Solar Desalination System Design for Irrigation/Drinking Water and Electricity Generation in Desert or Arid Areas

Jose Izquierdo, Richard E. Blanchard *

Loughborough University, Loughborough LE11 3TU, UK

* Correspondence: Richard E. Blanchard; Email: r.e.blanchard@lboro.ac.uk.

SUPPLIMENTARY DATA FILE

APPENDIX A: MAP WITH LOCATION OF THE PROJECT

From http://www.un.org/Depts/Cartographic/map/profile/wsahara.pdf

Coordinates: 26.172147,-11.0875829

APPENDIX B: SURFACE METEROLOGY AND SOLAR ENERGY DATA FROM NASA (ATMOSPHERIC SCIENCE DATA CENTER)

SSE Homepage | Find A Different Location | Accuracy | Methodology | Parameters (Units & Definition)

ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy - Available Tables

Latitude 26.172 / Longitude -11.088 was chosen.

Geometry Information

Elevation: **306** meters
taken from the
NASA GEOS-4
model elevation

	Northern boundary **27**	
Western boundary **-12**	Center Latitude **26.5** Longitude **-11.5**	Eastern boundary **-11**
	Southern boundary **26**	

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:

Monthly Averaged Insolation Incident On A Horizontal Surface ($kWh/m^2/day$)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	3.81	4.68	5.89	6.98	7.39	7.56	7.35	6.80	5.87	4.83	3.95	3.38	5.71

Minimum And Maximum Difference From Monthly Averaged Insolation (%)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	-9	-14	-7	-6	-6	-7	-8	-5	-8	-11	-9	-15
Maximum	7	10	6	4	6	7	7	10	6	9	13	15

Parameter Definition

Monthly Averaged Diffuse Radiation Incident On A Horizontal Surface ($kWh/m^2/day$)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	1.09	1.28	1.48	1.65	1.86	1.93	1.93	1.83	1.68	1.43	1.16	1.07	1.53
Minimum	0.99	1.07	1.32	1.51	1.66	1.69	1.71	1.54	1.54	1.26	0.96	0.89	1.35
Maximum	1.19	1.48	1.63	1.83	2.04	2.14	2.14	1.97	1.83	1.58	1.26	1.18	1.69
22-year Average K	0.58	0.60	0.63	0.66	0.66	0.66	0.65	0.64	0.61	0.59	0.57	0.55	0.62
Minimum K	0.53	0.51	0.59	0.62	0.62	0.61	0.60	0.60	0.56	0.52	0.52	0.47	0.56
Maximum K	0.62	0.66	0.67	0.69	0.70	0.71	0.70	0.70	0.64	0.64	0.65	0.63	0.67

NOTE:	*Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

Parameter Definition

Monthly Averaged Direct Normal Radiation ($kWh/m^2/day$)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	5.56	6.14	7.07	7.92	8.00	8.13	7.83	7.26	6.48	5.88	5.49	4.90	6.72

Minimum And Maximum Difference From Monthly Averaged Direct Normal Radiation (%)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	-9	-13	-5	-5	-4	-5	-6	-1	-7	-10	-4	-13
Maximum	5	8	4	1	4	5	4	10	4	7	14	17

NOTE:	*Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

Monthly Averaged Insolation Incident On A Horizontal Surface At Indicated GMT Times (kW/m^2)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average@00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Average@03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Average@06	n/a	0.00	0.00	0.02	0.03	0.04	0.03	0.02	0.01	0.00	0.00	0.00
Average@09	0.16	0.21	0.32	0.43	0.49	0.50	0.46	0.40	0.32	0.27	0.23	0.16
Average@12	0.55	0.64	0.75	0.87	0.89	0.88	0.86	0.85	0.79	0.69	0.59	0.51
Average@15	0.46	0.56	0.70	0.77	0.80	0.79	0.78	0.76	0.68	0.55	0.43	0.39
Average@18	0.05	0.09	0.13	0.17	0.19	0.23	0.25	0.17	0.10	0.05	0.03	0.03
Average@21	n/a	n/a	n/a	n/a	0.00	0.00	0.00	n/a	n/a	n/a	n/a	n/a

Parameter Definition

Monthly Averaged Insolation Clearness Index (0 to 1.0)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average K	0.58	0.60	0.63	0.66	0.66	0.66	0.65	0.64	0.61	0.59	0.57	0.55	0.62
Minimum K	0.53	0.51	0.59	0.62	0.62	0.61	0.60	0.60	0.56	0.52	0.52	0.47	0.56
Maximum K	0.62	0.66	0.67	0.69	0.70	0.71	0.70	0.70	0.64	0.64	0.65	0.63	0.67

Parameter Definition

Monthly Averaged Insolation Normalized Clearness Index (0 to 1.0)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	0.53	0.55	0.58	0.61	0.60	0.61	0.60	0.58	0.56	0.54	0.53	0.50

Parameter Definition

Monthly Averaged Clear Sky Insolation Incident On A Horizontal Surface (kWh/m^2/day)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	4.28	5.26	6.45	7.52	7.69	7.74	7.31	6.91	6.21	5.33	4.44	3.86	6.08

Parameter Definition

Monthly Averaged Clear Sky Insolation Clearness Index (0 to 1.0)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	0.65	0.67	0.70	0.72	0.69	0.68	0.65	0.65	0.64	0.65	0.65	0.63

Parameter Definition

Monthly Averaged Clear Sky Insolation Normalized Clearness Index (0 to 1.0)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	0.60	0.62	0.64	0.65	0.63	0.62	0.59	0.59	0.59	0.59	0.59	0.57

Parameter Definition

Monthly Averaged Surface Albedo (0 to 1.0)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	0.30	0.30	0.30	0.31	0.34	0.36	0.37	0.34	0.31	0.30	0.31	0.30	0.32

Parameters for Sizing Battery or other Energy-storage Systems:

Minimum Available Insolation Over A Consecutive-day Period (%)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min/1 day	4.19	17.9	24.1	35.8	23.4	22.3	59.5	22.2	43.2	4.34	17.2	14.2
Min/3 day	47.5	37.2	47.7	51.1	59.1	42.3	80.7	62.3	57.8	41.2	54.8	24.4
Min/7 day	69.3	57.6	77.3	66.5	65.9	76.9	89.6	76.7	73.3	61.6	74.1	62.6
Min/14 day	79.1	70.7	83.9	83.3	80.1	83.8	91.4	87.3	84.5	77.1	85.1	74.3
Min/21 day	84.2	78.8	91.3	89.7	85.9	89.3	91.8	92.2	89.1	83.6	89.8	81.3
Min/Month	90.8	85.7	93.3	93.6	93.7	92.7	92.1	94.5	91.9	89.2	91.3	85.2

Parameter Definition

Solar Radiation Deficits Below Expected Values Incident On A Horizontal Surface Over A Consecutive-day Period (kWh/m^2)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 day	3.65	3.85	4.47	4.48	5.66	5.87	2.97	5.29	3.33	4.62	3.27	2.90
3 day	6.00	8.83	9.23	10.2	9.05	13.0	4.25	7.68	7.42	8.52	5.35	7.66
7 day	8.17	13.9	9.34	16.3	17.6	12.2	5.32	11.0	10.9	12.9	7.15	8.82
14 day	11.1	19.2	13.2	16.2	20.5	17.0	8.76	12.0	12.6	15.4	8.21	12.1
21 day	12.6	20.8	10.7	15.0	21.8	16.8	12.5	11.0	13.3	16.5	8.39	13.2
Month	10.8	18.7	12.0	13.2	14.2	16.5	17.9	11.4	14.1	16.1	10.2	15.5

Equivalent Number Of NO-SUN Or BLACK Days (days)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 day	0.95	0.82	0.75	0.64	0.76	0.77	0.40	0.77	0.56	0.95	0.82	0.85
3 day	1.57	1.88	1.56	1.46	1.22	1.72	0.57	1.12	1.26	1.76	1.35	2.26
7 day	2.14	2.96	1.58	2.34	2.38	1.61	0.72	1.62	1.86	2.68	1.81	2.61
14 day	2.91	4.09	2.25	2.32	2.77	2.25	1.19	1.76	2.16	3.19	2.07	3.59
21 day	3.30	4.44	1.82	2.16	2.95	2.23	1.70	1.62	2.27	3.43	2.12	3.91
Month	2.84	4.00	2.05	1.89	1.92	2.18	2.44	1.68	2.40	3.33	2.58	4.58

Meteorology (Temperature):

Monthly Averaged Air Temperature At 10 m Above The Surface Of The Earth (°C)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	14.7	17.0	19.4	20.9	22.6	25.3	28.7	29.1	27.2	24.1	20.0	16.4	22.1
Minimum	9.53	11.1	13.1	14.3	15.8	18.3	20.9	21.9	20.9	18.5	14.8	11.5	15.9
Maximum	20.6	23.4	26.0	27.7	29.5	32.6	37.3	37.4	34.2	30.2	25.6	22.0	28.9

Parameter Definition

Average Daily Temperature Range (°C)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	11.0	12.3	12.8	13.4	13.7	14.3	16.3	15.4 *	13.3	11.7	10.8	10.5

*** Warmest month**

Monthly Averaged Total Column Precipitable Water (cm)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	1.05	1.09	1.15	1.29	1.54	1.80	2.12	2.44	2.36	1.98	1.56	1.26	1.64

Parameter Definition

Monthly Averaged Precipitation (mm/day)

Lat 26.172 Lon -11.088	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	0.35	0.34	0.28	0.11	0.06	0.04	0.10	0.24	0.37	0.35	0.36	0.47	0.25

APPENDIX C: AQUIFER TYPE AND PRODUCTIVITY WITH LOCATION POINT

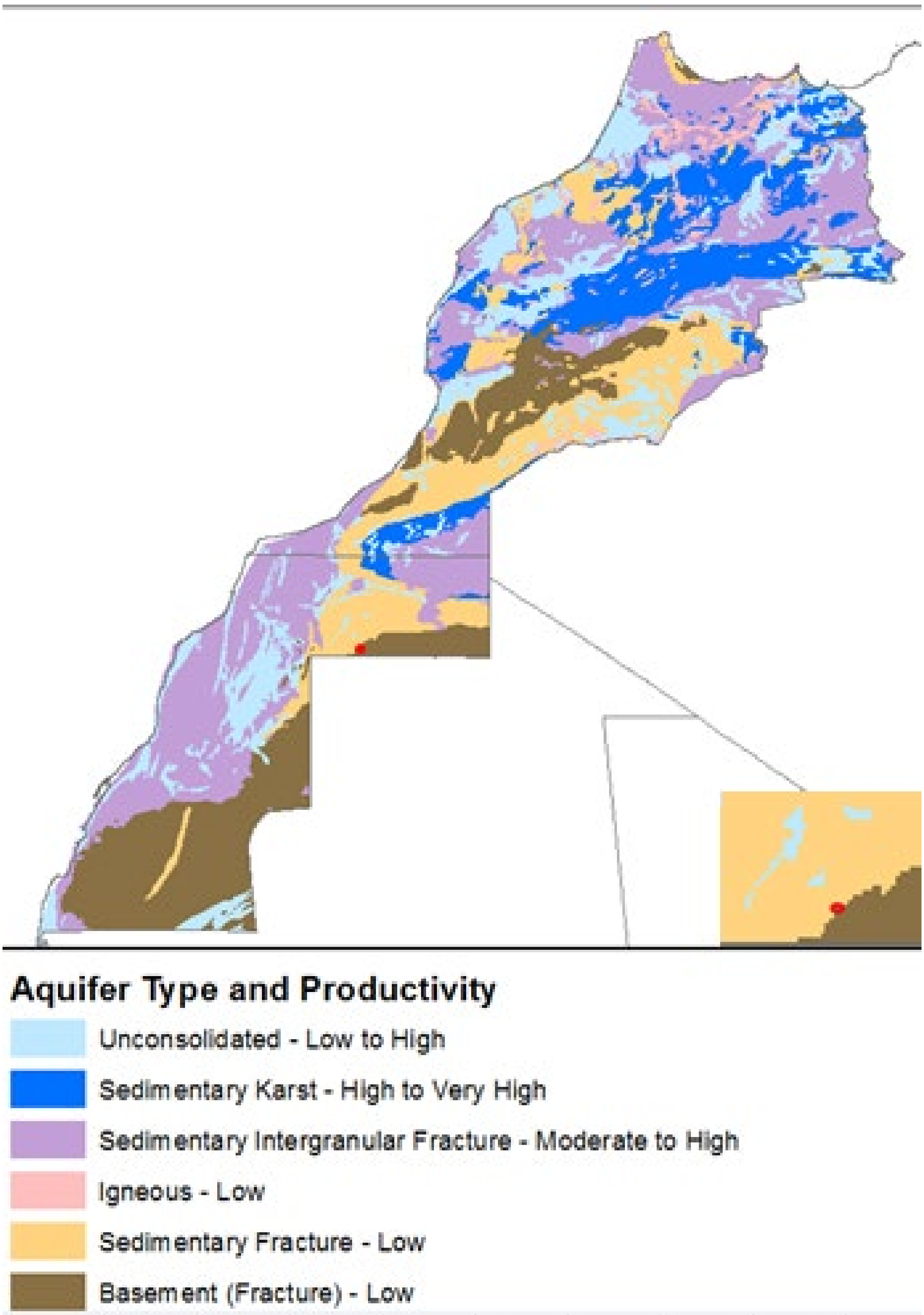


Figure 1: Aquifer type and productivity with location point

APPENDIX D: IRRIGATION WATER REQUIREMENT DATA FROM [23]

Table 1: Potential irrigation efficiency and water requirements for 84 zones in Africa (see zone 14)

IWR zone	Irrigation crop zone	Irrigation efficiency %	Irrigation water requirement (mm/year)	
			Net	Gross
1	1	60	400	700
2	1	60	500	850
3	1	60	450	750
4	1	60	800	1 350
5	1	60	700	1 200
6	1	60	900	1 500
7	2	70	900	1 300
8	1	60	650	1 100
9	1	60	750	1 250
10	5	80	900	1 150
11	5	80	1 000	1 250
12	5	80	1 250	1 600
13	2	70	900	1 300
14	2	70	1 250	1 800
15	2	70	1 600	2 300
16	2	70	1 200	1 750
17	7	80	1 400	1 750
18	7	80	1 200	1 500
19	7	80	900	1 150
20	7	80	750	950
21	3a	50	400	800
22	3a	50	350	700
23	3a	50	600	1 200
24	3a	50	250	500
25	6	50	350	700
26	17	50	500	1 000
27	3a	50	150	300
28	6	50	100	200
29	6	50	250	500
30	3b	50	1 200	2 400
31	3b	50	750	1 500
32	8	50	750	1 500
33	8	50	450	900
34	3b	50	500	1 000
35	3b	50	850	1 700
36	3b	50	200	400
37	4c	50	1 500	3 000
38	3b	50	350	700
39	10	50	400	800
40	10	50	850	1 700
41	10	50	350	700
42	10	50	600	1 200
43	10	50	350	700
44	10	50	600	1 200
45	11	45	550	1 250
46	9	50	500	1 000
47	9	50	400	800
48	9	50	650	1 300
49	9	50	850	1 700
50	4a	45	2 200	4 900
51	4a	45	1 650	3 700
52	4a	45	1 400	3 150
53	12a	45	1 250	2 800
54	12a	45	900	2 000
55	4b	50	800	1 600
56	12a	45	700	1 600
57	12a	45	550	1 250
58	12a	45	500	1 150
59	12b	45	500	1 150
60	12b	45	550	1 250
61	12b	45	650	1 450
62	12b	45	900	2 000
63	14	65	200	350
64	13	50	300	600
65	14	65	350	550
66	14	65	400	650
67	14	65	600	950
68	16	60	400	700
69	16	60	950	1 600
70	16	60	800	1 350
71	16	60	600	1 000
72	16	60	500	850
73	4d	50	1 000	2 000
74	4e	50	450	900
75	4d	50	750	1 500
76	11	45	500	1 150
77	11	45	550	1 250
78	11	45	450	1 000
79	15	60	650	1 100
80	18	60	300	500
81	18	60	1 500	2 500
82	13	50	200	400
83	18	60	150	250
84	2	70	900	1 300

< 250
< 500
< 750
< 1000
< 1500
< 2000
< 2500
< 3000
< 4000
< 4900 mm/year

Inland water body

84 Irrigation water requirement zone

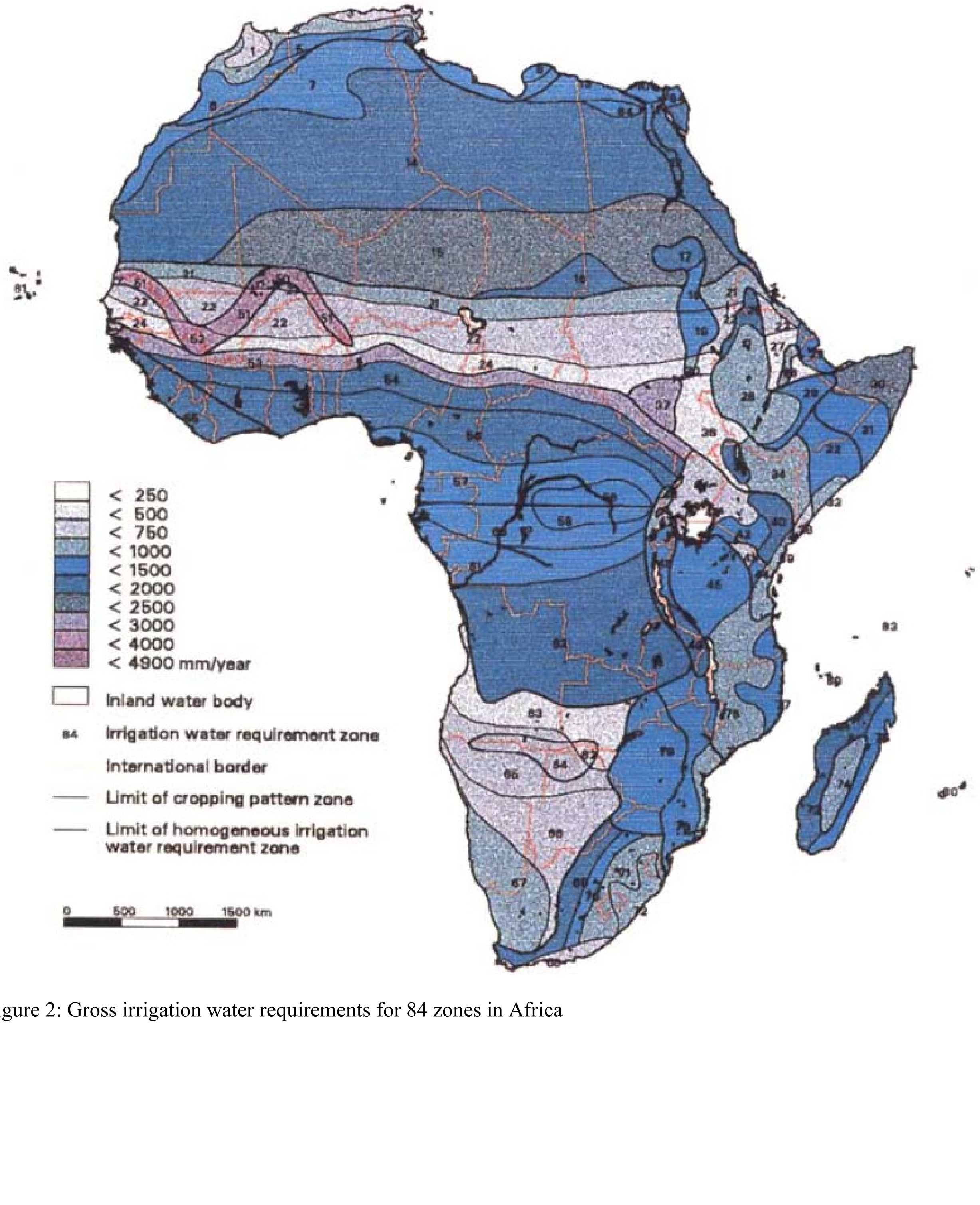


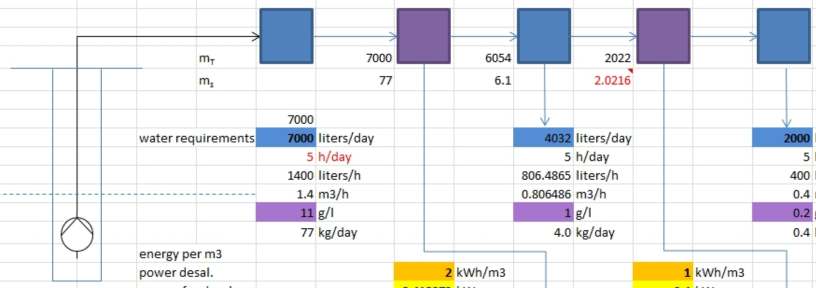
Figure 2: Gross irrigation water requirements for 84 zones in Africa

APPENDIX E: CALCULATIONS WITH EXCEL

CASE 2

CALCULATIONS PROJECT

Hydraulics & Balance



	raw water	D1	irrigation water	D2	drinking water
m_T	7000	6054		2022	
m_s	77	6.1		2.0216	

Pumping

				7000								
well depth:	75	m	water requirements	7000	liters/day		4032	liters/day		2000	liters/day Q	
additional height	25	m		5	h/day		5	h/day		5	h/day	
head (H):	100	m		1400	liters/h		806.4865	liters/h		400	liters/h	40 l/person/day
flow rate (Q):	1.4	m3/h		1.4	m3/h		0.806486	m3/h		0.4	m3/h	50 persons
	0.000389	m3/s		11	g/l		1	g/l		0.2	g/l C	
density (ρ)	1007	kg/m3		77	kg/day		4.0	kg/day		0.4	kg/day m	
g	9.81	m/s2	energy per m3									
eff	0.75		power desal.		2	kWh/m3			1	kWh/m3		
			energy for desal.		2.412973	kW			0.4	kW		
					12.06486	kWh/day brine			2	kWh/day brine		
Power (hydraulic)	0.384171	kW	Power = $Q\rho gH$			14%	946	liters/day	1%	22	liters/day	
Power required	0.512227	kW					75	g/l		75	g/l	
n. hours pumping	5	h/day	(PSSH: 5.94)				70.9	kg/day		1.6	kg/day	
Energy	2.561137	kWh/day										
check	2.543333											

Detailed pressure drop calculations: not required for now, dP losses included in additional height (conservative)

Method A

Energy hydr.	E_h	2.6	kWh/day
Energy desal.	E_{des}	14.1	kWh/day
Energy dwell.	E_{dw}	0.0	kWh/day
Energy other	E_{other}	0.0	kWh/day
Energy Total	E_T	16.6	kWh/day
eff. from Ee	η_s	0.80	
Energy PV	Ee	20.8	kWh/day
eff. PV	η_{pv}		η_{op}
eff. PV ref.	η_r		η_{STC}
eff.PV ref/PV	η_r/η_{pv}	1.18	1/PR
Irradiance	$G_{T\,min}$	4.4	kWh/m²/day
Power (size)	P	5556.8	Wp
with min G		5.556819	kWp
	$G_{T\,opt}$	6.28	kWh/m²/day
Power (size)	P	3893.3	Wp
with average G		3.893312	kWp
	G_T	5.94	kWh/m²/day
Power (size)	P	4116.2	Wp
		4.12	kWp
Estimated area		25.0	m²

$$E_h = \eta_s E_e = \rho g h V \qquad A_{pv} = \frac{\rho g h V}{G_T \eta_{pv} \eta_s}$$

$$E_e = A_{pv} G_T \eta_{pv}$$

$$P = A_{pv} G_r \eta_r \qquad P = 1000\, A_{pv} \eta_r$$

$$P = 1000 \frac{\rho g h V \eta_r}{G_T \eta_{pv} \eta_s} \qquad \eta_o = \frac{P_h}{P_{in}} = \frac{\rho g h V}{A_{PV} G_T}$$

$$PR = \frac{\eta_{op}}{\eta_{STC}}$$

PR: 0.85

$$P\,[Wp] = 1000 \left[\frac{W}{m^2}\right] \times \frac{Ee\,[kWh]}{G_T \left[\frac{kWh}{m^2}\right] \times PR}$$

$$P = 1000 \frac{\rho g h V \eta_r}{G_T \eta_{PV} \eta_s}$$

V (m³

where, P = PV array power (Wp)
ρ = density of water (1000 K/m³)
g = acceleration due to gravity (9.81 m/s²)
h = total pumping head (m)
V = daily water production (m³)
G_T = daily solar radiation energy on the PV array surface (kWh/m²)
η_r = array efficiency at 1000 W/m² and 25°C
η_{PV} = array efficiency (%)
η_s = subsystem efficiency (%)

Specific energy yield: 4.0392 kWh/kWp

Method B

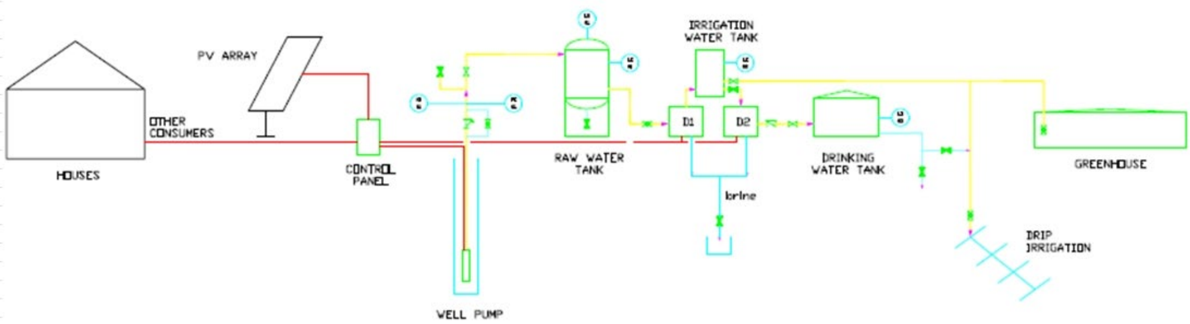
Energy To	E_T	16.6	kWh/day
thermal factor	F_{TH}		0.83
mismatch factor	F		0.85
operating factor			0.75
battery efficiency	η_{BA}		0.9
inverter efficiency	η_{INV}		0.9
pump/motor efficie	η_{Mot}		0.84
Total efficiency			0.6723

$$E_{generated} = P_{peak} * PSSH * F_{th} * \eta_b * \eta_{inv}$$

	PSSH	5.94	h
Power	P	4163.3	Wp
		4.16	kWp

CALCULATIONS PROJECT

Overall



		1.4 m3/h	7000 liters/day		968 liters/day	2000 liters/day
		0.512 kW			72.6 kg/day	
		5.00 h/day		2.4 kW	0.4 kW	
0 kWh/day	16.6 kWh/day	2.6 kWh/day		14.1 kWh/day		
	20.8 kWh/day					
	4.12 kWp					
	25.0 m²					

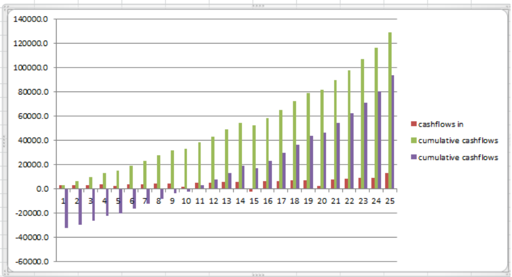
4032 liters/day

Costs												
										Lifecycle cost no inflation		
Specific Costs of diesel pumps & d.water										life (yrs)	TOTAL (25 years)	
fuel (diesel for pump)	2.56	kWh/day	0.20	€/kWh	0.5122	€/day	95%	177.61	€/year	25	4 440.4	€
drinkable water	2	m^3	3.6	€/m^3	7.2	€/day	100%	2628	€/year	25	65 700.0	€
											70 140.4	€
diesel pump					1000	€				10	2 000	€
diesel generator					1000	€				5	5 000	€
tank and other costs for irrigation											5 000	€
maintenance (pumps, borehole, tanks...)											10 000	€
TOTAL											92 140.4	
											3686	
Costs with PV panels, solar pump and desalination												
Main equipment costs												
solar panels	4.12	kWp	700	€/kWp						25	2 881	€
racks and supports	4.12	kWp	200	€/kWp						25	823	€
pump	1				2000	€				10	6 000	€
tanks (and structure/support)	60.22	m^3	50	€/m^3						25	3 011	€
desalination 1 (irrigation)	7	m^3	800	€/m^3							5 600	€
desalination 2 (drinking)	2	m^3	800	€/m^3							1 617	€
batteries	4.12	kWp	500	€/kWp	2058.1					5	10 290	€
control unit / regulator-controller					1000	€				15	2 000	€
inverter (DC to AC)					1000	€				15	2 000	€
pump controller					1000	€				15	2 000	€
Other equipment costs												
cables	500	m	5	€/m						25	2 500	€
breaker switches and other electrical											500	€
piping	300	m	10	€/m						25	3 000	€
valves											500	€
borehole drilling (deeper)	50	m	30	€/m	1500					25	1 500	€
miscellaneous (bolts, screws...)											500	€
transport											2 000	€
installation											2 000	€
commissioning											1 500	€
security to prevent theft/vandalism											500	€
maintenance (pumps, borehole, tanks...)											5 000	€
											55 723.1	€

Costs										
Specific Costs of diesel pumps & d.water										
fuel (diesel for pump)	2.56	kWh/day	0.20	€/kWh	0.5122	€/day	95%	177.61	€/year
drinkable water	2	m^3	3.6	€/m^3	7.2	€/day	100%	2628	€/year
diesel pump					1000	€			
diesel generator					1000	€			
tank and other costs for irrigation									
maintenance (pumps, borehole, tanks...)									
TOTAL									
Costs with PV panels, solar pump and desalination									
Main equipment costs									
solar panels	4.12	kWp	700	€/kWp					
racks and supports	4.12	kWp	200	€/kWp					
pump	1				2000	€			
tanks (and structure/support)	60.22	m^3	50	€/m^3					
desalination 1 (irrigation)	7	m^3	800	€/m^3					
desalination 2 (drinking)	2	m^3	800	€/m^3					
batteries	4.12	kWp	500	€/kWp	2058.1				
control unit / regulator-controller					1000	€			
inverter (DC to AC)					1000	€			
pump controller					1000	€			
Other equipment costs									
cables	500	m	5	€/m					
breaker switches and other electrical									
piping	300	m	10	€/m					
valves									
borehole drilling (deeper)	50	m	30	€/m	1500				
miscellaneous (bolts, screws...)									
transport									
installation									
commissioning									
security to prevent theft/vandalism									
maintenance (pumps, borehole, tanks...)									
fuel (diesel for pump)	0.66	€/liter	0.3	l/kWh	3.5	kW	0.693	€/h	
gas	3.5	€/bottle	4	bottles/	168	€/year			

	Lifecycle cost no inflation: life (yrs)	TOTAL (25 years)		inflation	Lifecycle cost with inflation: TOTAL (25 years)	Lifecycle - replacement scheme: invest	1: year 1	2: year 2	3: year 3	4: year 4	5: year 5	6: year 6	7: year 7	8: year 8	9: year 9	10: year 10 (276)
fuel (diesel for pump)	25	4 440.4	€	5%	8 477.0	0	178	186	196	206	216	227	238	250	262	276
drinkable water	25	65 700.0	€	5%	125 426.8	0	2628	2759	2897	3042	3194	3354	3522	3698	3883	4077
		70 140.4	€	5%	133 903.9	0	2806	2946	3093	3248	3410	3581	3760	3948	4145	4352
diesel pump	10	2 000	€	5%	4 078.3											1551
diesel generator	5	5 000	€	5%	10 498.8						1216					1551
tank and other costs for irrigation		5 000	€	5%	5 000.0	5000										
maintenance (pumps, borehole, tanks...)		10 000	€	5%	19 090.8		400	420	441	463	486	511	536	563	591	621
TOTAL		92 140.4		5%	172 571.8	5 000.0	3 205.6	3 365.9	3 534.2	3 710.9	5 112.0	4 091.3	4 295.8	4 510.6	4 736.2	8 075.6
		3686		5%	6903											
Costs with PV panels, solar pump and desalination																
Main equipment costs						invest	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
solar panels	25	2 881	€	5%	2 881.3	2 881										
racks and supports	25	823	€	5%	823.2	823										
pump	10	6 000	€	5%	10 156.6	2 000										3103
tanks (and structure/support)	25	3 011	€	5%	3 010.8	3 011										
desalination 1 (irrigation)		5 600	€	5%	5 600.0	5 600										
desalination 2 (drinking)		1 617	€	5%	1 617.3	1 617										
batteries	5	10 290	€	5%	17 028.0	2 058					2502					3193
control unit / regulator-controller	15	2 000	€	5%	2 979.9	1 000										
inverter (DC to AC)	15	2 000	€	5%	2 979.9	1 000										
pump controller	15	2 000	€	5%	2 979.9	1 000										
Other equipment costs																
cables	25	2 500	€	5%	2 500.0	2 500										
breaker switches and other electrical		500	€	5%	500.0	500										
piping	25	3 000	€	5%	3 000.0	3 000										
valves		500	€	5%	500.0	500										
borehole drilling (deeper)	25	1 500	€	5%	1 500.0	1 500										
miscellaneous (bolts, screws...)		500	€	5%	500.0	500										
transport		2 000	€	5%	2 000.0	2 000										
installation		2 000	€	5%	2 000.0	2 000										
commissioning		1 500	€	5%	1 500.0	1 500										
security to prevent theft/vandalism		500	€	5%	500.0	500										
maintenance (pumps, borehole, tanks...)		5 000	€	5%	9 545.4		200	210	221	232	243	255	268	281	295	310
		55 723.1	€		74 102.4	35 491	200	210	221	232	2745	255	268	281	295	6606
				cashflows in			3005.6	3155.9	3313.7	3479.4	2367.2	3836.0	4027.8	4229.2	4440.7	1469.9
				cumulative cashflows			3005.6	6161.5	9475.2	12954.6	15321.8	19157.8	23185.6	27414.8	31855.5	33325.4
				cumulative cashflows			32485.1	29329.2	26015.5	22536.2	20168.9	16332.9	12305.1	8075.9	3635.2	2165.3
				fraction calculations			-	-	-	-	-	-	-	-	-	-
				cumulative cashflows			-32485.1	-29329.2	-26015.5	-22536.2	-20168.9	-16332.9	-12305.1	-8075.9	-3635.2	-2165.3

Costs	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Specific Costs of diesel pumps & d.water															
	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20	year 21	year 22	year 23	year 24	year 25
fuel (diesel for pump)	289	304	319	335	352	369	388	407	427	449	471	495	520	546	573
drinkable water	4281	4495	4720	4955	5203	5463	5737	6023	6325	6641	6973	7322	7688	8072	8476
	4570	4799	5038	5290	5555	5833	6124	6431	6752	7090	7444	7816	8207	8618	9048
diesel pump										2527					
diesel generator					1980					2527					3225
tank and other costs for irrigation															
maintenance (pumps, borehole, tanks...)	652	684	718	754	792	832	873	917	963	1011	1061	1114	1170	1229	1290
TOTAL	**5 221.6**	**5 482.7**	**5 756.8**	**6 044.7**	**8 326.8**	**6 664.2**	**6 997.5**	**7 347.3**	**7 714.7**	**13 154.3**	**8 505.5**	**8 930.7**	**9 377.3**	**9 846.1**	**13 563.5**
Costs with PV panels, solar pump and desalination															
Main equipment costs	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20	year 21	year 22	year 23	year 24	year 25
solar panels															
racks and supports															
pump										5054					
tanks (and structure/support)															
desalination 1 (irrigation)															
desalination 2 (drinking)															
batteries					4075					5201					
control unit / regulator-controller					1980										
inverter (DC to AC)					1980										
pump controller					1980										
Other equipment costs															
cables															
breaker switches and other electrical															
piping															
valves															
borehole drilling (deeper)															
miscellaneous (bolts, screws...)															
transport															
installation															
commissioning															
security to prevent theft/vandalism															
maintenance (pumps, borehole, tanks...)	326	342	359	377	396	416	437	458	481	505	531	557	585	614	645
	326	**342**	**359**	**377**	**10411**	**416**	**437**	**458**	**481**	**10760**	**531**	**557**	**585**	**614**	**645**
fuel (diesel for pump)	4895.8	5140.6	5397.7	5667.5	-2083.8	6248.5	6560.9	6888.9	7233.4	2394.4	7974.8	8373.5	8792.2	9231.8	12918.5
gas	38221.3	43361.9	48759.5	54427.1	52343.3	58591.7	65152.6	72041.5	79274.9	81669.3	89644.1	98017.6	106809.8	116041.6	128960.1
	-2730.5	-7871.2	-13268.8	-18936.3	-16852.5	-23101.0	-29661.9	-36550.8	-43784.2	-46178.5	-54153.3	-62526.9	-71319.1	-80550.9	-93469.4
	0.056652	0.062971	0.161428	0.243791	0.361772	0.287626	0.354567	0.411733	0.461064	0.536116	0.515132	0.552486	0.585404	0.614599	0.624619
	2730.5	7871.2	13268.8	18936.3	16852.5	23101.0	29661.9	36550.8	43784.2	46178.5	54153.3	62526.9	71319.1	80550.9	93469.4



Economic analysis

Payback

$$Simple\ Payback\ (yrs) = \frac{Cost\ of\ installed\ system}{Net\ annual\ cash\ inflow}$$

Cost of installed system	35491				
net annual cash flow	3006				
SPB (no inflation,first year ref.)	11.8	years			
PB (with inflation)	**10.1**	**years**			

Net Present Value NPV

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

i	0.05				
N	25 years				
initial investment	-35 491				
Years 1-5 CF	3006	3156	3314	3479	2367
Years 6-10 CF	3836	4028	4229	4441	1470
Years 11-15 CF	4896	5141	5398	5668	-2084
Years 16-20 CF	6248	6561	6889	7233	2394
Years 21-25 CF	7975	8374	8792	9232	12919
NPV	**EUR 26 886.87**				

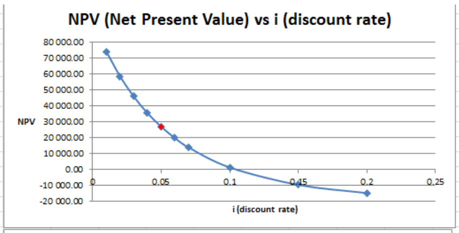
Internal rate of return

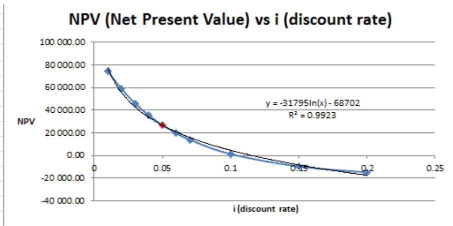
NPV must be equal to 0 (check)	EUR 0.00	
IRR	0.104126481	10.41%

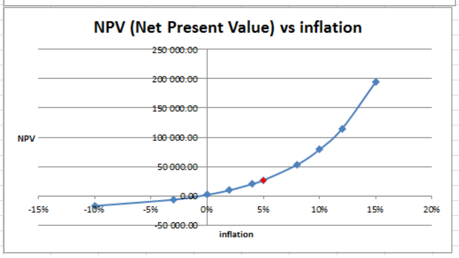
Sensitivity analysis

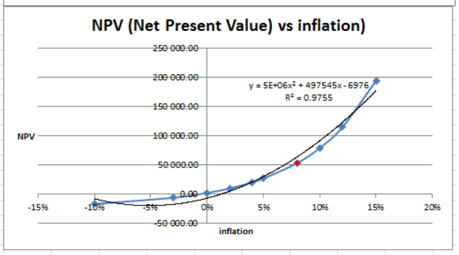
i (disc. r.)	inflation	€/kWh fuel cost	€/m³ water cost	NPV	i %
0.01	5%	0.20	3.60	74 257.83	1%
0.02	5%	0.20	3.60	58 656.03	2%
0.03	5%	0.20	3.60	45 924.68	3%
0.04	5%	0.20	3.60	35 486.05	4%
0.05	5%	0.20	3.60	**26 886.87**	5%
0.06	5%	0.20	3.60	19 770.08	6%
0.07	5%	0.20	3.60	13 853.25	7%
0.1	5%	0.20	3.60	1 277.54	10%
0.15	5%	0.20	3.60	-9 706.33	15%
0.2	5%	0.20	3.60	-14 850.36	20%

i (disc. r.)	inflation	€/kWh fuel cost	€/m³ water cost	NPV
0.05	-10%	0.20	3.60	-16 608.86
0.05	-3%	0.20	3.60	-6 059.94
0.05	0%	0.20	3.60	2 233.66
0.05	2%	0.20	3.60	10 019.23
0.05	4%	0.20	3.60	20 413.70
0.05	**5%**	0.20	3.60	**26 886.87**
0.05	8%	0.20	3.60	53 405.69
0.05	10%	0.20	3.60	79 320.34
0.05	12%	0.20	3.60	114 836.47
0.05	15%	0.20	3.60	194 607.66

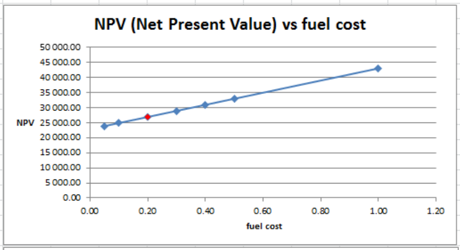


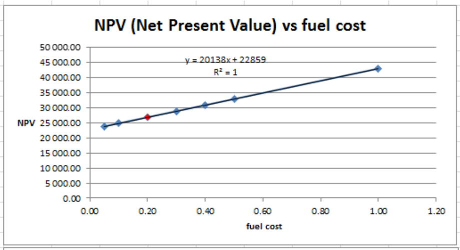




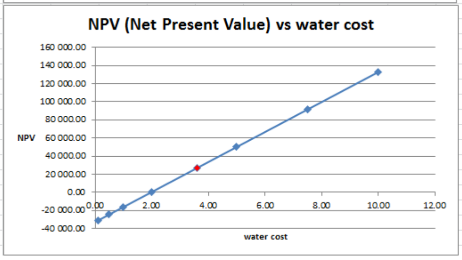


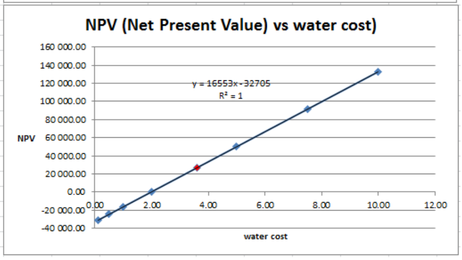
0.05	5%	0.05	3.60	23 866.21
0.05	5%	0.10	3.60	24 873.10
0.05	5%	**0.20**	3.60	**26 886.87**
0.05	5%	0.30	3.60	28 900.64
0.05	5%	0.40	3.60	30 914.42
0.05	5%	0.50	3.60	32 928.19
0.05	5%	1.00	3.60	42 997.06





0.05	5%	0.20	0.10	-31 049.64
0.05	5%	0.20	0.50	-24 428.32
0.05	5%	0.20	1.00	-16 151.68
0.05	5%	0.20	2.00	401.61
0.05	5%	0.20	**3.60**	**26 886.87**
0.05	5%	0.20	5.00	50 061.47
0.05	5%	0.20	7.50	91 444.69
0.05	5%	0.20	10.00	132 827.91
	16553.29			





CO_2							
Produced							
350	$kgCO_2/kWp$	4.12	kWp	**1.4**	tCO_2	(panels and supports)	
						(batteries)	
						(others: tanks, piping...)	
88	gCO_2eq/kWh	16.63	kWh/day	365	day/year	25	years
13.4	tCO_2					(PV system)	
10.0	tCO_2					(others)	
23.4							
Replaced compared to typical grid in Africa							
648	gCO_2/kWh	16.63	kWh/day	365	day/year	25	years
98.3	tCO_2						
Replaced compared to diesel pumps (and alternative water extraction)							
780	gCO_2/kWh	16.63	kWh/day	365	day/year	25	years
118.3	tCO_2						
Saved							
75.0	tCO_2	compared to grid					
95.0		compared to diesel					

PVSYST V6.63 | 24/08/17 | Page 6/6

Stand Alone System: CO2 Balance

Project : **Stand Alone Project at Mehaires**
Simulation variant : **Case 2 august**
Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	14	Pnom total	**4200 Wp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	6071 kWh/year

Produced Emissions	**Total:**	**7.60 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**122.8 tCO2**		
	System production:	7666.72 kWh/yr	Lifetime:	30 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	534 gCO2/kWh		
	Source:	IEA List	Country:	World
CO2 Emission Balance	**Total:**	**99.0 tCO2**		

Grid Lifecycle Emissions: 648 gCO2/kWh
Source: IEA List Country: Africa

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	343 kgCO2/kWp	4.40 kgCO2/kg
Quantity	15.0 kWp	560 kg
Subtotal [kgCO2]	5138	2465

CASE 3

CALCULATIONS PROJECT
Hydraulics & Balance

	raw water	D1	irrigation water	D2	drinking water
m_T	7000	6054	2022		
m_s	77	6.1	2.0216		

Pumping

well depth:	75	m	
additional height	25	m	
head (H):	100	m	
flow rate (Q):	1.4	m3/h	
	0.000389	m3/s	
density (ρ)	1007	kg/m3	
g	9.81	m/s2	
eff	0.75		
Power (hydraulic)	0.384171	kW	$Power = Q\rho gH$
Power required	0.512227	kW	
n. hours pumping	5	h/day	(PSSH: 5.94)
Energy	2.561137	kWh/day	
check	2.543333		

	raw water		irrigation water		drinking water			
	7000							
water requirements	7000	liters/day	4032	liters/day	2000	liters/day	Q	
	5	h/day	5	h/day	5	h/day		
	1400	liters/h	806.4865	liters/h	400	liters/h		40 l/person/day
	1.4	m3/h	0.806486	m3/h	0.4	m3/h		50 persons
	11	g/l	1	g/l	0.2	g/l	C	
	77	kg/day	4.0	kg/day	0.4	kg/day	m	

	D1		D2	
energy per m3	2	kWh/m3	1	kWh/m3
power desal.	2.412973	kW	0.4	kW
energy for desal.	12.06486	kWh/day	2	kWh/day

brine	D1 (14%)		D2 (1%)	
	946	liters/day	22	liters/day
	75	g/l	75	g/l
	70.9	kg/day	1.6	kg/day

Detailed pressure drop calculations: not required for now, dP losses included in additional height (conservative)

Dwelling consumptions

	W	h/day	kWh/day	days/year	kWh/year
fridge	150	24	3.6	365	1314
tv and/or computer	200	5	1	365	365
washing machine	1000	1	1	365	365
air conditioning/boiler	1000	6	6	365	2190
electrical cook	0	0.5	0	365	0
lights	50	8	0.4	365	146
oven/microwave/other	1000	0.5	0.5	365	182.5
other					
			12.5		4562.5
number of houses	1		12.5 kWh/day		4562.5

Method A

Energy hydr.	E_h	2.6	kWh/day
Energy desal.	E_{des}	14.1	kWh/day
Energy dwell.	E_{dw}	12.5	kWh/day
Energy other	E_{other}	0.0	kWh/day
Energy Total	E_T	29.1	kWh/day
eff. from Ee	η_s	0.80	
Energy PV	Ee	36.4	kWh/day
eff. PV	η_{pv}		η_{op}
eff. PV ref.	η_r		η_{STC}
eff.PV ref/PV	η_r / η_{pv}	1.18	1/PR
Irradiance	$G_{T\,min}$	4.4	kWh/m²/day
Power (size)	P	9734.6	Wp
with min G		9.734626	kWp
	$G_{T\,opt}$	6.28	kWh/m²/day
Power (size)	P	6820.4	Wp
with average G		6.820439	kWp
	G_T	5.94	kWh/m²/day
Power (size)	P	7210.8	Wp
		7.21	kWp
Estimated area		43.8	m²

$$E_h = \eta_s E_e = \rho g h V$$

$$A_{pv} = \frac{\rho g h V}{G_T \eta_{pv} \eta_s}$$

$$E_e = A_{pv} G_T \eta_{pv}$$

$$P = A_{pv} G_r \eta_r \qquad P = 1000\, A_{pv} \eta_r$$

$$P = 1000 \frac{\rho g h V \eta_r}{G_T \eta_{pv} \eta_s}$$

$$\eta_o = \frac{P_h}{P_{in}} = \frac{\rho g h V}{A_{PV} G_T}$$

$$PR = \frac{\eta_{op}}{\eta_{STC}}$$

PR: 0.85

$$P\,[Wp] = 1000 \left[\frac{W}{m^2}\right] \times \frac{Ee\,[kWh]}{G_T \left[\frac{kWh}{m^2}\right] \times PR}$$

$$P = 1000 \frac{\rho g h V \eta_r}{G_T \eta_{PV} \eta_s}$$

V (m³

where, P = PV array power (Wp)
ρ = density of water (1000 K/m³)
g = acceleration due to gravity (9.81 m/s²)
h = total pumping head (m)
V = daily water production (m³)
G_T = daily solar radiation energy on the PV array surface (kWh/m²)
η_r = array efficiency at 1000 W/m² and 25°C
η_{PV} = array efficiency (%)
η_s = subsystem efficiency (%)

Specific energy yield: 4.0392 kWh/kWp

Method B

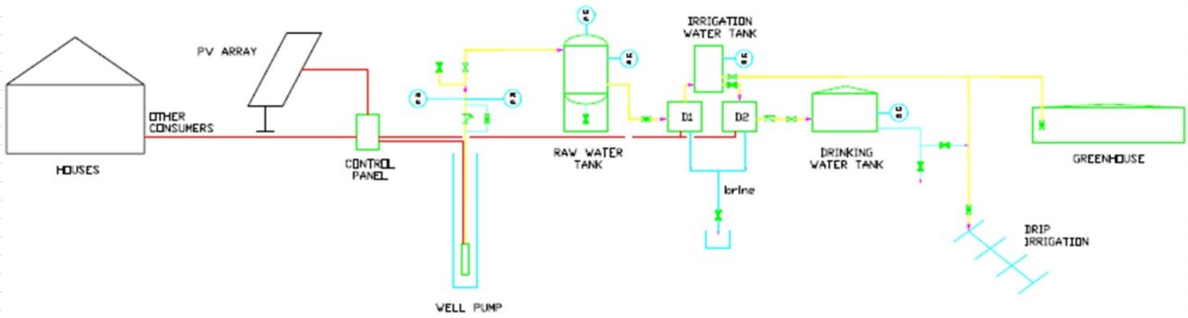
Energy To	E_T	29.1	kWh/day
thermal factor	F_{TH}		0.83
mismatch factor	F		0.85
operating factor			0.75
battery efficiency		η_{BA}	0.9
inverter efficiency		η_{INV}	0.9
pump/motor efficie		η_{Mot}	0.84
Total efficiency			0.6723

$$E_{generated} = P_{peak} * PSSH * F_{th} * \eta_b * \eta_{inv}$$

	PSSH	5.94	h
Power	P	7293.4	Wp
		7.29	kWp

CALCULATIONS PROJECT

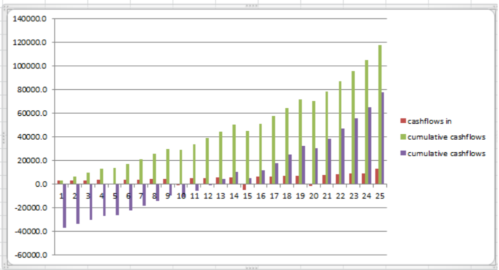
Overall



		1.4 m3/h	7000 liters/day		968 liters/day	2000 liters/day	4032 liters/day
		0.512 kW			72.6 kg/day		
		5.00 h/day		2.4 kW	0.4 kW		
12.5 kWh/day	29.1 kWh/day	2.6 kWh/day		14.1 kWh/day			
	36.4 kWh/day						
	7.21 kWp						
	43.8 m²						

Costs																1	2	3	4	5	6	7	8	9	10
										Lifecycle cost no inflation				Lifecycle cost with inflation											
Specific Costs of diesel pumps & d.water										life (yrs)	TOTAL (25 years)		inflation	TOTAL (25 years)		Lifecycle - replacement scheme									276
															invest	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
fuel (diesel for pump)	2.56	kWh/day	0.20	€/kWh	0.5122	€/day	95%	177.61	€/year	25	4 440.4	€	5%	8 477.0	0	178	186	196	206	216	227	238	250	262	276
drinkable water	2	m³	3.6	€/m³	7.2	€/day	100%	2628	€/year	25	65 700.0	€	5%	125 426.8	0	2628	2759	2897	3042	3194	3354	3522	3698	3883	4077
											70 140.4	€	5%	133 903.9	0	2806	2946	3093	3248	3410	3581	3760	3948	4145	4352
diesel pump					1000	€				10	2 000	€	5%	4 078.3											1551
diesel generator					1000	€				5	5 000	€	5%	10 498.8						1216					1551
tank and other costs for irrigation											5 000	€	5%	5 000.0	5000										
maintenance (pumps, borehole, tanks…)											10 000	€	5%	19 090.8		400	420	441	463	486	511	536	563	591	621
TOTAL											92 140.4		5%	172 571.8	5 000.0	3 205.6	3 365.9	3 534.2	3 710.9	5 112.0	4 091.3	4 295.8	4 510.6	4 736.2	8 075.6
											3686		5%	6903											
Costs with PV panels, solar pump and desalination																									
Main equipment costs															invest	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
solar panels	7.21	kWp	700	€/kWp						25	5 048	€	5%	5 047.6	5 048										
racks and supports	7.21	kWp	200	€/kWp						25	1 442	€	5%	1 442.2	1 442										
pump	1				2000	€				10	6 000	€	5%	10 156.6	2 000										3103
tanks (and structure/support)	60.22	m³	50	€/m³						25	3 011	€	5%	3 010.8	3 011										
desalination 1 (irrigation)	7	m³	800	€/m⁴							5 600	€	5%	5 600.0	5 600										
desalination 2 (drinking)	2	m³	800	€/m³							1 617	€	5%	1 617.3	1 617										
batteries	7.21	kWp	500	€/kWp	3605.4					5	18 027	€	5%	29 830.2	3 605					4382					5593
control unit / regulator-controller					1000	€				15	2 000	€	5%	2 979.9	1 000										
inverter (DC to AC)					1000	€				15	2 000	€	5%	2 979.9	1 000										
pump controller					1000	€				15	2 000	€	5%	2 979.9	1 000										
Other equipment costs																									
cables	500	m	5	€/m						25	2 500	€	5%	2 500.0	2 500										
breaker switches and other electrical											500	€	5%	500.0	500										
piping	300	m	10	€/m						25	3 000	€	5%	3 000.0	3 000										
valves											500	€	5%	500.0	500										
borehole drilling (deeper)	50	m	30	€/m	1500					25	1 500	€	5%	1 500.0	1 500										
miscellaneous (bolts, screws…)											500	€	5%	500.0	500										
transport											2 000	€	5%	2 000.0	2 000										
installation											2 000	€	5%	2 000.0	2 000										
commissioning											1 500	€	5%	1 500.0	1 500										
security to prevent theft/vandalism											500	€	5%	500.0	500										
maintenance (pumps, borehole, tanks…)											5 000	€	5%	9 545.4		200	210	221	232	243	255	268	281	295	310
											66 244.9	€		89 689.8	39 823	200	210	221	232	4626	255	268	281	295	9006
fuel (diesel for pump)	0.66	€/liter	0.3	l/kWh	3.5	kW	0.693	€/h					cashflows in			3005.6	3155.9	3313.7	3479.4	486.4	3836.0	4027.8	4229.2	4440.7	-930.5
gas	3.5	€/bottle	4	bottles/	168	€/year							cumulative cashflows			3005.6	6161.5	9475.2	12954.6	13441.0	17277.0	21304.8	25534.0	29974.7	29044.2
													cumulative cashflows			36817.7	33661.8	30348.1	26868.7	26382.3	22546.2	18518.4	14289.2	9848.6	10779.1
													fraction calculations			-	-	-	-	-	-	-	-	-	-
													cumulative cashflows			-36817.7	-33661.8	-30348.1	-26868.7	-26382.3	-22546.2	-18518.4	-14289.2	-9848.6	-10779.1

Costs	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Specific Costs of diesel pumps & d.water															
	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20	year 21	year 22	year 23	year 24	year 25
fuel (diesel for pump)	289	304	319	335	352	369	388	407	427	449	471	495	520	546	573
drinkable water	4281	4495	4720	4955	5203	5463	5737	6023	6325	6641	6973	7322	7688	8072	8476
	4570	4799	5038	5290	5555	5833	6124	6431	6752	7090	7444	7816	8207	8618	9048
diesel pump										2527					
diesel generator					1980					2527					3225
tank and other costs for irrigation															
maintenance (pumps, borehole, tanks…)	652	684	718	754	792	832	873	917	963	1011	1061	1114	1170	1229	1290
TOTAL	5 221.6	5 482.7	5 756.8	6 044.7	8 326.8	6 664.2	6 997.5	7 347.3	7 714.7	13 154.3	8 505.5	8 930.7	9 377.3	9 846.1	13 563.5
Costs with PV panels, solar pump and desalination															
Main equipment costs	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20	year 21	year 22	year 23	year 24	year 25
solar panels															
racks and supports															
pump										5054					
tanks (and structure/support)															
desalination 1 (irrigation)															
desalination 2 (drinking)															
batteries					7138					9111					
control unit / regulator-controller					1980										
inverter (DC to AC)					1980										
pump controller					1980										
Other equipment costs															
cables															
breaker switches and other electrical															
piping															
valves															
borehole drilling (deeper)															
miscellaneous (bolts, screws…)															
transport															
installation															
commissioning															
security to prevent theft/vandalism															
maintenance (pumps, borehole, tanks…)	326	342	359	377	396	416	437	458	481	505	531	557	585	614	645
	326	342	359	377	13474	416	437	458	481	14670	531	557	585	614	645
fuel (diesel for pump)	4895.8	5140.6	5397.7	5667.5	-5147.4	6248.5	6560.9	6888.9	7233.4	-1515.7	7974.8	8373.5	8792.2	9231.8	12918.5
gas	33940.0	39080.7	44478.3	50145.9	44998.4	51246.9	57807.8	64696.7	71930.1	70414.4	78389.2	86762.7	95554.9	104786.7	117705.2
	5883.2	742.6	-4655.0	-10322.6	-5175.1	-11423.6	-17984.5	-24873.4	-32106.8	-30591.1	-38565.9	-46939.4	-55731.6	-64963.5	-77882.0
	-	-	0.016696	0.09283	0.229399	0.100985	0.197614	0.277982	0.3458	0.455969	0.390247	0.444499	0.49123	0.531858	0.551916
	-5883.2	-742.6	4655.0	10322.6	5175.1	11423.6	17984.5	24873.4	32106.8	30591.1	38565.9	46939.4	55731.6	64963.5	77882.0



Economic analysis

Payback

$$Simple\ Payback\ (yrs) = \frac{Cost\ of\ installed\ system}{Net\ annual\ cash\ inflow}$$

Cost of installed system	39823		
net annual cash flow	3006		
SPB (no inflation,first year ref.)	13.2	years	
PB (with inflation)	**12.0**	**years**	

Net Present Value NPV

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

i	0.05				
N	25	years			
initial investment	-39 823				
Years 1-5 CF	3006	3156	3314	3479	486
Years 6-10 CF	3836	4028	4229	4441	-930
Years 11-15 CF	4896	5141	5398	5668	-5147
Years 16-20 CF	6248	6561	6889	7233	-1516
Years 21-25 CF	7975	8374	8792	9232	12919
NPV	**EUR 17 146.72**				

Internal rate of return

NPV must be equal to 0 (check)	-EUR 0.00	
IRR	0.082580449	8.26%

CO_2

Produced

350	$kgCO_2/kWp$	7.21	kWp	**2.5**	tCO_2	(panels and supports)	
						(batteries)	
						(others: tanks, piping...)	
88	gCO_2eq/kWh	29.13	kWh/day	365	day/year	25	years
23.4	tCO_2					(PV system)	
10.0	tCO_2					(others)	
33.4							

Replaced compared to typical grid in Africa

648	gCO_2/kWh	29.13	kWh/day	365	day/year	25	years
172.2	tCO_2						

Replaced compared to diesel pumps (and alternative water extraction)

780	gCO_2/kWh	29.13	kWh/day	365	day/year	25	years
207.3	tCO_2						

Saved

138.8	tCO_2	compared to grid
173.9		compared to diesel

CASE 6

CALCULATIONS PROJECT

Hydraulics & Balance

Pumping

well depth:	75	m
additional height	25	m
head (H):	100	m
flow rate (Q):	2.56	m3/h
	0.000711	m3/s
density (ρ)	1007	kg/m3
g	9.81	m/s2
eff	0.75	
Power (hydraulic)	0.702483	kW
Power required	0.936644	kW
n. hours pumping	5	h/day
Energy	4.683221	kWh/day
check	4.650667	

$Power = Q\rho g H$

(PSSH: 5.94)

	raw water	D1	irrigation water	D2	drinking water
m_T		12800		11070 / 2022	
m_s		140.8		11.1 / 2.0216	
	12800				
water requirements	12800 liters/day		9049 liters/day		2000 liters/day Q
	5 h/day		5 h/day		5 h/day
	2560 liters/h		1809.73 liters/h		400 liters/h
	2.56 m3/h		1.80973 m3/h		0.4 m3/h
	11 g/l		1 g/l		0.2 g/l C
	140.8 kg/day		9.0 kg/day		0.4 kg/day m
energy per m3					
power desal.		2 kWh/m3		1 kWh/m3	
energy for desal.		4.419459 kW		0.4 kW	
		22.0973 kWh/day brine		2 kWh/day brine	
		14%	1730 liters/day	0%	22 liters/day
			75 g/l		75 g/l
			129.7 kg/day		1.6 kg/day

40 l/person/day
50 persons

Detailed pressure drop calculations: not required for now, dP losses included in additional height (conservative)

Method A			
Energy hydr.	E_h	4.7	kWh/day
Energy desal.	E_{des}	24.1	kWh/day
Energy dwell.	E_{dw}	12.5	kWh/day
Energy other	E_{other}	0.0	kWh/day
Energy Total	E_T	41.3	kWh/day
eff. from Ee	η_s	0.80	
Energy PV	Ee	51.6	kWh/day
eff. PV	η_{pv}		η_{op}
eff. PV ref.	η_r		η_{STC}
eff.PV ref/PV	η_r / η_{pv}	1.18	1/PR
Irradiance	$G_{T\,min}$	4.4	kWh/m²/day
Power (size)	P	13797.0	Wp
with min G		13.79696	kWp
	$G_{T\,opt}$	6.28	kWh/m²/day
Power (size)	P	9666.7	Wp
with average G		9.666663	kWp
	G_T	5.94	kWh/m²/day
Power (size)	P	10220.0	Wp
		10.22	kWp
Estimated area		62.0	m²

$$E_h = \eta_s E_e = \rho g h V \qquad A_{pv} = \frac{\rho g h V}{G_T \eta_{pv} \eta_s}$$

$$E_e = A_{pv} G_T \eta_{pv}$$

$$P = A_{pv} G_r \eta_r \qquad P = 1000\, A_{pv} \eta_r$$

$$P = 1000 \frac{\rho g h V \eta_r}{G_T \eta_{pv} \eta_s} \qquad \eta_o = \frac{P_h}{P_{in}} = \frac{\rho g h V}{A_{PV} G_T}$$

$$PR = \frac{\eta_{op}}{\eta_{STC}}$$

PR: 0.85

$$P\,[Wp] = 1000 \left[\frac{W}{m^2}\right] \times \frac{Ee\,[kWh]}{G_T \left[\frac{kWh}{m^2}\right] \times PR}$$

$$P = 1000 \frac{\rho g h V \eta_r}{G_T \eta_{PV} \eta_s}$$

V (m³;

where, P = PV array power (Wp)
ρ = density of water (1000 K/m³)
g = acceleration due to gravity (9.81 m/s²)
h = total pumping head (m)
V = daily water production (m³)
G_T = daily solar radiation energy on the PV array surface (kWh/m²)
η_r = array efficiency at 1000 W/m² and 25°C
η_{PV} = array efficiency (%)
η_s = subsystem efficiency (%)

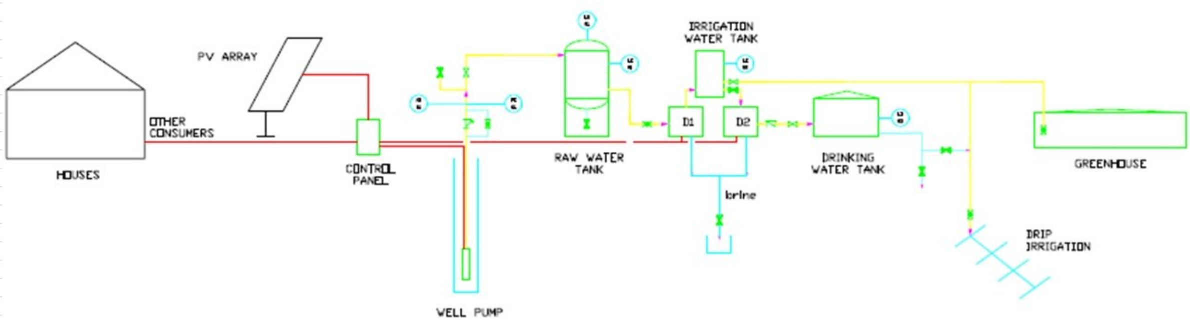
Specific energy yield: 4.0392 kWh/kWp

Method B			
Energy To	E_T	41.3	kWh/day
thermal factor	F_{TH}		0.83
mismatch factor	F		0.85
operating factor			0.75
battery efficiency	η_{BA}		0.9
inverter efficiency	η_{INV}		0.9
pump/motor efficie	η_{Mot}		0.84
Total efficiency			0.6723
	PSSH	5.94	h
Power	P	10337.0	Wp
		10.34	kWp

$$E_{generated} = P_{peak} * PSSH * F_{th} * \eta_b * \eta_{inv}$$

CALCULATIONS PROJECT

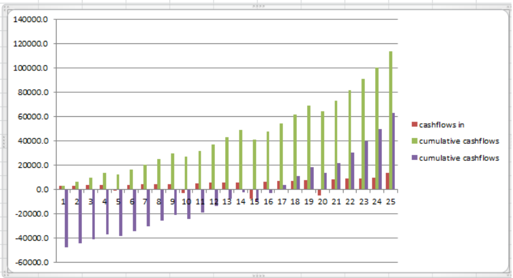
Overall



		2.56 m3/h	12800 liters/day		1751 liters/day	2000 liters/day	9049 liters/day
		0.937 kW			131.4 kg/day		
		5.00 h/day		4.4 kW	0.4 kW		
12.5 kWh/day	41.3 kWh/day	4.7 kWh/day		24.1 kWh/day			
	51.6 kWh/day						
	10.22 kWp						
	62.0 m²						

Costs																1	2	3	4	5	6	7	8	9	10
										Lifecycle cost no inflation				Lifecycle cost with inflation											
Specific Costs of diesel pumps & d.water										life (yrs)	TOTAL (25 years)		inflation	TOTAL (25 years)		Lifecycle - replacement scheme									504
															invest	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
fuel (diesel for pump)	4.68	kWh/day	0.20	€/kWh	0.9366	€/day	95%	324.78	€/year	25	8 119.5	€	5%	15 500.9	0	325	341	358	376	395	415	435	457	480	504
drinkable water	2	m^3	3.6	€/m^3	7.2	€/day	100%	2628	€/year	25	65 700.0	€	5%	125 426.8	0	2628	2759	2897	3042	3194	3354	3522	3698	3883	4077
											73 819.5	€	5%	**140 927.7**	0	2953	3100	3255	3418	3589	3769	3957	4155	4363	4581
diesel pump					1000	€				10	2 000	€	5%	4 078.3											1551
diesel generator					1000	€				5	5 000	€	5%	10 498.8						1216					1551
tank and other costs for irrigation											5 000	€	5%	5 000.0	5000										
maintenance (pumps, borehole, tanks...)											10 000	€	5%	19 090.8		400	420	441	463	486	511	536	563	591	621
TOTAL											**95 819.5**		5%	**179 595.6**	**5 000.0**	**3 352.8**	**3 520.4**	**3 696.4**	**3 881.3**	**5 290.8**	**4 279.1**	**4 493.0**	**4 717.7**	**4 953.6**	**8 303.9**
											3833		5%	7184											
Costs with PV panels, solar pump and desalination																									
Main equipment costs															invest	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
solar panels	10.22	kWp	700	€/kWp						25	7 154	€	5%	7 154.0	7 154										
racks and supports	10.22	kWp	200	€/kWp						25	2 044	€	5%	2 044.0	2 044										
pump	1				2000	€				10	6 000	€	5%	10 156.6	2 000										3103
tanks (and structure/support)	103.5	m^3	50	€/m^3						25	5 174	€	5%	5 174.1	5 174										
desalination 1 (irrigation)	12.8	m^3	800	€/m^4							10 240	€	5%	10 240.0	10 240										
desalination 2 (drinking)	2	m^3	800	€/m^3							1 617	€	5%	1 617.3	1 617										
batteries	10.22	kWp	500	€/kWp	5110					5	25 550	€	5%	42 278.6	5 110					6211					7927
control unit / regulator-controller					1000	€				15	2 000	€	5%	2 979.9	1 000										
inverter (DC to AC)					1000	€				15	2 000	€	5%	2 979.9	1 000										
pump controller					1000	€				15	2 000	€	5%	2 979.9	1 000										
Other equipment costs																									
cables	500	m	5	€/m						25	2 500	€	5%	2 500.0	2 500										
breaker switches and other electrical											500	€	5%	500.0	500										
piping	300	m	10	€/m						25	3 000	€	5%	3 000.0	3 000										
valves											500	€	5%	500.0	500										
borehole drilling (deeper)	50	m	30	€/m	1500					25	1 500	€	5%	1 500.0	1 500										
miscellaneous (bolts, screws...)											500	€	5%	500.0	500										
transport											2 000	€	5%	2 000.0	2 000										
installation											2 000	€	5%	2 000.0	2 000										
commissioning											1 500	€	5%	1 500.0	1 500										
security to prevent theft/vandalism											500	€	5%	500.0	500										
maintenance (pumps, borehole, tanks...)											5 000	€	5%	9 545.4		200	210	221	232	243	255	268	281	295	310
											83 279.3	€		**111 649.7**	**50 839**	**200**	**210**	**221**	**232**	**6454**	**255**	**268**	**281**	**295**	**11340**
fuel (diesel for pump)	0.66	€/liter	0.3	l/kWh	3.5	kW	0.693	€/h					cashflows in			3152.8	3310.4	3475.9	3649.7	-1163.5	4023.8	4225.0	4436.3	4658.1	-3036.3
gas	3.5	€/bottle	4	bottles/	168	€/year							cumulative cashflows			3152.8	6463.2	9939.1	13588.9	12425.4	16449.2	20674.3	25110.5	29768.6	26732.4
													cumulative cashflows			47686.5	44376.1	40900.2	37250.4	38413.9	34390.1	30165.1	25728.8	21070.7	24107.0
													fraction calculations			-	-	-	-	-	-	-	-	-	-
													cumulative cashflows			-47686.5	-44376.1	-40900.2	-37250.4	-38413.9	-34390.1	-30165.1	-25728.8	-21070.7	-24107.0

Costs	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Specific Costs of diesel pumps & d.water															
	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20	year 21	year 22	year 23	year 24	year 25
fuel (diesel for pump)	529	555	583	612	643	675	709	744	782	821	862	905	950	998	1047
drinkable water	4281	4495	4720	4955	5203	5463	5737	6023	6325	6641	6973	7322	7688	8072	8476
	4810	5050	5303	5568	5846	6139	6446	6768	7106	7462	7835	8226	8638	9070	9523
diesel pump										2527					
diesel generator					1980					2527					3225
tank and other costs for irrigation															
maintenance (pumps, borehole, tanks...)	652	684	718	754	792	832	873	917	963	1011	1061	1114	1170	1229	1290
TOTAL	**5 461.3**	**5 734.4**	**6 021.1**	**6 322.2**	**8 618.2**	**6 970.2**	**7 318.7**	**7 684.6**	**8 068.9**	**13 526.2**	**8 895.9**	**9 340.7**	**9 807.8**	**10 298.1**	**14 038.2**
Costs with PV panels, solar pump and desalination															
Main equipment costs	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20	year 21	year 22	year 23	year 24	year 25
solar panels															
racks and supports															
pump										5054					
tanks (and structure/support)															
desalination 1 (irrigation)															
desalination 2 (drinking)															
batteries					10117					12913					
control unit / regulator-controller					1980										
inverter (DC to AC)					1980										
pump controller					1980										
Other equipment costs															
cables															
breaker switches and other electrical															
piping															
valves															
borehole drilling (deeper)															
miscellaneous (bolts, screws...)															
transport															
installation															
commissioning															
security to prevent theft/vandalism															
maintenance (pumps, borehole, tanks...)	326	342	359	377	396	416	437	458	481	505	531	557	585	614	645
	326	**342**	**359**	**377**	**16453**	**416**	**437**	**458**	**481**	**18472**	**531**	**557**	**585**	**614**	**645**
fuel (diesel for pump)	5135.5	5392.3	5661.9	5945.0	-7835.0	6554.4	6882.1	7226.2	7587.5	-4945.8	8365.3	8783.5	9222.7	9683.8	13393.1
gas	31867.9	37260.2	42922.2	48867.2	41032.2	47586.6	54468.8	61695.0	69282.5	64336.8	72702.0	81485.6	90708.3	100392.1	113785.3
	18971.4	13579.1	7917.1	1972.1	9807.1	3252.7	-3629.4	-10855.7	-18443.2	-13497.5	-21862.7	-30646.3	-39869.0	-49552.8	-62945.9
	-	-	-	-	-	-	0.059717	0.058829	0.156687	0.286667	0.185654	0.268302	0.337855	0.397132	0.435494
	-18971.4	-13579.1	-7917.1	-1972.1	-9807.1	-3252.7	3629.4	10855.7	18443.2	13497.5	21862.7	30646.3	39869.0	49552.8	62945.9



Economic analysis

Payback

$$Simple\ Payback\ (yrs) = \frac{Cost\ of\ installed\ system}{Net\ annual\ cash\ inflow}$$

Cost of installed system	50839	
net annual cash flow	3153	
SPB (no inflation,first year ref.)	16.1	years
PB (with inflation)	**16.1**	**years**

Net Present Value NPV

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

i	0.05					
N	25	years				
initial investment	-50 839					
Years 1-5 CF	3153	3310	3476	3650	-1163	
Years 6-10 CF	4024	4225	4436	4658	-3036	
Years 11-15 CF	5136	5392	5662	5945	-7835	
Years 16-20 CF	6554	6882	7226	7588	-4946	
Years 21-25 CF	8365	8784	9223	9684	13393	
NPV	**EUR 4 533.61**					

Internal rate of return

NPV must be equal to 0 (check)	EUR 0.00	
IRR	0.057277275	5.73%

CO_2

Produced

350	$kgCO_2/kWp$	10.22	kWp	**3.6**	tCO_2	(panels and supports)	
						(batteries)	
						(others: tanks, piping...)	
88	gCO_2eq/kWh	41.28	kWh/day	365	day/year	25	years
33.1	tCO_2					(PV system)	
10.0	tCO_2					(others)	
43.1							

Replaced compared to typical grid in Africa

648	gCO_2/kWh	41.28	kWh/day	365	day/year	25	years
244.1	tCO_2						

Replaced compared to diesel pumps (and alternative water extraction)

780	gCO_2/kWh	41.28	kWh/day	365	day/year	25	years
293.8	tCO_2						

Saved

200.9	tCO_2	compared to grid
250.7		compared to diesel

APPENDIX F: CALCULATIONS WITH PVSYSTS

CASE 2

PVSYST V6.63		24/08/17	Page 1/6

Stand Alone System: Simulation parameters

Project :	**Stand Alone Project at Mehaires**			
Geographical Site	**Mehaires**		Country	**Western Sahara**
Situation	Latitude	26.17° N	Longitude	-11.09° W
Time defined as	Legal Time	Time zone UT	Altitude	375 m
	Albedo	0.20		
Meteo data:	**Mehaires**	NASA-SSE satellite data, 1983-2005 - Synthetic		

Simulation variant :	**Case 2 august**			
	Simulation date	24/08/17 18h10		
	Simulation for the	**first year of operation**		

Simulation parameters				
Collector Plane Orientation	Tilt	25°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics				
PV module Si-poly	Model	**REC 300PE 72**		
Original PVsyst database	Manufacturer	REC		
Number of PV modules	In series	2 modules	In parallel	7 strings
Total number of PV modules	Nb. modules	14	Unit Nom. Power	300 Wp
Array global power	Nominal (STC)	**4200 Wp**	At operating cond.	3781 Wp (50°C)
Array operating characteristics (50°C)	U mpp	66 V	I mpp	57 A
Total area	Module area	**27.3 m²**	Cell area	24.5 m²
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	19 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	1.0 % at STC
LID - Light Induced Degradation			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Module average degradation	Year no	1	Loss factor	0.4 %/year
Mismatch due to degradation	Imp dispersion RMS	0.4 %/year	Voc dispersion RMS	0.4 %/year
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter	System type	**Stand Alone System**		
Battery	Model	**Solar 12V / 160 Ah**		
	Manufacturer	Generic		
Battery Pack Characteristics	Voltage	48 V	Nominal Capacity	480 Ah
	Nb. of units	4 in series x 3 in parallel		
	Temperature	External ambient temperature		
Controller	Model	FLEXmax 60 - 48V		
	Manufacturer	Outback		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	98.1/96.8 %		
Battery management control	Treshold commands as	Battery voltage		
	Charging	54.0 / 50.1 V	Corresp. SOC	0.90 / 0.75
	Discharging	47.1 / 48.9 V	Corresp. SOC	0.20 / 0.45
User's needs :	Daily household consumers	Constant over the year		
	average	16.6 kWh/Day		

Stand Alone System: Detailed User's needs

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 2 august**

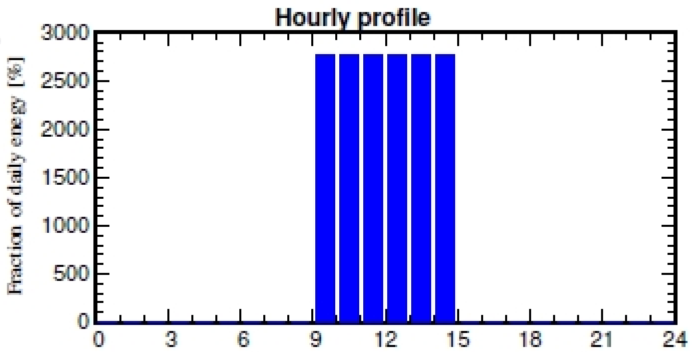
Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	14	Pnom total	**4200 Wp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	6071 kWh/year

Daily household consumers, Constant over the year, average = 16.6 kWh/day

Annual values

	Number	Power	Use	Energy
Other uses	1	2772 W tot	6 h/day	16632 Wh/day
Total daily energy				16632 Wh/day



Stand Alone System: Main results

Project : **Stand Alone Project at Mehaires**

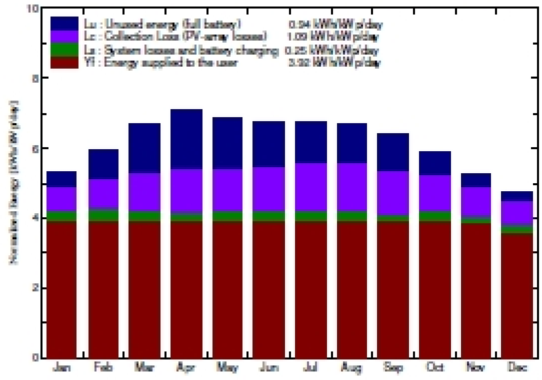
Simulation variant : **Case 2 august**

Simulation for the first year of operation

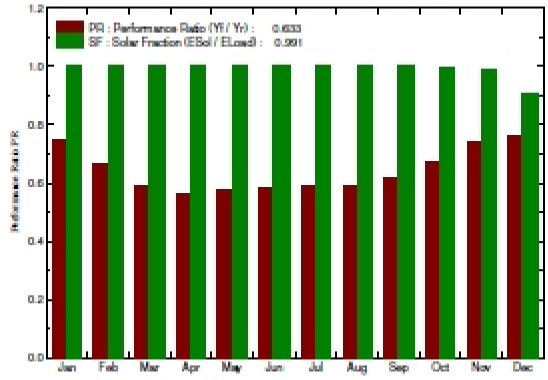
Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	14	Pnom total	**4200 Wp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	6071 kWh/year

Main simulation results				
System Production	**Available Energy**	**7.67 MWh/year**	Specific prod.	1825 kWh/kWp/year
	Used Energy	6.01 MWh/year	Excess (unused)	1.44 MWh/year
	Performance Ratio PR	63.32 %	Solar Fraction SF	99.07 %
Loss of Load	Time Fraction	0.5 %	Missing Energy	0.06 MWh/year
Investment	Global incl. taxes	13895 €	Specific	3.31 €/Wp
Yearly cost	Annuities (Loan 5.0%, 20 years)	1115 €/yr	Running Costs	7037 €/yr
Energy cost		**1.36 €/kWh**		

Normalized productions (per installed kWp): Nominal power 4200 Wp



Performance Ratio PR and Solar Fraction SF



Case 2 august

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	118.1	160.4	0.585	0.051	0.000	0.516	0.516	1.000
February	131.3	162.2	0.581	0.090	0.000	0.466	0.466	1.000
March	182.6	203.2	0.714	0.179	0.000	0.516	0.516	1.000
April	209.4	206.8	0.720	0.207	0.000	0.499	0.499	1.000
May	229.1	206.1	0.717	0.183	0.000	0.516	0.516	1.000
June	226.8	196.1	0.678	0.158	0.000	0.499	0.499	1.000
July	227.8	202.0	0.686	0.149	0.000	0.516	0.516	1.000
August	210.8	201.6	0.682	0.147	0.000	0.516	0.516	1.000
September	176.1	186.5	0.635	0.127	0.000	0.499	0.499	1.000
October	149.7	177.1	0.610	0.076	0.003	0.513	0.516	0.995
November	118.5	154.5	0.544	0.044	0.007	0.492	0.499	0.986
December	104.8	143.0	0.515	0.028	0.047	0.468	0.516	0.909
Year	2085.0	2199.4	7.667	1.440	0.057	6.014	6.071	0.991

Legends:

GlobHor	Horizontal global irradiation	E Miss	Missing energy
GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

Stand Alone System: Loss diagram

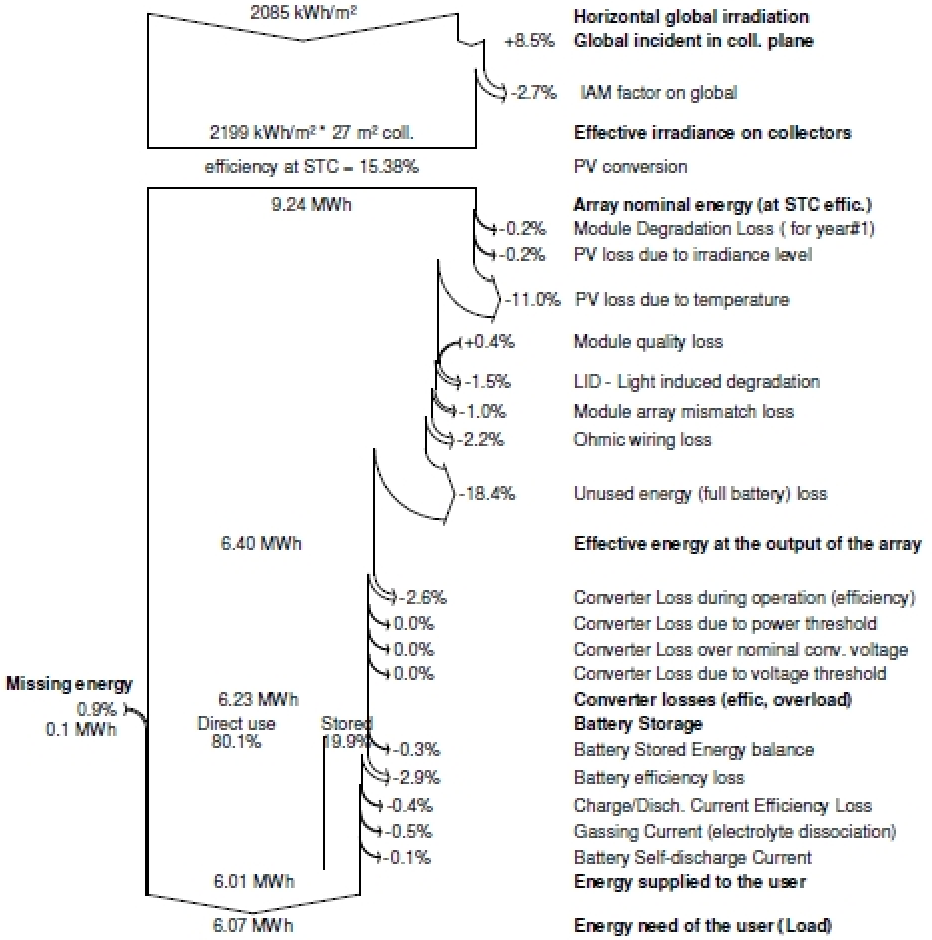
Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 2 august**

Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	14	Pnom total	**4200 Wp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	6071 kWh/year

Loss diagram over the whole year



Stand Alone System: Economic evaluation

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 2 august**

Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	14	Pnom total	**4200 Wp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	6071 kWh/year

Investment

PV modules (Pnom = 300 Wp)	14 units	202 € / unit	2828 €
Supports / Integration		83 € / module	1167 €
Batteries (12 V / 160 Ah)	12 units	174 € / unit	2088 €
regulator			5000 €
Settings, wiring, ...			1000 €
Substitution underworth			0 €
Gross investment (without taxes)			**12083 €**

Financing

Gross investment (without taxes)		12083 €
Taxes on investment (VAT)	Rate 15.0 %	1812 €
Gross investment (including VAT)		13895 €
Subsidies		0 €
Net investment (all taxes included)		**13895 €**
Annuities	(Loan 5.0 % over 20 years)	1115 €/year
Maintenance		0 €/year
insurance, annual taxes		0 €/year
Provision for battery replacement	(lifetime 100.0 years)	7037 €/year
Total yearly cost		**8152 €/year**

Energy cost

Used solar energy	6014 kWh / year
Excess energy (battery full)	1440 kWh / year
Used energy cost	1.36 € / kWh

Stand Alone System: CO2 Balance

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 2 august**

Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	14	Pnom total	**4200 Wp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	6071 kWh/year

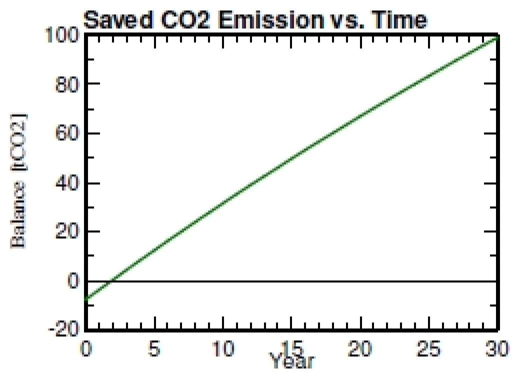
Produced Emissions — **Total: 7.60 tCO2**
Source: Detailed calculation from table below

Replaced Emissions — **Total: 122.8 tCO2**
System production: 7666.72 kWh/yr — Lifetime: 30 years
Annual Degradation: 1.0 %
Grid Lifecycle Emissions: 534 gCO2/kWh
Source: IEA List — Country: World

CO2 Emission Balance — **Total: 99.0 tCO2**

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	343 kgCO2/kWp	4.40 kgCO2/kg
Quantity	15.0 kWp	560 kg
Subtotal [kgCO2]	5138	2465



CASE 3

PVSYST V6.63		28/08/17	Page 1/6

Stand Alone System: Simulation parameters

Project :	**Stand Alone Project at Mehaires**			
Geographical Site	**Mehaires**		Country	**Western Sahara**
Situation	Latitude	26.17° N	Longitude	-11.09° W
Time defined as	Legal Time	Time zone UT	Altitude	375 m
	Albedo	0.20		
Meteo data:	**Mehaires**	NASA-SSE satellite data, 1983-2005 - Synthetic		

Simulation variant :	**Case 3 august 02 consumptions**			
	Simulation date	28/08/17 17h28		
	Simulation for the	**first year of operation**		

Simulation parameters

Collector Plane Orientation	Tilt	25°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm

PV Array Characteristics

PV module Si-poly	Model	**REC 300PE 72**		
Original PVsyst database	Manufacturer	REC		
Number of PV modules	In series	2 modules	In parallel	12 strings
Total number of PV modules	Nb. modules	24	Unit Nom. Power	300 Wp
Array global power	Nominal (STC)	**7.20 kWp**	At operating cond.	6.48 kWp (50°C)
Array operating characteristics (50°C)	U mpp	66 V	I mpp	98 A
Total area	Module area	**46.8 m²**	Cell area	42.1 m²

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	11 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	1.0 % at STC
LID - Light Induced Degradation			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Module average degradation	Year no	1	Loss factor	0.4 %/year
Mismatch due to degradation	Imp dispersion RMS	0.4 %/year	Voc dispersion RMS	0.4 %/year
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System Parameter	System type	**Stand Alone System**		
Battery	Model	**Solar 12V / 160 Ah**		
	Manufacturer	Generic		
Battery Pack Characteristics	Voltage	48 V	Nominal Capacity	480 Ah
	Nb. of units	4 in series x 3 in parallel		
	Temperature	External ambient temperature		
Controller	Model	FLEXmax 80 - 48V		
	Manufacturer	Outback		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.5/96.3 %		
Battery management control	Treshold commands as	Battery voltage		
	Charging	54.7 / 50.1 V	Corresp. SOC	0.90 / 0.75
	Discharging	47.0 / 48.9 V	Corresp. SOC	0.20 / 0.45

User's needs :	Daily household consumers	Constant over the year
	average	29.1 kWh/Day

Stand Alone System: Detailed User's needs

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 3 august 02 consumptions**

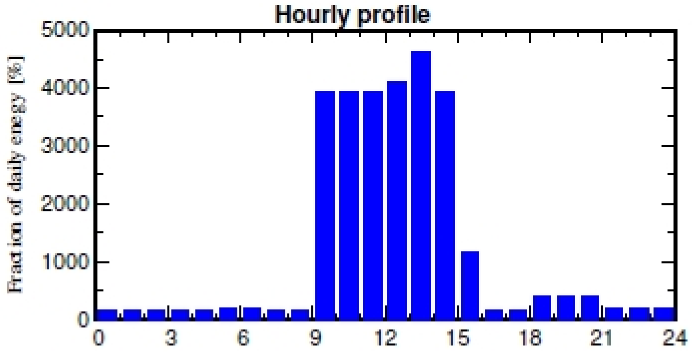
Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	24	Pnom total	**7.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	10.63 MWh/year

Daily household consumers, Constant over the year, average = 29.1 kWh/day

Annual values

	Number	Power	Use	Energy
Lamps (LED or fluo)	1	50 W/lamp	8 h/day	400 Wh/day
TV / PC / Mobile	1	200 W/app	5 h/day	1000 Wh/day
Domestic appliances	1	1000 W/app	6 h/day	6000 Wh/day
Fridge / Deep-freeze	1		24 Wh/day	3600 Wh/day
Dish- & Cloth-washers	1		1 Wh/day	1000 Wh/day
Other uses	1	2771 W tot	6 h/day	16626 Wh/day
Other uses	1	1000 W tot	1 h/day	500 Wh/day
Total daily energy				29126 Wh/day



Stand Alone System: Main results

Project : **Stand Alone Project at Mehaires**

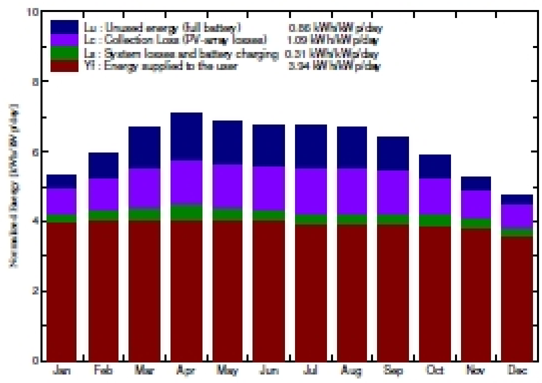
Simulation variant : **Case 3 august 02 consumptions**

Simulation for the first year of operation

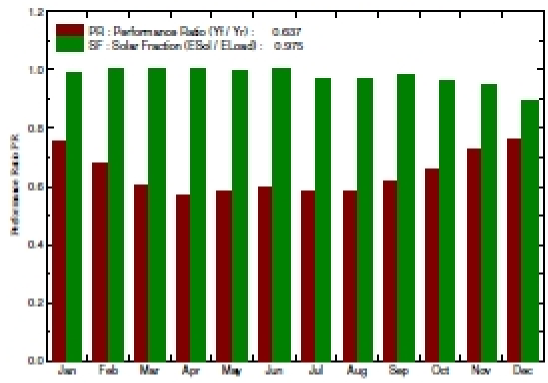
Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	24	Pnom total	**7.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	10.63 MWh/year

Main simulation results				
System Production	**Available Energy**	**12.87 MWh/year**	Specific prod.	1787 kWh/kWp/year
	Used Energy	10.36 MWh/year	Excess (unused)	2.26 MWh/year
	Performance Ratio PR	63.66 %	Solar Fraction SF	97.50 %
Loss of Load	Time Fraction	1.1 %	Missing Energy	0.27 MWh/year
Investment	Global incl. taxes	17176 €	Specific	2.39 €/Wp
Yearly cost	Annuities (Loan 5.0%, 20 years)	1378 €/yr	Running Costs	7037 €/yr
Energy cost		**0.81 €/kWh**		

Normalized productions (per installed kWp): Nominal power 7.20 kWp



Performance Ratio PR and Solar Fraction SF



Case 3 august 02 consumptions

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	118.1	160.4	0.981	0.079	0.009	0.894	0.903	0.990
February	131.3	162.2	0.968	0.137	0.000	0.816	0.816	1.000
March	182.6	203.2	1.186	0.264	0.000	0.903	0.903	1.000
April	209.4	206.8	1.184	0.290	0.000	0.874	0.874	1.000
May	229.1	206.1	1.199	0.271	0.005	0.898	0.903	0.995
June	226.8	196.1	1.149	0.252	0.000	0.874	0.874	1.000
July	227.8	202.0	1.168	0.262	0.028	0.875	0.903	0.969
August	210.8	201.6	1.159	0.254	0.028	0.875	0.903	0.969
September	176.1	186.5	1.070	0.198	0.018	0.855	0.874	0.979
October	149.7	177.1	1.023	0.132	0.037	0.865	0.903	0.959
November	118.5	154.5	0.912	0.072	0.043	0.830	0.874	0.950
December	104.8	143.0	0.856	0.050	0.098	0.805	0.903	0.891
Year	2085.0	2199.4	12.865	2.261	0.266	10.365	10.631	0.975

Legends:
- GlobHor: Horizontal global irradiation
- GlobEff: Effective Global, corr. for IAM and shadings
- E Avail: Available Solar Energy
- EUnused: Unused energy (full battery) loss
- E Miss: Missing energy
- E User: Energy supplied to the user
- E Load: Energy need of the user (Load)
- SolFrac: Solar fraction (EUsed / ELoad)

Stand Alone System: Loss diagram

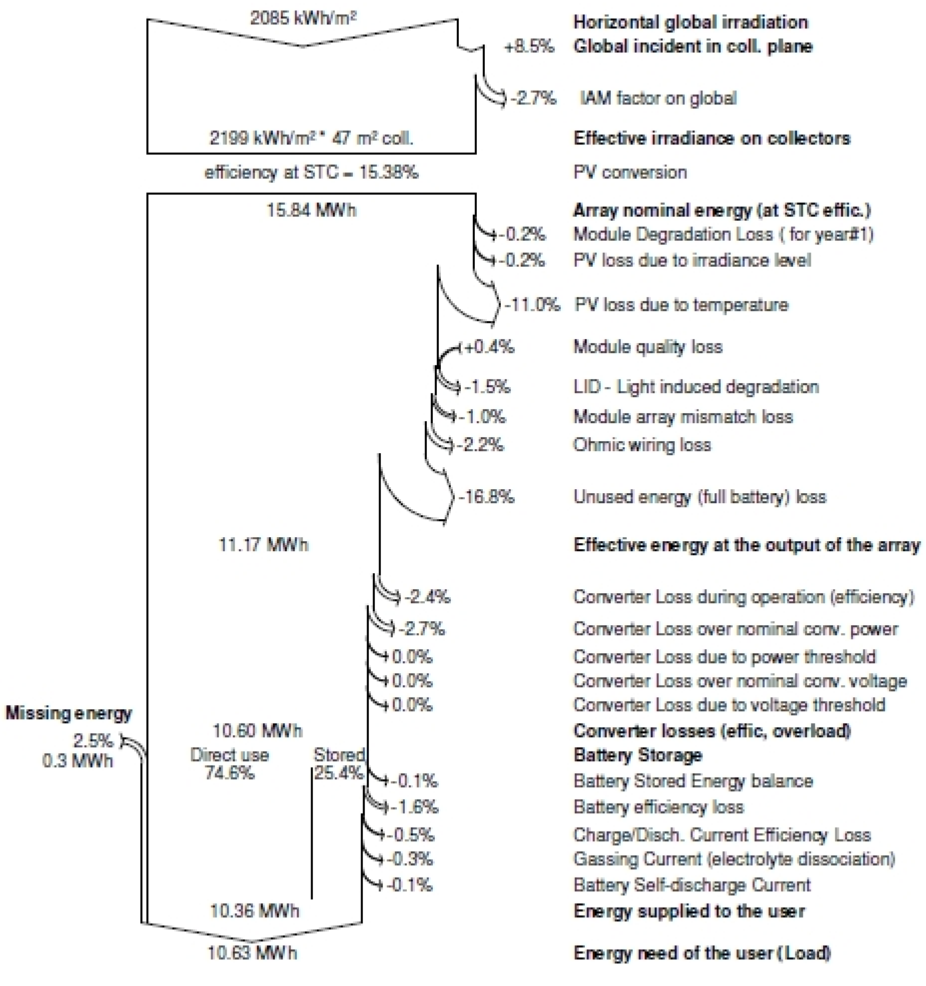
Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 3 august 02 consumptions**

Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	24	Pnom total	**7.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	10.63 MWh/year

Loss diagram over the whole year



Stand Alone System: Economic evaluation

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 3 august 02 consumptions**

Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	24	Pnom total	**7.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	10.63 MWh/year

Investment

PV modules (Pnom = 300 Wp)	24 units	202 € / unit	4848 €
Supports / Integration		83 € / module	2000 €
Batteries (12 V / 160 Ah)	12 units	174 € / unit	2088 €
regulator			5000 €
Settings, wiring, ...			1000 €
Substitution underworth			0 €
Gross investment (without taxes)			**14936 €**

Financing

Gross investment (without taxes)		14936 €
Taxes on investment (VAT)	Rate 15.0 %	2240 €
Gross investment (including VAT)		17176 €
Subsidies		0 €
Net investment (all taxes included)		**17176 €**
Annuities	(Loan 5.0 % over 20 years)	1378 €/year
Maintenance		0 €/year
insurance, annual taxes		0 €/year
Provision for battery replacement	(lifetime 6.5 years)	7037 €/year
Total yearly cost		**8415 €/year**

Energy cost

Used solar energy	10.4 MWh / year
Excess energy (battery full)	2.3 MWh / year
Used energy cost	0.81 € / kWh

Stand Alone System: CO2 Balance

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 3 august 02 consumptions**

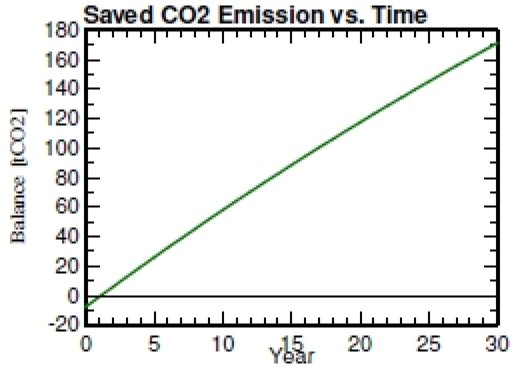
Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	24	Pnom total	**7.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	12	Voltage / Capacity	**48 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	10.63 MWh/year

Produced Emissions	**Total:**	**7.60 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**206.1 tCO2**		
	System production:	12.87 MWh/yr	Lifetime:	30 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	534 gCO2/kWh		
	Source:	IEA List	Country:	World
CO2 Emission Balance	**Total:**	**171.2 tCO2**		

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	343 kgCO2/kWp	4.40 kgCO2/kg
Quantity	15.0 kWp	560 kg
Subtotal [kgCO2]	5138	2465



CASE 6

Stand Alone System: Simulation parameters

Project :	**Stand Alone Project at Mehaires**			
Geographical Site	**Mehaires**		Country	**Western Sahara**
Situation	Latitude	26.17° N	Longitude	-11.09° W
Time defined as	Legal Time	Time zone UT	Altitude	375 m
	Albedo	0.20		
Meteo data:	**Mehaires**	NASA-SSE satellite data, 1983-2005 - Synthetic		

Simulation variant :	**Case 6 august 04 consumptions 60V**			
	Simulation date	28/08/17 18h24		
	Simulation for the	**first year of operation**		

Simulation parameters

Collector Plane Orientation	Tilt	25°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm

PV Array Characteristics

PV module Si-poly	Model	**REC 300PE 72**		
Original PVsyst database	Manufacturer	REC		
Number of PV modules	In series	2 modules	In parallel	17 strings
Total number of PV modules	Nb. modules	34	Unit Nom. Power	300 Wp
Array global power	Nominal (STC)	**10.20 kWp**	At operating cond.	9.18 kWp (50°C)
Array operating characteristics (50°C)	U mpp	66 V	I mpp	139 A
Total area	Module area	**66.3 m²**	Cell area	59.6 m²

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	7.8 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	1.0 % at STC
LID - Light Induced Degradation			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Module average degradation	Year no	1	Loss factor	0.4 %/year
Mismatch due to degradation	Imp dispersion RMS	0.4 %/year	Voc dispersion RMS	0.4 %/year
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System Parameter	System type	**Stand Alone System**		
Battery	Model	**Solar 12V / 160 Ah**		
	Manufacturer	Generic		
Battery Pack Characteristics	Voltage	60 V	Nominal Capacity	480 Ah
	Nb. of units	5 in series x 3 in parallel		
	Temperature	External ambient temperature		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control	Treshold commands as	SOC calculation		
	Charging	SOC = 0.90 / 0.75	i.e. approx.	67.6 / 61.9 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	58.0 / 60.3 V

User's needs :	Daily household consumers	Constant over the year
	average	41 kWh/Day

Stand Alone System: Detailed User's needs

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 6 august 04 consumptions 60V**

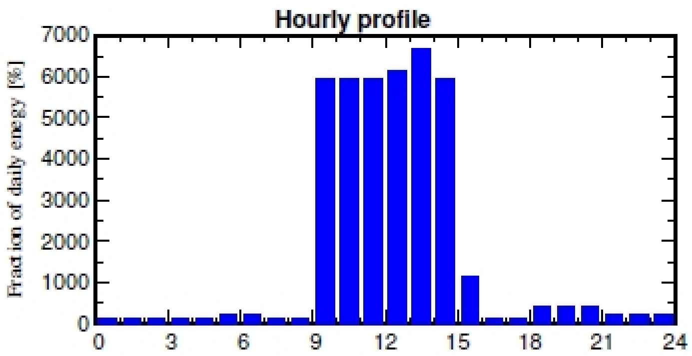
Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	34	Pnom total	**10.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	15	Voltage / Capacity	**60 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	15.07 MWh/year

Daily household consumers, Constant over the year, average = 41 kWh/day

Annual values

	Number	Power	Use	Energy
Lamps (LED or fluo)	1	50 W/lamp	8 h/day	400 Wh/day
TV / PC / Mobile	1	200 W/app	5 h/day	1000 Wh/day
Domestic appliances	1	1000 W/app	6 h/day	6000 Wh/day
Fridge / Deep-freeze	1		24 Wh/day	3600 Wh/day
Dish- & Cloth-washers	1		1 Wh/day	1000 Wh/day
Other uses	1	4797 W tot	6 h/day	28782 Wh/day
Other uses	1	1000 W tot	1 h/day	500 Wh/day
Total daily energy				41282 Wh/day



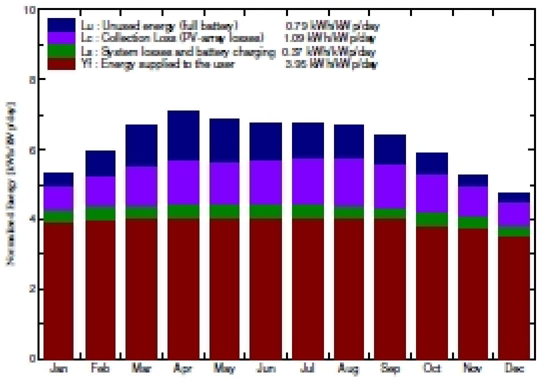
Stand Alone System: Main results

Project :	**Stand Alone Project at Mehaires**
Simulation variant :	**Case 6 august 04 consumptions 60V**
	Simulation for the first year of operation

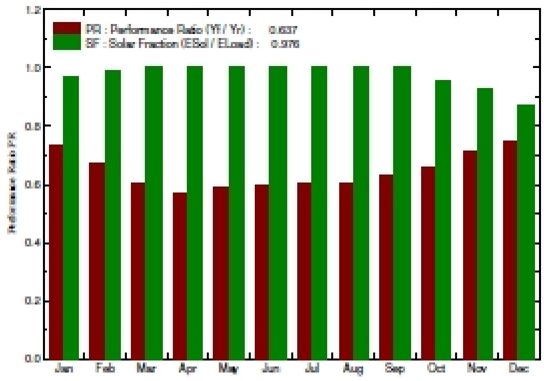
Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	34	Pnom total	**10.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	15	Voltage / Capacity	**60 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	15.07 MWh/year

Main simulation results				
System Production	**Available Energy**	**17.91 MWh/year**	Specific prod.	1756 kWh/kWp/year
	Used Energy	14.70 MWh/year	Excess (unused)	2.94 MWh/year
	Performance Ratio PR	63.72 %	Solar Fraction SF	97.55 %
Loss of Load	Time Fraction	2.2 %	Missing Energy	0.37 MWh/year
Investment	Global incl. taxes	21058 €	Specific	2.06 €/Wp
Yearly cost	Annuities (Loan 5.0%, 20 years)	1690 €/yr	Running Costs	7037 €/yr
Energy cost		**0.59 €/kWh**		

Normalized productions (per installed kWp): Nominal power 10.20 kWp



Performance Ratio PR and Solar Fraction SF



Case 6 august 04 consumptions 60V

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	118.1	160.4	1.360	0.104	0.041	1.239	1.280	0.968
February	131.3	162.2	1.353	0.188	0.015	1.141	1.156	0.987
March	182.6	203.2	1.672	0.370	0.000	1.280	1.280	1.000
April	209.4	206.8	1.687	0.417	0.000	1.238	1.238	1.000
May	229.1	206.1	1.679	0.376	0.000	1.280	1.280	1.000
June	226.8	196.1	1.587	0.319	0.000	1.238	1.238	1.000
July	227.8	202.0	1.603	0.297	0.000	1.280	1.280	1.000
August	210.8	201.6	1.593	0.294	0.000	1.280	1.280	1.000
September	176.1	186.5	1.483	0.240	0.000	1.238	1.238	1.000
October	149.7	177.1	1.424	0.173	0.062	1.218	1.280	0.952
November	118.5	154.5	1.267	0.096	0.090	1.148	1.238	0.927
December	104.8	143.0	1.198	0.068	0.161	1.118	1.280	0.874
Year	2085.0	2199.4	17.906	2.944	0.369	14.699	15.068	0.976

Legends:				
	GlobHor	Horizontal global irradiation	E Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
	E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
	EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

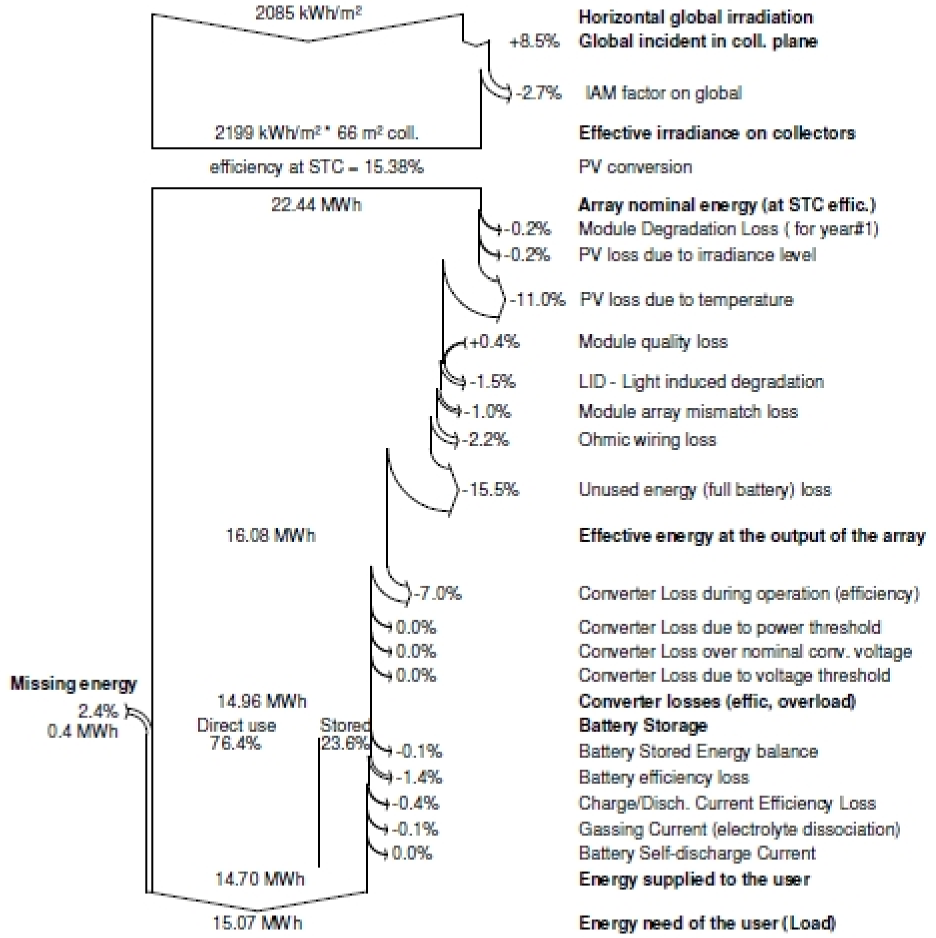
Stand Alone System: Loss diagram

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 6 august 04 consumptions 60V**
Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	34	Pnom total	**10.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	15	Voltage / Capacity	**60 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	15.07 MWh/year

Loss diagram over the whole year



Stand Alone System: Economic evaluation

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 6 august 04 consumptions 60V**

Simulation for the first year of operation

Main system parameters	System type	**Stand alone**			
PV Field Orientation	tilt	25°	azimuth	0°	
PV modules	Model	REC 300PE 72	Pnom	300 Wp	
PV Array	Nb. of modules	34	Pnom total	**10.20 kWp**	
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel	
battery Pack	Nb. of units	15	Voltage / Capacity	**60 V / 480 Ah**	
User's needs	Daily household consumers	Constant over the year	global	15.07 MWh/year	

Investment

PV modules (Pnom = 300 Wp)	34 units	202 € / unit	6868 €
Supports / Integration		83 € / module	2833 €
Batteries (12 V / 160 Ah)	15 units	174 € / unit	2610 €
regulator			5000 €
Settings, wiring, ...			1000 €
Substitution underworth			0 €
Gross investment (without taxes)			**18311 €**

Financing

Gross investment (without taxes)		18311 €
Taxes on investment (VAT)	Rate 15.0 %	2747 €
Gross investment (including VAT)		21058 €
Subsidies		0 €
Net investment (all taxes included)		**21058 €**
Annuities	(Loan 5.0 % over 20 years)	1690 €/year
Maintenance		0 €/year
insurance, annual taxes		0 €/year
Provision for battery replacement	(lifetime 6.8 years)	7037 €/year
Total yearly cost		**8727 €/year**

Energy cost

Used solar energy	14.7 MWh / year
Excess energy (battery full)	2.9 MWh / year
Used energy cost	0.59 € / kWh

Stand Alone System: CO2 Balance

Project : **Stand Alone Project at Mehaires**

Simulation variant : **Case 6 august 04 consumptions 60V**

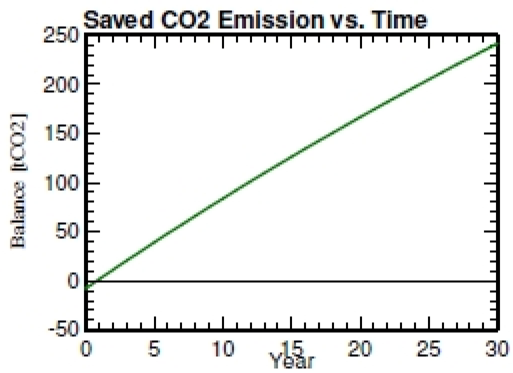
Simulation for the first year of operation

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	25°	azimuth	0°
PV modules	Model	REC 300PE 72	Pnom	300 Wp
PV Array	Nb. of modules	34	Pnom total	**10.20 kWp**
Battery	Model	Solar 12V / 160 Ah	Technology	sealed, Gel
battery Pack	Nb. of units	15	Voltage / Capacity	**60 V / 480 Ah**
User's needs	Daily household consumers	Constant over the year	global	15.07 MWh/year

Produced Emissions	**Total:**	**7.60 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**286.9 tCO2**		
	System production:	17.91 MWh/yr	Lifetime:	30 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	534 gCO2/kWh		
	Source:	IEA List	Country:	World
CO2 Emission Balance	**Total:**	**241.3 tCO2**		

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	343 kgCO2/kWp	4.40 kgCO2/kg
Quantity	15.0 kWp	560 kg
Subtotal [kgCO2]	5138	2465



APPENDIX G: PUMP CALCULATIONS

Cases 0-4

$$Power\ [W] = Q[m^3/s] \times \rho[kg/m^3] \times g[m/s^2] \times H[m] \quad (1)$$

$$Q = \frac{7\ m^3/day}{5\ h/day} = 1.4\frac{m^3}{h} = 1.4\frac{m^3}{h} \times \frac{1\ h}{3600\ s} = 0.000389\ m^3/s$$

$$Power\ (hydraulic) = 0.000389\frac{m^3}{s} \times 1007\frac{kg}{m^3} \times 9.81\frac{m}{s^2} \times 100m = 384.28\ W = 0.384\ kW$$

$$Power\ (required) = \frac{0.384\ kW}{0.75} = 0.512\ kW$$

$$Energy\ \left[\frac{kWh}{day}\right] = Power[kW] \times t\left[\frac{h}{day}\right]$$

$$Energy\ = 0.512\ kW \times 5\frac{h}{day} = 2.56\ kWh/day$$

$$Energy\ required\ for\ pumping\ [kWh/day] = \frac{Q[m^3/day] \times \rho[kg/m^3] \times g[m/s^2] \times H[m]}{\eta \times 3600[s/h] \times 1000[W/kW]} \quad (2)$$

$$Energy\ required\ for\ pumping\ \left[\frac{kWh}{day}\right] = \frac{7\frac{m^3}{day} \times 1007\frac{kg}{m^3} \times 9.81\frac{m}{s^2} \times 100\ m}{0.75 \times 3600\frac{s}{h} \times 1000\frac{W}{kW}} = 2.56\ kWh/day$$

Case 5-7

$$Power\ [W] = Q[m^3/s] \times \rho[kg/m^3] \times g[m/s^2] \times H[m] \quad (1)$$

$$Q = \frac{12.8\ m^3/day}{5\ h/day} = 2.56\frac{m^3}{h} = 2.56\frac{m^3}{h} \times \frac{1\ h}{3600\ s} = 0.000711\ m^3/s$$

$$Power\ (hydraulic) = 0.000711\frac{m^3}{s} \times 1007\frac{kg}{m^3} \times 9.81\frac{m}{s^2} \times 100m = 702.48\ W = 0.70248\ kW$$

$$Power\ (required) = \frac{0.70248\ kW}{0.75} = 0.9366\ kW$$

$$Energy\ \left[\frac{kWh}{day}\right] = Power[kW] \times t\left[\frac{h}{day}\right]$$

$$Energy\ = 0.9366\ kW \times 5\frac{h}{day} = 4.68\ kWh/day$$

$$Energy\ required\ for\ pumping\ [kWh/day] = \frac{Q[m^3/day] \times \rho[kg/m^3] \times g[m/s^2] \times H[m]}{\eta \times 3600[s/h] \times 1000[W/kW]} \quad (2)$$

$$Energy\ required\ for\ pumping\ \left[\frac{kWh}{day}\right] = \frac{12.8\frac{m^3}{day} \times 1007\frac{kg}{m^3} \times 9.81\frac{m}{s^2} \times 100\ m}{0.75 \times 3600\frac{s}{h} \times 1000\frac{W}{kW}} = 4.68\ kWh/day$$

APPENDIX H: DIAGRAM OF THE SYSTEM