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LOW COST WIND TURBINES FOR APPLICATION IN DEVELOPING COUNTRIES - A FEASIBILITY STUDY

Ref: 061386/3

Principal Investigator: R. E. Peacock
Research Officer: A. J. Garside

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CRANFIELD INSTITUTE OF TECHNOLOGY

A SUMMARY OF A REPORT

Prepared for:

The Ministry of Overseas Development

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INTRODUCTION

This document contains the summary and conclusions of a recently completed feasibility study [1] conducted on behalf of the U.K. Overseas Development Administration. A description of computer programs used in assessing the performance of wind turbines, water pumps and electrical generators, together with sample outputs are appended.

A cost of 15 p. per litre was assumed for the diesel fuel price, with the effect of other costs being considered in the full report. Wind turbine costs included provision of such equipment necessary to provide water at the well head, in the case of water pumps and a/c power at the output terminals in the case of electrical generators. Because of the wide variation no provision was made to allow for transport and customs duties and taxes on the wind turbines, diesel engines and associated equipment.

1) Low cost wind turbines for application in Developing Countries - A feasibility Study. Ref 061386/2b, R. E. Peacock et al, SME Cranfield Institute of Technology, Cranfield, Bedford, MK43 OAL.

SUMMARY

An investigation of the feasibility of Wind Energy Conversion Systems (WECS) for eight nominated territories has been completed, the Caribbean, India, Zambia, Sudan, Kenya, Upper Volta, Yemen and Tristan da Cunha. The areas are discussed in terms of physical and agricultural characteristics and the type of wind data. The sources of the data are described, and the wind characteristics discussed.

Power requirements for small communities are detailed including water provision and crop processing requirements. WECS are listed and analysed. These include aerogenerators from modest (200 watt) to large power (200 kW), and water pumpers from a 1 metre diameter rotor to a 9.1 metre diameter rotor. The best machines are highlighted.

Recent innovations in wind turbines are discussed and some are highlighted for investigation in low wind speed areas. The siting of a WECS is shown to have a significant impact on the power output of machines.

The output and economics of WECS are examined for each study area using specially-written computer programs, and the units giving the most useful and cost-effective match to the requirements of the areas are outlined.

The territories divide naturally into two groups: low wind speed where water supply irrigation requirements are high and Tristan da Cunha with high wind speed and a requirement for a cheaper prime energy source for its electrical utility.

Recommendations for further work are made, including on site studies and improvements in wind data requirements for WECS usage.

CONCLUSIONS

A study of eight nominated territories has indicated their feasibility for the economic use of wind power. The territories are divided naturally into two groups by the criteria

a) prevailing wind regimes

b) required energy application

c) geographic location with respect to the tropical belt.

The study shows that wind driven water pumps have a wider application than aerogenerators.

With diesel oil price at 15p/l, a discount rate of 8%, and machine lives based on known operations it is expected that regions where wind speeds are above

3.6 m/s, small water pumpers are economical (e.g. Dempster 3mϕ)

2.4 m/s, medium water pumpers are economical (e.g. Aermotor 4.3 mϕ)

2.2 m/s, large water pumpers are economical (e.g. Southern Cross 7.6 mϕ)

2.0 m/s, locally built water pumps costing £1000 are economical (e.g. ITDG pump)

4.4 m/s, certain aerogenerators are economical (e.g. Kedco 1620, 3 kW
Enag No. 1, 650 W
P.I. Engineers 3 kW)

4.2 m/s, an optimised 6 mϕ, 3.5 kW output machine similar in principle to the Aerowatt machines but with the cost at a level of non specialist commercial machines.

The study has indicated the following regions of the study areas to show promise for wind power application.

i) The Caribbean area.

The islands in the southern lesser Antilles, and bordering the Caribbean sea - water pumping and electricity generation.

Much of the Greater Antilles and the Bahamas - water pumping and less extensively, aerogeneration.

ii) India

Coimbatore district, and parts of Gujrat - water pumping and electrical generation during the wet monsoon period.

Parts of Rajasthan, Bombay, Orissa and Madras - water pumping with the larger pumps and locally manufactured pumps during the wet monsoon period.

iii) Zambia

The areas around Lusaka, Mbala and Mongu - water pumping with the medium pumps, but larger pumps and locally manufactured pumps have a wider application.

iv) Sudan

The Red sea coast and areas adjacent to the lower Nile North of Khartoum, and the region around Gebel Marrah - water pumping with the larger pumps and locally manufactured pumps. The latter could be feasible in over half of the country.

v) Kenya

The region around Equator and Eldoret and a band running from the North-West to the South-East across the country - water pumping and electricity generation.

In the remainder of the country - water pumping, larger mills being necessary for economic operation as in the lower windspeed regions.

A home built pump is applicable over the whole country.

vi) Upper Volta

Regions around Bobo Dioulasso, Ouagadougou, and Fada N'Gourma - water pumping with a locally built pump and larger pumps.

vii) Yemen

The Southern Red Sea coast near Bab el Mandeb - water pumping and electrical generation.

The Red Sea coast and Kamaran Island - water pumping and electrical gneneration rather less economically.

viii) Tristan da Cunha

On present information both small (20 kW) and large (200 kW) aerogenerator systems would make significant and cost effective contributions to the island electricity.

- Among the aerogenerators of reasonable price none is suitable for the lower wind speeds encountered in our study sites.

- The aerowatt aerogenerator model 4100 FP7G performs well in wind regimes as low as 3.5 m/s, but the high cost renders the machine uneconomic. A machine of the aerowatt type at 30% of the cost of the aerowatt system (£6000) would be economic in regions where wind speeds are slightly lower than 5.0 m/s.

- The low price assumed for the ITDG machine (£1000) opens up some of the lowest wind speed areas for water pumping, although in higher wind speed areas this cost of the machine can be allowed to rise.

- Consistent and reliable wind data would enhance further studies, and enable mean daily power distributions to be predicted. This has been possible in two study areas and has enhanced the matching procedure.

APPENDIX 1 COMPUTER PROGRAM FOR AEROGENERATOR POWER OUTPUT PREDICTION

The program calls for several inputs:-

1) The wind regime for the study area must be specified. The program handles the information as 1460 blocks of 6 hours duration, split as the following bands per day; 0400 - 1000 (morning), 1000 - 1600 (lunch time), 1600 - 2200 (evening), 2200 - 0400 (night time). The 6 hour block is an unsatisfactorily long unit; a block of 30 mins would be more useful for firmness calculations and reliable power assessment, since the windspeed is rarely constant for six hours at a stretch.

   The information from the study areas ranged from acceptable (Upper Volta, 3 hr daily readings), to poor (N. Yemen, monthly readings). Ideally the readings should be in 1 m/sec velocity bands; in practice the information supplied was in a different form for every study area, and the resultant calculations contain some uncertainty. The readings from some areas were manipulated statistically to improve accuracy, but the use of statistical techniques was deliberately limited to avoid producing distorted calculations.

   The program can handle information in much shorter time blocks as required, and a series of simulated wind regimes of average velocity 3, 4, 5 and 6 m/sec and differing variances are also available for close investigation of WECS performance.

2) The expected life for the WECS must be estimated. The figures used for the appended printouts were 20 years life (aerogenerators), 25 years life (windpumps), and 10 years life (ITDG windpumps). This life figure can be altered at will by the program operator.

3) The program requires a discount rate input from the operator. This should represent the real rate of return on capital required in current cost terms (i.e. after discounting inflation). The investment is for long-term capital equipment, and on advice from the ODM a rate of 8% has been used to isolate promising WECS. Any chosen discount rate can be used on the program and 7.1%. is used on the appended print-outs.

4) The program requires several input parameters to allow it to compare the cost of generating an equal amount of electricity per year by diesel power:-

a/

a) The capital cost of a small 3 HP diesel unit. This unit was chosen since it gives a comparable output to many of the windturbines used. For the appended print-outs the value used was £500.

b) The cost to a small user of diesel oil. This figure is very uncertain at the time of writing. A nominal cost of £0.15/litre ($1.25/US gallon) was used for all computational work. This was approximately the landed cost of gas oil in most of the study areas, but the cost to a small user, after local tax, and after transport costs to a remote area are included could be a good deal higher. The figure of £0.15/litre can therefore be regarded as a very conservative estimate, and would be revised to the known local price for a particular installation.

c) It is generally assumed that the real cost of oil will rise in the coming years in comparison with other goods. The program calls for an estimation of the rate of rise per annum, and as a check, prints out the real cost of oil in ten years time when the rate of rise has been incorporated into the program. This figure is to some extent speculative; a rate of 5% has been assumed for the appended programs, and the aerogenerator diesel graphs for each study area are plotted for rates between 2 and 8%.

It should be noted that since the figures are operator inputs, the program can be used to predict costs for any given combination of the factors, or for a sensitivity analysis of one or more parameters.

5) The program contains a list of 13 commercial aerogenerators, ranging from the 200W wincharger to the 5 KW Dunlite 5000, although most of the machines produce 1 to 2 KW. The machines have widely differing rated windspeeds and rotor diameters, and can be taken as a representative cross-section of available units. In addition, the program contains the specifications for three possible machines using a 6m ϕ rotor but rated at different windspeeds (6, 7.5 and 10 m/sec), giving different rated output powers (1 KW, 2 KW, 4.5 KW). These were included to test the sensitivity of the wind regimes to a range of comparable machines.

For practical operation, the program runs on a PDP-11 digital computer equipped with a V.D.U. (visual display unit) and a keyboard/

keyboard. The program runs interactively, asking for the required inputs (wind regime, type of machine required, fuel oil prices and economic variables) and then prints out the results:-

a) Power produced by the WECS, in KWH, in the morning/lunchtime/evening/night bands.

b) Total power produced per year, in KWH

c) Cost of the generated power in pence/KWH, based on the discounted value of the future power from the WECS.

d) Firmness factor 1: the amount of time per year when the WECS output is greater than 20W per sq. metre of rotor area.

e) Firmness factor 2: the amount of time per year when the WECS output is > 0.5 KW.

f) The equivalent cost of generating the same amount of electricity with a diesel unit, over the same time period.

The pages of a typical print-out are reproduced on following sheets.

The program is effectively a "Which Guide" to aerogenerators for any set of inputs. It gives power output, cost and firmness of supply, and can be used to isolate the best available aerogenerator to suit a particular set of requirements.

```
THIS PROGRAM COMPUTES THE OUTPUT FROM A NUMBER OF COMMERCIAL
AEROGENERATORS  (ELECTRICITY GENERATING WINDMILLS )
IN A WINDY AREA


PLEASE ENTER THE  AEROGENERATOR(S) REQUIRED:-

        COMMERCIAL AEROGENERATORS                         1 - 13
        TEST AEROGENERATORS                              14 - 17
        ALL TEST UNITS                                        19
        ALL COMMERCIAL UNITS                                  20

TYPE NO. REQUIRED ? 20

                             COSTING INFORMATION
                             $$$$$$$$$$$$$$$$$$$

DISCOUNT RATE REQUIRED, % , IS ?  7.1

LIFESPAN OF MACHINE , IN YEARS , IS  ?  20

LOWEST USER PRICE OF GAS OIL, PENCE PER LITRE, IS ?  15

EXPECTED OIL PRICE INCREASE, PER YEAR, REL TO INFLATION, %, IS ? 5

(THIS IMPLIES A RETAIL COST FOR DIESEL
 OIL OF   24  PENCE PER LITRE
 IN TEN YEARS TIME,  IN TODAYS TERMS )

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

WINDMILL TYPE :-

COMMERCIAL AEROGENERATOR 11:- 650W
*****************************

MORNING        LUNCHTIME      AFT/EVENING    NIGHTTIME      TOTAL
POWER          POWER          POWER          POWER          POWER
KWH            KWH            KWH            KWH            KWH

 25 %           34 %           18 %           21 %           2483


NET PRESENT COST OF GENERATED POWER IS                       3.1  PENCE/KWH

FIRMNESS FACTOR (POWER >> 20 W/SQ.M ) =                      70  %

FIRMNESS FACTOR (POWER >> 500 WATTS ) =                      18  %


NET PRESENT COST OF DIESEL POWER         OIL= 15  P/LT       6.8 PENCE/KWH
(3HP UNIT RUNNING  4.5  HR/DAY)
                                              22             9.5  PENCE/KWH

                                              30             12.2  PENCE/KWH
```

COMMERCIAL AEROGENERATOR 12:- 3KW(VERT.AXIS)
****

MORNING POWER KWH	LUNCHTIME POWER KWH	AFT/EVENING POWER KWH	NIGHTTIME POWER KWH	TOTAL POWER KWH
26 %	34 %	17 %	21 %	8300

NET PRESENT COST OF GENERATED POWER IS 3.5 PENCE/KWH

FIRMNESS FACTOR (POWER >> 20 W/SQ.M) = 66 %

FIRMNESS FACTOR (POWER >> 500 WATTS) = 68 %

NET PRESENT COST OF DIESEL POWER OIL= 15 P/LT 5.8 PENCE/KWH
(3HP UNIT RUNNING 15.1 HR/DAY)

22 8.4 PENCE/KWH

30 11.1 PENCE/KWH

COMMERCIAL AEROGENERATOR 13:- 5KW
****

MORNING POWER KWH	LUNCHTIME POWER KWH	AFT/EVENING POWER KWH	NIGHTTIME POWER KWH	TOTAL POWER KWH
26 %	36 %	15 %	20 %	7787

NET PRESENT COST OF GENERATED POWER IS 4.7 PENCE/KWH

FIRMNESS FACTOR (POWER >> 20 W/SQ.M) = 55 %

FIRMNESS FACTOR (POWER >> 500 WATTS) = 55 %

NET PRESENT COST OF DIESEL POWER OIL= 15 P/LT 5.8 PENCE/KWH
(3HP UNIT RUNNING 14.2 HR/DAY)

22 8.5 PENCE/KWH

30 11.1 PENCE/KWH

APPENDIX 2 COMPUTER PROGRAM FOR WINDPUMP WATER OUTPUT PREDICTION

The windpump program closely follows the Aerogenerator program (q.v.) in asking for windregime, oil price, diesel pumpset, machine lifespan and economic parameters. The output is however in a slightly different format.

Most windpumps are remarkably similar in price and performance (according to manufacturers specifications) for a given rotor size. This is to be expected in an industry where development has been static for many years; the classic design works adequately under the correct conditions.

The program prints the output from a series of commercial windpumps of increasing rotor diameter, together with the cost of water supplied, the equivalent cost of using a diesel pumpset to supply the same amount of water, and a firmness factor to show the percentage of the year when the water pumped is greater than a set rate. The print-out can be used to cost out the various sizes of windpump in any given windregime, or to do sensitivity analyses of windpump costs, diesel costs, etc. It can also give an indication of the firmness of the water supply for any given output level.

The pages of a typical program run are reproduced on following sheets.

THIS PROGRAM COMPUTES THE OUTPUT OF SOME TYPICAL
WINDPUMPS IN A MEDIUM WINDSPEED AREA

COSTING INFORMATION
$$$$$$$$$$$$$$$$$$

DISCOUNT RATE REQUIRED, % , IS 7.1

LIFESPAN OF MACHINE, IN YEARS, IS 25

LOWEST USER PRICE OF GAS OIL, PENCE/LITRE, IS 15

EXPECTED INCREASE IN OIL PRICES, PER YEAR, REL TO INFLATION, %, IS
5

(THIS IMPLIES A USER COST FOR DIESEL
OIL OF 24 PENCE PER LITRE
IN TEN YEARS TIME, IN TODAYS TERMS.

$$

1 COMMERCIAL WINDPUMP (ROTOR DIAMETER = 3 METRES)

TOTAL WATER OUTPUT PER YEAR IS		7 MILLION LITRES
FIRMNESS FACTOR 1 (OUTPUT > 200 L/HR/SQ.M)		23 %
FIRMNESS FACTOR 2 (OUTPUT > 400 L/HR/SQ.M)		0 %
NET PRESENT COST OF WATER FROM WINDPUMP PENCE PER CUBIC METRE		.57
NET PRESENT COST OF WATER FROM DIESEL PUMP	OIL= 15 P/LT	.87
(3 HP PUMP RUNNING)	22	1.07
(1 HR/DAY)	30	1.28

2 COMMERCIAL WINDPUMP (ROTOR DIAMETER = 4.3 METRES)

TOTAL WATER OUTPUT PER YEAR IS			20.6 MILLION LITRES
FIRMNESS FACTOR 1 (OUTPUT > 200 L/HR/SQ.M)			61 %
FIRMNESS FACTOR 2 (OUTPUT > 400 L/HR/SQ.M)			2 %
NET PRESENT COST OF WATER FROM WINDPUMP PENCE PER CUBIC METRE			.35
NET PRESENT COST OF WATER FROM DIESEL PUMP (3 HP PUMP RUNNING) (2.9 HR/DAY)	OIL=	15 P/LT	.56
		22	.76
		30	.97

3 PROTOTYPE WINDPUMP (ROTOR DIAMETER = 6 METRES)

TOTAL WATER OUTPUT PER YEAR IS			36.2 MILLION LITRES
FIRMNESS FACTOR 1 (OUTPUT > 200 L/HR/SQ.M)			23 %
FIRMNESS FACTOR 2 (OUTPUT > 400 L/HR/SQ.M)			2 %
NET PRESENT COST OF WATER FROM WINDPUMP PENCE PER CUBIC METRE			.11
NET PRESENT COST OF WATER FROM DIESEL PUMP (3 HP PUMP RUNNING) (5.2 HR/DAY)	OIL=	15 P/LT	.49
		22	.69
		30	.89

4 COMMERCIAL WINDPUMP (ROTOR DIAMETER = 7.6 METRES

TOTAL WATER OUTPUT PER YEAR IS		57.6 MILLION LITRES
FIRMNESS FACTOR 1 (OUTPUT > 200 L/HR/SQ.M)		23 %
FIRMNESS FACTOR 2 (OUTPUT > 400 L/HR/SQ.M)		2 %
NET PRESENT COST OF WATER FROM WINDPUMP PENCE PER CUBIC METRE		.23
NET PRESENT COST OF WATER FROM DIESEL PUMP	OIL= 15 P/LT	.46
(3 HP PUMP RUNNING)	22	.66
(8.3 HR/DAY)		
	30	.86

STOP AT LINE 1020

READY