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Report

Preliminary study, Power for running pumps in Taveta city, Kenya

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ABSTRACT
Taveta Town in Kenya is a friendship city of Melhus municipal. The power for running a water supply is investigated. Hydropower was found not to be suitable, so a solar power plant of 200 kW (giving 200 kW at the centre of a sunny day, 230 kW peak effect) was investigated. The price was USD 434 000 for the panels and converters, and expected saving is USD 48 000 per year when grid connection is used.

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APPENDICES

1 Introduction, Melhus Municipality

Melhus Municipality and Taveta Town Council have been friends and partners since 2002. The municipalities cooperate within a number of exchange programs. One of them is a capacity building program concerning welfare and environment. Through physical planning and infrastructure projects, bringing up a new town area, Melhus and Taveta are focused on providing the Taveta community with water from the ground water resource Njoro Springs. This can be done by upgrading the water plant and bring in a new green energy solution. The problem Taveta faces today is an unstable power supply situation through the national grid system. Melhus Municipality, together with the Norwegian energy company TrønderEnergi AS, has initialized a project to investigate two different energy solutions to run the pumps at Njoro Springs; small hydro power turbines and solar energy systems. To seek out the best green energy solution, also considering costs, Melhus Municipality cooperates with SINTEF as part of Green Energy Pilot Project.

The Project is part of Taveta Town Council´s Development Plan, which objective is to improve the governance processes, which again will lead to efficient service delivery to the inhabitants. A stable and clean water delivery system is in addition expected to improve the health situation in Taveta. The Project is linked to a regional planning process in Taita Taveta County, and is regarded as a pilot that other local governments could learn from.

2 Existing water supply system

Taveta Town gets much of its water from Njoro springs, 3 km outside the city. The water is pumped by pipeline to the city by pumps with an effect of 131 kW. Because of the lack of power, the city is rationing the water. Figure 1 shows a sketch of the system and Figure 2 shows a photograph of the pump house as it is today. The water comes from Njoro Springs where Lumi River is close by. Figure 4 shows an overview photograph of the area. Njoro Springs is surrounded by a wall securing that the source water is not mixed with water from the Lumi River during the flood time. Near the pool there is a vacuum pump that pumps the water to a pump house. In the pump house there are three pumps, one pump of 75 kW, one of 56 kW, and one of 75 kW that does not work. The water then flows into a storage tank of 1360 m^3 which is located 73 m above the pumps([1]) [1]. The water is then guided through a pipeline with length of 4.2 km ([2]) and an inner diameter of 250 mm ([3]). The pipeline is made of carbon steel. From the storage tank the water flows downward to the town of Taveta.

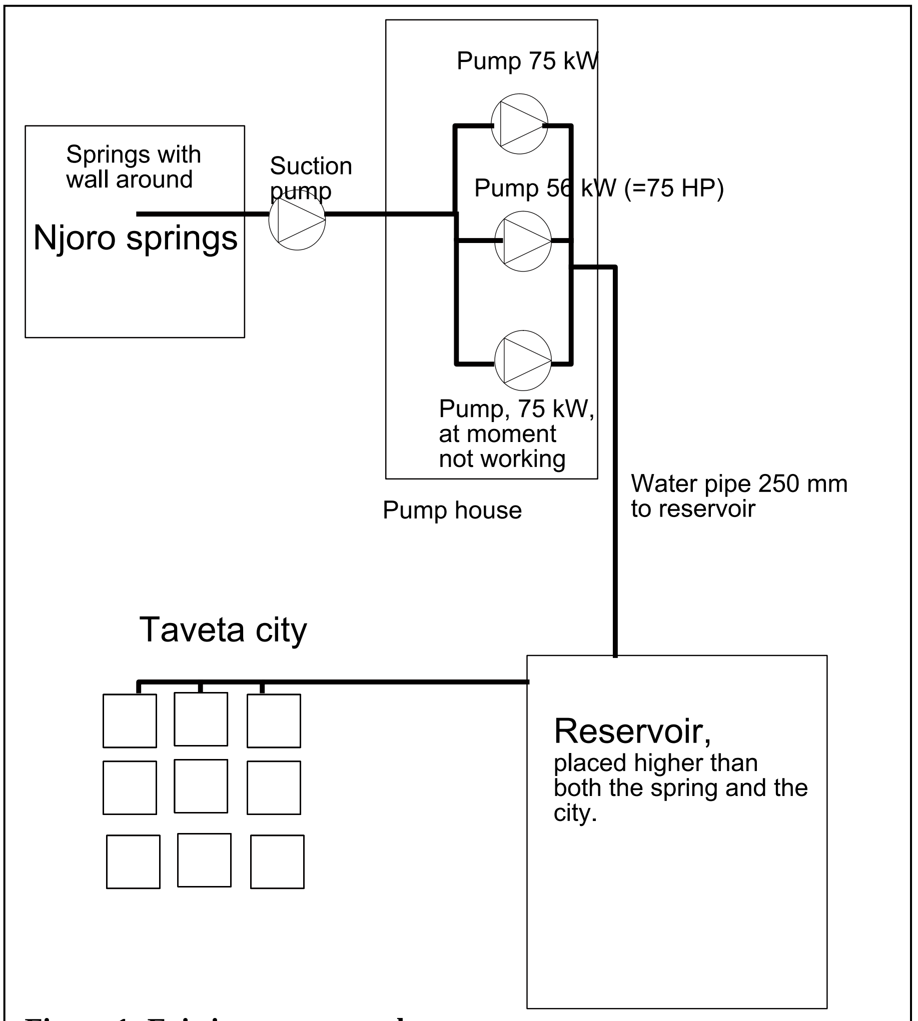

Figure 1: Existing water supply system

[1] The height difference from the spring to the reservoir is measured with GPS on a Samsung telephone to 73 m. People in Taveta said it was 91m height difference, and height difference is 64 m on Google maps where the head of the reservoir is not included.

[2] From GPS coordinates is straight length 4140 m between the pump station and the reservoir. The pile length was said to be 3000 m

[3] Got the diameter by speaking with the workers.

Figure 2: Pumps in the pump house for the water supply system in Taveta city

Today the pumps are driven by power from the grid. Authorities in Taveta state that the electricity is unstable and that the costs are 0.12 USD / kWh. Because of the high electricity price and the unstable electricity the usage of water must be limited.

At time being, the estimated need is 3000 m^3/day, which is expected to increase to 5000 m^3/day. If we base the calculations on a 50% pump efficiency, the required electricity will be 504000 kWh/year to a cost of $ 60500 per year for pumping 3000 m^3/day. Today, the electricity costs are stated to be $ 42000 per year (approximately 350000 kWh / year), and the water consumption is therefore rationed. By providing an extra power of 154000 kWh/year, the estimated needs will be covered.

The present work looks at ways to provide power to the pumps.

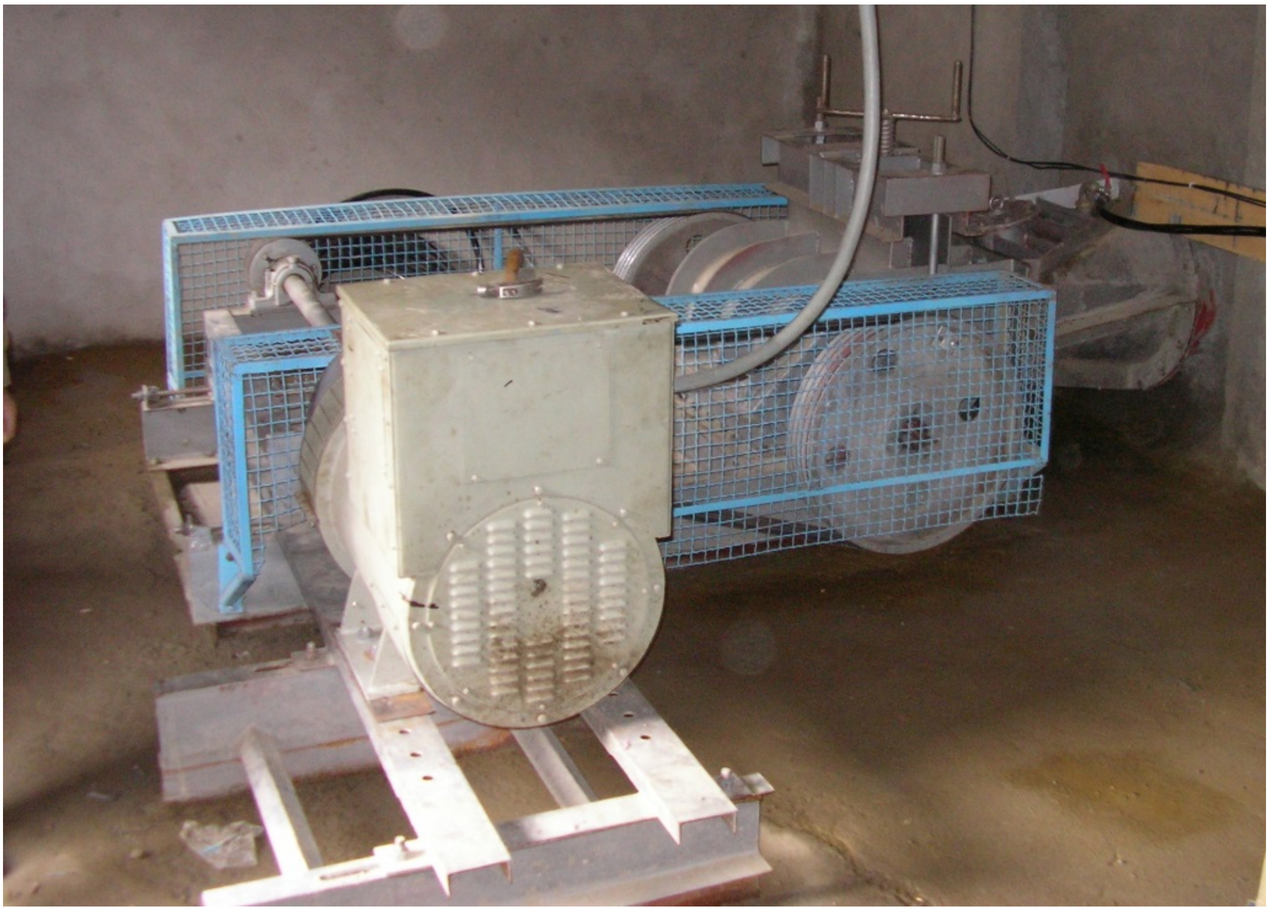

Figure 3 Example of turbine, a turbine of 70 kW at Pansjer, Afghanistan, installed by Remote HydroLight.

3 Evaluation of different ways to power the pumps in the water supply system

In this project, three ways to supply power to the pumps have been investigated: hydropower, electricity from the grid, and solar panel.

3.1 Hydropower

Hydropower is generally the cheapest way to produce power when practically possible. To produce hydropower, a river and a head are needed. The head is the height difference along the river. Produced power is head times flowing water quantity. Figure 3 shows an example of a hydropower turbine of 70 kW and a head of water of 16 m. The author has experience in Afghanistan of producing small hydropower with Remote HydroLight (www.remotehydrolight.com), and it has therefore been investigated to use the same technology in Kenya.

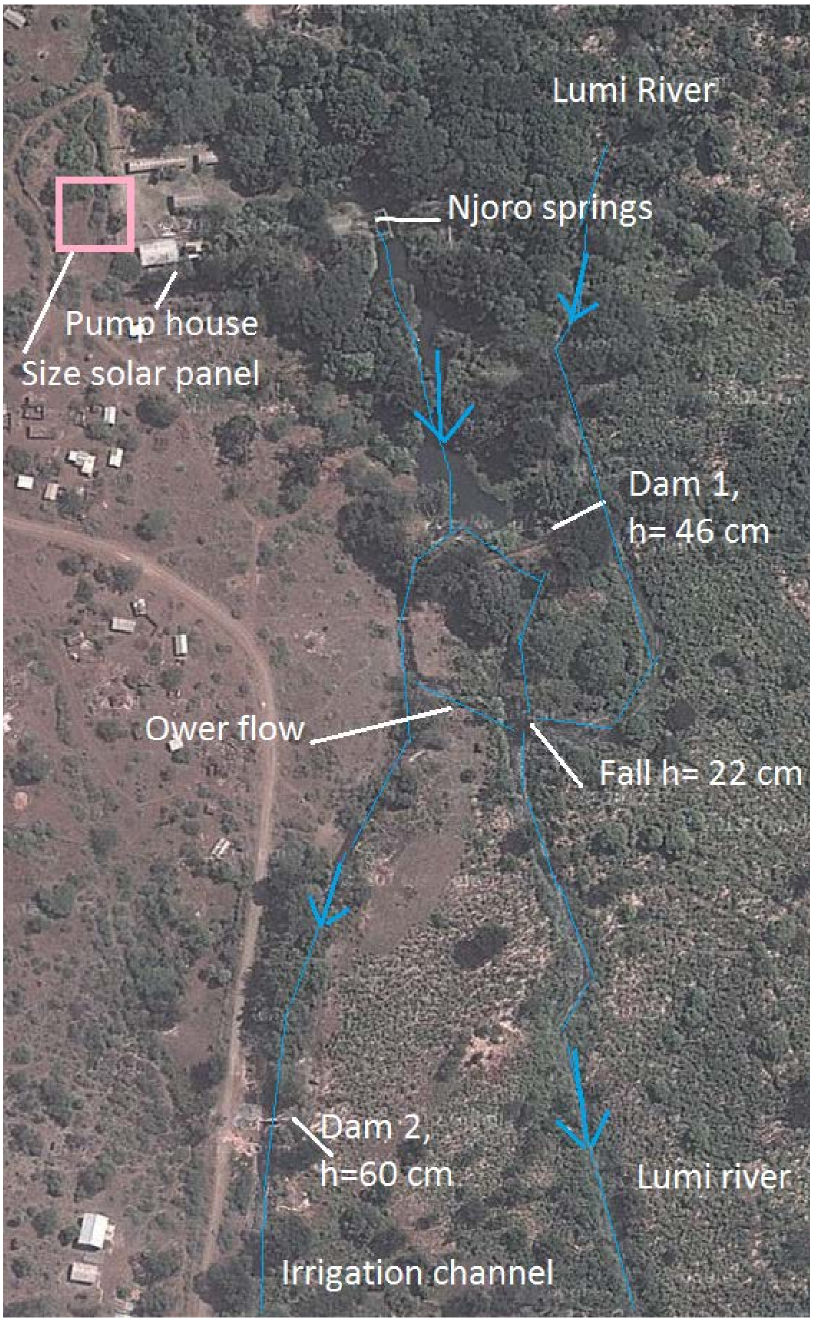

Figure 4: Map of the area with hydropower. The picture is from Google maps. The river is drawn as blue lines. The position to the source is 3°24'35"S, 37°41'44"Ø. The width of the picture is 305m.

Figure 4 shows a map of the area. Njoro springs runs on the surface, so no drilling is necessary and some of the water is pumped to Taveta City today. The water flows to a suction pump close to the spring. The water is here pumped to a pump house and then further as described in section 2.

Most of the water from the source is not used, some goes to an irrigation canal, and the rest goes to the Lumi River. During flood time, the water goes from Lumi River all the way back to the source. As stated in section 2, the source is, due to the flooding, protected with walls so the dirty water from the river Lumi does not mix with water from the source.

First, the source water goes to a small pond, where much of it goes back to the Lumi river and then to an irrigation canal. The irrigation has a dam with a fall of 0.6m (Dam 2 on Figure 4). The pond has a dam (Dam 1 in Figure 4) with a fall of 46 cm and then a fall in the river of 22 cm before it mixes with the water from the Lumi River. Lumi River itself has very little slope and the terrain is generally flat. This gives a total drop of 68 cm. Since the cross-flow turbine needs a drop of 4 m the drop here is too small for the use of cross-flow turbine. It is possible to get more by raising the water level at the source. In dam 2 in Figure 4 the water level is sometimes 3.3 m at flood time. However, this increases the water level at the springs and reduces the water from the springs and is not recommended. The fall of 3.3 m is still insufficient for cross-flow turbine.

Hydropower is for this reason not recommended.

3.2 Electricity from the grid in Kenya

Currently the pumps run on power from the grid in Kenya, Kenya Electric Power. Authorities in Taveta stated that the price was at least $ 0.12 /kWh, but sometimes $ 0.18 /kWh. State authorities also said that they cannot afford the necessary power, even today, and it is rationed so that people get power three days a week, and so that the power is switched off for two hours every day.

Lack of power also makes businesses more difficult.

3.3 Solar panels

Kenya has a high amount of sunny days per year, and the high solar energy is expected to be useful for driving the water supply system. For the size required here it is best to use photo voltage solar panels. Solar panels are environmentally friendly and the price of solar panels has fallen in recent years. The sunlight effect is measured in kW/m^2 and a certain percentage of it is converted to electricity in solar panels, typically 14 to 19% [2]. When the sun is in the zenith (right above us) and there are no clouds, the radiation at the Earth's surface is slightly over 1000 W/m^2. To set the size of the solar panels the term "peak" effect is used and indicated by kW_p. This size is important to characterize and compare the panels, but is not a direct indication of the power the panels give. Rated "peak" power indicates power output of the solar panel when:

- Solar radiation is perpendicular to the panel
- The effect of solar radiation is 1000 W/m^2
- The surface of the panel is 25°C
- The panel is new
- There is no shade on the panel
- The panels are clean

The efficiency decreases with temperature with 0.4% per °C. Due to heating from the sun the panels will have a higher temperature than this. How much depends on wind speed and how the panels are mounted. Typically, we will have a temperature that is about 25°C higher on the panel than the surrounding air when it is almost no wind (wind velocity 1m/s). This temperature is called NOCT (Nominal Operating Cell Temperature). Since the air temperature average is 25 °C in Kenya, the panels will be heated to 50 °C and loose 10% of the effect. (0.40% (50-25)°C) compared to the nominal power.

The efficiency goes down with time. The effect of the panel is reduced by typically 10% within the first 12 years.

Even a little shade reduces power significantly. If one cell is shaded the effect can be reduced by 50%.

Solar cells provide DC power and need to be converted to AC power before they can be used to drive the pumps.

Solar panels provide power only when it is sunny and a minimal area is in the shade. The problem of low performance on shady days can be solved in three ways:

1. Save energy in batteries
2. Pump water into the tank (Reservoir in Figure 1) when there is sun and use water from the tank when there is no sun.
3. Using electricity from the grid when there is no sun. Also with the ability to sell electricity to the grid when the power from the solar panels is not needed.

3.3.1 Solar panels with battery

The current from the solar cells can be stored in a battery, which can provide power when there is no sun. When solar batteries give power to a house or a small network, the power is usually stored in batteries. However, batteries are expensive and must be replaced after a few years.

3.3.2 Solar panels without battery together with power from the grid

Solar cells fit well with pumping since it can be used for pumping when it is sunny, and water can be taken from the tank even when there is no sun. In addition, the main power can be used when it is cloudy. Since batteries are expensive, photovoltaic solar cells combined with electricity from the grid, is the preferred solution. One can then use the following systems:

1. Isolated system where the power from the solar panel operates the pumps without the use of electricity from the grid. One can here still switch between AC power and power from the solar panel. This solution will not use all the effect of the solar panel.
2. A system where the solar panel is connected to the power supply. Electricity that is not used will be fed into the grid. This means that all the power from the solar panel is used. It also makes the starting of pumps easier. Converters for solar panels will generally support this. However, this will not work if there is no power.
3. Both systems 1 and 2, a system that can run when there is no power and when there is power. This is the preferred system.

4 Description of an actual solar system for Taveta

As described in chapter 3 is solar panels together with electricity from the grid the preferred system.

4.1 Power of solar system

Solar cells are described in Section 3.3. They provide direct current, where the current varies with the voltage of the cell. The current produced from one cell with a given voltage is shown in Figure 5. The various graphs give the current-voltage relationship at different solar radiation. The voltage is increased by connecting many cells in series. A converter is connected at the end of the line to transform the voltage to 220 V AC.

In order to provide the specified power and efficiency, the surface of the panel must be clean and not be in the shade.

4.2 Configuration of pump system

As stated earlier, the pump house contains 3 pumps, one of 75 kW, one of 56 kW and one of 75 kW that at the moment is not working. To make better use of the solar power it is advised to install a new pump of 30 kW. In addition there are some smaller pumps for sucking water from the springs.

4.3 Start of the pumps

All the motors are induction motors. They require many times more current when starting than when running. The inverter will cut the power if the electrical outlet is too high. It is advised to start a pump by first using switches which reduce start-up current for induction motors, called a star-delta switch. Each pump has a valve that should only be opened after the pump has started.

4.4 Solar radiation in Taveta City

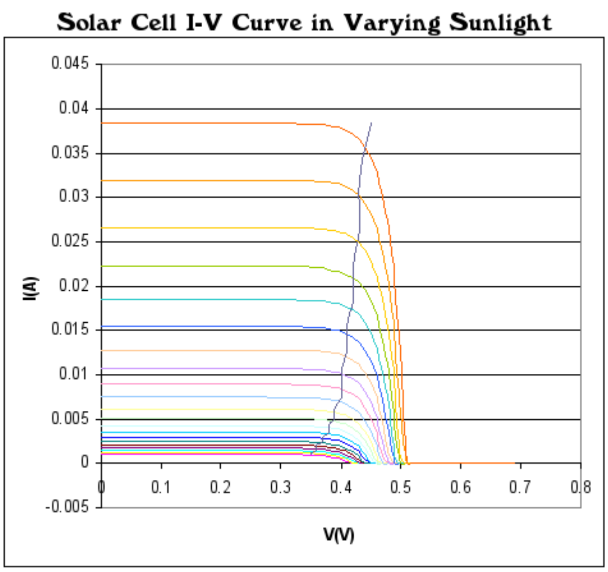

Figure 5: Current as function of voltage at different solar radiation and point of maximum effect

Wikipedia[3] has a map of the area in Taveta with average solar irradiation of 5.6 kWh/day/m^2. NASA Langley Research centre as measured the solar irradiation, presented by Tukiainen [4] that gives solar radiation in Nairobi and Mombasa, with results shown in Table 1.

Table 1: Solar radiation in kWh/day/m^2

City	Average	Month with most sun	Solar power (kWh/day/m^2)	Month with least sun	Solar power (kWh/day/m^2)
Nairobi	5.23	February	6.34	July	4.4
Mombasa	5.87	February	6.54	June	4.75
Average	5.55				

For the calculation in this report we have used an average of 5.6 kWh/day/m^2.

With a solar panel with peak power of 200 kW and a maximum received power of 1kW/m^2, the average electricity per day will be 5.6 * 200 = 1120 kWh.

4.5 Water delivered through pipeline from pump house to reservoir

With an efficiency of 50% for the pumps with a total effect of 131 kW (75 + 56 + 30 kW), the calculated flow of water will be 62 litres/second = 222 m^3/h.

The necessary power (P) becomes:

$$P = \frac{1}{\eta} Q g H_{Net} \rho$$

with:
P = Power in watts (131 kW here)
η = Total efficiency of the pumps and motor ($\eta = \eta_{Pump} * \eta_{Motor}$). (Here assumed to be 50%. It is somewhat higher for larger pumps and somewhat less for smaller pumps.)
Q = Water flow in litres/s (56 L/s here)
H_{Net} = Net head = 73 m height difference + friction in the pipe. (Here, the friction head is 35m, H_{Net} = 73 + 35 = 108m)
ρ = Density of water = 1.0 kg / L
g = gravity = 9.81 m/s^2
This is calculated by a Moody diagram [5].

Table 2 shows the water pumped at different powers to the pumps.

Table 2: Water pumped and friction with different power to the pumps

Power (kW)	200	161	131	100	75	56	50
Water pumped m^3/h	283	251	222	187	153	122	112
Head loss trough friction, m	57	45	35	25	17	11	9

The following assumptions are made:
Pipe length: 4500 m.
Roughness of the pipe: 0.5mm, corroded steel.
Efficiency of the pumps with motor: 50%.
Pipe diameter: 250 mm.
Height difference: 73 m.

4.6 Storage of electricity, capacity

Today, the required water consumption is 3000 m^3/day, which is expected to increase to 5000 m^3/day. The current pipeline between the pumping station and Taveta Town is able to deliver the required amount if it runs 24 hours a day. This will, however, not be possible if the pipelines only run when the sun is shining. The pressure drop in the pipelines will in this case be extensive.

If all solar electricity replaces grid electricity the savings become 1120 kWh / day * 365.25 days / year * $ 0.12 / kWh = 49,000 USD / year, where $ 0.12 / kWh is, as stated above, the electricity costs today. If the excess power is fed to the grid, the expected costs become less than $ 0.12 / kWh. If, on the other hand, the grid electricity is not used and solar panel is used to run two pumps, one at 75 kW and one of 75 hp (=56 kW) and the rest is not used, the saving becomes 35,000 USD / year and the average water pumped become 1400 m^3/day.

By installing additional solar panels and pumps, more water can be pumped, but the pressure drop in the pipelines will put restrictions on the water flow.

4.7 Price for a complete plant

A price estimate for a similar plant in Norway including panels, converters to 415 V – three phases, and construction costs were USD 322 000 for the complete plant. The total surface area of the plant will be 1300 m^2.

Request is sent to over 80 businesses in Kenya working solar power, and two serious feedbacks where retrieved. The firms were Think Solar and Value Line, both located in Nairobi. The quotes are shown in appendix B and C.

Table 3: Price estimate for two plants, both adjusted to 200 kW power at solar radiation of 1 kW/m^2 based on quote from two producers:

Company	Think Solar	Valueline
SOLAR PANELS		
Brand	LORENTZ	TAHIRA CORPORATION
Type		Poly crystalline
Serial number	LC300-P72	SYS250P
Nominal power per panel at 25°C(W)	300	250
Reduction %/°C[1]	0.42	0.39
Estimated temperatur[2]	50	50
Reduction in power	10.5%	9.75%
Power per panel at solar irradiation 1 kW/m^2	268.5	225.625
Efficiency at 25 C	15.4 %	15.4 %
Size of each panel (m^2)	1.95	1.62
Number of panels needed	768	914
USD / Panel	359	500

Company	Think Solar	Valueline
CONVERTER		
Type	Sunny Tripower	Sunny central 250U
Power for each converter(kW)	20	250
Loss in converter	3 %	3 %
Number of converters needed	20	1
USD/ Converter	3 587	180 000
Price		
Solar panels and converters (USD)	347 179	637 000
Installation	34 718	75 000
Accessories	52 077	
Taxes[3]	0	113 920
SUM	**433 974**	**825 920**
USD/W "peak"	1.88	3.61
Areal panels(m^2)	1 496	1 484
Nominal power ("Peak") (kW)	230	229

[1]: Reduction in power for each degree (°C) over 25°C
[2]: Assumed air temperature 25°C and that the panels is 25° C hotter from the heat of the sun
[3]: One quote gave 16% tax and the other told it was excepted from taxes.

Table 3 shows the estimated price for a plant. It displays the costs for solar panels, converters and installation of solar panels stated in the quotas. Additional costs include:

- Cables between the converters and the pump house
- Price of land
- Securing the area
- Pump 30kW
- House for the converters
- Controls and switches to allow the plant to run when the grid has no power
- Operating expenses and salary for operator

The solar panels shall give 200 kW power at a sun radiation of 1 kW/m^2, which determine the number of necessary solar panels. The quota from Think Solar included a unit with 200 kW "peak" power with panels of 280 W, and drivers for the battery. They stated that this company's order was exempt from tax. The order was later changed from panels of 280 W to 300 W with no increase in price. They provide 7 years warranty on the system. Think solar specified price in EURO and for conversion to USD a rate of 1.281 USD/EURO is used. Figure 6 shows an example of the construction of Think Solar. As seen in the picture, one must expect additional space than solely the area of the panels. Figure 3 indicates the size of the plant with a square. This square is 2500 m^2 assuming that 40% of the area is between the panels.

Valueline gave a quote with a plant with 375 kW "peak" power.

Since Think Solar was the most affordable option it is recommended to use Think Solar. Any higher quality by Value Line cannot justify the extra expenses. Alternatively, one can ask more companies for quotas. By choosing Think Solar, the price of solar cells and converters becomes 434,000 USD. It must be stressed that this is only an estimate and a new quote must be made before getting started where all expenses are included. One must also decide how to connect to the grid.

Figure 6: An example of a plant from Think Solar

In Section 4.9 it is stated that with electricity price of $ 0.12 /kWh and feed in tariff of $ 0.09 /kWh, the saving on the electricity bill become around 48,000 per year.

The lifetime of the plant is not known, but solar panels are durable and would normally work for at least 25 years.

4.8 Variation in effect during the day

The power of the plant is reduced at the evening, because the angle of the sun changes and because the radiation must pass through more of the atmosphere. Appendix A shows the calculation in detail, and the results are shown in Figure 7. The figure shows the estimated effect during a sunny day. This gives the total solar irradiance at 6.98 kWh / day. This is higher than the value for Taveta, 5.6 kWh / day, which is due to clouds.

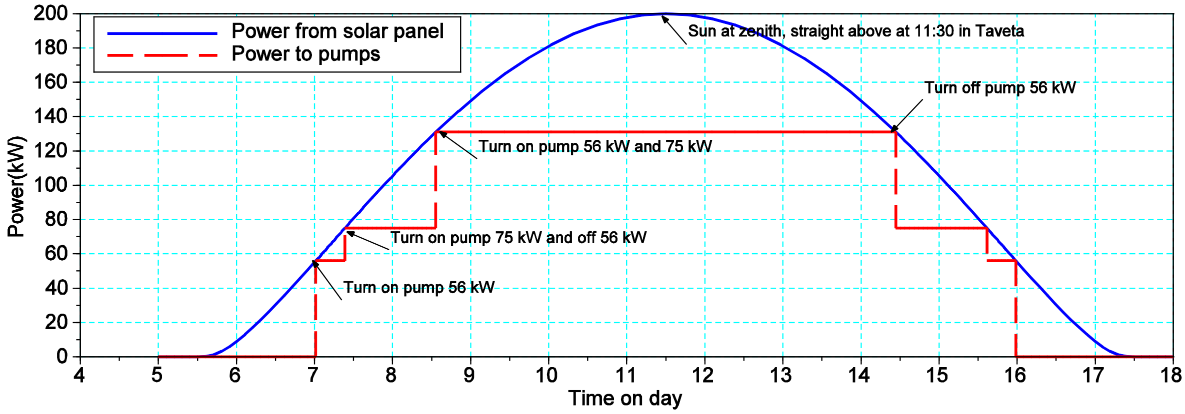

Figure 7: Power from the solar panel of 200 kW on a sunny day. The red curve shows the power used by two pumps (75kW and 56kW) in an isolated system. If a third power of 30 kW is installed, more of the power can be utilized.

4.9 Savings with different configurations

In section 3.3.2 the different configurations are described. Figure 7 shows the effect of the solar panel during the day for a sunny day as a blue line solid line. This gives 6.98 kWh in one day, while solar radiation is 5.6 kWh per day on average over the year. This is corrected by multiplying by 5.6 / 6.98 = 0.80. The solar panel provides on average 5.6 h/day * 200 kW = 1120 kWh per day.

The red dashed line shows the power that can be used to drive two pumps, one at 56 kW and another at 75 kW in an isolated system without connection to the grid. It provides in average of 793 kWh / day and 1420 m^3/day of water. By connecting in an extra pump of 30 kW, one can utilize more of the energy. This estimate is somewhat optimistic since one needs extra power for starting the pump and it will require a good operator.

Table 4: Saving in electricity bill for different configurations

	Type of connection from section 3.3.2	Connected pumps	Price of electricity (USD /kWh)	Feed in tariff (USD/kWh)	Average during the year[1]	
					Estimated saving each year in USD	Water pumped in m^3/dag
1	Isolated without power from the grid	56kW + 64 kW	0,12		34 800	1420
2		30kW + 56kW + 64 kW	0,12		42 000	1632
3	Isolated with a switch to the grid[2]	30kW + 56kW + 64 kW	0,12		42 000	1632 to 5000
4	Connected to the grid[3]		0,12	0,0	45 100	1941 to 6000
5			0,12	0,06	47 100	
6			0,12	0,09[4]	48 100[4]	
7			0,12	0,12	49 100	

[1]: Multiply by 0.80 to get average values
[2]: Use electricity from the grid when it is not sunny.
[3]: The savings assumes that the network has power every day. If not and it can run without electricity it become something between this and case 2. One should also consider pumps of 56kW + 64kW + 64 kW.
[4]: Used as the best estimate for saved expenses

When connected to the grid it is possible to use all the electricity from the panels and it is able to pump more water.

Feed in tariff is 0.12 USD / kWh for plants between 500 kW and 40 MW[6]. However, this plant is less than 500 kW.

5 Conclusion

A power for running pumps in Taveta was investigated. Use of hydropower was not possible because of low fall. Use of solar panels without batteries should be considered, but a quote including all expenses and clarity in feed-in tariff is necessary before a final conclusion can be made.

SINTEF

APPENDICES

A Irradiation at different part of the day

Honsberg and Browden [7] shows the reduction in sun radiation when the sun goes through the air. It is:

$$I = 1.1 \times I_0 \times 0.7^{(AM^{0.678})}$$

Where I_0=1353 W/m^2, the sun radiation outside the atmosphere. Air mass *AM* tells the number of air masses the sun goes through. It is one when the sun is in zenith. With sun angle ϕ it is:

$$AM = 1/\cos(\phi)$$

And irradiation effect of the sun on a horizontal surface is:

$$P = I \times \cos(\phi)$$

Taveta is close to equator with sun angle in radians:

$$\phi = 2\pi(T - T_{sen}) / 24h$$

With T_{sen} is time when the sun is in zenith (Straight above) which is at 11:30 in Taveta city.

B Quote from Think Solar

ThinkSolarTechnics
Diverting nature to Technology

P. O. Box: 64057- 00620 Nairobi.
Tel/Fax: (+254) 020 3567916
Cell: (+254) 720-464715/
(+254) 721-864562
E-mail: info@thinksolartechnics.com PIN No:PO51195822Y
www.thinksolartechnics.com VAT No:0191678N

	QUOTATION
Date	18/06/2014
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Document No.	QN-57667

QUOTATION A/C

NAME: RUNE MALMO

Deliver to / Attn

Malmo Tech Rep
Bergheimsvegen 28,
NO 7049 TRONDHEIM,
nORWAY Telephone: +47 913 99 660
Email: rune.malmo@gmail.com

Account	Your Reference	Tax Exempt	Tax Reference	Sales Code	Cost Code
SALE	Attn:Self	-	KBO25	AT023	-

Description	Model/Origin	Quantity	Unit Price		Net Price
SOLAR SYSTEM:					
------------------					
280 Watts Monocrystalline Solar Modules	LORENTZ / GERMANY	715 Pcs	280	€	200200
Sunny Island Master device 8.0H	SMA/Germany	9 Pcs	2750	€	24750
Sunny Island Slave device 8.0H		18 Pcs	2400	€	43200
Multi-Cluster Boy 36		1 Pc	10000	€	10000
Sunny Tripower 20kW		20 Pcs	2800	€	56000
Sunny Webbox		1 Pc	550	€	550
Installation cost 10% of the entire total cost					33470
Accessories cost 15% of the total cost					50205
Warranty:					
---------------					
on entire Solar System:7 Years					

Validity of quote: NTH

quote Prepaired By:

ANTHONY

Sub-Total	418,375.00
V.A.T 16%	-
Total	**Euro: 418,375.00**

Amount incl. of 16% VAT where applicable

With vast experience for superior products and service, Solar monocrystalline /polycrystalline modules and deep cycle batteries give the best value for money and system performance. Where applicable accessories estimates may vary with installation.
Guarantee; PV modules – 20yrs; Hot water 2yrs; Batteries/Inverter 1year.
Delivery upon stock availability; prices are subject to change without notice.

LORENTZ solar pump AIR X Wind Chargers TRIPP-LITE OutBack Power Systems xantrex Inverter Chargers

C Quote from Valueline

VALUELINE TECHNOLOGIES	12th June 2014
	VTL/NC/3/14

VALUELINE TECHNOLOGY LIMITED
Electrical Installations, Renewable Energy Management, Power Back Up Systems, Intelligent Metering Systems Installations, Environmental Monitoring Systems
Argwings Kodhek Road
P. O. Box 55939 - 00200, Nairobi
Tel: +254 (0) 725 270 145; +254 (0) 722 759 341
E-mail: valuelinetech@gmail.com

QUOTE TO:
Rune Malmo
Malmo Tech Rep
Norway

ITEM	DESCRIPTION	QTY	UNIT	RATE	AMOUNT
	Supply and Install:			USD	USD
A	**250kw three phase Inverter**				
i)	250kw three phase Inverter with input DC voltage of 300-600V, AC output of 480V WYE as SMA	1	No.	180,000.00	180,000.00
B	**Solar PV Panels**				
i)	250 watts 30V Polycrystalline solar PV	1500	No.	500.00	750,000.00
C	**Cabling**				
i)	Installation cables and accessories	Item	1	108,333.33	108,333.33
				Sub Total	**1,038,333.33**
				16% VAT	**166,133.33**
				GRAND TOTAL	**1,204,466.67**

COMMENTS
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