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Techno-economic feasibility study of solar and wind based Irrigation Systems in Northern Colombia

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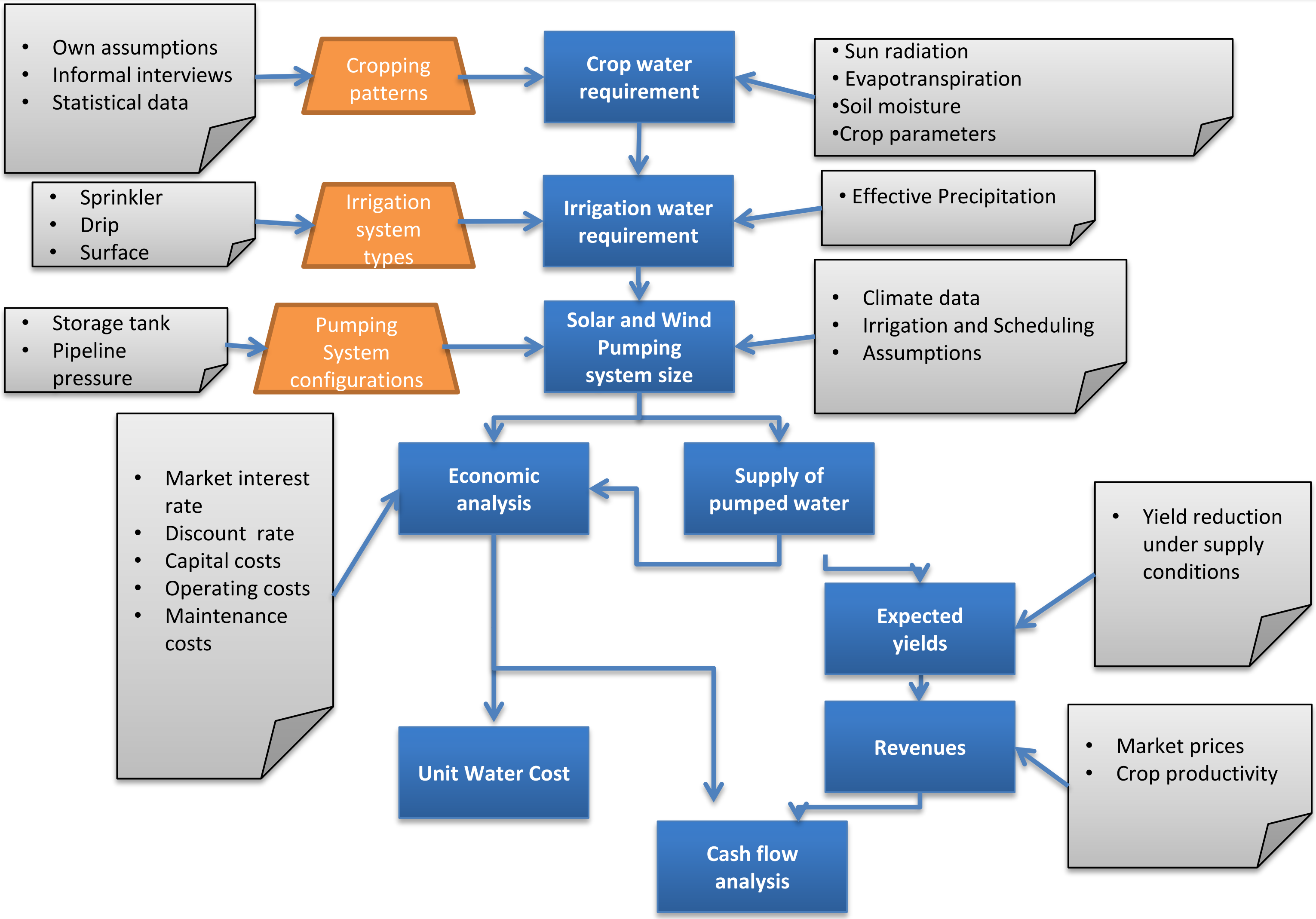
Introduction

- Irrigated agriculture is more productive than rain-fed agriculture
- About 2.8 billion people suffer from water scarcity, 50% of them in off-grid areas
- The need: To design systems which ensure water supply in dry periods
- Solar and wind based irrigation systems as a decentralized and cost competitive alternative
- Farmers can benefit from sales proceeds

Objectives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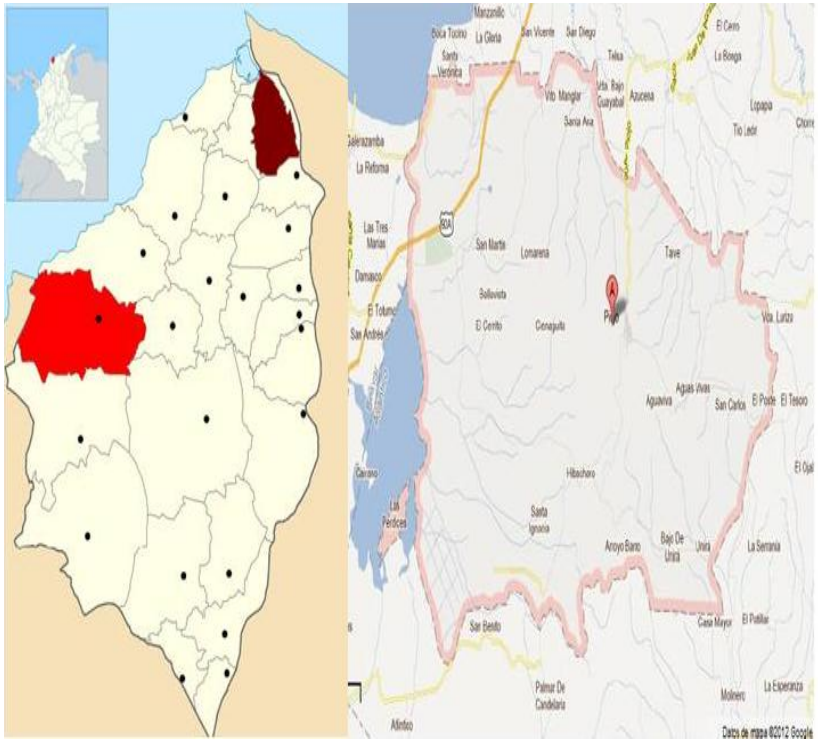
Irrigation in Colombia

- In the subhumid climates of the Caribbean Coast and the Eastern Plains (600-1000 mm yr-1) irrigation is necessary
- Irrigation management is centralized by the Irrigation Districts
- There is a need of improved applied research that fulfills farmers needs

The case study area

> The Municipality of Piojó in the Atlántico Department (Northern Colombia)

- Population: 5089 habitants
- Total extension: 258 km²
- Altitude: 314 m
- Climate: Semi-arid



The case study area

> Agriculture

- Traditionally two main agriculture tendencies
  - Medium productivity region
  - Low productivity region
- Millet, sorghum and corn for sub humid climate conditions
- Low production of permanent crops and horticulture

Crop pattern

> Common crop pattern

Crop	Area (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Manioc	13												
First semester													
Sorghum	17												
Corn	24												
Millet	17												
Watermelon	5												
Common bean	7												
Second semester													
Sorghum	32												
Corn	21												
Millet	7												
Watermelon	1												
Common bean	8												

Crop pattern

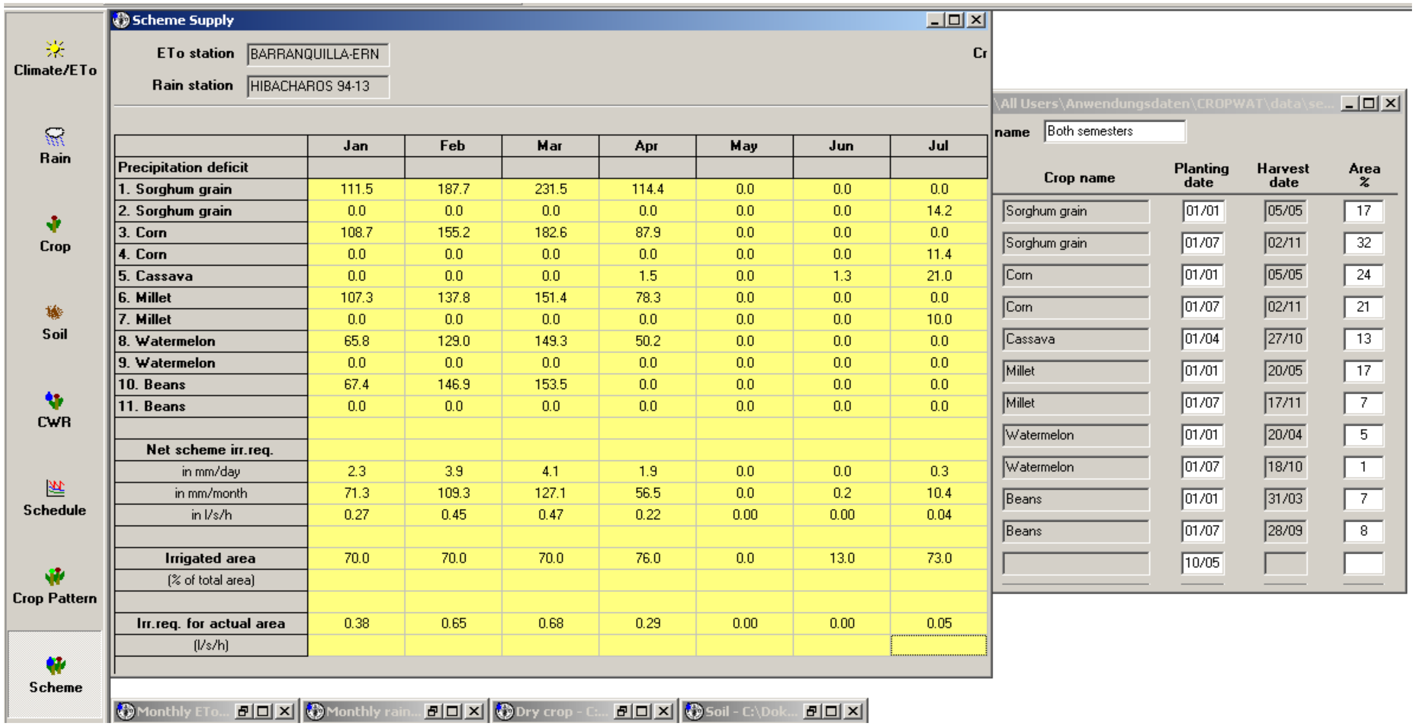
> Fruit cash crop pattern

- For established markets in the region

Crop	Area (%)
Mango	40
Avocado	30
Lemon	20
Guanábana (sour sop)	10

Methods and procedures

> Determination of the crop water requirements



Scheme Supply

ETo station BARRANQUILLA-ERN

Rain station HIBACHAROS 94-13

	Jan	Feb	Mar	Apr	May	Jun	Jul
Precipitation deficit							
1. Sorghum grain	111.5	187.7	231.5	114.4	0.0	0.0	0.0
2. Sorghum grain	0.0	0.0	0.0	0.0	0.0	0.0	14.2
3. Corn	108.7	155.2	182.6	87.9	0.0	0.0	0.0
4. Corn	0.0	0.0	0.0	0.0	0.0	0.0	11.4
5. Cassava	0.0	0.0	0.0	1.5	0.0	1.3	21.0
6. Millet	107.3	137.8	151.4	78.3	0.0	0.0	0.0
7. Millet	0.0	0.0	0.0	0.0	0.0	0.0	10.0
8. Watermelon	65.8	129.0	149.3	50.2	0.0	0.0	0.0
9. Watermelon	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10. Beans	67.4	146.9	153.5	0.0	0.0	0.0	0.0
11. Beans	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net scheme irr.req.							
in mm/day	2.3	3.9	4.1	1.9	0.0	0.0	0.3
in mm/month	71.3	109.3	127.1	56.5	0.0	0.2	10.4
in l/s/h	0.27	0.45	0.47	0.22	0.00	0.00	0.04
Irrigated area	70.0	70.0	70.0	76.0	0.0	13.0	73.0
(% of total area)							
Irr.req. for actual area	0.38	0.65	0.68	0.29	0.00	0.00	0.05
(l/s/h)							

name Both semesters

Crop name	Planting date	Harvest date	Area %
Sorghum grain	01/01	05/05	17
Sorghum grain	01/07	02/11	32
Corn	01/01	05/05	24
Corn	01/07	02/11	21
Cassava	01/04	27/10	13
Millet	01/01	20/05	17
Millet	01/07	17/11	7
Watermelon	01/01	20/04	5
Watermelon	01/07	18/10	1
Beans	01/01	31/03	7
Beans	01/07	28/09	8
	10/05		

Software CROPWAT 8.0

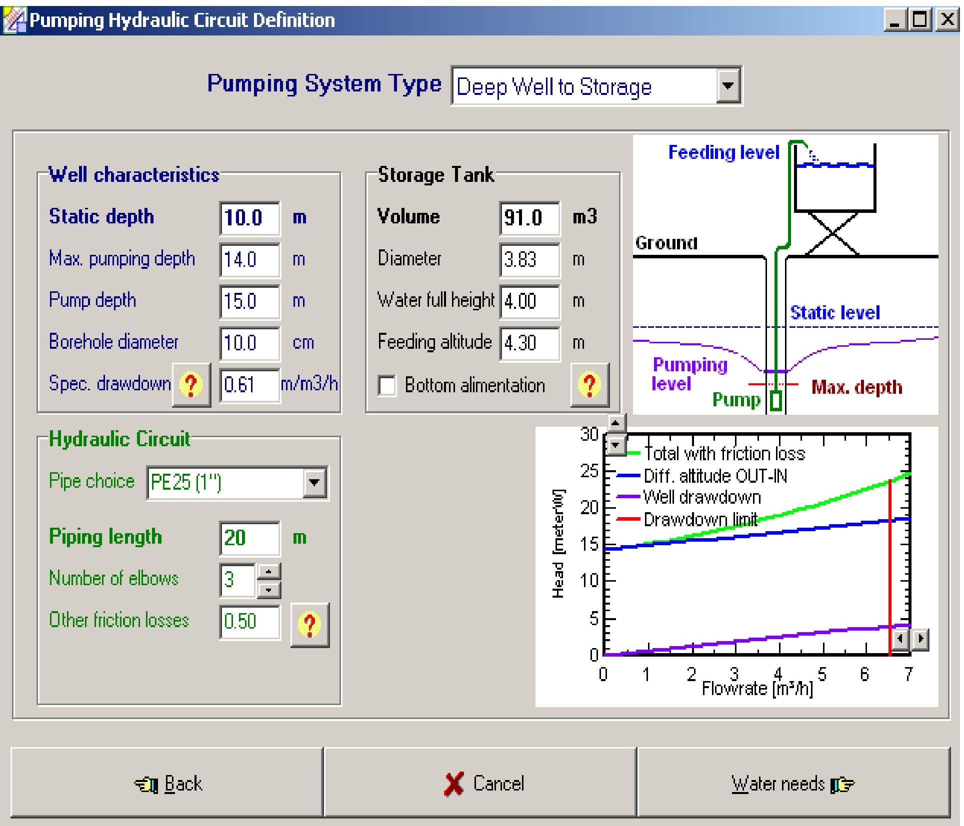
Methods and procedures

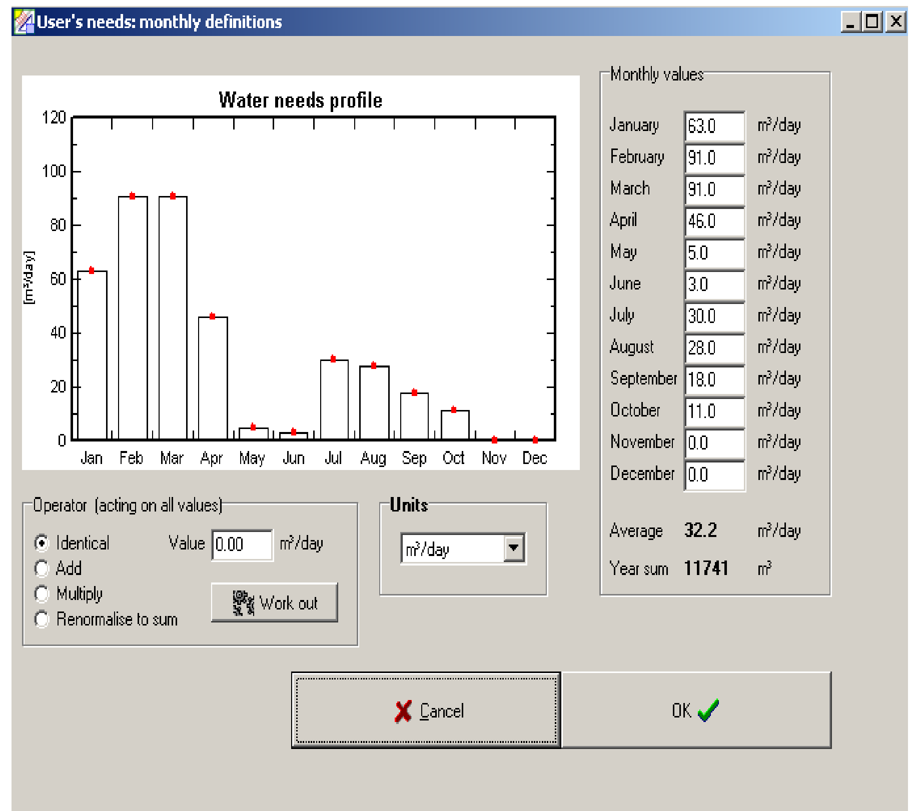
> Irrigation system configuration

- Storage tank
  - Common sizes: 20 – 200 m^3
  - Storage days: 0.5 – 2 days
  - Construction type:
    - Brickwork
    - Earth bund with lining
    - Ferrocement
    - Overhead storage tank of steel or concrete
- Pipeline head losses

Methods and procedures

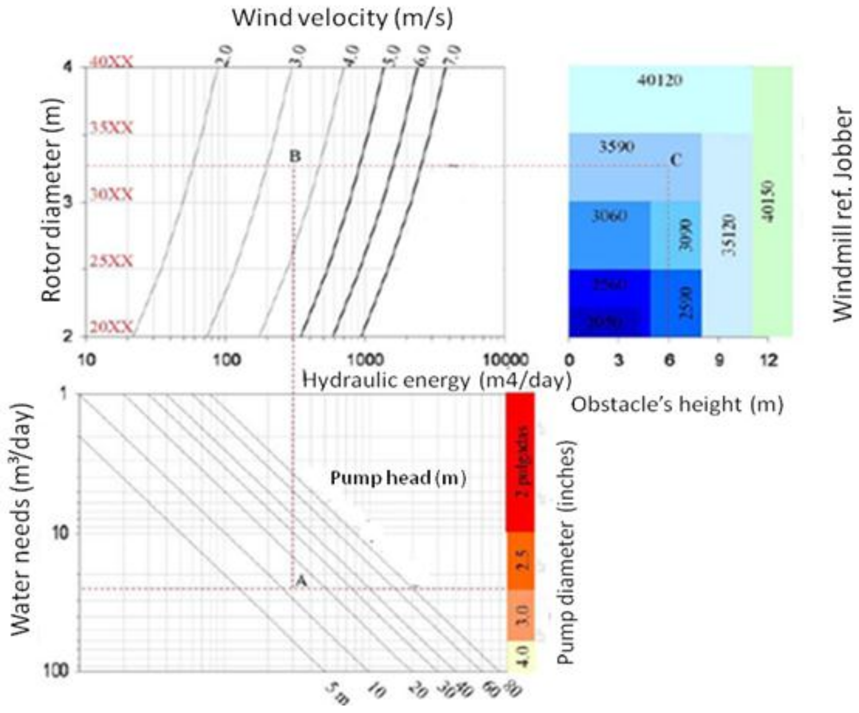
> Solar Pumping Sizing with PVSYST





Methods and procedures

> Windmill Sizing



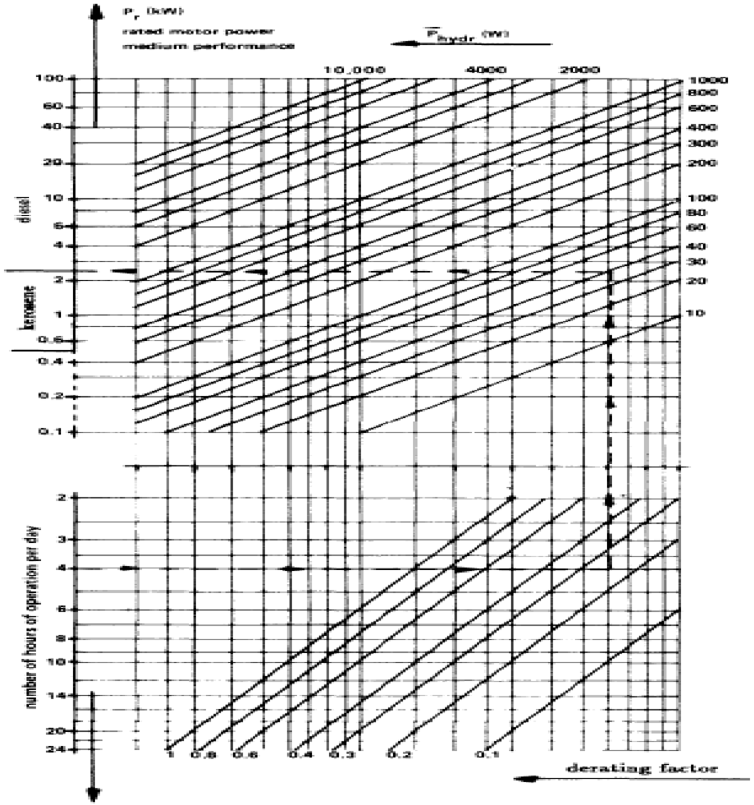
Source: Industrias Jober, 2014

1) Gathering wind data
2) Calculation of the specific wind power
3) Identify the design month
4) Sizing of the windmill according to Jober sizing diagram
5) Calculation of the number of hour of reliable wind speed

-> 80-250% of the annual average wind speed

Methods and procedures

>Diesel Pumping Sizing



- Theoretical pump size needed:
  - 2 – 6 kW
  - ➢ Barnes 5 HP pump selected
- Operation: 8 hours every second day

Methods and procedures

> Economic analysis

- To determine the least cost technology for water pumping (Unit water costs)
- All costs (investment + recurrent) are converted into an average capital cost (annuity)

$$a = PV \frac{d * (1+d)^n}{(1+d)^n - 1}$$

- Method for calculating a single future payment (replacement costs)

$$PV = fv * \left[\frac{(1+i_r)}{(1+d)}\right]^n$$

- Discount rate deduced from market interest rate

- Method for converting recurring annual payment in a net present value

Methods and procedures

> Cash flow analysis

- Costs and revenues are calculated over a specified period

-> To assess yearly project cash movements

- Benefit to Cost Ratios

-> B/C = [PV (All Benefits)] / [PV (All Costs)]

Data gathered and assumptions

> Irrigation system configurations

- Static head -> 10 m as constant parameter
- Dynamic head assumption for PVSYST

-> $0{,}61 \frac{m}{m^3/h}$

- Storage tank size (21 – 46 m^3)
- Head losses
- Pressure booster pump for sprinkler irrigation

Data gathered and assumptions

>Solar Pumping

- Main solar pump commercialized in Colombia -> Lorentz pump
- Solar pump type used for the simulations

  -> Lorentz PS1200 C-SJ5-8

Technical specifications

Model	PS1200 SJ5-8
MPTT converter	PS 1200 Converter
Motor type	DC motor, brushless (with MPTT input converter)
Min. MPP oper. Voltage	64V
Max. MPP oper. Voltage	108V
Max. Power	1200W
Max. Current	15A

Data gathered and assumptions

> Wind Pumping

- According to data of windmill manufacturer Jober
- Wind average speeds in case study area (1980-2000)

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Wind speed (m/s)	6	6.5	6	5	4	3.5	4	4	3	3	3.5	5

- Number of hours of reliable wind speed

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Hours of reliable wind speed	20	21	20	18	15	12	12	12	8	8	11	16

Data gathered and assumptions

> Economic analysis

- Market interest rate : 11 %
- Main capital costs for the economic analysis

Solar panel and support structure	1,17 €/Wp
Solar pump and controller	2108 €
Windmill	2375 €
Diesel pump	407 €
PV booster pump for sprinkler irrigation	953 €
Storage tank	2570-5340 € depending on the scenario
Irrigation method (€/ha)	Surface: 198 €/ha Sprinkle: 1661 €/ha Drip: 2769€/ha

Data gathered and assumptions

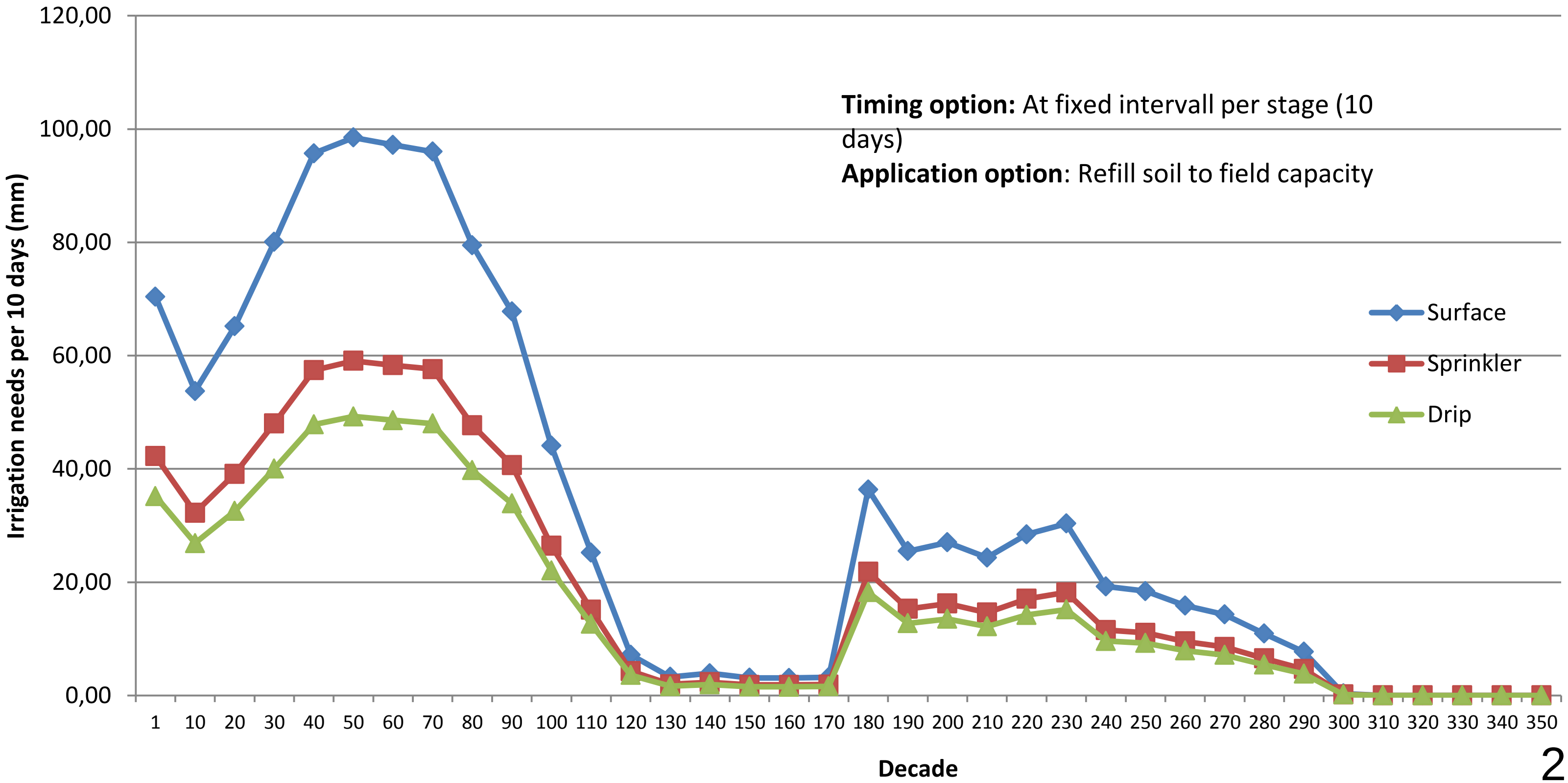
> Cash flow analysis

- Cash flow analysis of the 18 scenarios
- Data needed
  - Crop productivity
    - Local data of productivity in Piojó (2007-2012)
    - Productivity of irrigated crops in the region
  - Crop wholesale prices
    - Yearly average prices for the market of Barranquilla

Results

> Crop water requirements

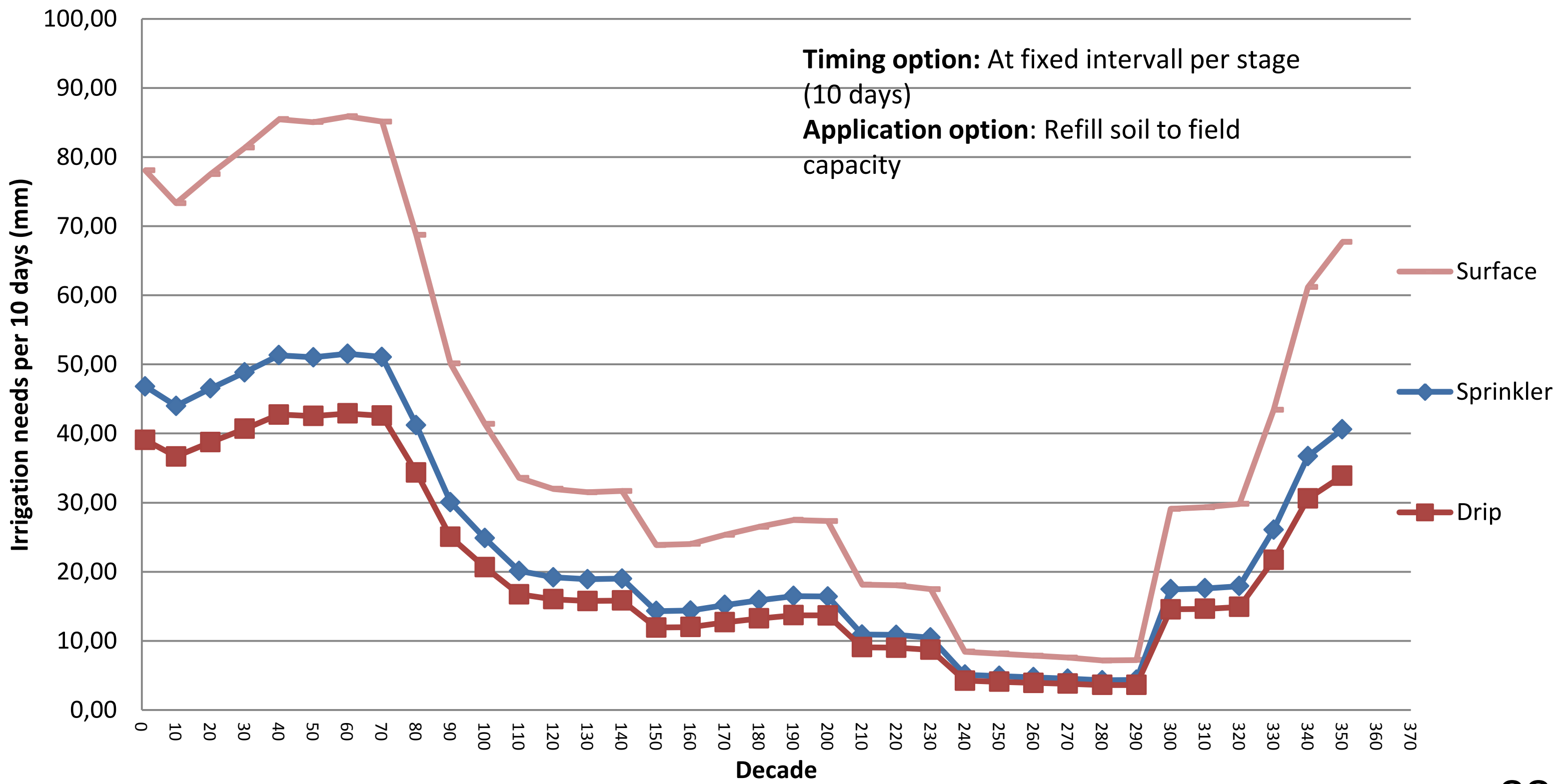
Common crop pattern



Results

> Crop water requirements

Fruit cash crop pattern



Results

> PVSYST Solar Sizing Results

	Suggested pump power (W)	Suggested PV power (Wp)	Pump model	Array selected	Water pumped in year (m^3)	Water needs (m^3)	Missing water (%)	Energy at pump (kWh)	Unused energy (kWh)	Specific energy (kWh/m^3)	System efficiency (%)	Pump efficiency (%)
Scenario 1, Surface Irr.	1068	1349	Lorentz PS 1200 SJ5-8	6 Modules Yingli 240 Wp 27V	7190	11626	38.2	2695	2472	0.37	36.8	53.3
Scenario 1, Sprinkler Irr.	623	787	Lorentz PS 1200 SJ5-8	4 Modules Yingli 210 Wp 25V	5834	7018	16.9	1946	1864	0.33	46.2	55
Scenario 1, Drip Irr.	525	663	Lorentz PS 1200 SJ5-8	4 Modules Yingli 170 Wp 19V	4720	5811	18.8	1625	1449	0.34	47.1	54.8
Scenario 2, Surface Irr.	1061	1340	Lorentz PS 1200 SJ5-8	6 Modules Yingli 210 Wp 25V	11022	14649	24.8	4133	1517	0.37	65.5	53
Scenario 2, Sprinkler Irr.	628	794	Lorentz PS 1200 SJ5-8	3 Modules Yingli 265 Wp 30V	7610	8808	13.6	2503	1149	0.33	61.9	55.3
Scenario 2, Drip Irr.	570	720	Lorentz PS 1200 SJ5-8	4 Modules Yingli 180 Wp 19V	6712	7386	9.1	2166	1136	0.32	58.8	55.2

Source: PVSYST 5.0

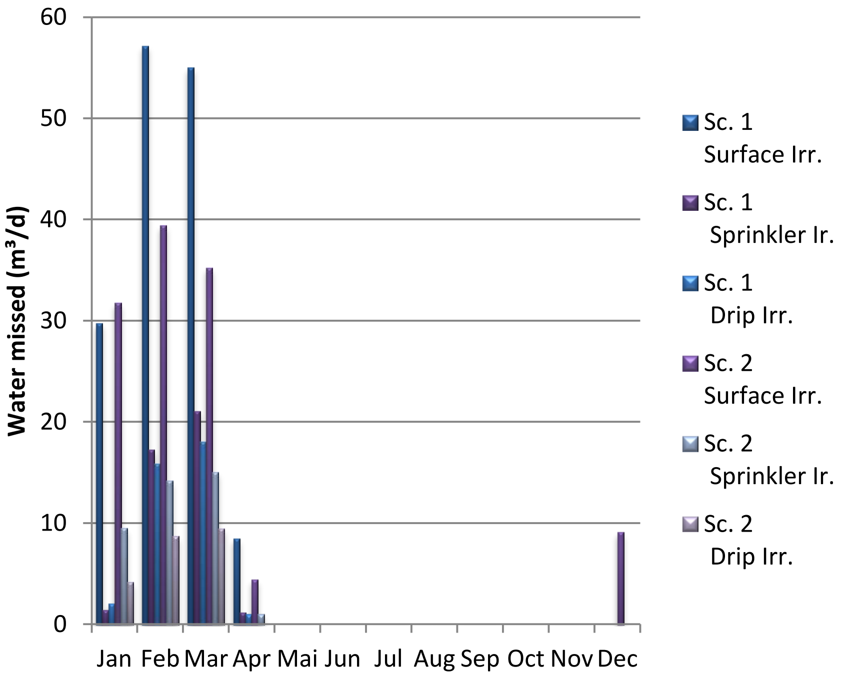
Results

> Wind sizing results

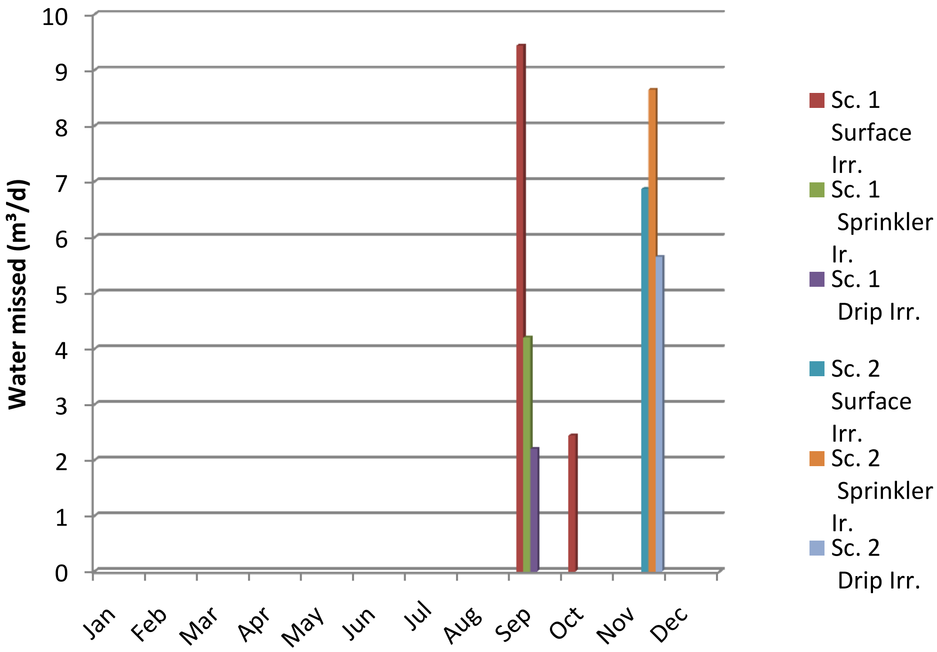
- Highest reference area in common crop pattern -> September
- Highest reference area in fruit cash crop pattern -> November
- Two different windmill types depending on the scenario!

Results

> Supply of pumped water



Solar Pumping



Windmill

Results

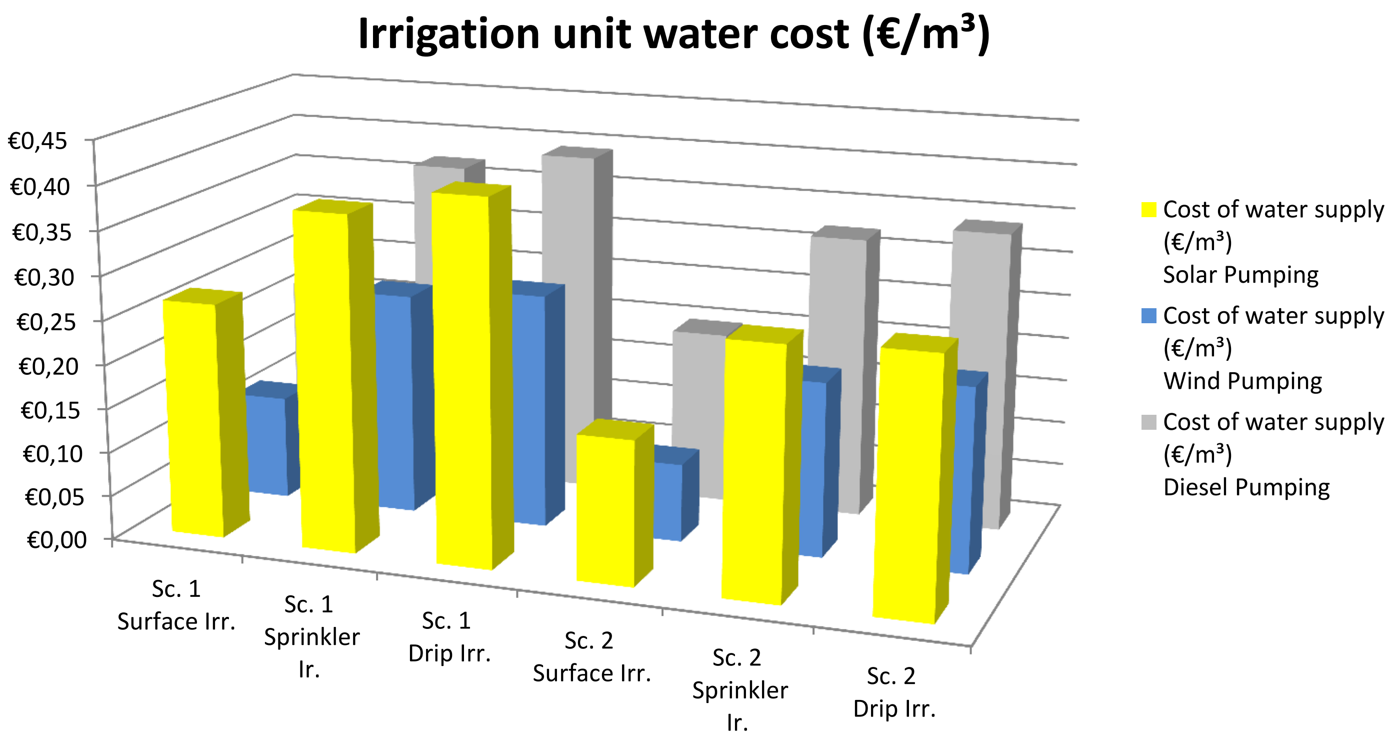
> CROPWAT Yield reduction

Common Crop Scenario					
Crop	Plant. Date	Harvest Date	Yield Reduction (%)		
			At critical depletion	At fixed intervals	Without Irrigation
Sorghum	01. Jan	05.May	0,1	8,5	78,1
Sorghum	01. Jul	02. Nov	0,2	0,4	6,8
Corn	01. Jan	05.May	0,2	10	100
Corn	01. Jul	02. Nov	0,3	0,7	0,9
Cassava	01. Apr	27. Oct	0,1	0,4	1,1
Millet	01. Jan	20. May	0,2	3,3	94,8
Millet	01. Jul	17. Nov	0,3	0,8	1
Beans	01. Jan	31. Mar	0,3	24,7	100
Beans	01. Jul	28. Sep	0,3	0,6	1,3
Watermelon	01. Jan	20. Apr	0,2	5,8	96
Watermelon	01. Jul	18 Oct	0,3	0,6	0,6

Fruit Cash Crop Scenario			
Crop	Yield Reduction (%)		
	At critical depletion	At fixed intervals	Without irrigation
Mango	0,1	2,5	22,7
Avocado	0	2,2	25,3
Lemon	0,1	3,7	35,8
Soursop	0,1	4,5	30,2

Results

> Unit water costs



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Results

> Cash flow analysis

Common Crop Pattern									
	SOLAR PUMPING			**WIND PUMPING**			**DIESEL PUMPING**		
	CP1 Surface Irr.	**CP1 Sprinkler Ir.**	**CP1 Drip Irr.**	**CP1 Surface Irr.**	**CP1 Sprinkler Ir.**	**CP1 Drip Irr.**	**CP1 Surface Irr.**	**CP1 Sprinkler Ir.**	**CP1 Drip Irr.**
Total Costs (€)	(€36.764)	(€41.156)	(€35.691)	(€26.937)	(€33.198)	(€29.085)	(€58.234)	(€49.385)	(€49.756)
Total Revenues (€)	€29.456	€34.150	€33.748	€37.809	€37.823	€37.832	€37.845	€37.845	€37.845
PV Costs (€)	€5.465	€6.118	€5.305	€4.004	€4.935	€4.323	€8.656	€7.341	€7.396
PV Revenues (€)	€4.378	€5.076	€5.016	€5.620	€5.622	€5.623	€5.625	€5.625	€5.625
B/C Ratio	**0,80**	**0,83**	**0,95**	**1,40**	**1,14**	**1,30**	**0,65**	**0,77**	**0,76**
Total Dividend in 20 y (€)	(€1.086)	(€1.041)	(€289)	€1.616	€688	€1.300	(€3.031)	(€1.715)	(€1.771)

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Results

> Cash flow analysis

Fruit Cash Crop Pattern									
	SOLAR PUMPING			WIND PUMPING			DIESEL PUMPING		
	CP 2 Surface Irr.	CP2 Sprinkler Ir.	CP2 Drip Irr.	CP2 Surface Irr.	CP 2 Sprinkler Ir.	CP2 Drip Irr.	CP2 Surface Irr.	CP2 Sprinkler Ir.	CP2 Drip Irr.
Total Costs (€)	(€34.846)	(€39.700)	(€35.376)	(€26.004)	(€32.266)	(€28.618)	(€67.499)	(€61.475)	(€57.424)
Total Revenues (€)	€206.598	€212.367	€212.367	€218.560	€217.869	€218.529	€219.534	€219.534	€219.534
PV Costs (€)	€5.180	€5.901	€5.258	€3.865	€4.796	€4.254	€10.033	€9.138	€8.536
PV Revenues (€)	€30.709	€31.567	€31.567	€32.488	€32.385	€32.483	€32.632	€32.632	€32.632
Payback year	8	8	8	7	8	7	8	8	8
B/C Ratio	**5,93**	**5,35**	**6,00**	**8,40**	**6,75**	**7,64**	**3,25**	**3,57**	**3,82**
Total Dividend in 20 y (€)	€25.530	€25.666	€26.309	€28.622	€27.589	€28.229	€22.599	€23.494	€24.097

Results

> Cash flow Rain-fed scenario

- Common crop pattern: € 2224
- Fruit cash crop pattern: € 17380
  - > € 5200 - € 11200 lower!
  - >Solar and Diesel Pumping:
    - Extra monthly income of €50 after 6th or 7th year
  - >Windmill
    - Dividends could be doubled if larger areas are irrigated

Discussion

- The importance of the crop pattern
- Windmill: Use of surplus water
- Solar pumping: More profitable with a water efficient method
- Diesel fuel escalation proportional to the annual inflation rate
- Irrigation method
- The ½ day capacity of storage tank

Conclusion

- Technically can be sized for the 2 cropping patterns proposed
- Windmills are the most cost-effective solution
- Solar pumping vs. Diesel pumping
- Irrigation alone is not economically feasible
  - > A cropping pattern of commercial products is needed

Thank you for your attention!