The Potential of Renewable Energy for Rural Groundwater Supply in the Elundini Municipality

Gordon Kernick

The Energy Research Centre (ERC), Department of Mechanical Engineering,
University of Cape Town, South Africa.

June 2014

UCT KNOWLEDGE CO-OP

The UCT Knowledge Co-op facilitated this collaborative project.

The report is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike license: http://creativecommons.org/licenses/by-nc-sa/2.5/za/deed.en

ABSTRACT

Historically, groundwater has been supplied to the rural Inhabitants of the Elundini municipality in the Eastern Cape by diesel powered borehole pumps which have proved to be problematic in recent times with water supply to the inhabitants being inadequate. There are several reasons for this such as the ever increasing cost of the diesel, the transportation of it to the rural sites and insufficient maintenance of the systems. This study investigated how suitable the use of solar and wind powered groundwater pumping would be in the region based on the respective natural energy resources available and how these would compare with currently used diesel powered options. This was done by designing notional systems for a sample of existing villages with their respective water supply requirements comprised essentially of the head required to be pumped from borehole water depth to the village, as well as daily water requirements based on 25 litres per person per day (pppd). It was found that solar PV pumps provided an excellent alternative being far cheaper over their lifetime and requiring less maintenance than diesel powered options. Although technically viable, wind powered options were found to have prohibitively expensive upfront costs due to the large systems required to provide the necessary water supply requirements as a result of the relatively poor wind resources available.

1 INTRODUCTION

The Elundini municipality, similar to many other sparsely populated rural regions of the world, have difficulty in providing inhabitants with a reliable supply of fresh water [1]. This is further exacerbated by the economically poor nature of the region [2]. Groundwater is the most suitable water source in the area, due to a lack of widespread surface water sources as well as the generally cleaner nature of groundwater [3]. This study was conducted in order to determine whether solar and wind powered borehole pumps could provide an attractive alternative to the currently used diesel powered borehole pumps, with comparisons made across functionality, life time cost and maintenance requirements.

Several studies into the potential of solar and wind in powering borehole pumps have been performed for other regions in the world with the majority of them, presuming favourable natural resource potential, indicating that they provide an extremely viable and cost effective alternative to diesel powered pumps [4,5,6].

These systems were than compared to one another through a life cycle cost analysis with the most appropriate system being determined by not only the least cost but applicability for implementation in the unique environment of the Elundini municipality from both a social and technical perspective. This included factors such as the amount of maintenance, as well as the level of expertise, required for servicing each respective system; the reliability of the systems; the potential for social acceptance of the systems and potential for theft.

2 METHODOLOGY

The methodology adopted in determining the viability of renewable energy for borehole water pumping, apart from research into previous studies on the matter, involved determining a sample of villages in the area currently sourcing their water from borehole pumps and then designing notional diesel, wind and solar powered systems for these boreholes that would provide a minimum level of water for the inhabitants of 25 litres pppd [7]. This was done by determining the depth to water of the boreholes of each village and adding this height to the distance the water will need to be pumped to the village itself, taking into consideration pipe losses through the network, this distance or head was then multiplied by the daily water requirements of the village resulting in a value of m^4/day. The hydraulic energy required to provide this volume of water over a height in kWh/day was then determined by multiplying it by the density of water ρ and gravity g and dividing by 3.6. Substituting in the constants of water density and gravity results in the simplified equation

$$P_E = 0.002725HQ \qquad \textbf{EQUATION 1}$$

where H is the head and Q the flow rate in m^3/day. [8]

Once this value had been determined for each of the villages, the notional systems were designed for each power source i.e. wind, solar and diesel respectively. For the solar systems equation 2 illustrated below was used to determine the power required by the system:

$$\frac{\mathrm{P_E}}{Average\ daily\ solar\ irradiation\left(\frac{kWh}{m^2}\right)\mathrm{X\,F\,X\,E}} \qquad \textbf{EQUATION 2}$$

where F = array mismatch factor, E = sub-system efficiency (between 0.25 and 0.4) [9].
The solar irradiation value was sourced through NASA data for latitude tilted panels, i.e. the systems will be designed with their panels facing North at the angle of the borehole's latitude which resulted in an average insolation value of 5.3 kWh/m^2 [10].
For wind systems, the characteristics of the wind regime was determined based on long term wind data from the closest weather station, Barkly East, the calculated scale parameter c and shape factor k were then used with the average wind speed for the Elundini municipality sourced from NASA data and then used in equation 3 to determine average power in the wind $\overline{P}w$ which was 54.8 W/m^2 [10, 11]

$$\overline{P}w = \frac{\rho A\bar{v}^3\Gamma(1+3/k)}{2[\Gamma(1+1/k)]^3} \qquad \textbf{EQUATION 3}$$

Once this had been determined, a cut in, cut out and rated wind speed for the chosen wind pumps being Kijito wind pumps with a cut-in wind speed of 2.5 m/s, cut-out wind speed of 9.33 m/s and rated wind speed of 7 m/s was used in conjunction with the average power, c and k values to determine the amount of time, on average, that the wind pumps would be pumping which equated to 14.74 hours per day [12]. The hydraulic energy, determined by equation 1, required by each of the villages was then divided by this time in order to determine the power required by the wind pump. The size of the windmill rotor area was then determined by these two values through the use of the equation

$P = cp \times A \times W_p$ **EQUATION 4**

Where: cp = co-efficient of performance for windmill taken as 0.25
A = wind swept area of the rotor in m^2
W_p = power available in the wind in W/m^2
P = power required by the wind pump in Watts

To be conservative, the minimum expected wind power, derived from the NASA data, was used in sizing the system. For Elundini this equated to 37.5 W/m^2 [10, 13]

In sizing diesel powered systems, the same process to calculate the hydraulic energy was used with the resultant diesel pump size being determined by using an average pumping time of 8 hours and co-efficient of performance factor of 0.2 resulting in equation 5 below

$P = Pe/(8*e)$ **EQUATION 5**

Where: P = design power of the diesel pump
Pe = the hydraulic energy required
e = efficiency of the system

In the case of the wind and solar powered systems, due to only being able to operate when the wind is blowing and the sun is shining respectively, days of autonomy need to be provided for when they don’t. This was done by sizing a reservoir that would store a sufficient volume of water to provide for days when the sun wasn’t shining or wind wasn’t blowing. For the solar powered systems, a worst case scenario was chosen being the worst month of solar insolation, September with 7 days of No-Sun. To provide for these no-sun days during the prior days of sunshine (presuming that average insolation occurs prior to these 7 days occurring consecutively) the size of the system would be increased by 30/23; 30 days in the month less the 7 days of no pumping giving 23 days of insolation to not only provide water to the village but also fill up the reservoir, sized by multiplying the daily water requirements by the extra required for the 7 days of autonomy [9]. This value of 30/23 or 1.3 was multiplied by the designed size of the solar system in order to provide for extra pumping required to fill the reservoir for each system.

For the wind powered systems, a similar design was used to confirm whether the conservatively designed system would suffice in providing extra water storage, however the amount of time without enough wind for pumping was determined by the wind availability i.e. 100 – 61.4 = 38.6 % of days in the month not having sufficient wind for pumping or 11 days in a typical 30 day month. As the systems were designed conservatively initially i.e. 37.5 W/m2 as opposed to the average wind power calculated of 54.8 W/m2, the actual average wind power 54.8 W/m2 was used in determining whether

19 days of average power pumping would provide the extra amount of volume required i.e. 11 days multiplied by the daily water requirements of the village [10, 13]. In the villages where this check was performed, the pumps were found to provide enough water to maintain design levels as well as fill the required reservoir.

Once the various systems had been designed, a life time cost analysis was performed for each of the systems which involved discounting all expected future costs that each system would incur including fuel for the diesel system, maintenance, repairs and replacement parts to today's value. These discounted costs were then added to the current capital costs of the systems to give the net present value (NPV) in order to make a cost comparison between the systems [14]. Discounting the future values was done using the equation:

$$p = f\,\frac{1}{(1+i)^n} \qquad \textbf{EQUATION 6}$$

Where: p = present value
f = future value
i = discount rate
n = year in which cost incurred

For this study a discount rate of 5% was used as this was the government repo rate at the time of writing and it was though that Elundini, being a local municipality would have access to government funding should they wish to install these systems [15].

3 RESULTS

Table 3-1 below presents the hydraulic energy required by each of the villages as well as the theoretical power required by each pumping technology to provide water to the sample of villages calculated using the methodology presented in chapter 2.

Table 3-1: Village hydraulic energy requirements and calculated notional system sizes

Name	Proposed Water pppd (l)	Population	Water required per day (m^3)	Total Dynamic Head (m)	m^4 Required per day	Total Daily Energy Required (kWh)	Diesel Pump and Generator (kW)	Solar PV Pump (kW)	Wind Pump (kW)*
Mgcantsi	25	90	2.3	16.5	37.1	0.101	0.093	0.073	0.007
Gamakulu	25	186	4.7	104.5	485.8	1.324	1.222	0.958	0.092
Kwalanga	25	228	5.7	16.7	95.1	0.259	0.239	0.188	0.018
Jojweni	25	300	7.5	57.1	428.1	1.167	1.077	0.844	0.081
Gobo	25	396	9.9	56.7	561.2	1.529	1.412	1.107	0.106
Emaladini	25	414	10.4	75.6	782.3	2.132	1.968	1.543	0.148
Polokoe	25	516	12.9	50.6	653.0	1.779	1.643	1.288	0.124
Tabatlala	25	576	14.4	30.7	442.7	1.206	1.113	0.873	0.084
Jojoweni	25	630	15.8	57.0	898.3	2.448	2.260	1.772	0.170
Moleko	25	648	16.2	101.4	1643.1	4.478	4.133	3.241	0.311
Hopedale	25	750	18.8	66.1	1238.6	3.375	3.116	2.443	0.234
Makhuleng	25	786	19.7	90.4	1775.4	4.838	4.466	3.502	0.336
Mohoabatsana A	25	792	19.8	18.4	364.7	0.994	0.917	0.719	0.069
Makhalong	25	822	20.6	67.7	1390.6	3.790	3.498	2.743	0.263
Katkop	25	864	21.6	29.5	637.1	1.736	1.602	1.257	0.121
Upper Sinxako	25	918	23.0	99.2	2276.0	6.202	5.725	4.489	0.431
Khalatsu	25	996	24.9	55.1	1372.3	3.739	3.452	2.707	0.260
Umfanta	25	1086	27.2	110.6	3003.4	8.184	7.555	5.924	0.568
St Augustins	25	1110	27.8	101.2	2809.4	7.656	7.067	5.541	0.532
Setaka	25	1128	28.2	73.1	2062.3	5.620	5.187	4.068	0.390
Lower Sinxako	25	1338	33.5	86.7	2900.0	7.903	7.295	5.720	0.549
Sekoteng	25	1410	35.3	55.6	1959.5	5.340	4.929	3.865	0.371
Moroka	25	1680	42.0	72.4	3041.1	8.287	7.649	5.998	0.575
Thembeni	25	1794	44.9	102.6	4601.0	12.538	11.573	9.075	0.871
Etyeni	25	1884	47.1	87.5	4122.1	11.233	10.369	8.131	0.780
Tsolobeng	25	5226	130.7	777.1	101529.6	276.668	255.386	200.262	19.213

*For wind pumps, due to the square relationship between windmill size and power, only the net power is presented, i.e. without system efficiencies considered. These are taken into account when calculating the power provided by a proposed wind pump.

Table 3-2 below illustrates the annual hydraulic energy requirements of each of the chosen villages and the corresponding NPV of each of the systems life time costs. The size of the system chosen was the closest commercially available sized system to the theoretically calculated size.

Table 3-2 Net Present Value (NPV) of each of the systems life time costs calculated over 20 years

Village	Annual Hydraulic Energy Requirements (m^4)	Diesel NPV	Solar NPV	Wind NPV
Mgcantsi	17 675	R 159 093.71	R 108 517.11	R 187 183.25
Gamakulu	231 333	R 472 254.52	R 169 677.11	R 313 159.74
Kwalanga	45 323	R 229 957.55	R 145 497.11	R 227 030.75
Jojweni	203 882	R 433 500.61	R 180 617.11	R 346 077.24
Gobo	267 230	R 473 414.05	R 211 777.11	R 428 048.03
Emaladini	372 531	R 593 139.75	R 245 557.11	R 433 245.53
Polokoe	310 973	R 588 520.12	R 236 977.11	R 462 698.03
Tabatlala	210 843	R 466 512.30	R 227 577.11	R 425 772.24
Jojoweni	427 792	R 715 240.78	R 249 917.11	R 495 615.53
Moleko	782 380	R 971 331.69	R 489 613.57	R 558 252.90
Hopedale	589 811	R 1 098 426.10	R 348 117.11	R 566 654.41
Makhuleng	845 381	R 1 017 709.27	R 518 593.57	R 598 100.40
Mohoabatsana A	173 771	R 465 326.01	R 277 937.11	R 488 142.24
Makhalong	662 207	R 1 000 706.72	R 363 237.11	R 587 444.41
Katkop	303 440	R 650 494.83	R 310 057.11	R 563 183.03
Upper Sinxako	1 083 705	R 1 120 263.28	R 546 313.57	R 661 064.98
Khalatsu	653 491	R 782 068.46	R 399 777.11	R 637 686.91
Umfanta	1 430 060	R 1 359 230.32	R 727 512.30	-
St Augustins	1 337 720	R 1 286 640.81	R 732 552.30	-
Setaka	982 021	R 969 084.58	R 473 497.11	-
Lower Sinxako	1 380 885	R 1 320 541.83	R 780 432.30	-
Sekoteng	933 133	R 1 060 693.93	R 649 633.57	R 778 280.40
Moroka	1 448 089	R 1 500 795.68	R 852 252.30	-
Thembeni	2 190 753	R 2 298 497.43	R 733 357.11	-
Etyeni	1 962 769	R 2 119 270.55	R 752 257.11	-
Tsolobeng	48 337 797	R 44 161 873.82	-	-

4 DISCUSSION

As can be seen from the results, solar powered systems offer the most attractive option from a cost perspective. This is due to the fact that maintenance and running costs are far lower than those of diesel engines and the natural conditions of the Elundini municipality lend themselves more to solar systems as opposed to wind as the solar resource is stronger than that of wind.

Choosing a system however, if one was to be implemented, cannot be done purely from a technical and financial perspective and several other considerations need to be taken into account. These include the fact that theft of solar panels has been identified as a problem in similar installations, from a social perspective, the number of employment opportunities each system could create was also important [5]. When looking at implementing a new technology into a society, the ultimate requirement for them to be implemented effectively and accepted by the community is that they provide a better alternative to what came before them. A system that doesn’t work well, regardless of how many jobs it creates, will not be readily accepted. For instance if solar panel theft is not mitigated, and solar powered pumps are installed, no solar panels mean no power and no water, therefore a non-functioning system.

5 CONCLUSIONS

This study has conclusively illustrated the fact that village level water supply in the Elundini municipality can be achieved effectively with the use of renewable energy; wind and solar power. Specifically for the Elundini area, with its natural solar and wind resources, solar powered pumps provide the most cost effective means for water supply to the sample of rural villages. Although wind pumps were technically feasible, their high capital costs and higher life cycle costs, due largely to the unfavourable wind conditions, made them an unattractive alternative to solar powered systems. From a societal perspective however, if solar powered pumps were chosen to replace the current diesel powered systems, allowance would need to be made for protecting panels from theft. An effective means of doing this, and in fact something which should be considered when rolling out any new technology to a community, is ensuring that some level of ownership is imbued onto the inhabitants of the villages.

Although historically, solar PV pumps have not been used in the poor, rural setting of the Elundini municipality due to their high capital costs when compared with diesel pumps, the maturing of solar PV technology as well as the exorbitant rise in diesel fuel costs over the last 5-10 years has now made solar powered borehole pumps far more attractive than diesel powered ones. Coupled to this is the fact that they require far less maintenance than diesel engines, therefore offering a more reliable, lower maintenance and cost effective means of providing rural villages with water than their diesel counterparts.

6 REFERENCES

[1] Qotoyi, C. 2011. Verbal communication with author on 20th December. Elundini municipal offices.

[2] Mackintosh, G., Colvin, C. 2003. Failure of rural schemes in South Africa to provide potable water. Environmental Geology (2003) 44:101–105. Cape Water Programme, CSIR: Stellenbosch.

[3] Statistics South Africa. 2006. Income and expenditure of households 2005/2006. Analysis of results. Pretoria

[4] Ramos, J.S., Ramos, H. M. 2009. Solar powered pumps to supply water for rural or isolated zones: A case study. Energy for Sustainable Development 13 (2009) 151–158. Lisbon

[5] Short, T.D., Thompson, P. 2003. Breaking the mould: solar water pumping—the challenges and the reality. University of Durham: Durham.

[6] Emcon. 2006. Feasibility assessment for the replacement of diesel water pumps with solar water pumps, Ministry of Mines and Energy, Barrier Removal to Namibian Renewable Energy, Programme (Namrep), Final Report. Namibia.

[7] Department of Water Affairs and Forestry. 2002. Draft White Paper on Water Services: Water is Life, Sanitation is Dignity. Draft policy document. October 2002

[8] Practical Action, 2006. Technology challenging poverty; Solar PV Water pumping. Available at:http://practicalaction.org/practicalanswers/product_info.php?products_id=196.

[9] Markvart, T (ed.) 2000. Solar Electricity. 2nd edition, UNESCO. John Wiley & Sons.

[10] NASA Surface meteorology and Solar Energy. https://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?skip@larc.nasa.gov+s01#s01 [Accessed 24 July 2012]

[11] Lu, L., Yang, H., Burnett, J., Investigation on wind power potential on Hong Kong islands-an analysis of wind power and wind turbine characteristics. Renewable Energy 27 (2002) 1-12. Pergamon

[12] Harries, M. 2002 Disseminating Windpumps in Rural Kenya - Meeting Rural Water Needs using Locally Manufactured Windpumps. Energy Policy, Volume 30, Issues 11–12, September 2002, Pages 1087-1094.

[13] Szewczuk, S. 2010. Wind atlas for South Africa: Wind measurement and micro-scale modelling. CSIR, Built Environment. Pretoria

[14] International Atomic Agency. 1984. Expansion Planning for Electrical Generating Systems – Technical Reports Series No. 241, IAEA Chapters 5 and 6. 1984. Vienna

[15] South African Reserve Bank. <https://www.resbank.co.za/Pages/default.aspx> [Accessed 28 October 2013]