Journal of Energy in Southern Africa 19(3): 30–34
DOI: http://dx.doi.org/10.17159/2413-3051/2008/v19i3a3328

A system methodology for an energy planning model and renewable energy technologies for agriculture in Nigeria

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Abstract
This paper analyses the system methodology of an energy planning model and renewable energy technology for agricultural operations in Nigeria. The study applies an energy building scenarios approach and with a computer software FORTRAN regression method. Agricultural productivity and value added depend very much on certain factors such as the area of the land under cultivation, extent of multiple cropping, the choice of crop, use of high yielding varieties, use of organic and inorganic fertilizers, the coverage of surface and ground water irrigation schemes, and the extent of mechanization for land preparation.

Keywords: system methodology, energy planning, agricultural operations, energy technology, scenario building, software regression model

1. Introduction

The agriculture policy of both the Nigerian Federal Government and State Government is to increase agricultural output substantially as a weapon to fight malnutrition and as a means to improve the standard of living of Nigerians. This paper deals with a system methodology for an energy planning model and renewable energy technology for agricultural operations in Nigeria. An energy scenario building and a computer regression model are used for the study.

2. Technical and experiment al methods

Direct commercial energy is mainly required for lift irrigation and agricultural operations. Energy demand for lift irrigation may be projected in different ways. The simplest method is to extrapolate the number of diesel and electric pumpsets from their present populations to certain large levels specified for the horizon year on the basis time series data. It may also be assumed that the average diesel/electricity consumption norms, average pumpset capacity and annual utilization rates will remain essentially unchanged from a past level.

In this approach, efficiency improvements in pumpsets may be incorporated by reducing the average energy consumption norms appropriately. It may be noted that only commercial energy consumption norms are projected, and the extent of human/animal energy replaced by additions to mechanized pumping systems is not accounted for. Despite this shortcoming, this approach is adopted because the underlying objective is to only project commercial energy demand. This approach has certain other shortcomings too, although it entails relatively small data requirements.

In the context of agricultural operations, the population of agricultural tractors, power tillers and crawler tractors are projected for a few years through past observations. A constant rate of growth of their numbers is assumed. Here again, energy consumption norms, average hp rating and annual utilization rates are assumed to remain unchanged from past levels. Therefore, the energy demand for lift irrigation and land preparation in year t (Et) is estimated as follows:

$$Et = It + Lt$$
$$It + \Sigma^2{}_i + 1 \text{ NiViPti;Lt} + \Sigma^5{}_i + 3 \text{ NiViPti} \quad (1)$$

Where:
It = energy demand for lift irrigation in year t (mtoe)
Lt = energy demand for land preparation in year t (mtoe)
i = 1 for electrical pumpsets; availability + 100%
i = 2 for diesel pumpsets; availability + 100%
i = 3 for agricultural tractors; availability + 88%
i = 4 for power tillers; available + 95%,
i = 5 for crawler tractors; availability + 95%
Ni = energy consumption norms for farm machinery (kgoe/hour)
Ui = annual utilization rates for farm machinery I (thousand hours/year).

Pti = population of farm machinery I in operation year t (million). This takes into account the availability factors specified above.

As little is known about energy consumption of other farm machinery for winnowing, threshing and crop drying, it is assumed that their total energy consumption will remain at about 6% of diesel demand and for lift irrigation and land preparation in Scenario I projections, where the norms are assumed to remain essentially unchanged from past levels.

3. Scenario I demand projections

The commercial energy demands for agriculture (electricity and diesel for lift irrigation and diesel for agricultural land preparation and other agricultural operations) are projected for the target years of 1995, 2000, 2005 and 2010 in two stages as shown in Table 1. Firstly, the available time-series data (see Table 1a) for the number of water lifts, electric pumpsets, diesel pumpsets, tractors, factors in operation, agricultural tractors, agricultural power trailers and crawler tractors for agricultural operations from the established statistics (Ministry of Agriculture, Federal Republic of Nigeria 1984) were used to identify both significant and explanatory growth and relationships in the form of the following regression equations. This is done with the application, Software Fortran program 1995.

$$Y = 0.24410 \times 10^5 + 0.5955 \times 10^4 X; R^2 = 0.931 \quad (2)$$

(0.5705×10^4) (0.67009×10^3)
{99.9%} {99.9999%} [99.99%]

Where Y = number of water lifts in thousand(s),
X = Time in years (1978 = 1)

Table 1: Scenario I energy demand projections for agriculture

	1995	*2000*	*2005*	*2010*
No. of water lifts	328110	4472110	566310	685410
No of electric pumpsets	21800	278000	3338000	398000
No. of diesel pumpsets	650 000	850 000	1 050 000	125 000
No. of tractors	383 500	502 300	621 000	739 800
Agricultural power tiller	151 460	198 860	246 260	24 763
Crawler tractors	13 399	17 187	20 975	24 763
c) Energy demand (mtoe)	-4	-4	-4 -4	
i. Electricity for irrigation	1.82956x10 0.0001829	2.33311x10 0.0002333x10	2.83665x10 0.00028366	3.3402x10 0.000334
ii) Diesel for irrigation (mtoe)	0.309465	0.404685	0.499905	0.595125
iii) Diesel for land prepa (mtoe)	0.2668573 0.3692	0.482 057478		
iv) Diesel for other machine (mtoe)	0.091181	0.1290269	0.1606587	0.1923259

Table 1a: Forecast s of the number of various agricultural equipment

	1978	*1979*	*1980*	*1981*	*1984*
No of water lifts	316 320	48 230	60 140	72 050	83 960
No of electric pumpsets	72	81	89	97	105
No of diesel pumpsets	160	180	200	220	240
Number of tractors	689 130	807 872	926 614	1 045 356	1 401 582
No of tractors in operation	66 079	76 911	87 743	98 575	131 071
No of agric tractors	2 585	3 059	3 533	4 007	5 429
No of trawler tiller	33 617	37 405	41 193	44 981	56 345
No of crawler tractors	32 816	41 292	49 768	58 244	83 872

Table 1b: Norms for energy consumption for electric and diesel pump sets

	Electric	*Diesel*
Average engine hp	5	7.5
Number of hours used p/a	900	900
Energy consumption p/hr	3.73 Kwh	1 litre

Table 1c: Land prep aration norms for energy consumption and utilization rates

	Diesel consumption (litres/hr)	*Utilization (No. of hrs p/a)*
Agricultural tractors	3.7	1000
Power tillers	1.25	1000
Crawler tractors	6.5	1000

$Y = 0.6528 \times 10^2 + 0.3985 \times 10_1 X$; $R^2 = 0.9470$ (3)

(0.29633×10^1) (0.477×10^1)

{99.999%} {99.998%} [99.99%]

Where Y = number of electric pumpsets in thousands, X = time in years (1978 = 1)

2

$Y = 0.1473 \times 10^3 + 0.1001 \times 10^2 X^2$; R = 0.9156 (4)

(0.964×10^1) (0.155×10^1)

{99.9999%} {99.98%} [(99.9%)]

Where Y = number of diesel pumpsets in thousands, X = Time in years (1978 = 1)

6 5

$Y = 0.332904 \times 10 + 0.593715 \times 10X$, $R^2 = 0.933$ (5)

$(4.49997 \times 10X^5)$ $(8.8057X10^4)$

{99.99%} {99.99%} [99.9%]

Where y = number of tractors in thousands, X = time in years (1978 = 1)

$Y = 0.33583 \times 10^5 + 0.5416 \times 10^3)$ X, $R^2 = 0.945$ (6)

$(0.4094X10^4)$ $(0.649X10^5)$

{99.99%} {99.99%} [99.99%]

Where Y = number of tractors in operation in thousands, X = Time in years (1978 = 1)

$Y = 0.1163 \times 10^4 + 0.2372 \times 10^3 x$; $R^2 = 0.885$ (7)

$(0.273x10^3)$ $(0.440x10^2)$

{99.8%} {99.9%} [99.9%]

Where y = number of agricultural tractors in thousands, X = Time in years (1978 = 1)

$Y = 0.22253 \times 10^5 + 0.1894 \times 10^4$ X; $R^2 = 0.945$ (8)

(0.1434×10^4) (0.1894×10^3)

{(99.999%} {99.99%} [99.99%]

Where y = number of agriculture power tillers in thousands, X = Time in years (1973 = 1)

$Y = (0.7388 \times 10^4) (0.4238 \times 10^4)$ X, $R^2 = 0.984$ (9)

(0.1679×10^4) (0.2894×10^3)

{(99.89%} {99.99} [99.99%]

Where y = Crawler tractors in thousands, X = time in year (1978 + 1).

Note that for these equations the figures in parenthesis indicate standard errors, figures in curly brackets indicate percentage confidence levels of significance of regression coefficients and the figure in the square bracket indicates the F test percentage confidence level for the significance of the regression equation as a whole. R square is the square of the correlation coefficient which is a measure of the explanatory power of the regression equation.

The upper half of Table 1 shows forecasts of the number of various agricultural equipment for the target years on the basis of the foregoing regression equations. Secondly, in the availability of Nigeria's specific data on energy consumption norms for electric and diesel powered equipment and machinery in use for lift irrigation, agricultural land preparation and other agricultural operations, the electric energy and diesel energy consumption norms were assumed to be the same as for India and are noted in Tables 1b and 1c for ready reference. With the help of these electric/diesel energy consumption norms, the electricity/diesel energy demands were computed for the target years as given in the lower half of Table 1, on the basis of growth trend projections of the numbers of machinery and equipment as given in the upper half of Table 1 (as already mentioned).

4. Scenario II demand projections

This scenario is assumed to be more energy intensive than Scenario I as a result of increased mechanization in lift irrigation as well as agricultural land preparation, which will substitute draught animal energy and human energy in the interest of improved productivity and quality of life. More specifically, it is assumed that the population of electric pumpsets and diesel pumpsets for lift irrigation and population of agricultural tractors for land preparation will each increase by 6% over Scenario I projections for the target years 2000, 2005 and 2010, while remaining at the same levels as in Scenario I until 1995. On the basis of technological choices for power/machinery and equipment remaining more or less the same as in Scenario I, it is reasonable to assume that the electric energy and diesel energy consumption norms for various equipment will also remain the same as in Scenario I (Njoku, 1990).

Accordingly, electricity and diesel energy demand for agricultural land preparation will go up by 6% with respect to Scenario I in the target years 2000, 2005, to 2010, while remaining at the same level as in Scenario I in the earlier horizon year, 1990. However, it is assumed that the population of agricultural power tillers and crawler tractors for other agricultural operations will remain the same as in Scenario I throughout the entire horizon period covering 1995, 2000, 2005 and 2010. In addition, diesel energy demand for agricultural power tillers and crawler tractors for agricultural operations will also remain at the same level as in Scenario I throughout the horizon period. The projections based on the foregoing assumptions for Scenario II with regard to population of different machinery and equipment and corresponding energy consumption demand are shown in Table 2 (Njoku, 2004).

5. Scenario III demand projections

With reference to the trend line in Scenario I, the following major changes are considered in Scenario III: (i) the average efficiency of electric and diesel pumpsets improve gradually by 5% for every five-year time interval reckoned since 1990 (no efficiency improvements in land preparation or any other mechanized equipment are considered); and (ii) renewable energy technology of windmill and photovoltaic (PV) pumping technologies are also propagated.

According to Thukral (1978), the scope for a reduction in energy consumption in electric and diesel pumpsets is substantial, as a result of correction of one or more of the following problems identified in this regard: (i) improper size of installed pumps and non-optimal operating conditions for the water lift head range; (ii) improper maintenance; and (iii) improper length of delivery pipes, air leak in suction pipe, redundant pipe fittings, high resistance and attendant increased friction losses in foot valves and strainers.

The two renewable energy technologies (RETs) are projected to be introduced very gradually. The underlying assumption is that the centralized electric utility grid is not extended at least to those areas where the wind/or solar energy potential is high enough to make either of the two RETs economically viable for pumping. This obviously calls for better coordination between conventional and non-conventional energy sources. Correspondingly, it is also assumed that the use of diesel pumpsets will

Table 2: Scenario II energy projections for agriculture

	1995	*2000*	*2005*	*2010*
No. of water lifts	328 110	4 472 110	566 310	685 410
No. of electric pumpsets	218 000	294 680	358 280	421 880
No. of diesel pumpsets	650 000	901 000	111 300	1 325 000
No. of tractors	383 500 (6%)	532 438 (6%)	658 260 (6%)	784 188 (6%)
Agriculture tractors	151 460 (6%)	210 791 (6%)	261 035 (6%)	311 279
- Agriculture power tiller	13 399	17 187	20 975	24 763
- Crawler tractors	25 743	34 219	42 690	51 171
c) Energy demand (mtoe)	-4	-4	-4	
i) Electricity for irrigation (mtoe)	1.82956x10 (6%)	2.4731x10 (6%)	3.0068x10 (6%)	3.5408
ii) Diesel for irrigation (mtoe)	0.309465 (6%)	0.428966 (6%)	0.5298993 (6%)	0.63088
iii) Diesel for land preparation (mtoe)	0.2668673	0.391352	0.51092	0.60928
iv) Diesel for other machinery (mtoe)	0.0971181	0.1290269	0.1606587	0.10

Table 3: Scenario III energy demand projections for agriculture

	1995	*2000*	*2005*	*2010*
No. of electric pumpsets	218 000	274 460	326 390	371 475
No. of diesel pumpsets	650 000	840 000	1 030 000	1 220 000
Wind pumpsets	0	540	3 380	7 960
Photovoltaic pumpsets	0	0	1 690	3 980
No. of tractors	383 500	502 300	621 000	739 800
No. of tractors in operation	353 100	461 400	569 700	678 000
- Agricultural tractors	151 460	198 860	246 260	293 660
- Power tillers	13 399	171 187	20 975	24 763
- Crawler tractors	25 743	34 219	4 269	57 171
c) Energy demand	mtoe	-4	-4	-4
i) Electricity for irrigation (mtoe)	1.82956x10	2.3034x10	2.73922x10	3.1176x10
	-4	-4		
ii) Diesel for irrigation (mtoe)	0.308465	3.9992x10	4.90383x10	5.80843x10
iii) Diesel for land preparation (mtoe)	0.2668673	0.3692	0.482	0.57
iv) Diesel for other machinery (mtoe)	0.0971181	0.1290269	0.1606587	0.192

reduce in such areas (NNPC, 1991).

As the wind pumping systems were expected to be commercialized before 2000, it is assumed that some experimental wind pumpsets would get installed by 2005, and that the number of wind pumpsets in operation in 2000 may represent a proportion equivalent to 1% of electric pumpsets in 2005 as depicted in Scenario I. The number of wind pumpsets in use in 2010 is expected to increase further to a level of approximately 2% of electric pumpsets in 2010 as depicted in Scenario I.

The PV pumpsets were commercially available in 2005 and will represent a proportion in that year equivalent to 0.5% of electric pumpsets (in 2005) as depicted in Scenario I. As a result of these assumptions, the number of electric pumpsets in Scenario III will reduce in number in comparison to that in Scenario I – due to 5% efficiency improvement every five years as well as substitution due to introduction of wind pumpsets and PV pumpsets in different horizon years. Also due to efficiency improvement of 5% every five years, the number of diesel pumpsets will also reduce correspondingly in different horizon years. Table 3 1n Scenario III energy demand in agriculture shows the numbers of various energy devices as well as their energy consumption demand based on norms of energy intensity as assumed in Scenario I. The implicit assumption of the demand projections in Scenario III is that the renewable energy based pumping systems do not have a conventional backup.

With this assumption, several research studies have shown that renewable energy pumping devices are, in general, not economical from society's viewpoint at present day costs. Similarly, if the two RETs under consideration operate with a conventional backup, they are, in general, not the least cost options. However, a case may still be made for promoting the RETs with a very long-term horizon in mind ultimately

6. Conclusion

This paper vividly illustrated the system methodology for an energy planning model and renewable energy technology for agricultural operations in Nigeria. Three scenarios built have illustrated the importance of this study to the Federal Republic of Nigeria.

References

FORTRAN programme III TD, 1995.

Ministry of Agriculture, Nigeria, 1984.

Nigerian Federal Office of Statistics (1981), Lagos.

Njoku, Paul C. (1990) Regression FORTRAN program, Computer Centre IIT, Delhi.

Njoku, Paul C. (1991) NNPC Petro Chemicals and Nigeria Economy.

Njoku, Paul C. (2004) Systems approach to Petroleum Energy Process Engineering and

Environment DSC Thesis Mech. Engr. MMM Engr. Collage G.K.P, India.

Thukral, K. (1987) An analysis of India oil policy alternatives III T D.

Received 28 October 2007; revised 5 August 2008