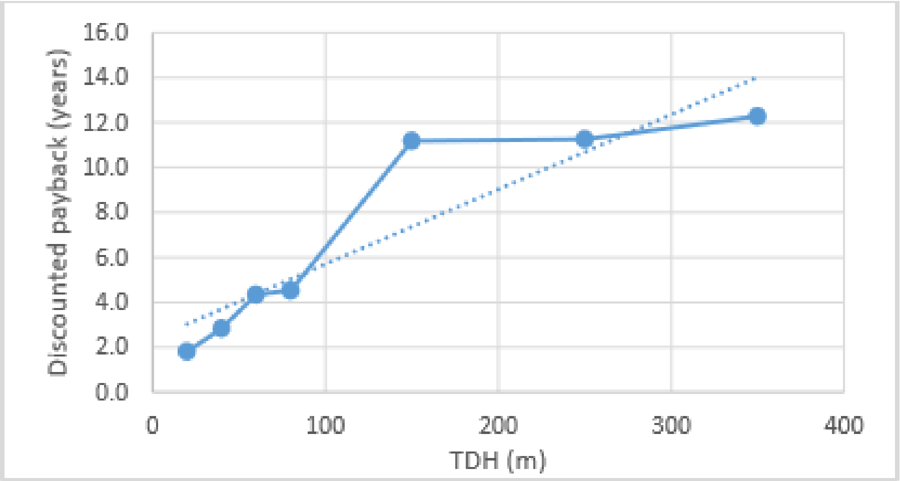
Sensitivity Total Dynamic Head (TDH)

TDH ⬆, UWCs ⬆⬆

Trend slope of the UWC of the PV pump shows faster increase



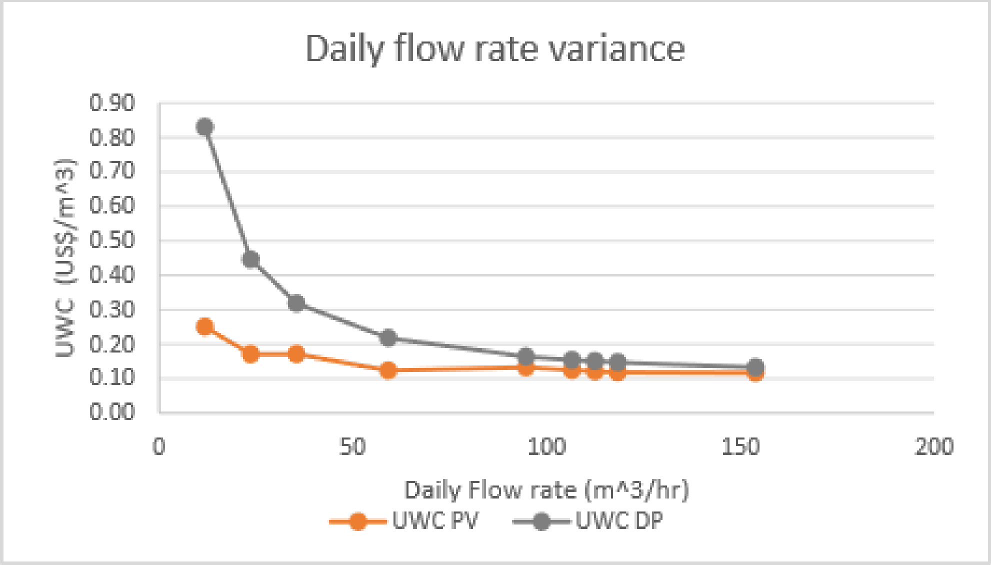
TDH ⬆, Payback period ⬆



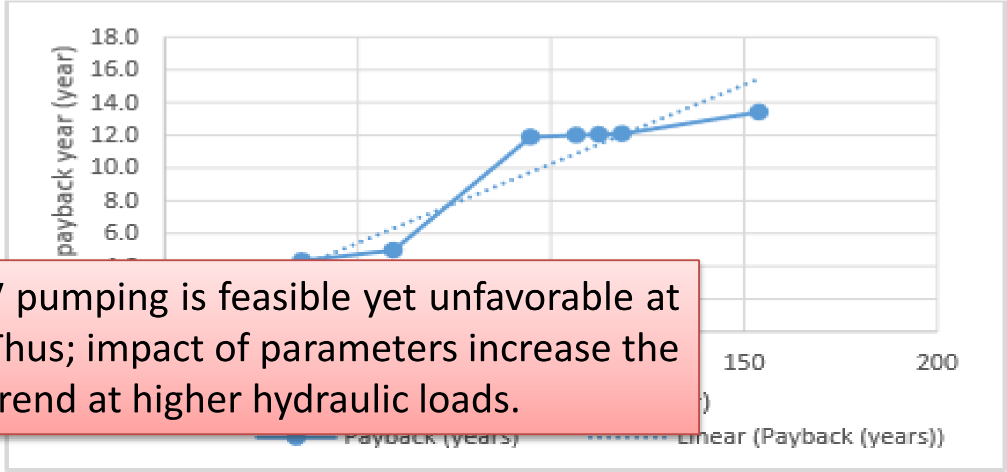
Daily water requirement

Daily water requirement ↑ , UWCs ↓↓

- Total LCC are divided by increased water production.
- In the PV system, increased daily water production means increased storage cost.



Daily water requirement ↑, Payback period ↑

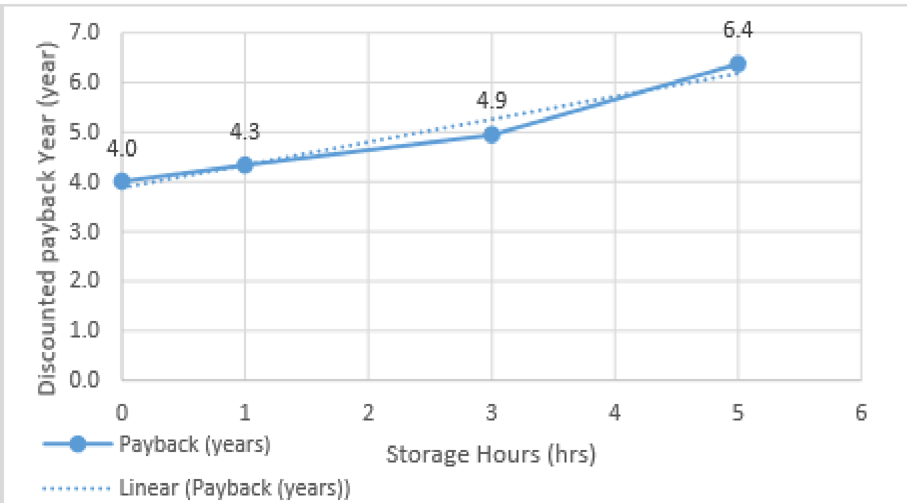


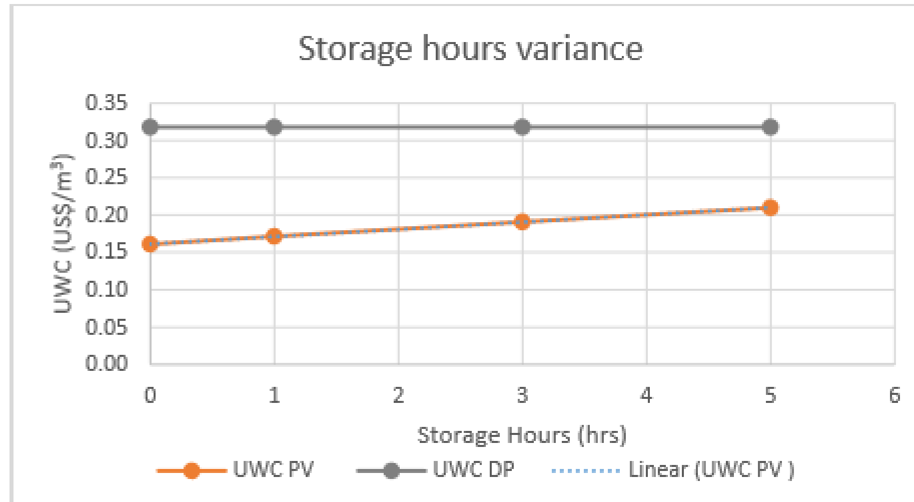
It can be concluded; PV pumping is feasible yet unfavorable at higher hydraulic loads. Thus; impact of parameters increase the UWCs will magnify the trend at higher hydraulic loads.

Storage

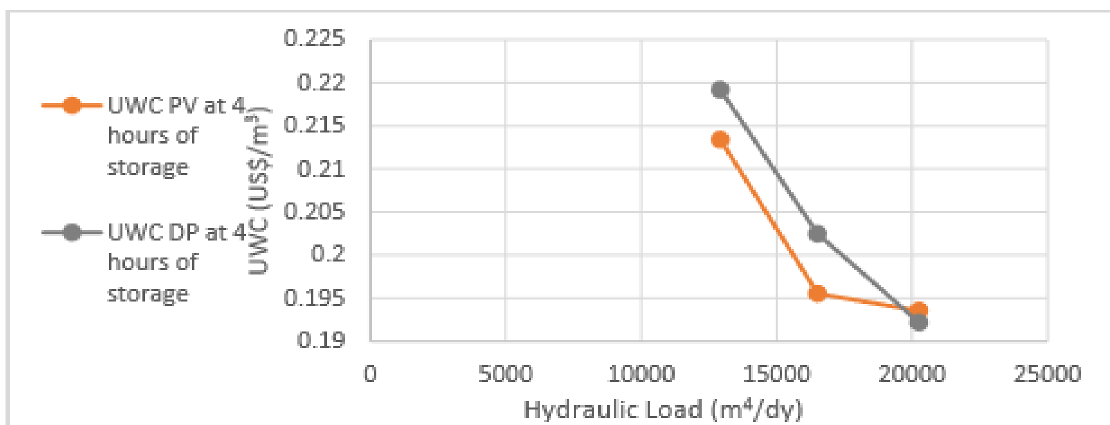
storage hours ↑, UWCs ↑, payback period ↑.

- Simultaneous increase in tank capacity and the TDH as of the increased tank height.



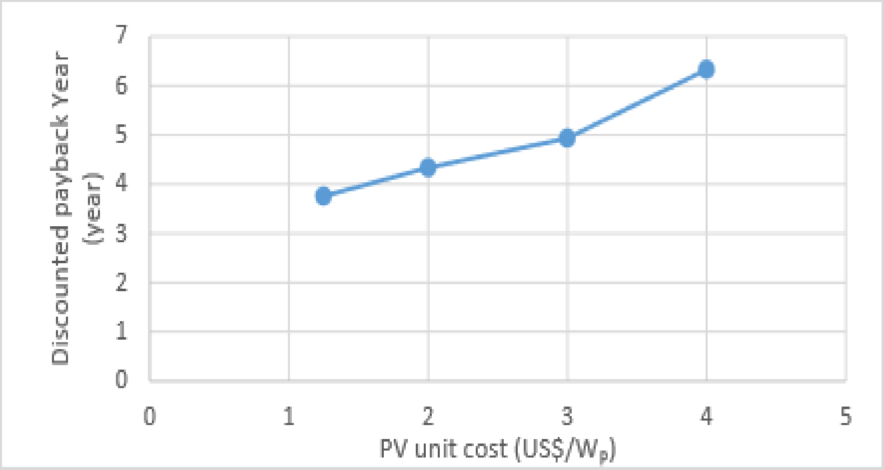


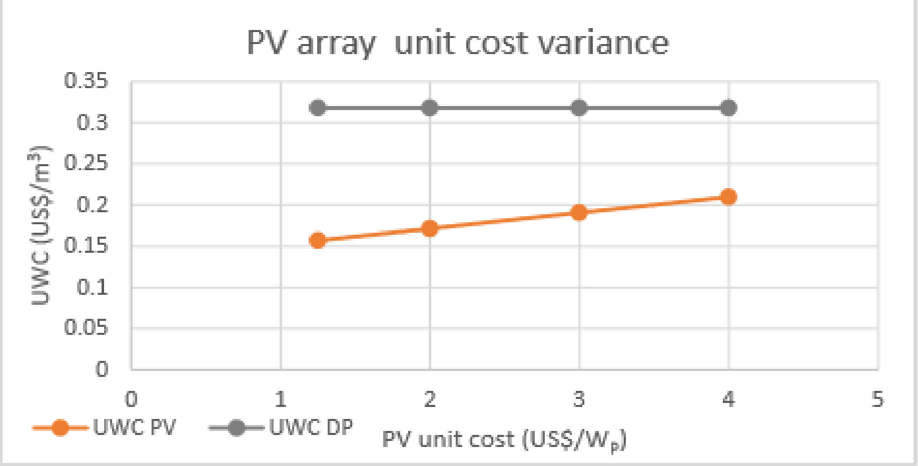
UWCs at 4 hours of storage.

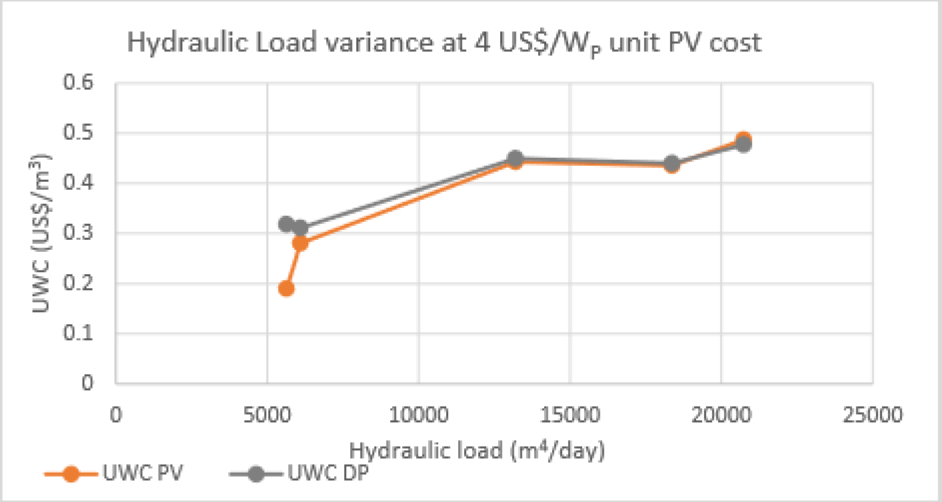


PV unit Costs

. PV arrays are the most expensive component PV unit costs ↑ , UWCS ↑ , Payback period ↑



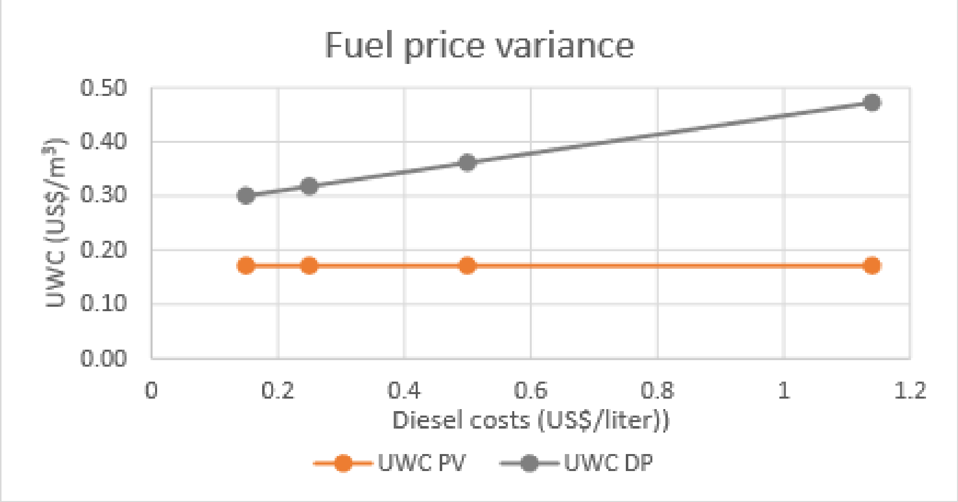


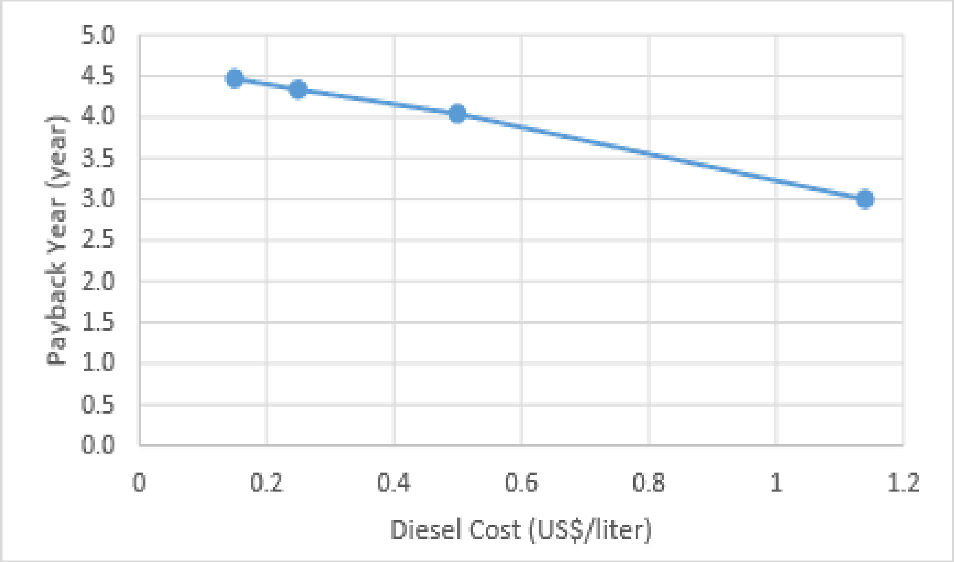


Fuel costs

Fuel prices ⬆, UWC ⬆, Payback period ⬇

- The fuel prices used are representative of the Egyptian diesel prices in comparison with the global average.

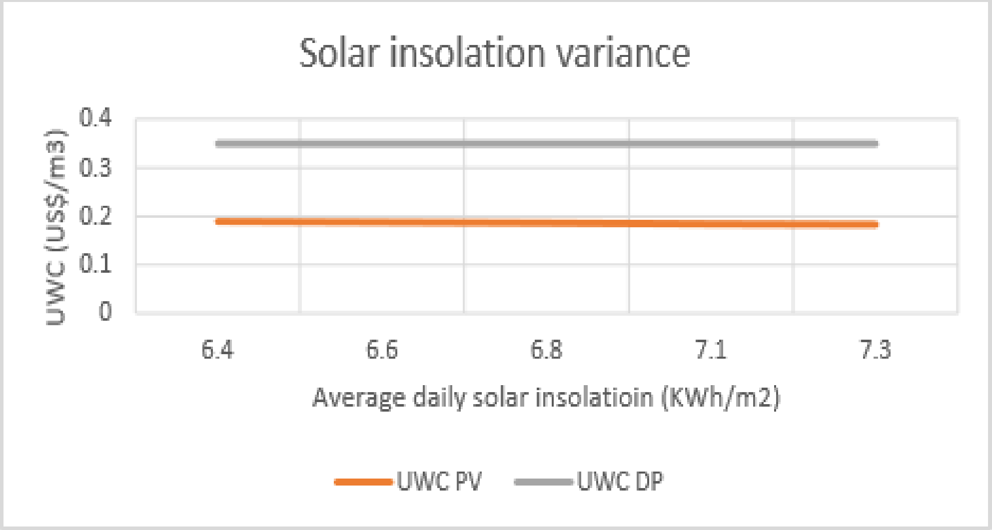


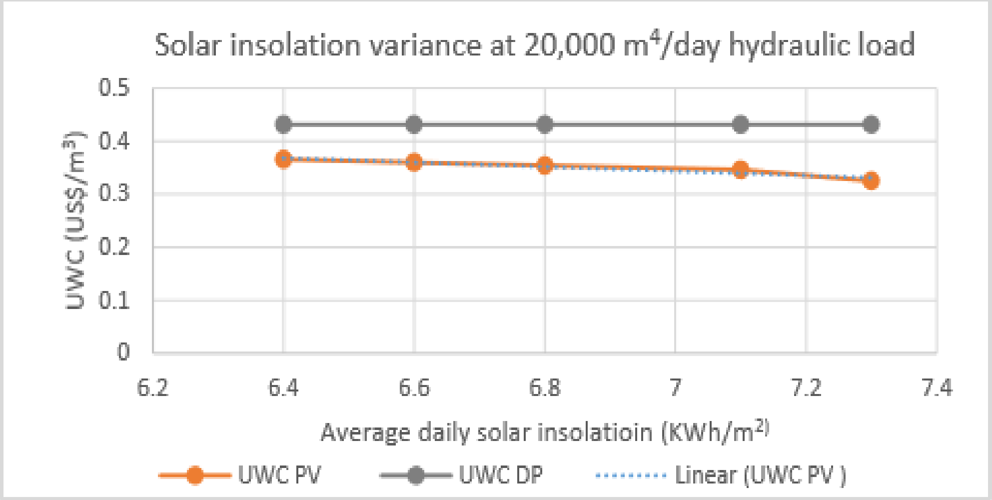


Solar insolation

Solar insolation ⬆, UWC ⬇

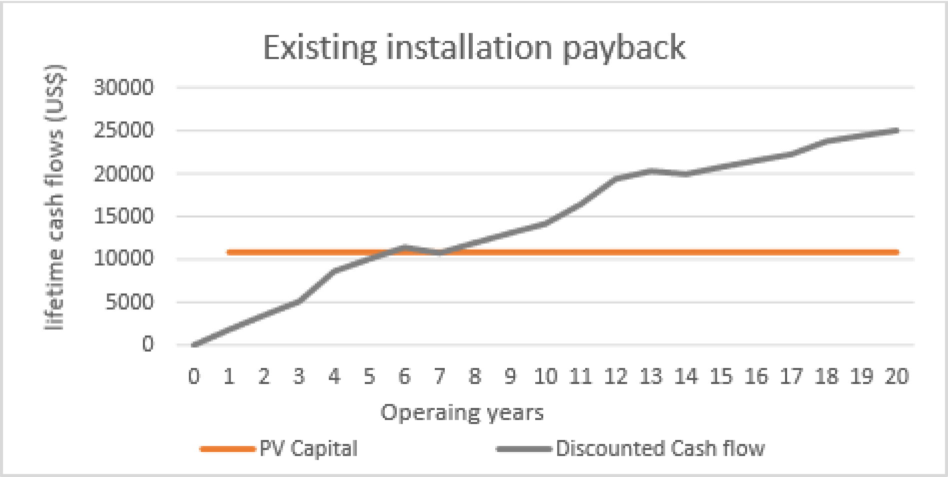
Higher solar insolation translates economically into a smaller PV Pumping system.

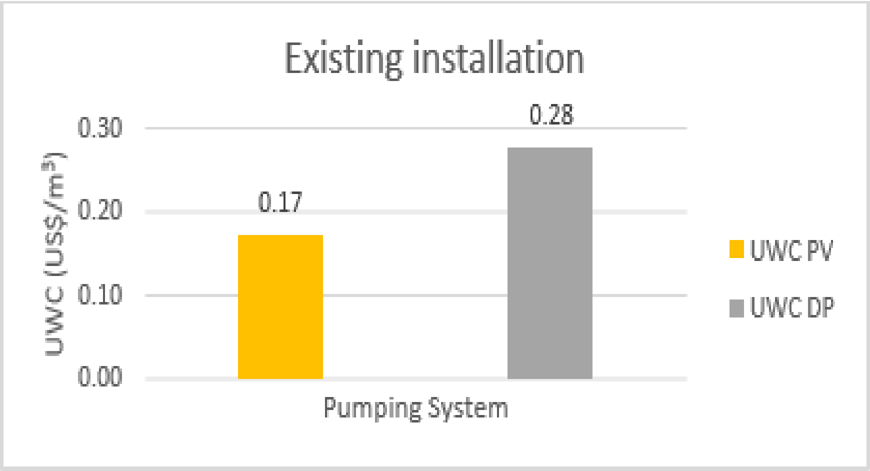


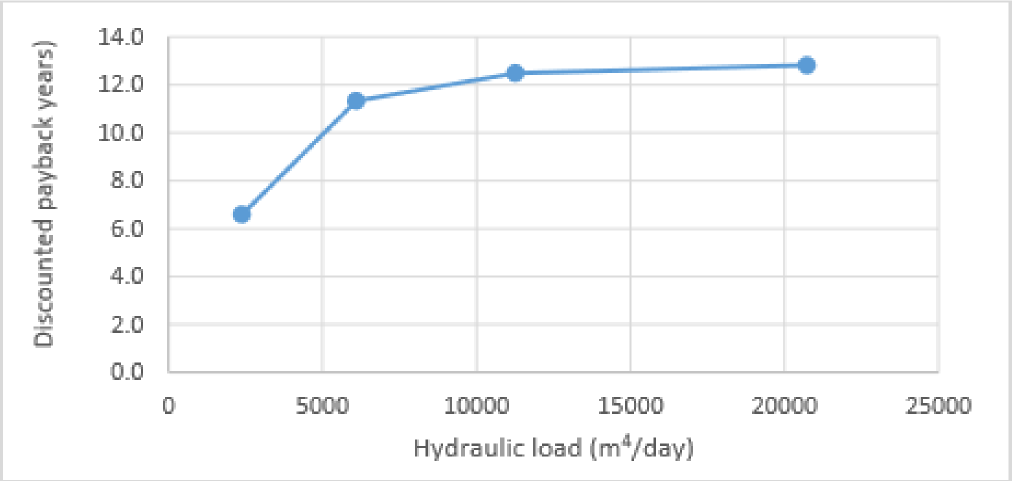


Existing diesel installation

Capital exhibits lowest cost fraction in diesel pumping







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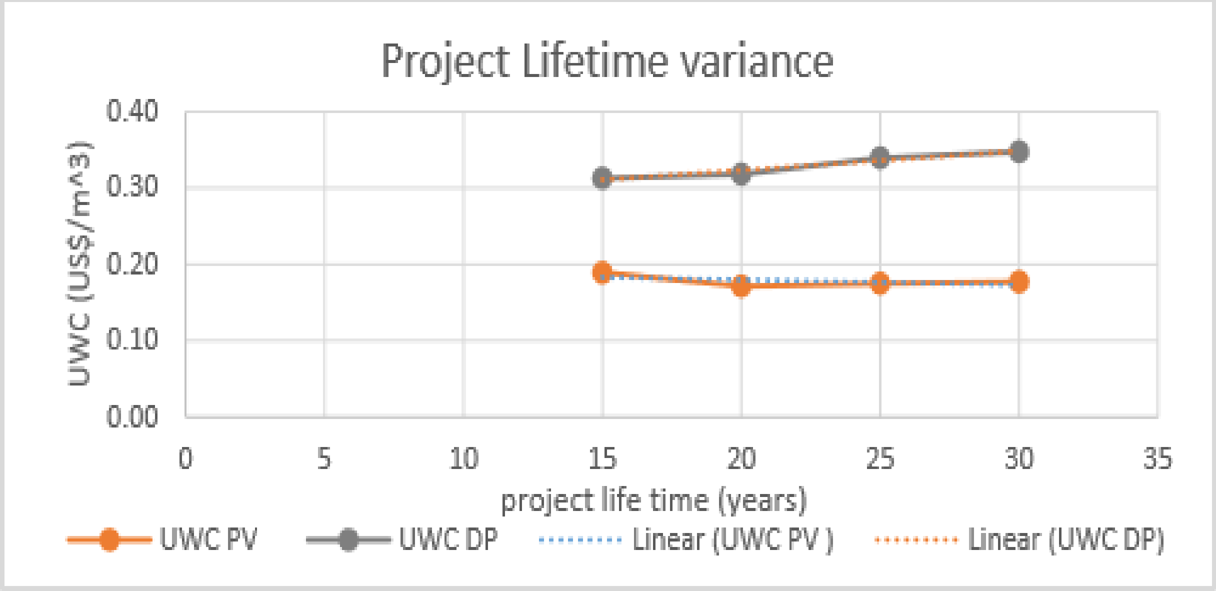
Project lifetime

As the project lifetime ⬆, UWCs ⬇⬆

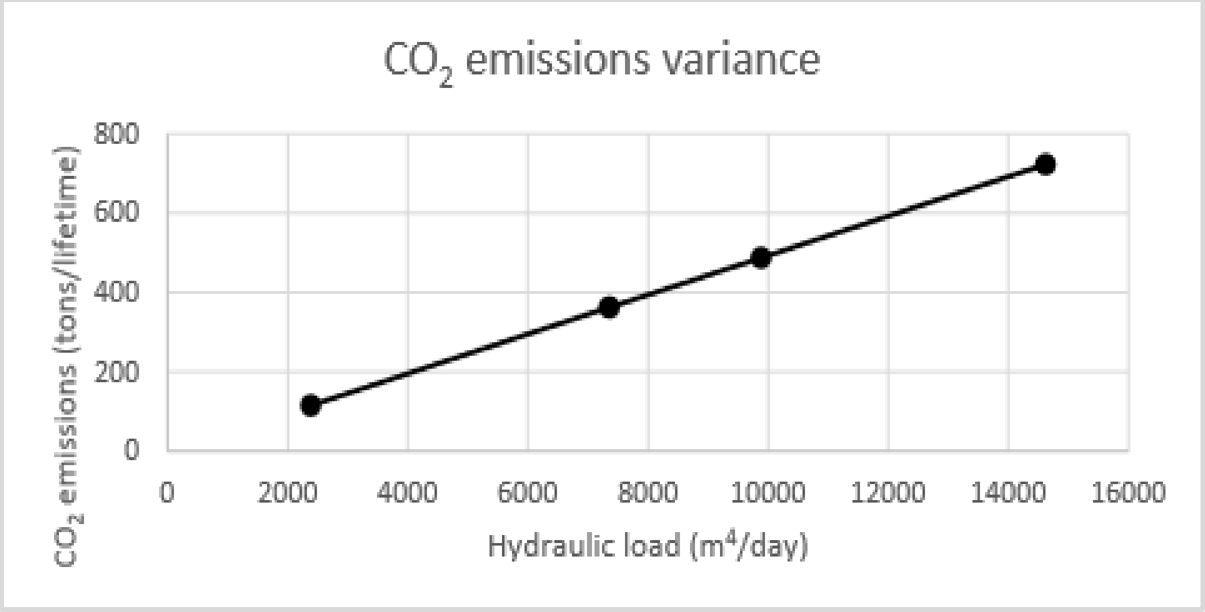
- Higher recurrent costs over a longer period of time with escalation rates.
- PV pumping annuities high upfront costs will be recovered over a longer period.



CO_2 Emissions

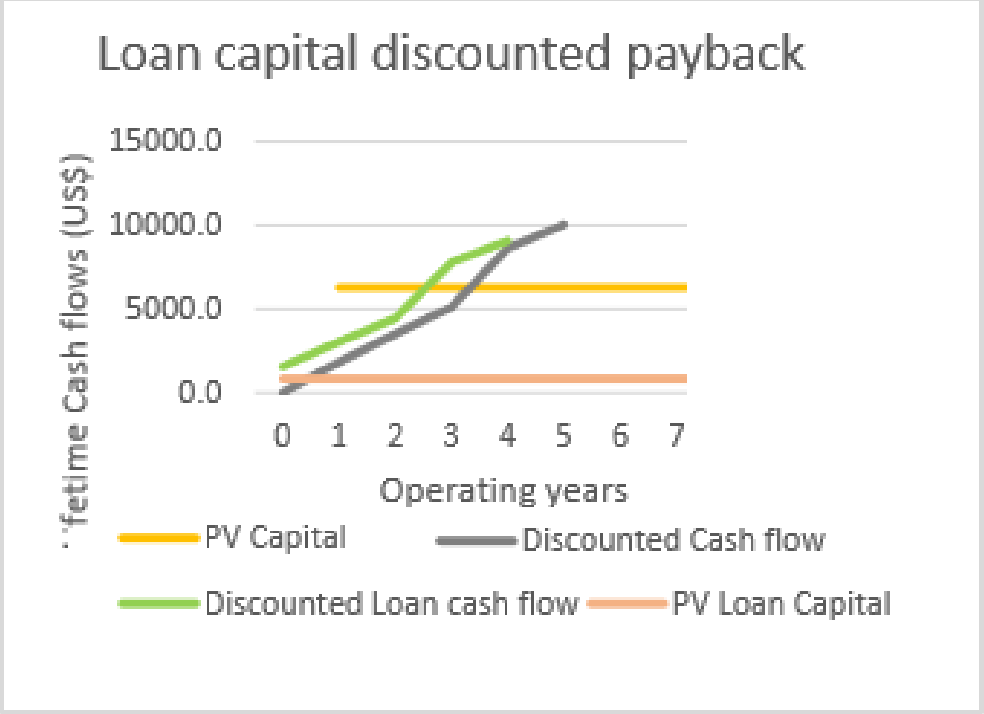
Daily hydraulic load ⬆, CO_2 emissions linearly ⬆

Emissions reach 750 tons at a hydraulic load of 15,000 m[4]/day over the project lifetime.



Finance

A loan capital would harmonize the high capital investment requirement to be more in pace with the negligible recurrent and high recovered capital costs of such long term PV pumping projects



Thank you

Questions?

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Back up slides

Economic diesel pumping inputs	Value
Existing installation (Yes/No)	No
Installation cost (%)	10
Generator quality (low/High)	High
$E_{f,minor}$, Minor service frequency (frequency/Years)	4
$E_{f,minor}$, Major service frequency (frequency/Years)	2
$E_{f,overhaul}$, Overhaul frequency (hrs)	10,000
$E_{f,Gen}$, Generator replacement (hrs)	35,000
U_{diesel}, diesel unit costs (US$/Liter)	0.25
$r_n{}^{fuel}$, Fuel Escalation rate (%)	8

Technical diesel pumping inputs	Value
η_p, Pump Efficiency (%)	0.6
L_F, Load Factor	0.7
$Specific_{fc}$, Specific diesel consumption (liter/KWh)	0.3
CO_2 Emitted (Kg/KWh)	1.05
H_{DP}, daily pumping hours (hr)	8

Economic PV pumping inputs	Value
n, Project lifetime (years)	20
$E_{f,PVp}$, frequency of PV pump replacement (years)	7
U_{PV}, PV generator unit cost ($US\$/kW_P$)	0.002
Installation costs (%)	10
U_{tank}, Water storage tank unit cost (US$/m^3)	200
$U_{shiping}$, Shipping unit Cost (US$/kg)	1.82
$U_{unskilled}$, Unskilled labor Cost ($/hr)	7

Technical PV pumping inputs	Value
Solar Insolation (KWh/m^2)	6.8
ET (varies/Constant)	Varies
T_a, Ambient Temperature (C°)	27
A_f, Area of Field (m^2)	6,000
Drip System (Drip/Channel)	Drip
Night Pumping Hours (hr)	0
Hours Of storage (hr)	1
$h_{Tank}/_d$, Height to Diameter Ratio	1
($Main\ line_{FL}$), Main Pipe length (m)	10
($U_{Pressure}$), Drip inlet pressure per area (psi/m^2)	0.001
Aquifer Depth (m)	60
η_{sub}, Subsystem Efficiency	0.6
SF, Safety Factor	1.2
I_{max}, Irradiation at STC (kW/m^2)	1
η_{PV}, module, PV Module Efficiency at STC (%)	0.14

Financial Inputs	Value
i, Interest rate (%)	10
r_n, escalation rate (%)	3
CI_{2014}, 2014 Cost Index	569.9
CI_{2010}, 2010 Cost Index	550.8

Series	Hydraulic Load (m^4/hr)	Price (US$)	Weight (Kg)
PS150	29	1,616	23
PS200	50	2,055.70	25
PS600	136	2,742.79	37
PS1200	207.5	2,742.79	38
PS1800	280	3,519.52	42
PS4000	720	5,747.01	49
PS9K2	1620	10,501.90	163
PS15k2	2730	12,979.00	197
PS21K2	3850	14,510.00	227
PS25K2	4620	16,000	233