

Renewable Energy Development in Africa

Volume 1



Commonwealth Science Council

Renewable Energy Development in Africa

Volume 1

**PROCEEDINGS OF THE AFRICAN ENERGY PROGRAMME CONFERENCE
25 - 29 MARCH 1985, MAURITIUS**

**COMMONWEALTH SCIENCE COUNCIL
COMMONWEALTH SECRETARIAT
Marlborough House, Pall Mall, London SW1Y 5HX**

A. POLICY AND INSTITUTIONAL ACTIVITIES

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INTRODUCTION

Background

In September 1979, a group of African researchers met in Arusha, Tanzania under the auspices of the Commonwealth Science Council. The main objectives of the meeting were to share their experiences and to explore the feasibility of establishing a regional programme of research and development activities on renewable energy technologies and their application in Africa. The meeting, which identified seven projects to form the basis of collaborative research projects in the region, led to the formal institution of the African Energy Programme (AEP) by the Commonwealth Science Council (CSC). In addition to the AEP, similar initiatives were launched by other national and international bodies to promote and harness the enormous renewable energy potential of Africa.

The AEP aims to promote work on the African continent in the field of renewable sources of energy and to co-ordinate and strengthen the African scientific and technical capabilities through cooperative activities. The Programme is concerned mainly with addressing the energy needs of the predominantly rural populations of Africa with the following eight projects forming the nodal points for collaborative research and development:

1. Biogas for rural development
2. Energy policy for planning
3. Resource assessment
4. Solar crop drying
5. Solar heating and cooling
6. Wind electricity generation
7. Wind water pumping
8. Wood/charcoal production and utilisation.

The major activities of the AEP fall into three broad categories:

1. National scientific research and technological development as part of a regional network.
2. Workshops whose main objectives are:
 - to provide training to developing country scientists in the techniques and methodologies for high quality scientific research;
 - to identify common areas for follow-up training through collaborative scientific research and technological development;
 - to provide fora for the interchange of ideas and comparison of scientific results and information derived from the application of common methodologies.
3. Training courses and fellowship attachments.

The common theme underlying all activities is to assist with the development of indigenous scientific and technological capability around common disciplines and methodologies.

The United Kingdom Overseas Development Administration (ODA) has provided substantial financial support to initiate research and development activities on three of the projects: Solar crop drying, Charcoal production and utilisation and Biogas systems. Activities in the other projects have been pursued through national programmes and a number of training workshops organised by the Commonwealth Science Council. The range of projects has been instrumental in demonstrating the practicability of a regional network approach to science and technology for development within the constraints of scarce human and institutional resources.

The International Conference on Research and Development of Renewable Energy Technologies in Africa was organised to offer the opportunity for the scientists working on the AEP to share their results and experiences with each other, as well as with colleagues working on similar problems elsewhere in Africa and other countries. The specific objectives of the Conference were:

- to report the results of research projects on renewable energy technologies in Africa covering both the activities of the African Energy Programme and those of other institutions/agencies;
- to provide an opportunity for international exchange of research ideas and information between African scientists and colleagues from elsewhere;
- to provide a forum for scientists and potential donors to explore modalities for future collaboration on energy research and development in Africa.

Organisation and management

The Conference took place at the Paul Octave Wiehe Auditorium of the University of Mauritius from 25-29 March 1985, and was attended by 100 scientists, researchers, policy makers and representatives of International Organisations from 30 countries.

The programme consisted of plenary technical sessions which discussed invited and submitted scientific papers under four generic schemes of **Resource Assessment; Energy Conversion Technologies; Energy Utilisation Technologies; Energy Policy and Planning and International Collaborative Programmes**. In all, about 70 papers were presented at the Conference. In addition, visits were organised to the Bagasse-fuelled power station at Champagne and the Renewable Energy Projects of the University of Mauritius.

The Conference was officially opened by His Excellency Sir S Ramgoolam, Governor-General of Mauritius. The Inaugural address was delivered by the Hon A K Gayan, Chairman of the Council of the University and Minister of External Affairs for Mauritius. Professor J Manrakhan, Vice-Chancellor of the University of Mauritius delivered the keynote address to the conference. Dr P Hutchinson, Deputy Secretary of the Commonwealth Science Council, welcomed the Conference delegates on behalf of the Secretary-General of the Commonwealth and the Chairman and Secretary of the Commonwealth Science Council.

Conclusions and recommendations

1. Organisation of the AEP

Since its inception, the African Energy Programme activities have covered a number of fields concerning energy resources. Some activities had been more successful than others. However it was clear that the Programme had fulfilled a need, and should be carried on and expanded.

Such expansion should, in the first instance, be in the inclusion of non-Commonwealth African countries. The attendance at the Conference of representatives from these countries already initiates such a step.

Representatives of the International Organisations outlined their various activities in the field of energy, emphasising thus the advantage of close co-operation between the various agencies within a single system or network. The UNEP representative indicated that his organisation was considering a round table meeting of agencies concerned with energy. The suggestion was noted that a full time Secretariat would be beneficial, though the difficulties of acquiring funds for this were noted.

2. Technical development

1. Exchange of information

The need for exchange of information was strongly expressed. It was mentioned that there was, perhaps, too much information available. However, the difficulties of exchanging the information had often led to the duplication of effort. What was required was a system for organising and selecting the information as well as the means for delivery to and between the scientists and engineers.

Several organisations had made a start, for example, the Solar Energy Society for Africa had come into being, and frameworks also existed with the African Network for Scientific and Technological Institutions (ANSTI) and the African Energy Commission. The UN agencies were also interested in becoming involved in information systems for energy.

The conclusion was clear that the time was ripe for an African Energy Information System.

2. Application of technology

There was consensus that sufficient scientific and technological knowledge had been accumulated in many aspects of Energy for the balance of effort to be tipped towards the application of the knowledge to development.

It was important that several avenues for implementation be investigated. These range from governmentally-sponsored schemes to those which were purely commercial. In the latter case, the involvement of entrepreneurs, manufacturers and sales people from the start of any project is important.

It was considered that it was insufficient merely to present to the public devices for the utilisation of energy. It was important to create a demand, for example, for dried products, which in turn would provide a demand for the implements.

3. Training

The need for appropriate training was expressed. Some courses already exist in the developed countries. However, the development of such courses within the region would be useful.

Not only was there a need for graduate training, but training of support staff at technician level was also a requirement.

4. Priorities

1. It was recognised that countries would each have their own priorities as far as the various aspects of energy utilisation were concerned. In general, though, Biomass utilisation, particularly that through biogas generation, and the design of solar appliances was well advanced. Two areas specifically mentioned requiring further work were pyrolysis and collection of solar and wind energy data.
2. Co-operative action, both on an organisational level between agencies, and by information exchange was seen as an essential way to optimise the effort which was going into the development of energy.
3. Taking the results of research and development to energy application through the medium of commercialisation was seen as the next major step forward.
4. Training at all levels, and by several means, was, as always, seen as an essential output.

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London

15 May 1986

**GOVERNMENT AND UNIVERSITY IN PARTNERSHIP IN THE
DEVELOPMENT PROCESS OF SMALL STATES -
SOME MAURITIAN REFLECTIONS***

Hon. A K Gayan, Minister of External Affairs,
Tourism and Emigration and Acting Chairman,
Council of the University of Mauritius

Universities in developing countries, particularly those in small states, cannot be just centres of higher learning dedicated to the pursuit of academic achievement, pure and simple. They have to act, and be seen to act, as instruments in national development strategies, being fully integrated in the development process. Universities must be able to convince Governments that they can be privileged partners for national development, with constant interactions between decision-makers at the national level and university staff.

Academic freedom is important but cannot be divorced from national priorities. Academics must play a significant role in the search for solutions to national problems. This must be so, not only because in many countries the Governments have to finance almost the total budget of their universities, as in Mauritius, but also because Governments attach considerable importance to the inputs from the University in all spheres of national life.

Universities are centres of research par excellence. Scientific research for the sake of research, devoid of practical application, cannot be encouraged at a time when resources are scarce, at a time when countries are going through a bad economic spell. At a time when there is real pressure to reallocate resources from theoretically unproductive activities to productive ones, the temptation to slash university budgets becomes hard to resist. This is not a problem faced only by poorer nations: Britain has not hesitated in reducing the budget on tertiary education. I am not in any way suggesting that universities must not have substantial state financial support certainly for the present. However, universities must be tuned to the social, economic, industrial and technological problems of the nation, if they are to avoid indictment. In any case, Universities must lead the way and cannot be followers.

One area in which, as a lawyer, I have been closely involved, namely the challenge of the sea for development. Mauritius exercises jurisdiction over an immense extent of maritime space, and which certainly does not lack in renewable and non-renewable resources. The time has come for the University of Mauritius to tackle the problem frontally, as, indeed, it proposes to do - for its own good as well as that of the country. Hitherto, for a variety of reasons, it has tended, in the area of marine resources, to restrict itself to piecemeal studies or some training activities.

Proposals for short-term strategies must be included within the framework of long-term plans. The Mauritian Government accepts that a comprehensive programme of applied research relies on continuing basic research specially to underpin technologies that could be harnessed for a country's development. Nevertheless it is highly desirable that any research undertaken by the University produces results in as short a time as possible. Scarce resources cannot be bound up in time consuming research with esoteric aims and marginal benefits. Pure research as a mere slogan must give way to research which has relevant, direct and, as far as possible, immediate bearing on national development.

* Extracts from welcoming address to the conference.

Nations must develop and utilise indigenous expertise within and outside the campus, in their quest for solution of development problems. Recourse to foreign expertise can no longer be justified in areas where we have better practical experience. Rather than supporting programmes of technical assistance when the need for such assistance does not really exist, foreign governments would make a greater contribution by helping to strengthen local expertise.

Shridath Ramphal in his address at the Thirteenth Congress of the Universities of the Commonwealth urged Vice-Chancellors (and others) to widen their enquiry when addressing the question of the role of universities in relation to technological innovation within the context of small states. He went on:

"What technology?", of course, becomes a pertinent question; but, even more to the point, "what university?". Such necessary questionings will inevitably lead you into exploring a range of co-operative measures at the regional, inter-regional and Commonwealth-wide level in supplementation of the resources of these very small states. For them, a part of the challenge of technological innovation is innovation in the role of universities, innovation that emerges out of the traditional springs of university improvisation and perhaps out of technology itself.

Similar considerations led to the establishment of the University of Mauritius in the mid-1960s, with generous help from the UK. The University, indeed, was conceived in the developmental context as the one appropriate and relevant for Mauritius.

The university has had to continually adapt and make provision for new courses warranted by the changing economic climate of the country. Government-university collaboration in teaching and training is likely to grow. Moreover, since we have adopted a pragmatic approach to development, we have to look towards more and more effective government-private sector-university linkages.

To promote multi-disciplinary research and consultancy for the practical solution of our manifold societal problems, in what, after all, is both a small and a poor country, the university drew up proposals known as the "Mauritius 2000 concept". The thinking, aims and objectives of this concept are in broad agreement with those in the Report Science for Technology for Development of the Commonwealth Science Council. Within the framework of the "Mauritius 2000 Concept" the University of Mauritius is being transformed to contribute fully in the development process in Mauritius whilst retaining its position and standards among the Universities of the Commonwealth.

The Higher Education Division of the British Council has been staunch supporter of the Mauritius 2000 concept. The help and support of international agencies such as the Commonwealth Science Council, UNESCO and other United Nations agencies, is vital in the promotion of North-South and increasingly South-South, collaborative efforts such as "Mauritius 2000".

Sir Seewoosagur Ramgoolam, Governor-General of Mauritius, in his message to this Conference stated:

"Mauritius is proud of her African heritage and traditions. Our Continent, of vast potential, is currently facing innumerable difficulties. But many of these would be solved or attenuated considerably were Africa to

obtain, and exploit rationally, cheap, reliable and plentiful supplies of energy; hence the need both for research and development of appropriate renewable energy technologies, and for proper monitoring and evaluation of endeavours therein, and hence the need for the International Conference."

The Conference itself, structured in four broad scientific subject areas, namely energy resource assessment, energy conversion technologies, energy utilisation technologies, and energy policy formulation and planning, has the following three broad objectives:

- (1) to report the results of research projects on renewable energy technologies in Africa covering both the activities of the Commonwealth Science Council's African Energy Programme, and of other institutions and agencies;
- (2) to provide an opportunity for the international exchange of research ideas and information between African scientists and colleagues from elsewhere;

and

- (3) to provide a forum for scientists and potential donors to explore modalities for future collaboration on energy research and development in Africa.

I have deliberately steered clear of energy issues in Mauritius although these are, inevitably and inextricably, connected with several of the points I have raised. These issues will be covered elsewhere in the Conference.

**SCIENCE AND TECHNOLOGY, RESEARCH AND DEVELOPMENT,
ENERGY AND THE LDCs :
RAMBLING THOUGHTS FROM AN ACADEMIC**

Prof. J Manrakhan
Vice-Chancellor, University of Mauritius, Reduit, Mauritius

TERMINOLOGY

There are innumerable ways of looking at "science", "technology", "research" and "development". In line with evolution of thinking and practice over the last few decades, it would be best to think in terms of a science-technology continuum. That continuum should be regarded as a strongly interacting "know-why/know-how" system, and for our purposes, the emphasis should be on the "know-how" part of the continuum. The "know-how" part of the continuum, in particular, has to operate within socio-politico-economic contexts, both national and international. Along similar lines, research and development (R&D), should best be regarded in "know-why/know-how" continuum terms, again operating within socio-politico-economic contexts; part of the science-technology continuum prior to, and excluding, mass industrial and commercial production operations. Moreover, "technology" would also include management concepts and techniques.

FROM TERMINOLOGY TO MODEL: MAURITIUS 2000

The view of science and technology outlined above has found expression, and practical application in the "Mauritius 2000" concept of the university.

- (i) There is nothing particularly extraordinary about the year 2000 as such. The Mauritius 2000 concept is a flexible one which enables the university to use a fairly long time-horizon to build alternative internally consistent scenarios, working backwards to the present in attempting to find practical solutions to existing and foreseeable problems, within an integrated and dynamic context.
- (ii) Various working groups at the University, operating on the 'swim or sink' principle, aim to cover among others biotechnology; energy; employment, productivity and industrial relations; macro-economic modelling; microelectronics and physical resources planning. And, among the new areas the Mauritius 2000 studies will shortly cover are food and nutrition; women studies; the small farmer concept; the welfare state; and industrialisation.
- (iii) As anticipated there are interactions between the several exercises. Indeed, energy considerations have required review of initial aims of most of the Mauritius 2000 exercises in progress and planned. There is a need to develop a methodology concerning measurement systems to enable the integration of the various Mauritius 2000 exercises from the point of view of science and technology, and their repercussions in society. Energy considerations appear to constitute a useful starter here, for example, by adopting a "carrying capacity" approach.

CERTAIN ISSUES CONCERNING ENERGY RESTATED

It is convenient, at this stage, to restate certain general remarks on Energy.

- (a) The distribution of non-renewable energy resources in the world is very uneven; "poor" countries are, in general, also "poorly off" in those energy resources (except for certain oil-exporting countries). Moreover these are becoming scarcer: at current rates of consumption, presently known oil resources are estimated to last 30 to 50 years, while coal resources may last 200 to 500 (possible 800) years. Any major increase in coal use may lead to environmental problems. In any case Africa, as far as is known at present, is deficient in coal reserves.
- (b) The consumption of energy is also uneven throughout the world. Around 70% of the world's population, accounting for 20% of the world's annual energy consumption, have a per capita consumption of goods and services of between one-tenth and one-twentieth of the corresponding figure in highly industrialised countries. There is a relationship between gross national products (GNP) per head and energy consumption per head. Because of increasing population and rising average energy consumption per head, the world's energy consumption is increasing, although less rapidly than previously since the mid-1970s. Relationships, expressed in the language of mathematical statistics have been, and are being, found - for example, between GNP per head and commercial energy consumption per head, or in inter-sectoral input-output tables. These relationships, besides providing further insights into economic development processes are also very useful in more specific energy studies, particularly if non-commercial energy could be brought into the reckoning with implications for renewable energy resources.
- (c) There is a need for considerable increases in costly and time-consuming efforts (including R&D) to explore and exploit new fossil fuel resources, geothermal resources, nuclear fission and fusion systems, and in connection with renewable energy resources (eg direct solar, wind, tide, hydroelectric and biomass conversion). Even so, most forecasts (1) seem to indicate that by 2000 AD the maximum contribution of renewable energy resources to overall world energy demand would be in the range of 5% to 10%. But Africa is more favourably placed than these world-wide estimates suggest. And in Mauritius biomass prospects are well beyond such estimates.
- (d) It is sobering to reflect that, only a few years ago, most forecasts were to the effect that the long-term trend in the world average energy price would be an increasing one in real terms. But by how much? Could renewable energy resources not come to the rescue?; if so, how and when? -these are some of the questions we need to reflect upon (2).

ENERGY AND THE LEAST DEVELOPED COUNTRIES:
THE BROOKHAVEN STUDY

The Brookhaven National Laboratory, commissioned by the US Agency for International Development, produced a report in 1978 covering the energy needs, uses and resources of developing countries up to the year 2000 AD (3). Many non-OPEC developing countries were already in serious difficulties with increasing energy costs, growing populations and urbanisation, worsening unemployment and balance of payment problems, and with recurrent food shortages. In the absence of remedial measures, the Brookhaven study concluded, the position in those countries would be aggravated and become catastrophic, with the whole ecosystem supporting the rural poor increasingly at risk.

That study, by no means the most pessimistic at the time, recommended finding solutions to the energy problems of the LDCs, in terms of exploration and exploitation of renewable and non-renewable resources, production and consumption aspects and stressed both technological as well as social aspects. Energy, it stated, "drives the machinery of a nation in all its vast human, cultural and economic complexity"; energy assistance programmes would only succeed if conceived and implemented with "due respect" to that complexity. The Brookhaven study estimated the total investment required, up to the year 2000, to enable non-OPEC LDCs, as a whole, to reach energy self sufficiency at US \$125,000 million in terms of 1976 prices.

APPEAL TO THE CONSCIENCE OF MANKIND

The Brandt Commission (1980) was to appeal to the conscience of mankind for the elaboration of a New International Economic Order (4). It addressed itself to energy thus:

- (i) Energy cannot be examined in isolation but within a generalised and integrated context of major world problems (including food, hunger, poverty, unemployment, health, education and so on).
- (ii) Until the turn of the century, the main energy source of the world will continue to be oil; arrangements have to be made as a matter of urgency to protect the economies of 'poor' countries against sharp price increases in energy and to provide security of supplies to those countries.
- (iii) Transitional measures are necessary in shifting from oil to other energy sources, including supply planning and management, very costly exploration and development of energy resources; the 'South' must not be forced to adopt expensive new technologies for alternative energy sources; a World Energy Research Centre should be set up under UN auspices.
- (iv) Energy conservation is crucial and may necessitate international agreement and surveillance for all countries; however, the world's energy (and other) problems must be solved by peaceful means and not by force.

SHOCK WAVES

On the other hand, Toffler (1980), striving to shock us into becoming conscious of the advent of a new 'Third Wave' civilisation, has highlighted the following features:

1. Prior to the "Industrial Revolution", mankind lived within its energy "income" on many, dispersed and renewable energy sources, in the main. Thereafter, industrialisation, using concentrated and few energy sources, led to depletion of energy capital as a result of building "towering technological and economic structures" on the assumption that cheap fossil fuels would be "endlessly available".

In the process, there was a "dramatic reworking of the landscape" requiring more complex coordination between city and countryside than hitherto, with considerable flows of people, food, energy, raw materials, on the one hand, and manufactured goods and services, including information, on the other. Moreover, while fossil fuels accelerated

markedly technological and economic growth, "energy-thirsty, brute technology" exploited those very fossil fuels ever more rapidly. So much so, that the civilisation we know of today is in the throes of violent disintegration with many a crisis, including ecological, socio-politico-economic ones.

2. Many new ideas for centralised and decentralised large-scale and small-scale energy production have been thought of already. With other developments will come a new civilisation which will draw upon a very wide variety of energy sources - "hydrogen, solar, geothermal, tidal, biomass, lightning discharges, ultimately perhaps advanced fusion power, as well as other energy sources not yet imagined in the 1980s". The technological base of such a civilisation will be far more diversified, "springing from biology, genetics, electronics, materials science as well as outerspace and under-the-sea operations". Most technologies will use less, not more energy - thus the energy required to produce 90 miles of copper can even now be used to turn out 80,000 miles of optical fibre. They will be small in scale, simple and safe to operate, with "wastes of one industry pre-designed for recycling into primary materials for another". Major societal changes, however, will only be felt when the new technologies such as biotechnology, sea nodule extraction and utilisation, microelectronics and computers, link together with a new multi-source, renewable energy base.

Significantly, both the Brandt Commission (1983) and Alvin Toffler (1983) have maintained their previous views; if anything, the latter have indeed become reinforced.

THE DONS IN CONGRESS AT VANCOUVER, 1978

Less than six months after the publication of the Brookhaven study, the Executive Heads and other representatives of Commonwealth Universities met in congress at Vancouver in August 1978. Topic 1 on the agenda dealt with 'The World Food Problem and the Universities'; there were to be four subtopics; namely 'production potential', 'population', 'energy' and health'. (7)

Significantly, the interrelationships among food, energy, poverty and general socio-economic factors as well as more obvious scientific and technological considerations loomed large in the papers presented (illustrated with statistical tables) and the ensuing discussions. Among topics raised and debated were energy budgets, sources and potentials on a world scale and for certain individual countries, the uneven distribution of energy production and consumption, effects of prices, international issues including a New Economic order, renewable energy technologies including conservation ones, new social arrangements to utilise energy (eg communal cooking, biogas generation), energy farming, energy analysis of agricultural systems (including subsistence ones), how to increase energy efficiencies on farms, the transition from traditional energy resources to more commercial ones, energy dependencies of LDCs, scientific technological assistance to LDCs and so on.

Obviously, the role of universities was highlighted. Apart from teaching and the ability to provide a forum of discussion for clarifying and sharpening arguments objectively, the multidisciplinary nature of most universities provide the latter with undoubted advantages in energy studies and research:

"Universities, through the skills and dedication of their staff and students, have unlimited possibilities to contribute to the solution of national and international energy problems. Specialised research contributions on the scientific and technological aspects of energy production, storage and consumption represent obvious areas for detailed work and much is already going on in these domains. As research moves away from the fundamental end of the spectrum towards the development and demonstration stages, university personnel may need to contribute more in governmental and industrial settings than within their own laboratories, but this is a familiar concept not restricted to energy research. The techniques of energy analysis and modelling (with a view to assessing the complex interactions of economic, social and environmental factors with medium and long-term projections of energy supply and demand) are still at an early stage of their development and can present an intellectual challenge to the problem of providing energy for developing countries is a challenge to the idealism (hopefully) in us all."

George (1979)

MEANWHILE IN MAURITIUS

Energy considerations were also to loom large on the University's agenda in Mauritius, as well as on those of organisations and persons outside the Reduit campus.

Put briefly, the number of Mauritian qualified scientists, engineers and economists (in terms of full-time equivalents) working on one aspect or another of the energy situation in Mauritius over the past 5 years would be of the order of 10 to 15, of which the University would have contributed between half to one-third. Taking recurrent expenditures and cost of supporting staff into account, the value in 1980 prices would be of the order of Rs 1.5 million to Rs 2.5 million per annum. The above-mentioned estimates exclude:

- (a) Capital Costs of R&D - where these largely utilise resources energy projects already available for other purposes.
- (b) Foreign R&D costs associated with bagasse pelletisation, Champagne Hydro-Electric Project, Medine & FUEL power generation bagasse/coal generation plants, and the Riambel Sea Wave Project.

Three national seminars and conferences were held (in February 1977, December 1980 and February 1981) by the University, singly or in conjunction with other institutions and agencies, both governmental and private. The last national seminar led to the elaboration of a National Plan of Action on Energy, which was presented at the UN Conference on New and Renewable sources of Energy held at Nairobi in August 1981. I understand that Plan of Action was received with fair interest there.

The following are relevant:

1. <u>Analysis of Papers presented in February 1977 and December 1980</u>		1-Day Energy Seminar (8) Feb 1977		1-Week National Conference (9) Dec 1980		
1.	Energy Resource Assessment	2	(0)	6	(0)	
2.	Energy Conversion Technologies	4	(4)	23	(23)	
3.	Energy Utilisation Technologies	3	(2)	11	(5)	
4.	Energy Policy Formulation and Planning	0	(0)	8	(2)	See (ii) below
		9	(6)	48	(30)	

Notes: (i) The numbers in brackets denote those specifically devoted to renewable energy.

(ii) The National Energy Conference of December 1980 was followed by a 1-day National Energy Seminar held in February 1981; both were organised in integrated fashion to help elaborate a National Plan of Action on Energy until 2000 AD (10).

2. Among the main features of the National Energy Plan of Action were:

- (i) With GNP per head increasing at 2% per annum in real terms, the total amount of energy demand projected up to 2000 AD was 440,000 tonnes of oil equivalent (toe) from 210,000 toe including 190,000 toe of net imports in 1979. This was projected to be met thus:

	'000 toe
A. Renewable Energy except from Sugar Industry	89
Hydro	21
Woody Biomass	33
Solar	15
Wave	20
B. Renewable Energy via Sugar Industry (Bagasse, Cane Tope, Ethanol)	114
C. Conservation	94
D. Oil Imports (electricity, transportation)	<u>143</u>
Total (exclusive of autoconsumption in sugar industry)	<u>440</u>

- (ii) The investment required over the period 1980-2000 in real terms would be of the order of Rs 2500 million. Of this amount, investment in the sugar industry for energy purposes was estimated at Rs 1300 million (Rs 1000 m for electricity generation and Rs 300 m for ethanol production).
- (iii) It was stressed that no document on energy could be expected to remain up-to-date for very long, and would necessitate frequent revisions; in any case a 2% GNP increase per head per annum might not be sufficient. On the other hand, the projections in the National Energy Plan of Action suffice to illustrate the considerable prospects which exist in terms of renewable energy resources in Mauritius - well beyond the 5 to 10% of total energy consumption by the year 2000 and into the range of between one-half and two-thirds of the total (exclusive of autoconsumption in agricultural industries almost wholly renewable).
- (iv) Various proposals relating to R&D in the energy field were made.

MORE ON R&D CONSIDERATIONS

An account of the thinking and work of the University of Mauritius in R&D of energy technologies will be presented at this Conference. Here and now, I restrict myself to the following:

1. Since 1980-81, further steps in the elaboration of energy models have been made; some exercises have begun producing results towards the 2020

time horizon. Another interesting example is that of attempting to discover the possibilities of 'tunnelling' through the 'hump' which empirically seems to exist in commercial energy consumption/GNP per head curves with increasing industrialisation: various energy input-output models are being worked out.

2. A further scrutiny of the R&D proposals in the National Energy Plan of Action has been made, first, to assess current R&D capabilities and, second, the extent to which such capabilities can be harnessed at the University in the light of other, and competing, tasks. The results of such a scrutiny are illustrated in Appendix IV.
 3. Among some of the questions, with R&D implications which we are asking ourselves at the University are:
 - (i) Is pelletisation the 'best' techno-economic solution for storing bagasse without significant deterioration for periods up to 6 months?,
 - (ii) Can biotechnology provide a satisfactory answer to the problem of the disposal of "vinasse", the residue left over in the fermentation of molasses to alcohol?,
 - (iii) Is there any really effective R&D work left to be done on the Riambel Sea Wave Project unless the proposed 1 MW 'prototype' be constructed even if the cost of the latter at Rs 10 million appears high?,
- and
- (iv) What are the prospects of increasing the usefulness of the River Champagne Scheme to the national electricity grid?; what about other sources of renewable energy which were not incorporated in the National Energy Plan of 1981, for example, agricultural wastes, marine algal ocean thermal conversion, and geothermal energy, among others?
4. Thoughts such as those which inspired the various texts I have mentioned in my address, have also guided us in Mauritius: the necessity to look at energy in a more generalised and integrated context; problems and prospects associated with renewable energy resources, particularly biomass; the ever-growing impact of science and technology in society, changing at ever-faster pace, among other considerations.

But, undoubtedly, most of the energy studies in Mauritius, inside and outside the campus, have tended until recently to be unduly dispersed and insufficiently interconnected and coordinated. Certain fields of enquiry have, in consequence, been unnecessarily over-subscribed in terms of efforts but not necessarily in terms of results, while others have been left untouched or only timidly covered. A natural process of rationalisation has come about over the past few years, particularly within the University, with the help of the Higher Education Division of the British Council and the Commonwealth Science Council, within the context of Mauritius 2000. Is it fast enough? And what about the rationalisation of R&D efforts on energy in Mauritius as a whole?

In parenthesis, may I point out that, as a University, we must also think in terms of teaching and training. Apart from workshops and seminars, we are giving thought to the incorporation of energy components in various subdegree and degree courses as well as in proposed Masters' courses in Administration, Management and Technology.

INTERNATIONAL SUPPORT

Finally, it gives me great pleasure in acknowledging, with gratitude, the support from overseas which the University of Mauritius is deriving for its work in the energy field. In particular, thanks must be expressed to the Commonwealth Science Council and the Higher Education Division of the British Council, whose efforts (supplemented occasionally from the United States) underpin much of our efforts in the energy field. Although I would like to think that we have earned such support through hard sweat, I must also regard that support in the context of efforts in the international community to help the LDCs in science and technology and in other fields of endeavour.

This Conference itself would never have been possible without the support, financial and otherwise, of the international community, competently motivated, marshalled and managed by the Commonwealth Science Council. If perchance, I have said anything that might be of some use to the participants to this Conference, I shall be delighted.

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and

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**CHARACTERISTICS OF SCIENCE COMPARED WITH
THOSE OF TECHNOLOGY AND INDUSTRY**

Science	Technology	Industry
understanding	utilisation	mass production
from unknown to known	from known to useful	from useful to popular use
system of thought	system of method	system of production and sale
passive (natural)	active (artificial)	passive to active (demand-supply to produce-consume)
objective	subjective	objective to subjective
meaning	means	efficiency (organisation & management)
discovery	invention	development
truth convenience	convenience	profit = output/input (organic system)
satisfaction of mind	satisfaction of body	satisfaction of economy
academic	professional	entrepreneurial
scholar	specialist	entrepreneur
100 year scale	10 year scale	1 year scale

Source:

Chan, Y.W., Evolution of Scientific Thought in Physics, Chinese University of Hong Kong; Professional Inaugural Lecture Series 3; Supplement 10, 1982

Appendix II

In general R&D is defined as any creative systematic activity undertaken to increase the stock of scientific and technical knowledge and to devise new applications.

It should exclude scientific education, scientific and technical information, general-purpose data collection, routine testing, standardisation and other technological activities related to production or use of established products or processes, as well as large-scale mineral and petroleum prospecting for exploitable deposits and not essential for basic geological knowledge. In the social sciences include activities of a research nature related to the solution of economic or social problems, but exclude routine activities such as censuses, market studies, etc. In the medical sciences exclude intensive medical care. In general, defence R&D should be included.

The criterion for distinguishing R&D from non R&D activities in the presence or absence of an appreciable element of novelty or innovation.

source: UNESCO 1978

RESEARCH AND DEVELOPMENT

The following broad lines of research and development need to be given priority in the light of the discussions which had taken place during the National Energy Conference held on 15th to 19th December 1980.

1. A systematic collection/compilation of data/statistics on energy and their analysis.
2. Use of the energy statistics for the construction of a proper energy balance for the country, and within the framework of an input-output table.
3. Using (1) and (2) above, to work out an appropriate aggregate energy demand model which will eventually be used for planning and policy-making purposes.
4. Detailed studies (both technical and economic) of the following projects are to be carried out:
 - (i) Hydro-power - A proper re-assessment of the total potential of hydro-power will be required.
 - (ii) Electricity from bagasse (including close cropping, use of cane-tops and leaves), improvement of thermal efficiencies, etc, need to be looked carefully into.
 - (iii) The use of coal as a substitute for oil in electricity production and for out-of-season electricity production from sugar estates should be objectively examined.
 - (iv) Woody biomass. Rational studies and surveys on woody biomass and energy forms as a source of energy and otherwise have to be undertaken as a matter of urgency, being given that maximum use of solar energy can thus be obtained.
 - (v) Ethanol from molasses as an energy source. A complete study of the technical feasibility, production costs, effects on the government and the balance-of-payments of the ethanol project is required to settle once and for all the differences of opinion on this issue. (The new Lonrho report will be helpful in this respect).
 - (vi) Solar water heaters. Further investigations for locally constructed, low cost and cyclone resistant water-heaters, and their financial implications for the government and the public should be looked into.
 - (vii) Wave power. Careful consideration of this new venture is required with special emphasis on technological, environmental, economic and other aspects.

- (viii) Conservation. Various conservation measures have been proposed at the Conference. New conservation methods have to be looked into.
 - (ix) Nuclear energy option. Relevant information to be collected and analysed so as to keep options under continuous review.
 - (x) Wind. Statistical data on wind potential at relevant sites to be collected and analysed. Information on wind generators to be compiled and updated periodically.
 - (xi) Geothermal. Present investigations to continue.
 - (xii) Miscellaneous. Investigations to be initiated and/or continued: OTEC, photovoltaics, efficient wood stoves, biogas, diesel poor gas, oil refinery, methanol from bagasse, vacuum distillation of ethanol, use of straight alcohol, contingency planning for fuel (warfare and isolation), examination of possibilities of local manufacture of equipment.
5. The research and development aspects relating to energy should be continuously examined by the proposed National Research Council, the latter should make relevant recommendations to the High Level Committee proposed for sorting out energy policy matters.

ASSESSMENT OF UNIVERSITY OF MAURITIUS R&D IN ENERGY

	Current Capability	Present Use of Capability	Two Main Reasons for Underuse of Capability	Explanatory Notes
1.	Collection, compilation and analysis of energy data	....	B, C	Very high
2.	Utilisation of (1) for input-output tables and Energy Balance	....	B, F	High Fairly high Medium Low
3.	Energy Modelling Planning & Policy, incl integrated energy strategy	....	B, D	Excellent Very good Good Average Poor
4.	Techno-Economic Studies			
(i)	Hydro (incl mini-hydro)	X	F, G	National policy
(ii)	Electricity from bagasse and other fibrous residues	XX	F, G	Computing facilities
(iii)	Coal as alternative energy source	XX	A, E	Funding
(iv)	Woody biomass	XX	C	Coordination
(v)	Ethanol/methanol from molasses/fibre	XX	A, G	Information
(vi)	Direct solar	XX	B, G	Staff resources
(vii)	Wave, Ocean	X	C, F	Infrastructure/ equipment
(viii)	Conservation	X	A, D	
(ix)	Nuclear	X	E, F	
(x)	Wind	X	B, F	
(xi)	Geothermal	X	E, F	
(xii)	Biogas	XX	A, D	

**RENEWABLE ENERGY R&D AND AFRICA'S
SOCIO ECONOMIC DEVELOPMENT**

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ABSTRACT

The close correlation between the proximity of the energy resources to the potential beneficiaries, coupled with the favourable supply prospects, have led to an enormous increase in interest and activity among African governments, multilateral and bilateral aid agencies, the multinational companies and individual entrepreneurs in the development and utilisation of renewable energy resources in developing countries. This increased activity has resulted in a proliferation of the number of possible technical options. Although the development work is by no means complete, a number of technologies have been demonstrated to be technically feasible and thus ready to be considered as alternatives to the more conventional sources of energy.

This paper discusses the principal issues pertaining to the scientific research and technological development that must be considered if the enormous potential of renewable energy is to be translated into a beneficial facilitator of Africa's socio-economic development in the next century.

INTRODUCTION

The 1970's were dominated by two interlinking themes: energy and economic recession. For Africa and most other developing countries, the major impact of the massive increases in energy prices were to create severe constraints on the financial resources of most countries, as a direct consequence of the need to spend a substantial proportion of foreign exchange earnings on oil imports, which situation resulted in deep economic recessions in virtually all countries. The crisis demonstrated the close link between energy and socio-economic development and the importance of having secured sources of energy supply; which conditions were best guaranteed by the development and utilisation of indigenous energy resources. This development had to take account of the need to maintain existing levels of socio-economic development, as well as plan for future growth.

Most African countries possess enormous renewable energy resources. In most cases these already constitute the most substantial sources of supply to meet the demand of the majority of their populations. Given that the rural sectors, which are the major users, are also those that most require socio-economic improvement, it would appear that the development of the indigenous renewable energy resources could contribute substantially to easing both the energy and developmental problems of many African countries.

The close correlation between the proximity of the energy resources to the potential beneficiaries, coupled with the favourable supply prospects, have led to an enormous increase in interest and activity among African governments, multilateral and bilateral aid agencies, the multinational companies and individual entrepreneurs. This increased activity has resulted in a proliferation

of the range of technical options for renewable energy applications. Although the development work is by no means complete, a number of technologies have been demonstrated to be technically feasible and thus ready to be considered as alternatives to the more conventional sources of energy.

In the long run, if the major objectives of renewable energy resource development in Africa are to substitute for current oil imports and provide for the next generation of industrial development, then it is desirable, and eventually imperative that the development of all facets of the technologies must be carried out in the user countries.

AFRICA'S SOCIO-ECONOMIC DEVELOPMENT: HOPES VERSUS REALITIES

"We view with distress, that our continent remains the least developed of all continents: the total Gross Domestic Production of our countries being only 2.7 per cent of the world's per capita income Yet if the world economic forecast for the next decade is to be believed, the overall poor performance of the African Economy over the past 20 years may even be a golden age compared with future growth rate".

Extracts from Preface to the Lagos
Plan of Action 1980-2000 (1)

In acknowledging the failures of Africa's post-independence efforts at socio-economic development, the leaders of Africa also set out an agenda for future action. The Lagos Plan of Action represented an attempt to rationalise the multi-faceted issues of development into a coherent and sustainable policy for the next twenty years. (1980-2000). Sadly in the first five years of the Plan's birth, the prophetic forebodings for the future have already been borne out. At the same time, the great Plan is taking an inordinately long time to translate into practical action.

Africa's agricultural production has failed to achieve the minimum indicative goal set by the World Food Conference for the decade 1974-1983 (2). The growth rate achieved was 1.9%, against a target of 3.9%, dropping to a low 1.6% between 1979-83. The latter represented a decline in per capita food production in the region of 1.4 per cent per annum. The industrial picture fared little better, with the continent contributing only 0.8 per cent of the world's manufactured added value in 1975, compared to Latin America's 5.1 per cent and Asia's 2.3 per cent. The 0.8 per cent figure translated to about 9% of the total GNP in 1979 (3). Against this must be set the optimistic hopes of the Lagos Plan, which placed the emphasis for future action on Food and Agriculture, and Industry (Table 1).

WHAT ROLE ENERGY RESOURCES?

A fair proportion of the blame for the failures of Africa's socio-economic development in the recent years has been attributed to the problems created by our favourite bogey "**The Energy Crisis**". Indeed, there is an almost "Pavlovian" tendency to confine the conceptualisation of the issues behind Africa's recent failures simply to the consequences of the trends and impacts of global energy supply and price structures. In my humble view, this approach is flawed on two basic counts in respect to Africa:

Firstly, it presents a blinkered assessment of the energy picture in Africa, concentrating on the so-called "commercial energy" resources. For at best, these sources are estimated to account for no more than 10 to 20% of the continents' total energy demand (Table 2).

Africa's demand structure for energy can be represented broadly as comprising of three main sources (Table 3):

- (1) Traditional renewable energy: mainly fuelwood, but encompassing charcoal, crop and other plant residues and animal waste (dung); these form the bulk of energy sources to meet subsistence needs;
- (2) Commercial energy: which comprises not only hydro-carbons, oil gas and coal, but also include the renewables of nuclear and hydroelectric power;
- (3) Unexploited renewables: such as solar, geothermal, wind, ocean and waves.

The classification given here is not quite in line with accepted trends. For example, commonly accepted renewables such as hydropower and nuclear energy are grouped under the commercial classification. Also the renewables are split into "traditional" and "underexploited". The regrouping is quite deliberate and is intended to introduce the notion of "Indigenisation" into the perceptions of global energy resources and demand considerations. It is also worth noting that the word "alternative" has not been used in either the classification or sub-groupings. The reason being a wish to avoid the implications that the fossil resources equals mainstream orthodoxy for all countries and that renewables are somehow of fringe interest. The notion is real enough, given that in the developed world, enthusiasm for renewables is highest amongst the so-called environmental (Green) parties.

The second problem of the conventional versus alternative approach is that it automatically couples the level of scientific and technological activity on renewable energy resources to the prevailing global perceptions of fossil fuel supply and price. This is as true of the pre-colonial Drake period of the late 18th and 19th Century, which saw the development of many solar technologies, to the current 1985 situation of falling oil prices on the Amsterdam spot markets.

Thus, in the space of a decade, we seem to have moved from a serious crisis in the energy field to the benign quizzical enquiry of "**CRISIS, WHAT CRISIS?**"

In most of the developed world, the result of the recent falls in oil prices has been a massive disengagement from research and development activities or renewables, though the effects have not been limited to these countries. For developing countries in general, and Africa in particular, a most welcome outfall of the R&D programme of developed countries was the opportunity to share in the results of scientific and technological innovations. The combinations of a high level of technical capability (95% of the world's R&D capability) and generous research grants created the climate in the developed world for an exciting and challenging investigation of "future" energy sources. As long as the price of oil held, we were all confident of near-term technological breakthroughs, to the extent of being able to set target dates for technical and commercial viability.

Alas, we have come to the end of the unofficial "Renewable Energy Decade" of 1974-1984. As with most such euphoric expressions of international concern, the major results seem to have been thus:

"the problems have been thoroughly aired, yet the problems are still with us"

Reputations have been made, as well as fortunes and careers. At the end of it all the label ALTERNATIVE has shifted to some other concern, be it the 'implications of new technologies', 'sustainable development' or 'fragile earth'. However, we are left with a still persistent and growing problem and a smaller, albeit dedicated cadre of scientists, technologists and resources to investigate and secure rational and sustained solutions.

SETTING THE FRAMEWORK FOR R&D

The international Conference and R&D of Renewable Energy Technologies in Africa is called to review Africa's scientific and technological responses to the problems of energy resources and socio-economic development. It marks the end of almost six years of collaboration among researchers from both developed and developing countries under the umbrella of the African Energy Programme (AEP). Nevertheless, our judgement as to success or failure of the various endeavours should not be restricted merely to the technological advances or innovations that are reported in the various technical presentations. There is a need to reflect on the changing climate for support of research and development and its possible consequences for the future. Also, due note should be taken of the changing international perceptions as to priorities for external aid support to development projects.

For many of us, the challenges of the 1970's were instrumental in shaping the directions of our future intellectual development. We have acquired the basic academic and technological tools necessary to make a meaningful contribution to Africa's energy problems.

Now, as we enter a period of relative decline in popularity in our chosen disciplines, perhaps we can take solace as well as inspiration from the examples of some of our developed country colleagues, a number of whom have devoted a substantial proportion of their lives to addressing the very same problems of renewable energy development and exploitation. A few have carried out their tasks for over 30 years in such unlikely settings such as the United Kingdom. Others have practiced in more beckoning environments such as Australia. Whatever the setting has been, these scientists and technologists have sustained their investigations and enthusiasm for many years, and have been able to make significant contributions to our current understanding of the principles and technologies of solar energy application and utilisation.

The dedication of these scientists serves both as an example and inspiration for us, and this conference provides a welcome opportunity to share in their expertise for our own efforts in Africa. For me, the most exciting discovery when I began to look at the possibilities for solar energy was the realisation that many of the fundamental scientific concepts and principles had been brought together as far back as 1961 at the United Nations Conference on New and Renewable Energy Resources.

Apart from the sustained efforts of scientists, it is also useful to note that the countries which have been most successful in exploiting renewable energy have been those who have developed and sustained rational national programmes over several years, such as Australia, Israel, Cyprus, South Africa and Zimbabwe.

A recent study of global energy prospects has suggested that in the long-term, biogas and charcoal could meet up to 16 per cent of Africa's household and industrial final energy needs by the year 2010. All renewables combined (including hydroelectric) could account for between 20-30 per cent of total primary energy by 2030. The important point is not necessarily the projected percentage. It is the fact that the first of the target dates is still 25 years away. It is also about the remaining period of productive working life for most of the African scientists attending the conference. It would be comforting to be able to think that we will be able to sustain our commitment to this intellectually satisfying and technologically relevant research and development of Africa's renewable energy resources to assist its socio-economic development.

A CONDUCIVE ENVIRONMENT FOR RESEARCH

The climate for scientific research and development in Africa has never been particularly encouraging. Unfortunately, the situation is in many cases, deteriorating as the numbers of trained scientists and technologists increase. The combination of economic difficulties, lack of support and recognition and the burdens of bureaucratic overload have all conspired to deprive Africa of a sustained scientific and technological intellectual base. It is nowadays a rare sight to encounter an African researcher who has actively pursued their discipline for more than 10 years.

The importance of human resources to a country's development is well recognised. A distinguished academician, Prof Frederic Harbison states (4):

"Human resources constitute the ultimate basis for the wealth of nations. Capital and natural resources are passive factors of production; human beings are the active agents who accumulate capital, exploit natural resources, build social, economic and political organisations and carry forward national development. Clearly, a country which is unable to develop the skills and knowledge of its people and to utilise them effectively in the national economy will be unable to develop anything else".

EVOLVING A CREDIBLE STRATEGY

To achieve the Lagos Plan targets for Food and Agriculture Production, it is estimated, will require financial investments of \$125 billion (1980) over the 15 year period of 1975-1990; a figure that excludes the investments in infrastructure and other support services such as research, extension and training. The Lima Declaration set for Africa to achieve a share of manufacturing added value of 2.0% in 2000, as against the 1975 level of 0.9%. For Africa the implications for future development of energy resources would seem quite clear.

The achievement of the Lagos and Lima Plan's targets would demand substantial energy inputs. For many countries the only realistic long-term option for supplies of energy are the indigenous "traditional and unexploited" renewable resources. Even for the oil-rich African countries, renewables will be just as

important if the thrust of future developmental efforts is to be in the rural areas.

The combination of inadequate technical capabilities and competing sectoral claims on limited financial resources will require us to evolve achievable and pragmatic programmes of future R&D. To ensure its continuing relevance, the overall scheme must involve a strategy that focuses on meeting existing needs, whilst at the same time searching for new technological approaches and innovations. Such a strategy might involve a sequential scale of priorities that:

- (1) strengthens the efficiency of current applications; such as improvements in fuelwood and charcoal stoves;
- (2) substitutes renewable resources which indicate near-term technical and economic viability; such as solar water heaters for domestic and industrial applications;
- (3) establishes long-term research schemes to increase the resource base and to develop new technologies for secondary power generation; such as afforestation and development of biomass conversion technologies.

WHAT OF THE FUTURE

This Conference provides a timely opportunity to evolve such a strategy as an essential element of the review of our efforts over the past "ten years of plenty". In order to arrive at some sensible conclusions as to past achievements and future needs, we must address ourselves to the following four questions:

- (1) What constitutes Africa's primary renewable energy resources and how much of each is available?;
- (2) What useful energy forms can be produced from these primary resources and what are the available technological options?;
- (3) What end-uses and processes lend themselves to renewable energy applications; and
- (4) Which combinations of resources, technologies and end-uses would be most beneficial to the socio-economic developmental efforts of individual countries?

Therein lies the rationale for the technical framework developed for the Conference, namely:

- (1) ENERGY RESOURCES ASSESSMENT:
- (2) ENERGY CONVERSION TECHNOLOGIES:
- (3) ENERGY UTILISATION TECHNOLOGIES:
- (4) POLICY PLANNING & IMPLEMENTATION.

A former United States Cabinet Secretary made the following observation of renewable energy resources:

"Solar Energy will have as much impact as a flea's bite on an elephant's fanny"

James Patterson.

Should we arrive at a similar conclusion at the end of this Conference, we should all prepare to join the current alternative bandwagons.

Somehow I know we shall finish up admiring the wit and not the substance of that remark.

TABLE 1: SECTORAL GROWTH TARGETS FOR LAGOS PLAN OF ACTION (1)

SECTOR	Rate of Growth (% p.a.) (at constant 1980 prices)
GDP	7.0
Agriculture	4.0
Manufacturing	9.5
Exports	7.0
Imports	8.2

TABLE 2: ESTIMATED NATIONAL RELIANCE ON TRADITIONAL FUELS IN AFRICA (5)
(each group arranged in ascending order of per capita GNP)

Modest Reliance (less than half)	Medium Reliance (approximately one-half to three-quarters)	Heavy reliance (three-quarters or more)
Mauritius	Togo	Benin
Morocco	Gabon	Burundi
Zimbabwe	Liberia	Cameroon
Egypt	Mauritania	Cape Verde
Algeria	Senegal	Central African Empire
Tunisia	Zambia	Chad
Libya		Ethiopia
		Gambia
		Guinea
		Guinea Bissau
		Kenya
		Lesotho
		Madagascar
		Malawi
		Mali
		Mozambique
		Niger
		Rwanda
		Sierra Leone
		Somalia
		Sudan
		Tanzania
		Uganda
		Upper Volta
		Zaire
		Angola
		Botswana
		Congo
		Eq. Guinea
		Ghana
		Nigeria
		Swaziland

Source: Energy Strategies for Developing Nations, Johns Hopkins University Press, 1981.

TABLE 3: CLASSIFICATION OF AFRICA'S ENERGY RESOURCES STRUCTURE

CLASS	CONSTITUENTS
A. Traditional Renewable Energy	Fuelwood, including charcoal; agro waste, draught animal power.
B. Commercial Energy	Oil, gas, coal, nuclear power, hydroelectric power.
C. Unexploited renewables	Solar thermal & photovoltaic, geothermal, wind, ocean power, & wave power.

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FOOD SELF SUFFICIENCY AND ENERGY RELATED CONSTRAINTS IN SUB SAHARAN AFRICA - CRITICAL REVIEW

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ABSTRACT

Agricultural production in a selected number of countries in Sub Saharan Africa (Tanzania, Kenya, Zambia, Botswana, Ethiopia, Zimbabwe and Malawi) over the past decade is reviewed. With the exception of Zimbabwe, agricultural production has in most of these countries relied on hand tool technology and is mostly rainfed agriculture. The adoption of a more settled type of agriculture in place of the shifting type of agriculture will undoubtedly necessitate increased utilisation of support energy inputs such as fertilisers, pesticides and machinery which may be beyond the capacities of these countries and the international aid programmes. It is argued that the current policy in agricultural research and extension in most African countries of emulating the green revolution type of technology is unlikely to solve Africa's food problems. Irrigation would seem to be an appropriate solution, but is expensive and demands technical expertise lacking in most African countries. Various other options are discussed and reviewed.

INTRODUCTION

Within less than fifteen years Sub Saharan Africa is again featuring prominently in the world press due to the severe food crisis and famine. Virtually all the countries in Sub Saharan Africa have been affected by the current crisis unlike the 1973-75 crisis which was more serious in the Sahel Region. The poor crop can again be explained partially by the drought. However the continent's vulnerability to famine would seem to be increasing and a recurring event.

The annual rates of increase of the major staple food crops in the region was about 1.3% during the 1960's and early 1970's compared to 3% in Asia and Latin America. Population growth in Sub Saharan Africa however has been quite high averaging around 2.7% in the 1970's and is projected to be 3% per year over 1980-85 with some countries having a growth rate of as high as 3.5% (IBRD 1982). The increases in production of major crops have come about through increases in area under cultivation rather than through gains in productivity per unit of input. Per hectare yields of many subsistence food crops have stagnated and in some cases have declined and are quite low compared to those of other continents.

The majority (60-90%) of the population in Sub-Saharan African countries live in rural areas and engage in subsistence farming. These farmers practise low input/output agriculture. Fertiliser application rates are the lowest in the world. Hand tool technology predominates. Animal powered technology is used in only about 10-15% of the cultivated land and mechanically powered technologies in less than 5%.

Increased productivity will only be possible if the vast majority of the farmers switch from traditional and subsistence agriculture to modern agriculture

involving the use of high yielding varieties, irrigation, fertilisers, and better implements including animal and mechanically powered tools for field operations. All these inputs are energy intensive and their increased utilisation in particular on the Asian Subcontinent has significantly increased food production. This green revolution technology however seems to have eluded Sub Saharan Africa.

It is unlikely however that any of the countries in Sub Saharan Africa can afford such an energy intensive agriculture. In this paper energy related constraints affecting food production in Sub Saharan Africa will be reviewed. Medium and long term implications of the current low input agriculture will be presented and policy options discussed.

FACTORS AFFECTING FOOD PRODUCTION

Production of food is influenced by:

- i. solar energy;
- ii. land availability;
- iii. moisture in the soil;
- iv. labour;
- v. soils and soil fertility;
- vi. machinery and implements;
- vii. plant protection measures.

Although there are some intervening economic factors, eg agricultural marketing, pricing, land tenure, I believe these are of secondary importance to the lack of farming technology. Of the factors listed above, solar energy is more than adequate and only in a few countries such as Zimbabwe and Kenya is land tenure a problem.

Moisture in the soil

Most of Sub Saharan Africa practises rainfed agriculture and less than 5% of the cultivated land is irrigated (IBRD 1982). Rainfall exceeds evaporation for only a very short season. The timing of field operations (land preparation, planting, and weeding) is therefore critical for crop production. To most farmers therefore, the most critical scarce resource is labour at the start of the rainy season. To overcome this constraint farmers have two options:

- i. Develop irrigation farming
- ii. Grow drought resistant plant varieties

Irrigated agriculture has not traditionally played a significant role in Sub Saharan Africa, but the potential for irrigation is quite high (Mrema 1984; Toksoz 1981). The main constraints to increasing the role of irrigated agriculture in Africa are the capital costs involved and the lack of trained manpower to profitably manage such schemes. It is estimated, that in 1980 the capital costs involved in bringing one hectare of land under irrigation in Africa was in the region of US \$10,000 (IBRD 1982). In addition, many of the existing irrigation projects are not well managed and hence not profitable due to lack of adequately trained manpower (Chambers and Morris 1973; Mrema 1984; Palmer Jones 1981). Irrigation may however be the answer for the future if properly and gradually developed.

The second option of growing drought resistant varieties seems to be more feasible. However, drought resistant varieties are generally low yielding (eg drought resistant Katumani maize variety in Kenya yields less than 1000 kg/ha while hybrid maize grown 100km away can yield up to 6000 kg/ha (Alcober et al 1983).

Labour

Since quite a high percentage of the population in Africa is engaged in agriculture (60-90%) it would seem that there is no shortage of labour for agricultural production. This is however quite misleading. When account is taken of the age/sex distribution of populations, less than 40% of the economically active population of most countries is engaged in agriculture. If the role of women is considered (since they perform most of the life support jobs - eg fetching water, firewood, child caring etc) then the percentage of the population fully engaged in agricultural production is greatly reduced.

Therefore, in essence about 20% of the population are required to produce enough food not only to feed themselves but to feed the remaining 80% (children, old people, lactating mothers, urban dwellers).

This would be quite possible if the productivity per unit of labour input in agriculture were high. But, farming carried out using handtool technologies can rarely exceed subsistence level. Brandt (1979) has argued that an annual labour input of 1100-1200 hr per year represents an upper limit for many farmers unless new production techniques are introduced. Given that the labour in handtool agriculture is in the region of 120 man days/ha it is unlikely that a family can handle more than 2 ha of land. If draught resistant varieties of maize are grown this will yield less than 2 tonnes which is barely sufficient for subsistence.

Labour therefore represents a major constraint in food production. Given that land is not a major constraint in Africa, efforts should be directed more at increasing the productivity of labour inputs rather than productivity of unit area of land as was done in Asia in the green revolution system.

Soils and soil fertility

The application rate of fertiliser is quite low in most of Sub Saharan Africa at less than 5kg/ha (Mudahar 1980). The increase in population and the change from shifting cultivation to a more settled type of agriculture has resulted in a serious decline of soil fertility in many countries in Africa (Eicher and Baker 1982) due to continuous tilling of the same land. Methods of restoring soil fertility such as use of animal manures are difficult to practise because of labour shortages and the large amounts which need to be applied (30-50 /ha) (Mrema 1985) to be effective.

The solution suggested by most agricultural research scientists is to rely increasingly on inorganic fertilisers. What is often forgotten is that inorganic fertilisers are quite energy expensive. For example a tonne of nitrogenous fertiliser is equivalent to two tonnes of crude petroleum (Leach and Slesser 1973; Pimentel 1973; Smil et al 1983). To this must be added energy used in the distribution and freight. This is estimated at about 10% of the manufacturing energy costs in the more advanced countries (Fluck and Baird 1979). Given the poor infrastructure and inefficient transport system this is likely to consume about three times that figure in most of Africa.

If the agronomically recommended rates of fertiliser application were to be applied for only nitrogen, the total nitrogenous fertiliser requirements for Sub Saharan Africa would be about 15 million tonnes for 1980, instead of the about 600,000 tonnes used. This will be equivalent to 30 million tonnes of crude petroleum in energy terms, and if the distribution energy costs are to be added this represents an equivalent of total energy expenditure of about 40 million tonnes of crude petroleum. All the nine countries in SADCC consumed only about 3.42 million tonnes of crude petroleum and 3.78 million tonnes of refined petroleum products in 1980 (Simoes 1984). In addition the logistics and managerial capabilities of distributing such a huge amount of fertiliser would seem to be beyond the capacity of most countries in Sub Saharan Africa.

Fertilisers can only increase yields when the other inputs (rainfall, crop husbandry) are present in optimum amounts. Given the uncertain nature of the rains the feasibility of fertiliser use at the rates recommended by research agronomists is doubtful. It may be more economical to aim at lower yields, and hence lower levels of fertiliser application and other soil fertility restoration techniques (crop rotation, growing of N fixing varieties), and cultivate more extensive areas. This type of system has been quite successful in Australia and New Zealand (McChesney et al 1981). This however requires greater mechanisation of farming.

Agricultural machinery and implements

Population trends indicate that less and less people will be engaged in agriculture especially handtool type of agriculture (population growth rates of most cities in Africa are the highest in the World, 6-15% per annum). The logical technological step to overcome labour shortages would be animal powered systems. However about two thirds of Sub Saharan Africa is tsetse infested. The cost of making these areas tsetse free is high and there are associated environmental hazards. In addition it is generally accepted that it requires at least a generation before people who are traditionally not livestock keepers adopt the tradition of keeping livestock and use them for draught power purposes. Further, animal traction may not be that timely compared to handtool technology (Gemill, 1971) and creates subsequent labour bottlenecks, eg in weeding and feeding of animals etc. As Eicher and Baker (1982) have noted there is a range of technical, economic and logistical constraints on the spread of total packages of animal traction in Africa.

Mechanically powered technology is still not very widely used in Africa (less than 5% of cultivated land). However, a significant proportion of the marketed food surplus in many African countries is produced from large scale farms which rely, on mechanically powered technologies (eg Zambia, Zimbabwe, Kenya,). The number of tractors in use in the whole of Africa in 1980 was only 443,000 (compared to 418,000 in India) with only about 27% of them being in Sub Saharan Africa (FAO 1982).

The history of mechanisation in Africa however is littered with failed tractorisation schemes. The main reason for their failure is lack of qualified and competent manpower both at operator and at managerial level, (Gemill and Eicher, 1973; Hall, 1968; ILO, 1976; Kolawole, 1974; Mrema, 1981; Winch 1976; Wuyts, 1981).

The other main constraint of mechanically powered technologies is their fuel requirements especially after the oil price increases of the 1970's. However as

shown in Table 1 the energy expended on machinery and implements is much less than that expended in other inputs like fertilisers and pesticides. Studies in India show that energy in machinery and implements as well as in animal feeds in bullock powered irrigated farms is 38.7 GJ/ha whereas on tractor operated, irrigated farms it is 14.6GJ/ha when growing wheat, (Gupta et al 1983; Malik et al 1981).

Plant protection chemicals

The other energy intensive input in agricultural production is plant protection chemicals against weeds, diseases, insects, and other pests. This however is not extensively used in African small holder agriculture and through plant breeding efforts, disease and pest resistant plant varieties may be developed.

FUTURE STRATEGIES AND ENERGY IMPLICATIONS

The advanced countries have increased yields and total food production quite significantly over the past three decades (wheat yields of about 10 tonnes/ha are quite common in Europe and USA) by increasing energy expenditure per unit area as well as per unit of labour. On the Asian subcontinent the green revolution has enabled these countries to increase yields as well as total food production quite significantly by use of more energy per hectare and per input of labour as well as more added labour per hectare.

In Africa however, in the absence of irrigation and with entire reliance on rainfed agriculture, and very little support energy inputs in the form of machinery and fertilisers it is unlikely that food self sufficiency can be achieved if the trend of the past decade is maintained. No precise figures of energy consumed in agriculture in particular the peasant agriculture, are available. However the figures given in Table 2, can be regarded as indicative. Energy consumed is less than 1000 MJ/ha for maize production most of it being animate energy derived from human muscles. This compares favourably with figures from other countries, eg USA between 19,600 and 32,160 MJ/ha (Smil et al 1983) and China with national average 12,000 MJ/ha (Jin et al, 1983). In both cases the bulk of the energy is in the form of chemical fertilisers.

China, with a huge population (1 billion) most of whom live in rural areas and a much smaller cultivated land than Sub Saharan Africa, has managed in the past three decades to mechanise the most difficult field operations (like ploughing, harrowing and planting (ARSSID 1977)) and the average power input in the form of machinery is 0.4 hp/ha with a further 0.23 hp/ha applied in irrigation equipment. This compares with a total of less than 0.1 hp/ha in most of Sub Saharan Africa (Giles, 1975; Mrema, 1981).

In order to overcome their food crisis Sub Saharan African countries must be ready to spend more energy in their agriculture. At the moment less than 10% of commercial energy imports is used directly in agricultural field operations (Simoes 1984). Energy is expensive but there are no alternatives if the increasing population has to be fed. Most African countries have used agriculture as a source of foreign currency. In most African countries there are less than 10% as many tractors as saloon cars. Yet there is more concern on the fuel used in these tractors than the huge amounts used to run these limousines.

RESEARCH IMPLICATIONS

Energy research is quite a recent development, but even in the USA energy research in agriculture has received much less attention compared to the other sectors. In the developing countries the situation is even worse.

The need to use more energy per unit land area as well as per unit labour input is not in dispute. The main question is which energy rich input should African governments encourage their farmers to use: fertilisers, pesticides and irrigation, or less fertilisers, no irrigation and extend the area under rainfed agriculture.

Research will assist, at least in the short term, in identifying which energy related constraints will have the most pronounced effect in increasing food production. Answers will be needed to questions such as: Which is the most efficient way of increasing energy expenditure in agriculture? What mix of handtool, animal powered, mechanically powered machinery and implements, fertilizers, pesticides and irrigation is the most efficient energy wise. This area requires urgent and detailed study in Africa to assist policy makers in formulating both short and medium term policies.

CONCLUSION

An attempt has been made to identify the energy related constraints to increased food productivity and production in Sub Saharan Africa. It is shown that energy inputs into African agriculture are quite low compared to other countries whether developed or developing. To overcome their food problems African countries ought to be prepared to increase the use of energy rich input in agriculture like fertilisers, pesticides, machinery and implements as well as irrigation where this is feasible, both per unit of land area as well as per unit of labour input.

Energy studies have grossly under estimated the energy related constraints of agricultural production in Africa and have concentrated mostly at commercial energy resources like petroleum products which are used more by the industrial, domestic and transportation sectors of the economies of most Sub Saharan African countries. Such studies and reports, which are often used by African policy makers as a basis for future policy formulation can provide a misleading picture which may lead to African countries being continuously in famine crisis. With a rapidly increasing population, Sub Saharan African countries have no option but to increase utilisation of energy rich inputs in their agriculture if they are to meet food requirements of their populations which will double in the next two decades.

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**Table 1 Energy consumption per hectare, mechanically-powered-technology
Morogoro, Tanzania - maize**

Tractor MF265 - 62hp; disc plough, harrow, planter. Fuel consumption total 150 cc/hp hr. (Bullard et al 1976): 1 litre = 47.3 MJ/litre.

	MJ/hr	MJ/ha
1. Machinery costs		
- Tractor	91.5	183
- Disc plough	24.0	24
- Disc harrow	28.0	28
- Sprayer	16.0	16
- Planter	18.0	18
Total Machinery Cost	337.5	429
2. Fuel Costs		
- Diesel 9.3 l/hr 47.3 MJ/l x 6 hrs (for ploughing (2), harrow (1), spray (2 x ½), plant (1), harvest (1))		2639
- Repairs 118 MJ/h x 6 hrs		708
- Lubricants - 4% of fuel costs		106
Total Fuel Costs		3848
3. Other Inputs		
- Fertiliser 100 kg N		4560
100 kg P205		1400
Total Fertiliser		5960
- Pesticides 5 kg		3679
4. Grand Total		13906 MJ/ha

Machinery: Fuel: Fertiliser: Pesticides = 3%: 28%: 43%: 26%.

Human energy contributions insignificant

Yields: 2500 kg/ha poor rains, 4500 kg/ha good rains.

Table 2 Energy requirements per hectare - using handtool technology: maize plot - Mgeta Village, Morogoro Region (Province), Tanzania (Mrema, 1983)

Activity/Input	Man days/ha	Energy MJ/ha
1. LABOUR		
Land Preparation	44.5	280.4
Weeding	37.1	233.7
Harvesting	24.7	156.6
Post harvest operations: shelling, bagging	12.4	78.1
SUB TOTAL LABOUR	118.7	748.8
2. OTHER INPUTS	MJ/kg	
(i) Fertiliser*		
100 kg Ammonium Sulphate	45.0	4560.0
50 kg P ₂ O ₅	14.0	700.0
SUB TOTAL FERTILIZER		5260.0
(ii) Pesticides		
3 kg	459.9	1379.7
(iii) Implements		
6 kg of hoes, axes, matchet	9.96	59.8
SUB TOTAL OTHER INPUTS		6698.8
GRAND TOTAL		<u>7447.6</u>
Yields 1000 kg/ha		

Sample size 59 households observed over a year. Yields 100 kg/ha.

* Fertiliser application rate is as recommended by research stations and what extension agents recommend to farmers. Actual application rates are however quite low around 5kg/ha giving a total energy input of $748.8 + (5 \times 45.6) + 60 = 1040$ MJ/ha

RENEWABLE ENERGY OPTIONS FOR REMOTE AREA POWER SUPPLY

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ABSTRACT

Stand alone systems based on photovoltaic modules with battery storage or wind power generation with battery storage, in a range of system sizes from a few watts to several hundred kilowatts; and grid connected systems based on the same technologies and on solar thermal electric technologies, are available in demonstration form up to 1-10 MW of electrical output with plans for 100 MW schemes in the conceptual design stage. These solar and wind technologies may prove most cost effective in the small scale when combined with a hybrid plant using petrol or diesel engine generators. Specific examples are cited to show the relative economics of the various systems using up-to-date Australian data, where remote area applications are possibly more similar to those in developing countries than those in the developed nations of the world.

INTRODUCTION

The technology associated with remote area grid extension is well known and significant improvements are not likely. Connection to the main state grids in Australia is now only economically viable for those homesteads located within a few kilometres of existing network systems (Figure 1). The cost of the connection depends heavily on the type of terrain traversed, the connection length, and the particular system employed. In Australia, the cheapest system used is the single wire earth return using a single steel wire which is operated at 10-20kV with a step down transformer providing up to 20kW at 240V AC (Figure 2). These lines are often limited in length by safety requirements to about 20km total length. If longer connections are envisaged more sophisticated and hence more expensive systems must be used.

Typical costs of electricity to the customer are given in Table 1 for Victoria, a heavily industrialised state in SE Australia, and for a selection of countries in SE Asia and the Pacific. The large variations in charges are due to many socio-economic and political factors as well as the power generation technology and cost of fuel used. The process of tariff setting for electricity and other fuel prices is really beyond the scope of this paper but the availability of remote area energy subsidies in many countries tends to mask the real costs to the community of providing power to remote locations. It should be noted that a connection cost of A\$40,000 equates to an electricity supply cost of 65¢/kwh. Typical costs for electricity generation from diesel engines in Australia lie in the range of A\$0.14-A\$3/kwh.

As the discussion will be limited to the available options for electrical or mechanical power supply in areas not serviced by main electrical grid systems, the following renewable energy options are available for consideration:

1. Wind generations systems
2. Solar thermal systems

3. Photovoltaic systems
4. Mini and micro hydro plant
5. Biogas or biomass engine plant
6. Hybrid systems involving two or more of the previous options (Figure 3).

In many remote areas the power is generated at present using small scale petrol or diesel generators with or without battery storage depending on the expected power usage pattern. Recent developments in load management control involving the use of large scale battery storage can substantially reduce the costs associated with conventional diesel generation and are appropriate for consideration with connection to renewable energy technologies. Virtually all hybrid plants based on windpower, photovoltaics, other renewable energy options and a conventional engine generator include the facility to charge a battery bank.

ESTIMATION OF TOTAL LOAD

Before an electrical supply system can be designed, it is essential to have a realistic appraisal of the likely peak and average loads associated with particular appliances and the usage patterns to calculate the expected daily energy demand. A listing of typical appliances is given in Table 2 and the energy demand on a daily basis is shown on the same table. This type of preliminary analysis is vital because of the high capital cost of the renewable energy plant particularly the photovoltaic systems. Careful note should be made of the fact that the peak demand of some of the appliances is of the order of 2-5 times the appliance rating and that the installed system has to cope with this instantaneous requirement.

BASIS FOR COSTING OF RENEWABLE ENERGY SYSTEMS

The cost of electricity generation from all renewable energy sources has to be costed over the total life of the installation if a fair comparison is to be made with conventional electrical generating plant. As the systems will be installed away from main grid systems no credit can generally be given, in an economic sense, to power generated above the amount considered necessary for operation of the connected plant. This life cycle costing method can lead to two forms of comparison one based on least present worth and one based on annualised cost of electricity. Assumptions which need to be made include the actual plant life, rates of inflation and discount, fuel costs and fuel usage rates, battery bank conversion efficiencies, and costs for operation and maintenance of the plant. The assumed capital costs of the various system components have been taken from current retail prices within Australia with no allowance being made for subsidies, taxation, or other economic factors. The estimation of plant life is based on manufacturers data and current commercial guarantees.

OUTLINE OF RENEWABLE ENERGY TECHNOLOGIES FOR POWER GENERATION

Wind generation systems

Recent developments in wind generators have led to the increased availability of well designed units with the horizontal axis machine still the most preferred design. Modern machines offer considerable improvements in performance through the use of low speed, permanent magnet, brushless alternators which are available up to 15kw rated output and have a long service life in excess of 20 years. They are available with full wave rectification to produce low ripple DC for charging battery storage and with overcharge control using simple voltage limiter shut down.

The installed cost of small machines in the order of 1 to 5 kW is approximately A\$2000-3000 whereas the cost of medium to large machines 15-150kW capacity may be as low as A\$1000. Most studies indicate economic viability for wind systems when there is wind availability at a site corresponding to an average wind speed of 5m/s. In practice special attention must be paid to the particular design characteristics of the chosen machine, and the characterisation of wind at the site including wind turbulence effects.

A modern wind turbine rated at 4.5 kW may be expected to produce more than 4500 kWh/yr at a site with an annual average wind speed of 4-5m/s, at a machine cost including tower of about A\$1600 per rated kilowatt. The full system cost, including all the power conditioning, would be about A\$17,500 giving an electricity cost of about A60¢/kWh.

Solar thermal systems

The central receiver or power tower systems so far installed have nearly all been in excess of 1MW rated output and it appears unlikely that these solar systems would be cost effective in small module sizes. Studies carried out in Australia for the Northern Territory indicate that such systems could produce electricity at a cost in excess of A\$1.33/kWh and at an installed cost of about A\$8,500 per installed kilowatt.

In the smaller power ranges the preferred options would appear to lie with fixed concentrators, with low temperature systems using flat plate collectors, and with solar ponds. Although it is difficult to extract much hard data on costs for these solar thermal systems, a tentative costing of the price of electricity produced can be obtained using a discounted cash flow analysis. Under the assumptions given a comparison is made in Figure 4. Lower costs of electricity are achieved using flat plate systems or fixed concentrator systems. Central receiver systems are vastly more expensive. From this preliminary analysis, vacuum tube collectors and salt gradient solar ponds lie somewhere in the mid range but hold out the promise of substantial reduction with further development.

Photovoltaic systems

From the operational and maintenance point of view, these systems appear to offer the simplest method of power generation (Figure 5). The panels are usually designed to charge a 12V battery but may be connected to charge 24, 32, 48 or even 110V battery banks. A typical polycrystalline silicon panel, encapsulated

with a clear low reflective cover, may be purchased off the shelf at about A\$400 for 37 watts peak output. Such a panel will supply an open circuit voltage of 20V with a short circuit current of 2.5A. It is reasonable to assume that the balance of a system component cost will be of the same order as the cost of the panels in most installations requiring storage. Some recent work from the USA indicates the advantages to be gained from tracking PV systems but the output gain must be weighed always against the increased system complexity and requirement for maintenance.

Micro and mini hydro plant

In the correct locations, as for wind systems, small scale hydro is both technically and economically viable. Design and installation of such systems tends to be straightforward but there is a minimum requirement of 20m head and about 40L/s flow to ensure a continuous rated turbine output of 4kW. The total installed cost of such plant tends to lie in the range of A\$1000-2000/installed kW.

Biomass or biogas engine power plant

In some areas it may be feasible to consider the production of wood as a renewable resource. Wood production rates vary substantially with soil types, tree species, rainfall and soil conditions. Coppicing systems generally provide faster production after harvesting and minimise the need for replanting. Indications are that a farmer in the 350-400 mm rainfall areas could be energy self-sufficient using fuelwood from a plantation of 2-4 hectares. Considerable work has been undertaken recently to improve wood stove efficiencies so that direct combustion in a wood boiler can be considered for steam production (Table 3).

Methane production for use in relatively conventional internal combustion engines is yet another option through the biogas route. The digestion process proceeds well provided the temperature control is maintained either at 32-37°C or at 50-55°C depending on the type of bacteria chosen. Animal wastes tend to require about 10-15 days residence time and about 20% of the gas produced may have to be used for maintaining digester temperatures. After removal of the CO₂ contained the gas may be compressed and used in internal combustion engines at a conversion cost of about A\$1000.

Hybrid systems

Each of the methods so far discussed of producing electricity has inherent advantages and disadvantages. With hybrid systems the aim is to combine two or more of the technologies to provide an improved overall efficiency. The penalty is that a hybrid system will require more sophisticated and expensive control equipment for regulation of the plant and for matching the plant output to the required load. Various hybrid options are open including diesel/wind and diesel/PV with or without battery bank storage. Some typical examples are appended to this paper in the Australian case studies quoted.

STORAGE AND POWER CONDITIONING

For virtually all renewable energy options it is critical to provide adequate storage for lull periods in order to satisfy the load requirements, and power

conditioning of the output to successfully match the appliance characteristics. Recent developments have included the production of efficient high power inverters at relatively low cost. Typical efficiencies are in the order of 90% over the full load range and the inverters are available at 10kW or 20kW capacity, with power supply of 240V AC. The life of battery banks is highly dependent on the rate of discharge required, the boost facility provided, and the type of battery used. Boost charging is necessary at least once per month to ensure complete conversion of the plates which is not a problem with wind or diesel systems but may be difficult in minimal design PV arrays. Batteries must be of the deep discharge pure lead type which are now commercially available for lighting systems from several companies world wide. A figure of 3-5 days demand is often used when sizing the battery storage for wind or PV systems.

TECHNICAL AND ECONOMIC ANALYSES OF POWER GENERATION OPTIONS

Table 5 summarises several analyses extracted from the reference literature. The results depend to a large extent on the underlying assumptions which include capital cost of the plant, expected life for various components, maintenance and overhead charges, and other economic parameters involved with inflation and discount analyses. A typical case of water pumping, of particular reference to developing countries, is illustrated in Figure 6.

ACKNOWLEDGEMENTS

Most of the data used in this paper has been extracted from work published in Australia over the last two to three years as a result of a series of studies on remote area power supplies. These studies have been commissioned by state and federal governments in an attempt to evaluate directions for further work and to select existing options for demonstration plants in various locations within Australia.

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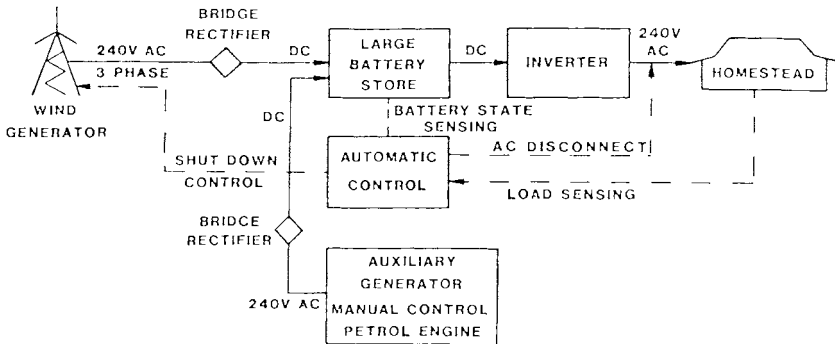
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CASE STUDIES

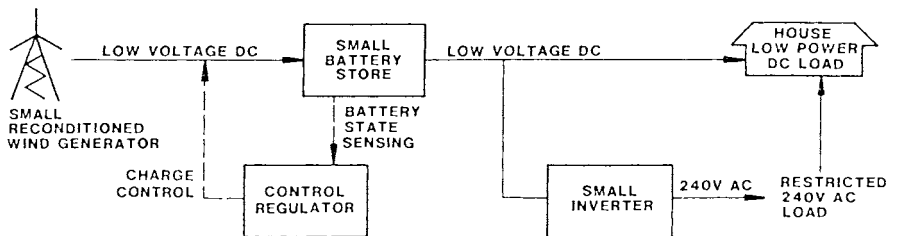
Economic Analysis 1 - Wind-driven generator system

Power System	Wind-driven generator system. Powered by a 4.5kW peak rated wind generator in an average wind speed of 5m/s. It is assumed that the wind generator is used in conjunction with a battery bank and a high efficiency inverter.
Typical User	Isolated farm within the grid services region or western district grazier, where the site is well exposed to the wind.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of \$17,500 for the complete system including battery bank, inverter, control and auxiliary generator. Residual value assumed is \$2,000.
Peak Capacity	10kW, 240V AC.
Power Supply Available	24 hours per day.
Net Demand Assumed	Daily demand of 8kWh (2920 kWh pa) is considered typical and equates this system to others.
Fuel Used	Depends on wind speed distribution as to whether the auxiliary generator will be used. In this instance it is assumed the auxiliary generator does not contribute to the load.
Cost of Fuel Used	Negligible
Total Hours run	Diesel - period maintenance running only.
Payments Assumed	Batteries replaced every 7 years at \$3000; operation and maintenance \$100 p.a.
Discount Rate	5% over inflation.
Net Present Worth	\$21,640
Annual Cost	\$1730
Cost of Electricity Supplied	59 ¢/kWh



Economic Analysis 2 - Small wind generator system

Power System	A small wind driven generator power system for lighting and minor 240V AC demand. The wind generator considered is a lower cost reconditioned unit as typically used. New small wind generators are often too expensive for this type of installation. The system cost includes a small inverter (1.5kW, 240V AC) supply.
Typical User	Holiday home or small dwelling.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of \$5000 for the complete system with nil residual value.
Peak Capacity	1.5kW, 240V AC
Power Supply Available	24 hours per day DC, 1 hour per day 240V AC
Net Demand Assumed	1kWh (365 kWh p.a.)
Fuel Used	Nil
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	Batteries replaced every 7 years at \$800; wind generator replaced every 7 years at \$1000; operation and maintenance \$50 p.a.
Discount Rate	55 over inflation.
Net Present Worth	\$7800
Annual Cost	\$630
Cost of Electricity Supplied	173 ¢/kWh

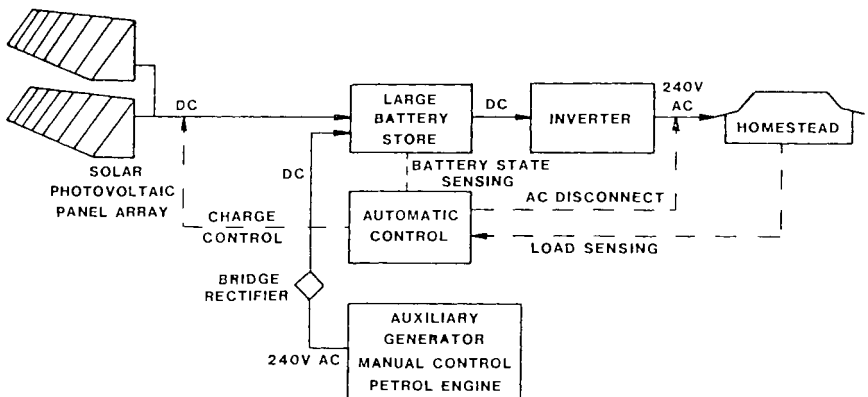


Economic Analysis 3 - Wind driven generator as a fuel saver on a large diesel generator set

Power System	A large (8kW peak rated output) wind driven generator can provide fuel saving when run in conjunction with a diesel generator where the load is consistently high or a dummy load is used. Dummy load is of no economic value. In this analysis, the full output of the wind generator is assumed to be of economic value.
Typical User	Roadhouse, small town or hotel.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of \$11,254 with a residual value of \$2000 plus \$9000 for diesel replacement every 6.5 years.
Peak Capacity	20kW, 240V AC.
Power Supply Available	24 hours per day.
Net Demand Assumed	Total demand 70kWh/day (25,550 kWh p.a.). Contribution from wind generator would be 17,520 kWh p.a. (in an average wind speed of 6m/s).
Fuel Used	10,600 p.a. This assumed diesel is well loaded with running, ie no loss in performance compared with diesel-only system.
Cost of Fuel Used	\$3922.
Total Hours run	Diesel run-time 6.6 hours/day (2,409 hrs p.a.)
Payments Assumed	Diesel replaced every 6.5 yrs at \$9000. Fuel \$3922 p.a. Operation and maintenance of diesel and wind generator \$500 p.a. and \$150 p.a. respectively.
Discount Rate	5% over inflation.
Net Present Worth	Total system \$87,800. Wind generator only \$12,370.
Annual Cost	Total system \$7,040. Wind generator only \$990.
Cost of Electricity Supplied	Total system 28 ¢/kWh. Wind generator only 6 ¢/kWh.

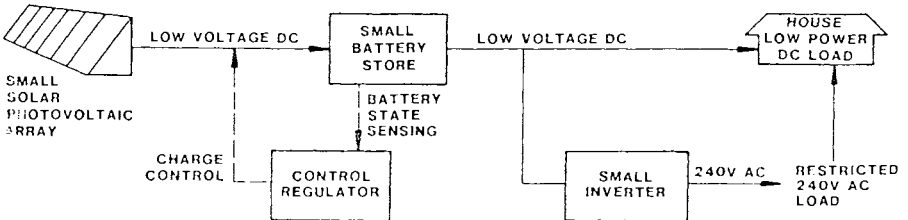
Economic Analysis 4 - Photovoltaic power system

Power System	It is assumed that a high efficiency inverter is used to achieve the required output to supply equivalent power to that of the diesel-only or diesel plus battery system. This prime source is, in this case, photovoltaic panels rather than diesel or weak generator.
Typical User	Isolated farm within the grid serviced region.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of \$34,000 for the complete system. 60 panels constitute the photovoltaic array with an expected peak output of 2.2kW. Residual value assumed is \$2000.
Peak Capacity	10kW, 240V AC.
Power Supply Available	24 hours per day.
Net Demand Assumed	Daily demand of 8kWh (2,920 kWh p.a.). The array would just meet this load and expansion of the system to meet short term higher load would require an auxiliary generator to be costed in.
Fuel Used	Nil assumed if load strictly 8kWh per day or less.
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	Batteries replaced every 7 years at \$3000; operation and maintenance \$50 p.a.
Discount Rate	5% over inflation.
Net Present Worth	\$37,250
Annual Cost	\$3010
Cost of Electricity Supplied	103 ¢/kWh



Economic Analysis 5 - Small photovoltaic system

Power System	A small photovoltaic power system for lighting and minor 240V AC demand. Six 40W peak rated panels in the array. Includes a 1.5kW inverter for 240V AC supply.
Typical User	Holiday home or small dwelling.
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of \$6000 for the complete system with a nil residual value.
Peak Capacity	1.5kW, 240V AC
Power Supply Available	24 hours per day DC, 1 hour per day 240V AC
Net Demand Assumed	1kWh (365 kWh p.a.)
Fuel Used	Nil
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	Batteries replaced every 7 years at \$800; operation and maintenance \$50 p.a.
Discount Rate	5% over inflation.
Net Present Worth	\$7600
Annual Cost	\$610
Cost of Electricity Supplied	167 ¢/kWh



Economic Analysis 6 - Remote grid extension

Power System	It is assumed that the grid is to be extended 5-8km from the distribution line. A SWER line is to be constructed and a step-down transformer installed. To equate the real cost of electricity supply with other systems, the electricity charge per kWh is taken as the gate price paid by the local authority rather than the tariff paid by the consumer (which includes profit).
Typical User	Isolated farm or western districts grazier. (Roadhouse small town or hotel - note that any extension of the grid is likely to go through such centres and not require 8km connections).
Life Cycle	20 year life assumed.
Cost and Residual Value	Capital cost of \$35,000 with nil residual value.
Peak Capacity	10kW, 240V AC (20 kW)
Power Supply Available	24 hours per day
Net Demand Assumed	8kWh, of 2920 kWh p.a. (70 kWh or 25,550 kWh p.a.)
Fuel Used	Nil
Cost of Fuel Used	Nil
Total Hours run	Nil
Payments Assumed	At 3 ¢/kWh supply charge totals \$88 p.a. (\$770). Operation and maintenance \$200 per km, totalling \$1600 p.a.
Discount Rate	5% over inflation.
Net Present Worth	\$56,000 (\$64,530)
Annual Cost	\$4,490 (\$5,175)
Cost of Electricity Supplied	154 ¢/kWh (20 ¢/kWh)

**TABLE 1: Comparison on indicative energy prices
Australia and South East Asia & Pacific Region
(as of December, 1984)**

Country	Electricity c/kWh	Gas (LPG) c/kg	Distillate c/litre	Petrol c/litre
Aust, Vic.	8 (2.8 off peak)	21	44	45
Fiji	20	98	46	62
Malaysia	11	70	28	55
Philippines	6	60	47	54
Thailand	8.5	45	33	50
Tonga	23	53	50	58

* All figures quoted in Australian currency (1984 dollars)
A\$ = US\$ 0.75

TABLE 2: Typical appliance energy loads

Appliance	Rating watts	Typical Peak Demand watts	Energy Demand kWh/day
Refrigerator	300	1500	2.0
Freezer	300	1500	2.0
Fan	100	100	2.0*
Lights (total)	500	200	1.0
Kitchen:			
* Blender	350)		-
* Coffee Pot	600)		0.2
* Exhaust Hood	60)	1000	0.1
* Toaster	1000)		-
* Mixer	300)		0.1
Washing machine	300	1000	0.5
Pump (small)	450	1000	0.5
Iron	1000	1000	0.5
Drill	250)		0.1
Stereo	100)		0.3
Radio/TV	100)	1000	-
Sewing machine	100)		-
Vacuum cleaner	600)		-
Total	NA	8300	9.8
Other loads			
Air conditioner	1600	2000	38*
Dishwasher	2400	2400	1
Hot water (storage)	3600	3600	8
Stove	6000	6000	4

* Assumes 24 hr usage

**TABLE 3: Typical efficiencies and wood requirements
for running wood heaters**

Type	Annual heating load 5GJ (Typical of warmer areas of Australia eg Queensland) tonnes*	Annual heating load 10GJ** (Typical of many areas of Australia eg SA, NSW) tonnes	Annual heating load 30GJ (Typical of colder areas of Australia eg Tasmania) tonnes
Open fire place 10 per cent efficient	3.1	6.3	18.8
Pot-bellied stove 30 per cent efficient	1.0	2.1	6.3
Slow combustion stove 60 per cent efficient	0.5	1.0	3.1

Source S A Department of Woods and Forests and Department of Mines and Energy

Notes

- * Calculated on 16 GJ + 20% moisture content, air dried wood.
- ** 10 GJ is the heating load required to maintain the living room temperature of a typical brick veneer house in Australia (with insulated ceiling) at about 20°C during waking hours.

TABLE 4: Economic summary for comparison of system costs

System	Daily demand kWh	240V AC Power available daily, hr	Run time for engine, hr	Net present worth A\$	Annual cost A\$	Power cost A4/kWh
Wind 4.5kW peak & batteries	8	24	-	21,640	1730	0.59
Wind 750W peak & batteries	1	1 (24 hr DC)	-	7800	630	1.73
PV 2.2kW peak & batteries	8	24	-	37,250	3010	1.03
PV 240W peak & batteries	1	1 (24 hr DC)	-	7600	610	1.67
25kVA diesel & wind 8kW peak	70	24	6.6	87,800	7040	0.28
Grid extension	8 (70)	24 (24)	- (-)	56,000 (64,530)	4490 (5175)	1.54 (0.20)

Figure 1: Remote areas - cost effective options for electricity generation, 1983

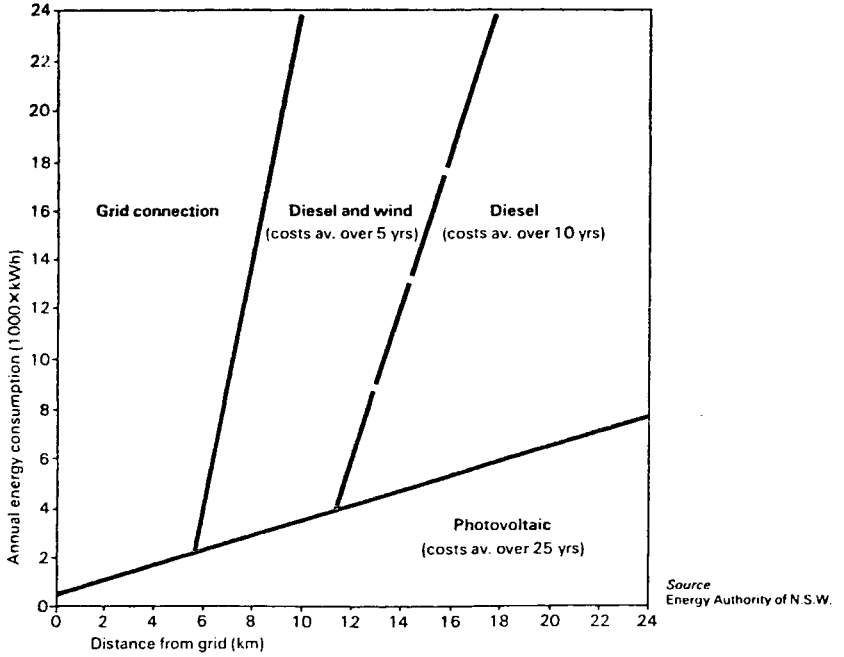


Figure 2: Remote Electricity Grid Extension

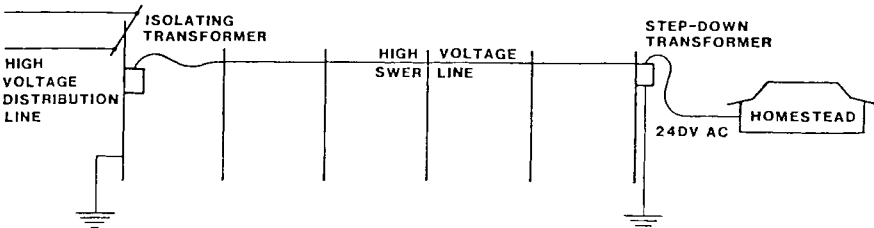


Figure 3: A hybrid power supply system layout

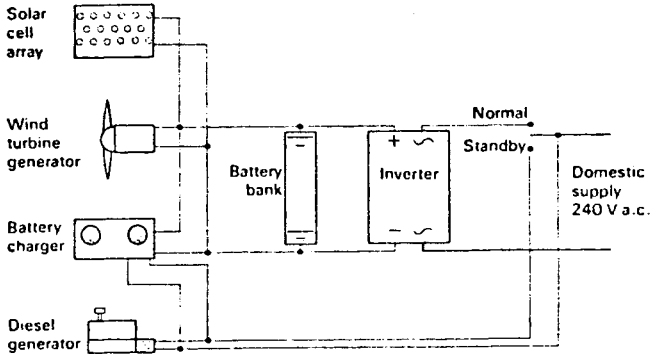


Figure 4: Solar collector cost comparison

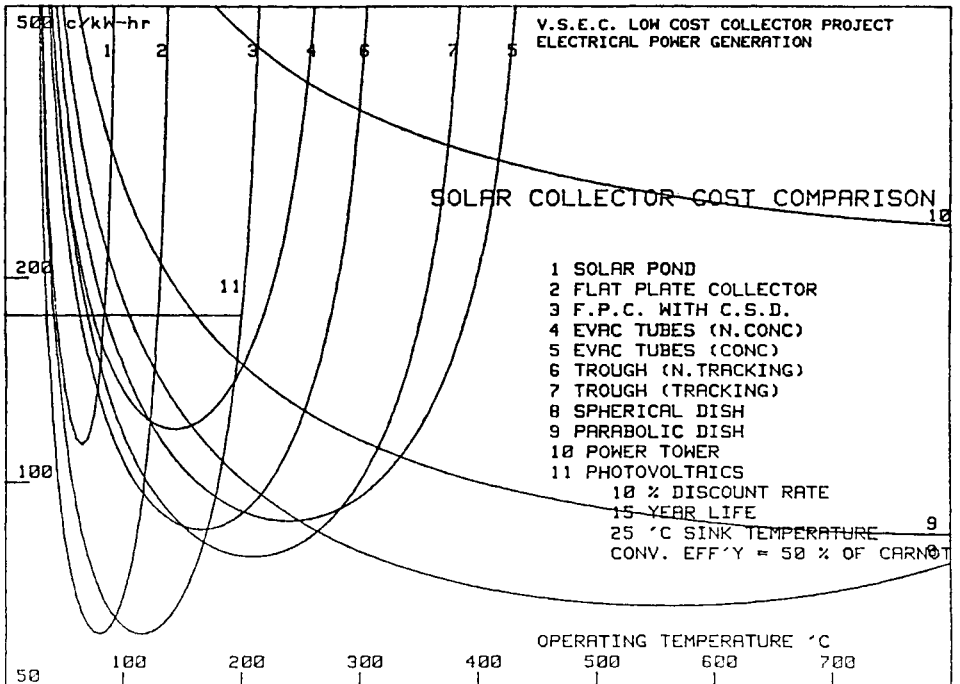


Figure 5: A typical photovoltaic system circuit

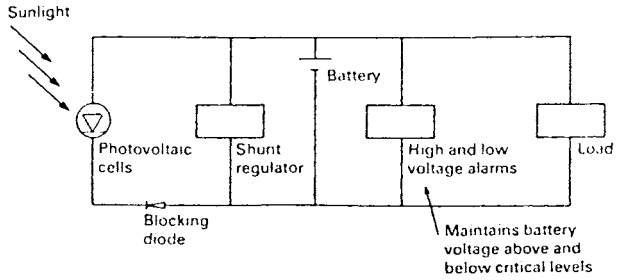
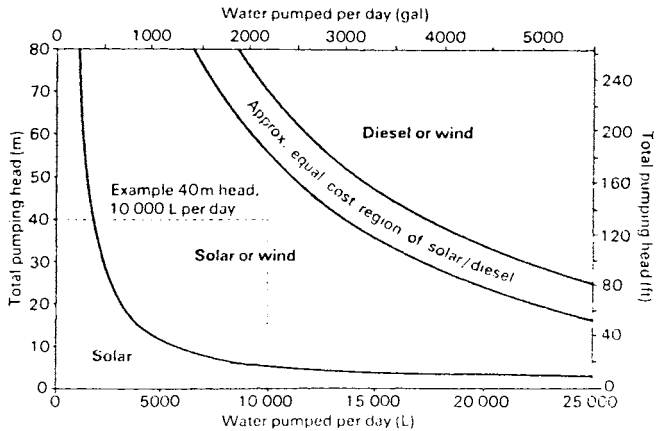


Figure 6: Bore pump sizes showing region where wind, diesel and solar (photovoltaic) systems are estimated to be most cost effective (1983 costs)



Source
Energy Authority of N S W

RENEWABLE ENERGY POLICY FORMULATION AND IMPLEMENTATION

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ABSTRACT

An important and virtually neglected area in the development of renewable energy technologies (RETs) is the formulation of a rational and coherent renewable energy policy, and its implementation. This paper presents a general approach to formulating such a policy. The methodology is based on a series of evaluations of energy demand, renewable energy base, RETs available, socio-cultural constraints, economics of RETs, and institutional arrangements. After formulating a coherent policy it is also important to examine the methods and constraints on implementing such a policy. Issues, such as, resource requirements, self-reliance, access to information, technical cooperation amongst developing countries (TCDC), research and development, adaptation of techniques, skill requirements, and channels for RET transfer are examined. Finally, in order to demonstrate the general methodology in relation to a specific situation, the case of power alcohol implementation in Kenya and Zimbabwe are evaluated.

INTRODUCTION

Renewable energy technologies (RETs) are capable of satisfying most of the dominant energy end uses in developing countries with the possible exception of diesel fuel.

The extent to which RETs can substitute for conventional energy sources such as petroleum and coal depends on the renewable energy source base of the country, the per capita energy consumption, and the energy end-use. In most cases RETs will not be able to satisfy the total energy demand of developing countries, and in the future energy supply will be comprised of a mix of fossil fuels, macro-hydro and RETs.

While investment in certain RETs appears attractive to many developing countries, governments should be aware of the financial, manpower and organisational resources required to mount a large scale programme. The benefits accruing from the use of these resources should be evaluated against other investment options in the areas of, for example, agriculture, public health, education, infrastructure, to ensure that the optimum "public good" arises from the use of these scarce commodities.

Besides providing energy, one of the objectives of the installation of RETs should be to reduce the disparity in "quality of life" between the rich and poor in developing countries. Unfortunately, like most technical interventions in developing countries, RETs have the potential of exacerbating rather than alleviating this disparity in equity. Capital required to purchase RETs means that only the people able to pay will enjoy the benefits. Wealthier people have a greater access to information and credit and will usually be more aware of the energy/financial savings available. Finally, the use of certain RETs, eg, biogas, gasifiers, will tend to put a premium on certain feedstocks such as dung and agricultural residues previously collected for free by the poor. This process may eventually exclude the poor from their main source of fuel.

Based on these considerations, governments should be aware of the ultimate effect of a renewable energy policy on income distribution and take certain steps, eg subsidies, widespread information dissemination and credit availability, and community energy projects to mitigate these effects.

Despite the considerable amount of work being carried out on RETs in developing countries, and the benefits which will accrue from the extensive use of an indigenous renewable energy source, few countries have a cohesive renewable energy policy or strategy for implementing such a policy.

This is essential to maximise the useful contribution of renewable energy to a developing country's energy budget. Hence, the objective of this paper will be to examine the formulation and implementation of national policies for increasing the contribution of renewable energy resources to energy supplies in developing countries.

FORMULATION OF A RENEWABLE ENERGY POLICY

How are energy policy makers in developing countries going to formulate a renewable energy policy which is able to rationally and efficiently meet the various end-users? The following section briefly details a methodology which can be used for such a purpose. The method consists of accumulating and assessing data under various sub-headings.

Energy demand

In formulating a national renewable energy policy it is essential to have a clear picture of energy demand in the country, not only in terms of end-use (by sectors) but also the forms of energy required, and the consequences of energy use (or lack thereof). With this information, governments can make explicit decisions on priority areas in which energy policy should be oriented.

Unfortunately, at present there is very little hard data on energy use in rural areas of LDC, although there is considerable activity in the field. Rural energy surveys require considerable inputs of time and labour (Howes 1984); however, after a body of data has been built up in different regions of the world it may become possible to reduce the effort required, or make relatively accurate predictions of rural energy use under certain conditions.

Finally, in order to match energy supply with demand, it will be necessary to have a fairly accurate idea of projected energy demand growth in the next twenty years. This would be based on population growth, targets for increased per capita energy consumption (UNIDO 1979), industrialisation, and projected fossil fuel prices.

In addition to determining the total energy demand in each sector, it is important to understand the type and form (solid, liquid, gas) of energy required so that supply can be matched both thermodynamically and in terms of convenience to the demand.

It would be useful to understand the reasons for the current patterns of energy use and their consequences. For example, the current pattern of energy use could be due to disparities in land and animal ownership forcing the rural poor to rely on public forests for fuel which results in rapid deforestation; or subsidies on fossil fuels such as diesel and kerosene could result in an over-reliance on these fuels.

The consequences of energy use should be delineated to ameliorate some of the more serious effects of current energy use. For example, deforestation, environmental damage, lack of an equitable access to energy, loss of productive time, dependence on imported fossil fuels leading to balance of payments problems.

Finally, from the data obtained on end-use above, an overt political decision should be taken on the priority sectors in which a renewable energy policy should be oriented.

Energy base

The next step in formulating a renewable energy policy is to evaluate the renewable energy base in the country, their seasonal variation, and estimates of present production and projected growth of the biomass resource base in the next 20 years.

Based on this information the percentage of the present energy demand which can be substituted for by renewable energy, and the potential for savings in foreign exchange can be estimated. This exercise will enable energy planners to determine what level of national resources should be devoted to the development of renewable energy sources.

Renewable energy technologies

The third step in formulating a coherent policy is to assess the RETs available including techniques and their inputs and outputs, thermodynamic efficiencies, and capital costs.

Based on primary technical considerations, a list can be drawn up of ultimate end-uses and the sources and techniques which are able to satisfy them most efficiently. Such a list should contain a ranking of energy paths for each end-use. The final selection of the RET will depend on other non-technical factors such as socio-cultural constraints, economics, and institutional infrastructure.

Socio-cultural constraints

To implement and diffuse RETs into a country it is extremely important to understand the societies in which they will be used, and how this will impose constraints on certain RETs.

One constraint is how the RET affects various groups within a village. If the RET is to provide energy for cooking, eg, stoves, biogas, then the primary effect will be to enhance the quality of life for the woman and children who are usually responsible for collecting fuel and cooking. However, the major financial decisions are usually made by men, although their wives often have considerable influence in such decisions. Nevertheless, if capital is to be outlaid without any financial return it may mean that the RET will not be accepted readily. In contrast, if the RET impinges on the responsibilities of the male, eg, providing energy to pump irrigation water, then the RET may have a greater chance of diffusing.

Finally, if the use of an RET runs counter to certain cultural beliefs, eg use of human waste in biogas plants, or involves a considerable change in established behaviour patterns, eg, use of solar cookers in the open during daylight hours to cook meals, then it is highly likely that the RET will not become popular.

In order to gain an insight into some of the serious constraints that could arise in the use of RETs, it is strongly suggested that some anthropological field work be carried out, and that village representatives be included in the planning stages to obtain feedback on the various courses of action.

Economics

The economics of RETs are also extremely important. If the use of a specific technique is not financially viable to its owner, or economically viable in terms of the country's broader social criteria, then obviously it is not worth the investment.

The normal method of evaluating projects is by cost-benefit (financial) analysis, or social cost-benefit (social) analysis. The latter method uses shadow prices and includes certain non-quantifiable parameters. In this analysis, a depreciation of the equipment (lifetime) is assumed together with an internal rate of return (IRR), and based on the annual benefits and costs a net present value (NPV) is calculated. If this is greater than zero then the project is deemed viable. Alternatively, an NPV of zero can be assumed, and IRR calculated. As French (1979) points out, in a developing country due to the lack of availability of capital many investors may not think a project is viable unless the IRR is around 35%, ie, a payback period of three years.

Surprisingly, despite the widespread use of certain RETs in developing countries there is still a dearth of technical information on the performance of most RETs, and the operational lifetime. In addition, there is lack of agreement on how to value the output from most RETs and, hence, considerable confusion amongst economic analysts as to which RETs are economically viable. This makes it difficult to economically compare the various competing RETs and their performance in relation to alternative fossil fuels. Hence there is an urgent need at present to define a common methodology on how to assess RETs.

Extending the analysis to include shadow prices and intangibles (eg, reduced deforestation, enhanced strategic position, improved public health etc.) makes the exercise even more complex. Nevertheless, it is important that a comprehensive economic analysis be carried out on the RETs being considered for use based on the data available. In this regard a sensitivity analysis may be used to pinpoint the key variables.

Finally, the other factor of importance in the overall economics is the "lumpiness" of the capital investment. If the initial investment is high, eg, photovoltaics in contrast to biogas, then even if the IRR is high there may be problems diffusing the technology unless institutional arrangements are available to finance or subsidise the initial cost.

Institutional

The final area that is important to consider in the formulation of policy is infrastructure. This general term covers such things as: R and D capacity, a network to diffuse the technique and provide technical back-up, the provisions and training of skilled manpower, the capacity of the local capital goods sector, and availability of finance.

The extent to which a developing country should build up an R and D capacity in RETs is very much case specific, and could vary considerably depending on the technique. This issue will be discussed in more depth later.

Another vital area in the widespread use of RETs is a network to diffuse the technique, and to provide technical back-up for repair, advice etc. The requirements for this will depend strongly on the size of the units, and hence their numbers, eg, two 120,000 l/day ethanol plants versus 500,000 family biogas plants. In the case of small scale rural techniques an existing infrastructure could be extended, eg, agricultural extension workers are used in Brazil to diffuse and provide technical advice with biogas units (Umana, 1982). It is important that this infrastructure be established before widespread diffusion begins otherwise many failures may occur, and the lack of technical back-up is cited as one of the reasons for failure of some biogas units in India.

Skilled manpower is an obvious prerequisite of a competent R and D and technical back-up infrastructure, and this issue will be examined later.

In terms of hardware, the capacity of the local capital goods sector has an important influence on the degree of technological self-reliance a country can achieve. If it is weak then the country has to depend strongly on "turn-key" projects. If it is well developed, the country has a number of advantages in shopping around for technology in the world market place. This point was extremely important in developing power alcohol projects in Kenya and Zimbabwe (Stuckey and Juma, 1984).

Finally, the financial infrastructure in a country is important since lack of access to capital and loans or subsidies can severely retard the diffusion of RETs, especially when they are small scale rural technologies where a large number of owners do not have any experience in negotiating loans. Hence some thought should be given to establishing a simple loan/subsidy scheme, and informing financial institutions on the viability of the various RETs. This latter point is important. Many of these institutions have no experience in lending money in this area, and hence no criteria to judge loan applications. This factor was important in Brazil where the Federal government provided money to the banks for loans but little of it was utilised due to the banks' lack of knowledge and confidence in the technology (Umana, 1982).

Formulation of policy

Based on the data collected and evaluated in the previous sections, ie energy demand, energy base, RETs, socio-cultural, economics and institutional, the energy planner should now be able to formulate a relatively cohesive renewable energy policy to meet specific end uses. However such a policy should also answer the following questions:-

- (i) the degree of technological self-reliance the country is aiming for, and whether this will change with time,
- (ii) the channels by which RETs are transferred from developed or other developing countries,
- (iii) how are the various skills required in R and D, diffusion, and the capital goods sector going to be built up.
- (iv) how can a suitable infrastructure for RET diffusion be established.

Hence, in addition to formulating a renewable energy policy, developing country governments should also give serious thought to the steps involved in

implementing it in the real world. In the next section the issues raised in these questions will be examined.

IMPLEMENTATION FOR UTILISING RETs IN DEVELOPING COUNTRIES

In order to implement a renewable energy programme, governments need to seriously consider factors such as access to information, technical cooperation amongst developing countries (TCDC), development of research and development skills, adaptation of existing techniques, the buildup of technical and administrative skills, and access to the international market. These factors, and their ramifications on the implementation of RETs will be analysed in this section. However, before examining these factors in detail it would be useful to look briefly at process of technical change in developing countries in order to provide a framework for such an analysis.

Technical change

As Bell (in Barnett *et al.* 1983) points out, there has been little written in the area of technical change in renewable energy technologies and hence in order to gain some understanding of the process examples have to be drawn from the general literature on technical change in developing countries. As we saw earlier, due to the primary end-use of many renewables, and the structure of the market, it seems unlikely that consumers of RETs will force a large scale reallocation of resources and the development of an appropriate infrastructure on the supply side. Hence, policy intervention appears necessary in order to develop, allocate and organise the resources needed to implement technical change in the renewable energy technologies. Amongst the questions which need to be addressed in this area appear to be fundamental ones:-

- (i) what type of resources will be needed to implement the renewable energy policy formulated by the government?
- (ii) what degree of self-reliance in terms of technical knowledge, services and goods should the government aim for?

Resource requirements

Often, in attempting to answer the first question, policy makers focus on the role of R and D. However, this appears to be due to a carry-over from the technical change policies originating in the more industrialised economies where there are a lot of implicit assumptions made about the chain involved in the process of technical change. For developing countries, R and D is only one facet of a process requiring a number of other levels of expertise. Bell (in Barnett *et al.* 1982) suggests that there is a "core" sequence of technological activities which create new technical knowledge, and progressively elaborate and transform it into specific systems which are in actual use. This core will consist of one or more of the following: creation of technical knowledge (formal and informal R & D); pre-investment and feasibility studies drawing on existing knowledge; production of designs and specifications for technical systems; transformation of designs into concrete elements of an operating system, eg hardware, software, training; storage and communication of technical knowledge and information.

In addition to these technological core components will be an over-riding management function. This will decide what is done, by whom, and the terms

upon which the technological activities are carried out. Management of technical change can either be passive where vested interests dictate the direction and change, as is the present case in RETs in developing countries, or it can be active where an explicit goal is aimed for.

It is commonly assumed that all the activities involved in the technological core will be necessary in order to implement technical change. However, on examining the types of change commonly encountered in implementing RETs it is apparent that this linear sequence will be the exception rather than the rule. For example (Barnett et al. 1983):-

- (a) System replication - this usually requires only a feasibility study to suggest minor modifications, and R and D and engineering activities would rarely be required. However, management would be essential, eg biogas plants.
- (b) System adaptations - in order to adapt an existing system to new constraints various engineering activities and turning specifications into functional software and hardware will be required. R and D will rarely be required.
- (c) Special purpose development - new knowledge may be required here. However R and D would probably focus on the overall system and on its software components rather than on developing new technology.
- (d) Innovations - in this case, it is highly likely that all the components of the core will be mobilised to effect technical change.

Hence, from this brief overview it is apparent that the technical and managerial resources required to implement RETs will vary considerably depending on the technique implemented. Thus, in considering the factors mentioned previously, eg development of R and D, skill requirements, access to information etc, governments should be cognisant of the different resource requirements for implementing a renewable energy policy. However, the assessment of resources required to implement such a policy needs to be placed in an international context in order to decide what degree of self-reliance the government should aim for. Thus, we will now turn to examine the second question posed.

Self-reliance

In attempting to define the degree of self-reliance, ie degree of local input, there will be a considerable degree of variation amongst the various core activities. Other factors affecting the degree of self-reliance include:-

- (i) the type of technique. Obviously, implementing village scale biogas plants will involve different degrees of self-reliance compared to large scale continuous culture ethanol plants.
- (ii) variation with time. The degree target could alter with time starting with a small local input initially which would build up to a high percentage in 5 to 10 years.

Furthermore, the degree of self-reliance is contingent to quite a strong extent upon the international market for the various inputs required. This market is dominated by the R and D efforts of a few developed countries. However,

developing countries rarely import R and D. Rather they import goods and services which have this knowledge embodied in them via the highly developed infrastructure resources of these countries. As Bell (in Barnett *et al.* 1982) suggests, "inequality in the availability of these resources matters perhaps more than inequality in R and D resources themselves".

Finally, there are a number of social considerations affecting the degree of self-reliance. In many situation, decisions by private entrepreneurs involved in the supply and purchase of inputs for technical change will result in local inputs lower than the optimum in terms of social development objectives due to their lack of financial return. This may occur in areas such as:-

- (i) generation of local employment
- (ii) social value of foreign currency
- (iii) the appropriateness of the systems used
- (iv) learning by doing
- (v) economies of scale

In summary then, the process of technical change is a complex one, and in considering the implementation of a renewable energy policy, governments should be sure to have a clear picture of the resources required in implementing certain techniques, and the degree of planned self-reliance. Using the above discussions as a general framework we will now turn to the consideration of more specific areas involved in the implementation of RETs.

Access to information

In order to keep abreast with current developments in RETs, and enable negotiators to maintain a strong bargaining position in the purchase of technology from external sources, it is important that developing countries obtain access to up-to-date information. In addition, they require skilled personnel to digest the information and give sound advice to policy makers.

The information required to implement a renewable energy policy falls into a number of general categories. Firstly, is the current research (both technical and socio-economic) being carried out in both developed and developing countries. Most of this is available through scientific journals and conferences. Secondly, is knowledge about firms involved in the manufacture and sale of RETs. Embodied in these goods and services is often a considerable degree of experience and potential knowledge which is difficult to obtain directly. Finally, there is the information generated by R and D in developed countries. In many cases this is patented and protected by law. Hence, it is usually only available by the purchase of equipment embodying these latest advances.

A major difficulty seems to be the assimilation of information and its application to rational policy decision making. A number of solutions are possible. Firstly, the establishment of an international renewable energy centre operated along the lines of IRRRI in the Philippines. This centre would carry out R and D and produce "state of the art" reviews on various techniques and end-uses. The second option would be to establish smaller "honest brokers" based at universities or consulting companies who would advise policy makers on the various options available in an impartial and informed fashion.

Finally, with respect to a long term strategy it would obviously be desirable to build up technical and assessment skills in the appropriate energy planning group of developing countries.

Technical cooperation amongst developing countries (TCDC)

Since the problems faced in implementing RETs in many developing countries are quite similar there is considerable scope for transferring knowledge between developing countries. This is already occurring with biogas in China, power alcohol in Brazil, and gasifiers in the Philippines. However, the wide variation in social conditions means that knowledge about diffusion may not be readily transferable, eg between China and Africa. Cooperation could occur in a variety of forms:

- (i) information exchange on all aspects of RETs including patents, an experts pool, listing of manufacturers and consultants in the field. ESCAP have published a series of documents on Solar, Wind and Biogas to enhance the accessibility of this type of information (ESCAP, 1980, 1981a, b).
- (ii) exchange of scientists and policy-makers
- (iii) assistance with implementing specific techniques, eg India (through KVIC) is helping a number of African countries implement biogas programmes.
- (iv) joint development of RETs. Through an FAO sponsored network on the gasification of agricultural residues a number of countries in the Asian region are developing designs for gasifiers, and running pilot and full sized units. (FAO, 1983).

Research and development (R and D)

The investment in R and D will vary in intensity and direction depending on the technique of interest. Where "mature" technology exists, eg for large scale alcohol production plants, then it would seem advisable to develop bargaining skills to purchase the technology from overseas companies and, perhaps, some on-site adaptation to suit local conditions.

In contrast, if small scale (500-2,000 l/day) village distilleries were of primary interest then development work based on well established principles would be a priority. Many developed countries are directing extensive R and D to "high technology" systems such as photovoltaics, large scale ethanol and wind turbines which are suited to their level of economic development. Techniques such as wood stoves, small biogas plants, small low cost windmills, and small gasifiers are of little interest in developed countries. Using existing basic knowledge, developing countries could mount an economically effective R and D programme oriented more towards development than basic research.

The private sector has rarely been involved in RET development, perhaps, owing to the lack of profit, especially in the small rural techniques such as biogas and stoves, the large scale government involvement and the lack of expertise with many of the techniques. There are a few exceptions to this: in China, what amounts to private companies are now heavily involved in constructing biogas plants (Stuckey, 1982) and in Nepal, a company established by the United Mission is also installing biogas plants with some degree of commercial success (Fulford, 1981). In order to diffuse RETs widely it would seem highly desirable to involve

private firms in all aspects of these techniques, from R and D through to diffusion.

Governments should seriously consider policies to encourage private firms to enter the market by providing subsidies, guaranteeing markets and enabling joint ventures to be undertaken.

Adaptation of techniques

The requirements for local adaptation will depend on local capabilities, the type of technology transfer arrangement, the degree of self-reliance aimed for, and the technique involved and its level of sophistication.

The adaptation of techniques requires the build-up of skills in both technical capability and the capital goods sector.

Skill requirements

In formulating and implementing a renewable energy policy, developing countries will require a considerable degree of expertise ranging from economists and policy makers through design engineers and research scientists to skilled craftsmen and fabricators. Many developing countries will be faced with a number of problems in building up the skills required. Firstly, there will be competition with other economic activities such as agriculture, industry and government for the scarce resource of skilled manpower. In this case there must be an explicit government policy to divert some of these skills in the direction of renewable energy. Secondly, by its nature, the field of renewable energy is highly multidisciplinary. Its apex, ie policy making, is a relatively new discipline with few, if any, specific courses designed to train people even in developed countries. Hence some of this expertise will have to be learnt on the job with little formal intellectual background to draw on.

Governments need to draw up a strategy to gradually increase expertise in the different areas required. The first step would be to build up a small policy making team which would carry out the initial surveys and formulate a national renewable energy strategy. Based on this, and a reasonable degree of technical expertise, it would then arrange to import a number of techniques with technology transfer agreements aimed at building up local participation in all phases of the various projects.

Ideally this would lead to an increase in competence in all areas of implementing RETs. Eventually a critical mass would be reached where much of the expertise would be local. Obviously, this scenario is very general and would be modified depending on local skills and conditions.

Channels for RET transfer

In 1980, Hoffman examined the market for RETs and concluded that conditions of future technological dependence for developing countries are currently being created in relation to RETs, and that these conditions are likely to be similar to those currently prevailing with respect to conventional energy technologies. Hoffman found that both private firms and public sector organisations were involved in marketing RETs, and that many of them were looking for markets in developing countries. In addition, he found that they often received assistance from multilateral and bilateral aid agencies in entering these markets. These

trends may result in distorting the direction of technical change in developing countries, and lead to a heavy dependence on imported goods and services for investment in RETs.

However, Hoffman based his conclusions primarily on two quite sophisticated RETs, ie photovoltaics and large scale ethanol, and the prognosis for other RETs may not necessarily be quite so gloomy. Obviously, market conditions and the availability of various RETs will vary quite strongly depending on their degree of sophistication, their profit potential (often related), and their appropriateness to developed country markets. RETs such as photovoltaics and large scale ethanol have considerable potential in developed countries and hence, large R and D efforts in developed countries are being mounted to produce economical hardware. Nevertheless, it may be possible to transfer these techniques without being totally dependent on the developed countries. Developing countries do hold a number of cards in the bargaining process, eg potentially large markets in some RETs, and field sites to test out state of the art techniques.

In contrast, techniques such as wood stoves, biogas plants, simple solar heaters and small scale ethanol plants lack a widespread market in developed countries. In general, the transfer of these RETs involves access to basic knowledge of the fundamentals underlying these processes, and in some cases, to hardware in a relatively "mature" stage of development. Due to its maturity there are a large number of firms in developed countries able to supply such hardware, and with appropriate bargaining skills most developing countries could obtain the required hardware under fairly equitable terms. In this case the relative openness of the field could provide a challenge to some developing countries to develop an expertise which eventually could be exported.

The policy question for developing countries in relation to RET transfer is how to avoid a strong dependency on developed countries, while trying to exploit the very real market "niches" which currently exist in the RET market. In this regard, it is apparent that passive policies oriented towards "waiting and seeing" will only lead to greater technological dependence on imported RETs. An active policy must be formulated based on a long term strategy for managing the supply-side of RETs to result in more favourable development paths. At the core of such a strategy must lie a set of well thought out objectives about the degree of self-reliance based on the benefits and costs of importing rather than relying on locally produced goods and services.

CASE STUDIES OF POWER ALCOHOL IMPLEMENTATION IN AFRICA

No renewable energy projects have been documented that were implemented following the above methodology. In order to examine how some governments have implemented renewable energy projects in practice, two case studies will be discussed in the area of power alcohol.

Zimbabwe

Zimbabwe built a 120,000 l/day power alcohol plant in 1980 (Stuckey and Juma, 1984). At the time the decision was made (1978) Zimbabwe did not have a clear picture of its energy end-use, especially in rural areas, and no renewable energy or even overall energy policy. The decision was based solely on economic grounds in relation to falling world prices for both sugar and molasses, the feedstocks for the alcohol plant. However, the resource requirements and the degree of self-reliance were considered seriously due to international sanctions

and the lack of foreign exchange. Due to a well developed capital goods sector, and construction skills a significant fraction (60%) of the total capital investment was spent locally.

These local capabilities, the availability of untied capital from the parent company in South Africa, and access to knowledge enabled the company involved, Triangle, to purchase the technology from West Germany under very favourable terms. This decision only came after an extensive world wide survey of equipment manufacturers and suppliers. In addition to the purchase of the technology, the contract stipulated on-site training for a number of local people. Since the plant has been installed the company has been carrying out tests to determine whether it can be adapted locally to improve its performance.

Since the capital cost and overall production cost per unit of output is extremely low by world standards the programme in Zimbabwe is considered to be extremely successful. While the initial steps in the formulation of a renewable energy policy were not undertaken, this case study shows that a relatively sophisticated RET can be transferred successfully without depending on "turn-key" projects.

Kenya

Kenya instigated the construction of two plants in 1977; a 60,000 l/day plant at Muhoroni producing bakers yeast as well, and a 30,000 l/day plant at Kisumu producing bakers yeast, citric acid, and vinegar. The Kisumu plant was a "turn-key" project with no local input. At the end of 1982 the project was suspended before completion at a cost of US\$120 million. The Muhoroni plant came on stream in June 1982 (Stuckey and Juma, 1984).

At the time the decision was made, Kenya did not have any renewable energy policy, or even an overall energy policy. The projects were evaluated on economic grounds, and deemed to be uneconomic by the relevant government departments. However, despite this advice the government still went ahead with both projects.

The plant at Muhoroni was based on a prefeasibility study carried out by an Austrian company. This company was eventually contracted to build a sophisticated continuous fermentation facility on a turn-key basis. Hence there was almost no local input in terms of construction. In addition, no technical training was provided and the plant is operated almost entirely by expatriate labour.

The choice of the technology was dictated strongly by the lack of availability of untied finance. Since the Austrian government offered to finance the plant, the company and technology used were not unnaturally, Austrian.

The above factors led to a plant which has relative high production costs and resulted in little if any increase in indigenous technical capacity. In this case, in contrast to Zimbabwe, it is difficult to argue that the acquisition of a renewable energy technology led to enhanced development, and an increase in skill in implementing renewable energy projects.

CONCLUSIONS

It is apparent that in order to fully exploit the potential of RETs in developing countries and to optimise their use, governments must take an active role. This does not mean that private enterprise should be excluded. To widely diffuse RETs, especially small scale ones, commercialisation is essential. However, governments should maintain a firm control over the evolution of RETs due to the many social factors involved which tend to receive a low priority in the private sector.

Government should be active in assessing sectorial energy demand, and formulating a cohesive and rational renewable energy policy. In implementing such a policy, developing country governments should aim to build up an indigenous technical capacity through technology transfer and developing local skills. It is only through the active pursuit of these goals that RETs will start to fulfill their potential in contributing to energy budgets in developing countries.

ACKNOWLEDGEMENT

The author would like to gratefully acknowledge the support of the Technology Transfer Division of UNCTAD in carrying out this work.

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INFORMATION NETWORKS FOR ENERGY PLANNING:
ROLE OF UNESCO/ROSTA

A Abdinaser

INTRODUCTION

In many developing countries a double energy crisis has emerged as a result of the sharp increase in the real price of oil in the past few years and a growing shortage of traditional fuels such as wood. Consequently attention is increasingly being paid to possibilities for enhancing both the importance and use of new and renewable energy sources.

ENERGY POLICY FORMULATION AND PLANNING

The energy component of the Lagos Plan of Action, including the development and exploitation of both new and renewable sources of energy and non-renewable sources of energy, will have to be determined at national and multinational levels. Common to all aspects of energy problems in Africa are fundamental weaknesses and deficiencies which require concrete and urgent rectification at national, subregional and regional levels. These deficiencies include:

- a. The absence of national energy policies and development programmes integrated into national development plans.
- b. The insufficient capabilities, human and institutional, for drawing up and using inventories of all energy resources and particularly of non-renewable sources.
- c. The lack of capability for planning and the composite exploitation of all available energy resources taking into account projected development by sectors and changes of technology in the exploitation of different forms of energy.
- d. The lack of adequate manpower for the evaluation, extraction and processing of all forms of energy for the design (including standardisation), manufacture and marketing of equipment components and spare parts for R&D.
- e. The tendency to use technologies from industrialised countries.
- f. Inconsistencies in policies, planning and programme and project designs and execution, and a lack of information at national and multinational level on achievements made in the development and utilisation of non-renewable energy resources, possibilities of equipment using such sources, its limitations, etc.
- g. The need to orient energy development policies and therefore the mobilisation and redeployment of financial resources in favour of small-scale development projects especially to meet the needs of rapid development in the rural sector.
- h. The inadequacy of cooperation between technical institutions concerned with resources inventory and planning, and joint feasibility studies and multinational enterprises responsible for production, standardisation and marketing, R&D manpower development, market surveys, etc.

In the African countries, energy policies and planning must take into account the socio-economic duality created by the co-existence of modern and traditional sectors. This duality is characterised by different patterns of energy

consumption and supply: in the modern sector, life style and technologies resulting in energy use mostly based on petroleum; in the traditional sector, a subsistence economy based on low-energy intensity, dispersed demand and supply, but often threateningly high consumption of limited fuel-wood resources, which leads to accelerated degradation of ecosystem.

Obtaining information on the most recent research, application, case studies, manufacturers, expert consultants, or patents, about alternative energy etc, is not easy. This information has been collected for only a few developed countries, sometimes in only one field of alternative energy.

There is very little consolidated energy information either on or available to developing countries as a whole. Energy information is provided, in most cases and particularly in Africa, by a wide variety of institutions and individuals in many different fields, including the physical and environmental sciences, life sciences, engineering and economics. This diversity creates problems for locating, evaluating and using such information. At present, some developing countries lack even the framework and resources to collect information which could be useful to them. Ways of channelling information to groups of users are often inadequate. The absence of standardisation prevents comparison of standards.

THE CONTRIBUTION OF UNESCO

UNESCO has accepted the challenge of helping to manage the world's energy information, especially as regards new and renewable sources of energy for developing countries. The purpose of its programme is to put the right information in the right hands at the right time. Launched in January 1981, the Energy Information Programme of UNESCO is conducted in association with UNESCO'S General Information Programme. This deals with scientific and technological information, libraries and archives and promotion of information systems and services at the national, regional and international levels and which includes UNISIST (Intergovernmental Programme for Co-operation in the Field of Scientific and Technological Information).

UNESCO is also supporting a Cooperative International Network for Training and Research in Energy Planning (CINTREP) which aims at the achievement of a set of stable inter-disciplinary and interactive academic centres in developing countries, which include training activities at different levels, and research on the technical, economic, social, environmental, international and related problems of the energy system of the countries or region.

While only one African Centre (ENDA) is currently participating in this Network, it is hoped that, other African centres will participate in the future.

One of the major programme activities of UNESCO with regards information on energy is the establishment of regional projects for enhancing existing information services and encouraging the sharing of information resources in an effort to link organisations in an international network. Pursuant to this overall objective, sub-regional and regional pilot projects are being launched in five regions of the world. In Africa, two sub-regional pilot projects on non-renewable energy resources information sharing networks have been established by UNESCO: one for Eastern and Southern Africa and the other for Western Africa.

An African Regional Symposium on Solar Energy was organised by UNESCO in November 1983 in Nairobi, Kenya. This symposium was a prelude to the formation of the Solar Energy Society of Africa (SESA).

ROLE OF UNEP IN RENEWABLE ENERGY DEVELOPMENT IN AFRICA

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INTRODUCTION

In Africa commercial energy consumption is relatively low, reflecting the low level of industrialisation and general low economic development. Consumption of commercial energy in Africa is typically concentrated in urban areas, where the beneficiaries are mainly industry, the commercial sector and those few belonging to the upper and upper-middle class societies. In rural areas and in urban slums, where the vast majority of the population live, most household's energy needs are still met by non-commercial energy such as fuelwood, agricultural residues and animal manure, as well as by human and animal power. Although no reliable regional statistics exist on the current use of non-commercial sources of energy, estimates indicate that these energy resources occupy more than 60 per cent of the total energy consumption in Africa. In Ethiopia, Sudan, Kenya and Nigeria, about 90 per cent of the population depend on fuelwood.

The consequences of heavy reliance on these non-commercial fuels are expanding deforestation, devegetation, declining water table, soil erosion, silting, and flooding as forests are destroyed - and rising prices for wood and charcoal. Where wood or charcoal are marketed, families may spend as much as 25 per cent of their household budget for cooking fuel, as is the case in parts of West Africa. Most fuelwood, however, never enters the market place. In central Tanzania, providing a family's annual firewood requires between 250 and 300 days of labour. And in parts of Upper Volta, women spend an average of four and a half hours a day for hunting for fuelwood. Since the burden of firewood collection almost always falls on women and children, critical but unpaid household tasks such as nutrition, sanitation and education suffer.

The cost of this mounting burden shows up not in conventional economic indicators, but in indices of infant mortality, disease and illiteracy. Recently, attention has been given to the development of technologies for the better harnessing and more efficient use of these non-commercial sources of energy and other renewable energy sources. This is increasingly being integrated into broader rural development programmes through the provision of adequate sources of energy.

International agencies have an important contribution to make to this process, through creating a forum for transfer of ideas, technology and training and also through promoting and supporting demonstration and pilot programmes. The work of UNEP in promoting renewable energy programmes to combat deforestation and desertification is offered as an example of the role of international agencies.

UNEP's ACTIVITIES ON RENEWABLE ENERGY SOURCES IN AFRICA

Great potential exists in Africa for the development of several renewable sources of energy. The development of one or more of these resources will vary

from one country to another depending on site suitability, natural resources, climate, manpower resources and national policies. Unfortunately, policy-makers tend to believe that "large" is beautiful. Priority is nearly always given to constructing large power plants rather than small decentralised plants based on renewable sources of energy.

UNEP's Energy Unit has followed a three pronged approach to alleviating deforestation and erosion. This includes the development and demonstration of appropriate renewable sources of energy using locally available resources as solar, wind, biogas, gasifiers and mini hydro-power.

Solar energy could be harnessed in several ways. Photovoltaic systems enable the conversion of one of the world's most abundant and wide spread energy resources into one of the most versatile and valuable forms of energy. In a photovoltaic cell solar energy is converted directly to electricity. Photo-voltaic systems offer individuals an opportunity to generate their own electricity. In Senegal, photovoltaic systems have proved their feasibility, reliability and environmental soundness. In Niaga Wolof in Senegal, a system of 5kW peak, produced between 16 and 23 kW hour per day of solar energy. This has been used in house lighting, running individual pieces of equipment like refrigerators, radios, televisions, in public lighting of the streets and in providing electricity for commercial equipment. Drinking water is now available, thanks to electricity provided by solar energy.

In Niaga Wolof in Senegal, windmills were used to produce electricity which was then stored in batteries and used in the same way as the electricity produced from solar energy. Two blade windmills produce from 40 to 87 kW hour per day depending on the average wind spread in each month.

Apart from substitution of fuelwood by other renewable energy resources, the improvement of the current extremely low efficiency of fuelwood stoves and open fires represents the second approach of UNEP to the main goal of decreasing fuelwood consumption. Several fuelwood stoves currently in use in Indonesia and rural areas were tested. Although fuelwood stoves have been constructed and used for a long time, only a few of them are efficient and very few are environmentally-sound. In Ruiru in Kenya, UNEP co-sponsored a project for the construction, testing and distribution of efficient, environmentally-sound and socially acceptable fuelwood stoves. The project included the construction of different types and their testing for efficiency within households in a village in Ruiru.

The women who are the real users of these stoves were then asked which type they preferred, thus ensuring the social acceptability of the stove. The villagers were then trained on the construction, operation and maintenance of the selected types.

The workshops currently produce two types of stoves. The first is round without a chimney, which take one pot supported by three bricks protruding from the stove's inside walls. The second takes two pots secured in the stove by a ring around their edge and has a chimney. It is called a "pogbi" stove, but in spite of its bigger size, still uses a very small firebox.

It is designed so that the fire has to go around the (first) pot. Then it goes through a hole in the next compartment. The hole leading to the chimney at the other side has a fire break in front of it, so that the flames have to go all around

both pots before exiting through the chimney. Thus, the "secret" of this technology is that the body of the cooking pot is completely immersed in the stove and the heat generated by the firewood does not have a direct escape route to the open air. Even when the firewood is used up in these stoves the clay retains the heat.

For the many families which now buy their fuelwood, the higher initial cost of such efficient and environmentally sound stoves should not be discouraging. The savings on fuelwood outstrip the capital cost in a relatively short period. Subsidies and loans for these families could be an effective investment.

Similar projects for the construction of efficient and environmentally-sound stoves was also launched by UNEP and CETEC in Bolivia and Brazil.

The third approach to alleviating the problem of fuelwood is a direct one through plantation of fast growing tree species. Several fast growing species have been tried in different countries. Leuceaua was found suitable in the Philippines whereas Kaliandra was recommended in Indonesia. Different species including Jacaranda, Acacia and Eucalyptus were found suitable to relatively higher altitudes in Kenya.

**THE ROLE OF RENEWABLE ENERGIES IN THE DEVELOPING COUNTRIES
AND THE POSSIBLE UNIVERSITY CONTRIBUTION**

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ABSTRACT

The paper summarises the general picture of energy use and needs in the developing countries. Some comments are made of the contribution of Universities in contribution to the problem of increasing the energy availability. The setting up of special M.Sc. courses in regional centres is proposed.

ENERGY USE IN DEVELOPING COUNTRIES

In most of the less developed countries there is a significant consumption of biomass mainly as wood and charcoal. This consumption level is in many cases much greater than the commercial fuel use. Most (typically 90%) of the commercial fuel is in the form of petroleum and is imported. These oil imports represent a major component of the total import bill of the less developed countries, and the oil price increases of 1973-74 and 1979 have had a very marked effect on their economies, particularly since oil price escalation has far out-stripped the corresponding price increases for the mainly agricultural produce which these countries export.

The energy balance for Kenya (Table 1) is typical of most sub-Saharan countries (excluding South Africa): 75% of the energy source is wood and virtually all the remainder imported petroleum.

TABLE 1: Kenya's Energy Balance

Energy Source	quantity (PJ)	% of Total
<u>Indigenous</u>		
Wood	306.7	73.5
Hydro	3.3	0.8
Residue	8.6	2.1
<u>Imported</u>		
Crude Oil	95.3	22.8
Refined Oil	1.2	0.3
Coal	1.4	0.3
Electricity	0.9	0.2
Total	417.1	100

It is highly desirable at the national level to substitute local fuels for imported fuels. There are at present considerable resources of fossil fuels and hydro-power in many less developed countries, much of which is yet to be exploited.

Renewable energy sources can be expected to make an increasingly greater contribution in the long-term.

Universities, in developed and developing countries, have a major contribution to make to the planning for a long-term shift to the renewable energy technologies.

THE ROLE OF HIGHER EDUCATION INSTITUTIONS

Higher Education Institutions can make a useful contribution to renewable energy; university departments can develop new equipment, and in the early days some of us regarded this as our major role. Over the years, however, we have become much more aware of the importance of relevant training of overseas personnel. This includes:

- i. Training at technician level
- ii. Short courses
- iii. Taught Masters Courses
- iv. PhD by research
- v. Linked programmes
- vi. Research Programmes which involve staff exchange between two or more institutions.

A very effective way of both transferring technology and providing training is through "joint project" between two institutions, one in a developed country and the other in a less developed country. At Reading we have carried out a number of such projects of which a study of wind pumping in the Sudan using Sudanese personnel is a typical example. A survey of wind data, windmill experience, and water requirements was carried out, and then an experimental programme on pumping windmills was conducted by a Sudanese graduate who, on receiving his PhD degree, returned to head the Sudanese Wind Pump Programme. Similar programmes which we have carried out include solar ponds for the Sudan and the use of alternative energy resources for rice cultivation in Thailand.

Although these programmes are time-consuming in that they are linked to a three-year PhD course, they have been found to be valuable in providing trained personnel.

There is also a need for shorter and more intensive courses, and at Reading we offer a one-year MSc course in Alternative Energy for Developing Countries. The syllabus covers all aspects of alternative energy, including implementation, small industry, and economic project evaluation. The major component of the course is an experimental project which, where possible, is chosen in collaboration with the student's home institution. In this way it is possible for the student to commence his new job whilst completing his course, thus contributing to a useful technology-transfer. The course is proving to be popular and was over-subscribed for the current year. Projects in progress in the year 1982/83 are as follows:

<u>Topic</u>	<u>Country of origin of student</u>
Wood combustion	Thailand
Charcoal stove	Zambia
Biogas for cooking	Tanzania
Wind power	Kenya
Pumping windmill	Grenada
Biogas generator with external heating	Sri Lanka
Concentrating photovoltaic cells	Ethiopia
Water pumping	Greece
Low cost solar water heater	Iran

The provision of relevantly trained personnel meets only one of the needs for the implementation of national programmes for exploiting local energy resources. It is, however, an essential requirement and one which the University system in both developed and developing countries can contribute to. There is much to be said for the setting up of courses such as the one described above at regional centres, for example, in East Africa where the content can be directed to areas of particular local importance.

**CRES - THE REGIONAL TOOL OF WEST AFRICAN NATIONS
TO PROMOTE THE USE OF RENEWABLE ENERGY**

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INTRODUCTION

Hit by a two-fold energy crisis - rising costs of importing oil and deforestation - the heads of the states of the CEAO (Communauté Economique de l'Afrique de l'Ouest) countries decided in 1978 to create the Centre Regional d'Énergie Solaire (CRES). The member states of CILSS (Comité Permanent Inter-Etats de Lutte Contre la Sécheresse dans le Sahel) countries joined them later, and the following countries are now members of CRES: Burkina Fasso; Benin; Cape Verde Islands; Chad; Gambia; Ivory Coast; Mali; Mauritania; Niger; and Senegal.

From the point of view of all of the member countries, CRES must become the regional tool used by West Africa in order to become more proficient and self-sufficient in the techniques and exploitation of renewable energy sources.

EXISTING EXPERTISE IN RENEWABLE ENERGY IN THE REGION

The region already has major experience in the field of renewable energy: research centres exist or are currently being established; production units have been erected; and a substantial range of equipment utilising renewable energy has been installed, financed to a great extent by foreign aid. Despite these efforts, renewable energy does not yet play a significant role in the energy supply of the region.

However, renewable energy equipment is positively accepted by the population provided it is well adapted to their needs and reliable, and there is potential for a massive promotion of renewable energies in the region.

The region has important renewable resources including solar energy, biomass and wind energy, as well as sites for mini and micro hydro-energy plants. However, these resources are unequally distributed and require detailed exploration.

The proposed CRES project

The region cannot afford to be a mere spectator to technological progress especially in a field such as energy which is of such importance to these populations. The policy proposed encompasses not only energy conservation and the development of renewable energy sources, but also the installation of production, engineering and research facilities necessary for this development within the West African region.

Priority objectives

The most important priority is the development of renewable energy sources in rural settings. Renewable energy sources are particularly useful in a rural setting, because there are modular units, autonomy, simplicity, and long lifespan.

The most important energy demands renewable energy resources could satisfy include: a. cooking; b. water pumping; c. health care; d. lighting; e. preserving food; and f. small electrical distribution networks (for a village, group of houses, etc).

The second priority is the reduction of marketed energy sources. The most important uses of marketed energy sources are: housing (air conditioning, hot water); transportation; and industry.

The following efforts will be made on a short-term basis:

- energy conservation;
- hydroelectric power, which could play a much bigger part in industry and housing;
- utilisation of organic refuse in industry;
- solar water heaters, to be used more widely.

In the mid-term future, efforts should be placed on the development of solar air conditioning. In the long-term, the widespread utilisation of biomass for electrical power and transportation must be developed.

GOALS OF CRES PROGRAMME

With the policy and the priority objectives as defined above, we can now turn to the goals for the development of renewable energy. These goals will be illustrated with some short and longer term targets as a model of what could be done in the region.

Fight against deforestation

Furnish the vast majority of households with wood or charcoal improved stoves as rapidly as possible.

1990 goal: 50% of all urban and rural households so equipped
year 2000: all urban households equipped.

High-yielding charcoal production should become the rule, and there must be more development of sectors involved in the manufacturing of charcoal from agricultural and industrial refuse. At the same time, active participation in reforestation programmes will be encouraged.

Rural development

Water supply for villages and livestock, micro-irrigation

Areas of water supply must be equipped with photovoltaic pumps whenever supply and demand exceed 5m³/hr per well.

1990 goal: over 50% of all wells will be pumped by means of electrical power
year 2000: all wells pumped by means of electrical power.

Irrigation

1990 goal: discontinuance of at least 50% of all diesel or gasoline engines
year 2000: almost total withdrawal of diesel or gasoline engines.

Alternatives planned include: hydroelectricity; photovoltaic pumps; thermodynamic pumps; diesel engines operating on plant oil, biogas, or ethanol; and wind turbines.

Health

Rural health centres to have supply of:

- bacteria-free water
- hot water
- lighting
- radio hook-up with major centres
- medication and vaccine refrigerators.

1990 goal: 50% of all health centres
year 2000: 100% of all health centres.

Rural electrification

Each village will be equipped with a public lighting system, and households will be encouraged to install modern lighting units. The foreseeable energy source is the photovoltaic generator.

1990 goal: 50% of all villages equipped with public lighting
year 2000: all villages equipped with public lighting.

Reduce consumption of electricity and fuel-oil

Solar heat should be widely encouraged for use in housing and industry.

1990 goal: all new public buildings, and a large proportion of private buildings, must be equipped with solar water heaters
year 2000: solar heat must be used in most industries where low and medium temperatures are required.

Systematic use of agricultural and industrial refuse, as well as refuse from wood industries must be the rule, so that these industries can become self-sufficient in energy.

1990 goal: all relevant companies should be making use of their own industrial refuse as an energy source.
From 1990: a programme should be developed to produce new types of fuel for transportation (methanol, ethanol and plant oil).

Improving the quality of public services and reducing recurring costs

Photovoltaic generators will power all telecommunications and signalling equipment in isolated areas which use under 1 KW permanently.

1990 goal: all units should be operating on photovoltaic energy.
year 2000: extension of this application to equipment operating on more than 1 KW permanently.

THE FUNCTIONS OF CRES AS A REGIONAL CENTER

CRES has been assigned to carry out the following functions at the regional level:

- documentation and information
- personnel training
- research
- engineering and consultancy
- production
- marketing
- financing

The official statute of CRES will divide CRES into two different parts under the umbrella of one general director of CRES. These two parts are:

1. A public institution for the promotion of "technology".
2. A share-holding private company to promote and participate in the field of "production". (The shareholders of this company will be the different governments of the member countries).

PHASES FOR THE IMPLEMENTATION OF CRES

The implementation of the CRES project includes several phases. The first one, "PREFAS", is now nearing completion. The next phase, "PRODIAG", for the years 1985-1987, developed out of a recent evaluation and is now in the process of being adopted by the officials of CEAO and the Orientation Committee.

In "PREFAS", the following actions have been or are being realised by an intermediate institution called BER (Bureau d'Etude et de Realisation), created to realise the phase "PREFAS".

Preparation of the organisation of CRES

All necessary steps have been fulfilled. It is foreseen that on the 1st July 1985, CRES will be officially installed with all corresponding governing and advisory bodies.

Support to national partners in establishing "National Centres"

In all nine member countries, National Centres have been identified and the question of who will take over the leading function clarified. In some countries, BER has initiated the creation of a national centre. For the years 1983 and 1984, 315,000,000 CFA francs and 180,000,000 CFA francs respectively have been made available for providing the National Centres with scientific research material and for the training of the personnel. The delivery of scientific material is at the moment under way.

A comprehensive study to develop a strategy for the promotion of production units

These production units should in future produce several devices to use renewable energy or to produce constant energy from renewable resources. Also industrial processes based on using renewable energy can be included in the promotion

which CRES has to carry out in the future. The study, called UPS, is now being finalised.

Programme planning for member countries

BER has been charged to assist the member governments in developing national plans for the next five years in order to increase the use of renewable energy. The different national plans are to be harmonised by BER in such a way that different regional programmes can be presented to different donors. Several regional programmes have been developed, for example:

A programme of village water supply, primarily using photovoltaic pumps and if possible wind mills.

An education programme to provide light to rural classrooms and supply electricity for school television.

A rural health programme to reinforce existing infrastructure of rural health and improve quality and efficiency of services (lighting, sterilisation, cooling of vaccines and hot and cold water).

A telecommunications programme to promote local and regional communication in order to overcome isolation.

A transport programme to improve traffic signals and guarantee security and better operation of air traffic and railway transport.

A distribution programme for improved stoves in order to fight deforestation through more efficient utilisation of wood.

Information and documentation

A special school booklet has been developed and tested in schools. This booklet, called "Gains of the Sun", is designed to inform children up to the age of 10 years about the possibilities for the utilisation of renewable energy and explains why this kind of energy can be regarded as renewable. The booklet is now ready for large scale printing and distribution to nearly all of the region's schools.

Construction of the CRES buildings

Construction of the CRES head office is now in progress on a 30 ha site in Bamako and will be completed within the next 18 months. This compound will house the administration, educational classrooms, conference rooms, a documentation centre, laboratories and workshops, a computer centre, student hostel and dining and living quarters for CRES permanent staff.

Financing of the CRES headquarters, as well as the phase "PREFAS", was assured by the following donors: African Development Bank; OPEC; UNDP; CEAO; European Community; France; Federal Republic of Germany; and United States of America.

IMPORTANT CONDITIONS FOR CRES TO SUCCEED

There are two factors involved in the successful development of the project.

1. Sound management of all activities which must be efficient and financially accountable.
2. Backing of political authorities of all member countries.

CRES tries hard to fulfill and assure these two prerequisites. For example, BER has installed a modern computer-based accounting system, called OCAM. And we have recently received fullhearted support from the political authorities.

The heads of State of the CEAO, which convened at their last summit conference in Bamako at the end of October 1984, declared the following concerning CRES:

"We commit ourselves individually and collectively in the values of our Governments and Peoples, to uphold the coordinating and orienting role of the Regional Solar Energy Centre (CRES) in putting these programmes into practise.

"We recommend that the national government structures of the member states should reinforce, or create, in 1985, the industrial capacity indispensable for partial or total production of equipment using renewable energy sources, in conformity with the industrial strategy defined in the framework of the survey by the Production System Unit (UPS) of the Regional Solar Energy Centre (CRES).

"Consequently, we commit ourselves to give the Regional Solar Energy Centre all forms of support and assistance necessary for the accomplishment of its community and international undertakings.

"The Conference of CEAO Heads of State meeting during the 10th Summit of the West African Economic Community, encourages all activities undertaken to promote renewable energy and to economise conventional sources of energy."

**ACTIVITIES OF THE ASSOCIATION OF AFRICAN
UNIVERSITIES IN AFRICA**

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ABSTRACT

Ever since its creation the Association of African Universities (AAU) has been involved in inter-university cooperation in Africa in areas of staff development and exchange programmes, conferences, seminars and workshops, and documentation and information.

The AAU supported Food and Nutrition project for Africa is being implemented. It is expected to contribute to training, equipment and literature in the field. The Association also sponsors scientific associations to bring together academic to discuss and solve common problems.

INTRODUCTION

Since the inception of the Association of African Universities (AAU) in November 1967, its activities have been carried out in conformity with its aims and objectives, namely:

- a. To promote interchange, contact and cooperation among university institutions in Africa;
- b. To collect, classify and disseminate information on higher education and research, particularly in Africa;
- c. To promote cooperation among African Institutions in curriculum development, and in the determination of equivalence of degrees;
- d. To encourage increased contacts between its members and the international academic world;
- e. To study, and make known the educational and related needs of African university institutions and as far as practicable, to coordinate the means whereby those needs may be met;
- f. To encourage the development and wider use of African languages;
- g. To organise, encourage and support seminars and conferences between African university teachers, administrators, and other dealing with problems of higher education in Africa.

In order to achieve the above aims, the Association has established:

- An INTERAF scholarship programme for the training of students and University staff
- A Documentation and Information Centre for the collection, classification and dissemination of information on higher education and research in Africa

A number of conferences and seminars have been organised to improve contacts among African university staff members and promote inter-university cooperation.

TRAINING PROGRAMMES OF THE AAU

Inter-African Universities Scholarship Programme (INTERAF)

Although African Governments were determined to see that the training of personnel became effective, they could not support all the various programmes involved. Thus some donor agencies were approached to help in implementing the programme (which is popularly known as the Inter-African Universities Scholarship Programme, "INTERAF"). These donor agencies were: Organisation of African Unity (OAU); US Agency for International Development (USAID); Canadian International Development Agency (CIDA); Inter-University Council for Higher Education of the United Kingdom (IUC); German Academic Exchange Service (DAAD); and UNESCO.

A programme was designed at first to provide undergraduate training in the US, but later on, it became obvious that it would be preferable to train African students in their own environment at least for their first degree not only because this would reduce costs and brain-drain, but also because the courses would be more relevant. Thus by 1967, the INTERAF Programme was launched and the AAU was made responsible for its administration. From 1970 to 1980, over 2000 students were placed through the Programme in different member universities.

In 1978, the Vice-Chancellors and Presidents of African Universities decided that a postgraduate training programme for university staff and research fellows should be launched as a second stage of the INTERAF Programme. This was prompted by the fact that most African universities were in an early stage of development and depended largely on expatriate staff - a situation neither possible nor desirable to continue.

The programme was, likewise, referred to the AAU for implementation which it did along two lines:

- i. Offering scholarships
- ii. Giving study leaves, sabbaticals, etc to academic staff members in African or non-African universities.

Although the undergraduate programme has now been phased out, the following priority areas for staff training have been identified:

- Food and agriculture
- Science and technology
- Medical science
- Economics

So far AAU has procured donations for awarding scholarships to be taken up in African member university. We expect to raise at least 100 for the first phase of the programme. Contacts and submissions have already been made to overseas universities and results are expected soon.

The programme also makes provisions for training middle level personnel, eg laboratory technicians and library assistants, and refugees through:

1. Regional training centres to be set up in the four main regions in the continent (North Africa, East and Southern Africa, Central and West Africa). Nucleii institutes will be modernised with appropriate equipment.
2. Overseas training is planned in cases where specialisation and facilities are inadequate.

FOOD AND NUTRITION PROJECT FOR AFRICA (JOINT AAU/UNU PROJECT)

It is expected that EEC will fund the project in the framework of Lome II Convention (\$7 million in five years). The first phase (\$1.5m) is envisaged to start in May 1985. The objective of this project is to strengthen existing food and nutrition institutes by way of training, equipment and literature. Stress will be made in the first phase on post-harvest and technology of food preservation. (It is estimated that between 35-40% of food is lost at this stage.) Two studies are planned within this programme:

Information on "centres of excellence"

This is to complement the programme of training of academic staff. It is intended to gather information on where such training can best be carried out in Africa.

Computer science programme

The role of computers in Universities is gaining importance everyday. A consultancy is, therefore, intended to survey the state of the art of the subject in the member universities and indicate ways and means of cooperation and development.

STAFF EXCHANGE

This is also believed to be a very important programme, since through such exchange, research experience is gained while contributing to teaching of courses for which staff are in shortage.

OTHER PROGRAMMES

Who-is-Who in African Universities

The preliminary stage was published following the 6th General Conference. The next stage is underway. A country by country list of staff of African universities including speciality, department, etc is being compiled and is expected to be completed before the end of 1985.

Directory of African Universities

This includes all the basic information on the 86 member universities and is to be revised and up-dated periodically.

B. RESOURCE ASSESSMENT

THE ASSESSMENT OF SOLAR ENERGY IN AN AFRICAN CONTEXT

by
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INTRODUCTION

A lot of lip service has been paid to the value of solar energy. Rather less effort has been devoted to the factual assessment of the actual value of solar energy in different territories, especially in the tropical world. The problem is of course difficult because of the sparseness of supporting scientific data in tropical countries. The value of solar energy can only be established if three pieces of information can be assembled and interrelated:

1. the amount of solar energy available per unit area on the differently orientated surfaces used to capture that energy;
2. the efficiency with which that energy can be harnessed in the different collection systems that can be used;
3. the capital costs of the collection system amortised on an annual basis together with the annual running and maintenance costs of the system.

The first factor is of course a variable quantity, so it is essential to explore the variability of the resource from month to month and from year to year. By dividing the annual costs by the annual yield, one can establish the average unit price of the energy produced. This price may then be compared with the price of the various fuels solar energy might displace. The value of the fuels that might be displaced varies considerably from place to place in a territory, as does the availability of the solar energy.

The costs of energy are often greater in rural areas because of the high costs of transportation of fuels, especially in regions with poor transportation infrastructures. A key problem in many parts of Africa arises from the overuse of the limited fuelwood resources to provide local energy for cooking and heating, which does so much to destroy the rural ecosystem (1). As energy is a centrally managed resource, there is a great tendency for governments to assume that energy systems are simply urban systems, so a systematic neglect of rural solutions develops. Rural electricity is very expensive, because the high distribution costs over big distances rule out grid systems, and diesel generators are used instead, producing high unit charges. If the adverse environmental impacts of excessive fuelwood consumption can be partially countered by solar energy systems, then the value of the associated environmental benefits must be thrown into the economic assessment on the positive side of the balance sheet.

Figure 1 attempts to illustrate the relative balance of these economic factors in areas of high insolation and low insolation competing in situations with different basic fuel costs. The competitiveness of solar energy systems clearly varies widely. Africa of course has many areas of high insolation combined with many areas of high fuel cost. The basic problem is to identify those areas showing the greatest potential, and to proceed to practical politics for achieving significant development on a sound economic basis.

The purpose of this paper is to discuss only the first of the above factors, namely quantifying the solar energy resource.

DATA REQUIREMENTS FOR SOLAR RADIATION APPLICATIONS

The data requirements for assessing the performance of solar systems obviously depend on the application. Quite sophisticated data requirements exist for complex installations like solar thermal power stations. Much simpler data will suffice for simple practical applications, like sun drying of crops and fish, water heating, and passive solar heating of buildings.

There is an important distinction to be made between focusing systems and non focusing systems. Focusing systems can only make use of the direct beam, while non focusing systems can also use the diffuse energy as well. The proportion of the solar energy which is diffuse will vary from climate to climate. However, in general, the proportion of diffuse radiation is higher than most people realise, especially in equatorial and other climates, where there is a lot of cloud.

There is another reason why knowledge of diffuse radiation is important. It is very difficult to estimate slope irradiation if the proportion of diffuse radiation in the horizontal surface radiation is not accurately known.

The variability of the energy supply also needs study. Assessments have to be made of the degree to which firm power can be supplied. The day to day variability of the supply can be compensated to some degree by appropriate storage policies for alternative energy. However to make such assessments a statistical foundation is essential. It is not enough to provide simply mean values.

The key problem is how to acquire such data in practice at an economic cost. A review of the whole range of problems encountered was given by the author to the World Solar Congress in Perth (2). Figure 2 extracted from that paper sets out the full range of studies that may be carried out. Any program however has to emerge by stages. In Africa it would appear that the immediate need is to make progress in the top half of the diagram, because work on slope irradiation, important for practical applications, can only proceed with full effectiveness from proper knowledge of the horizontal surface radiation climate.

SPECIAL PROBLEMS OF AFRICA

There are obviously a lot of special difficulties to be faced in the African region. For a start there is the sheer scale of Africa, which, given the levels of wealth available, makes it difficult to achieve adequate instrumentation over the spatial areas involved. Further difficulties often arise due to the inadequate and often unreliable electricity supplies which may make it difficult to achieve continuous records using data logging equipment. There are added problems associated with high humidities, and, in the maritime areas, salt spray, which can seriously damage instruments. Instruments suitable for developed countries may prove unsatisfactory in remote areas. It would seem that a greater collaborative effort ought to be devoted to achieving more appropriate instrumentation for remote tropical areas. Such instrumentation might usefully be powered by solar cell systems to improve system reliability in remote areas beset with electricity supply problems.

Another important practical difficulty is achieving adequate standards of calibration. Radiation measuring instruments are exposed throughout the year to strong sunlight, and often, at least in some seasons, to heavy rainfall with associated high humidities as well. In drier areas problems may also occur due to dust abrasion. The present standard technique of calibration by inter comparison against standard reference instruments produces acute difficulties in remote areas, and it is difficult and expensive to carry out such intercomparisons due to the large amounts of time required and the high cost of travel. More scientific effort needs to be given to techniques of calibration that are more self contained within specific site, but at the same time scientifically accurate. Unfortunately, because of these difficulties, many solar radiation records are relatively unreliable, though some rehabilitation of unreliably calibrated data can sometimes be achieved by studying noon irradiation values for days when cloudless conditions existed (3).

The archiving of the data within suitable computational structures, with adequate quality control also needs attention, if effective use is to be made of the data in practical applications. The rapidly falling costs of computational systems will offer important benefits to all developing countries in making proper data processing so much more effective.

The basic fact is the best use has to be made of what is actually available, and it would be wrong to hold back programs of applications until such time, as a reliable data base is available. Attention is particularly drawn to the key W.M.O. publications in this area (4) (5).

THE ATMOSPHERIC CLARITY IN AFRICA

Assessing the clarity of the atmosphere is very important in applied solar radiation studies. The atmosphere of many parts of Africa often contains large amounts of dust, especially in the dry season, and particularly so in the areas fringing on the vast deserts. The problems of rural development in these areas have tended to worsen the situation by removal of vegetation by overgrazing and fuel wood removal, so one must not make the assumption the air of Africa is necessarily very clear, simply because there is a lot of sunshine. High humidities also tend to produce skies in which a lot of scattering takes place. These effects can be assessed to some extent by looking carefully at the colour of the sky, and also examining the nature of the extinction of the sun's beam towards sunset. If there is a heavy dust burden, the sun's beam may be extinguished when the sun is still several degrees above the horizon, fading gradually through red until the image of the disc eventually disappears in the dusty sky. The colour of the sky lacks a full blueness throughout the day.

A very widely used measure of atmospheric clarity is the Linke Turbidity Factory T_L . The beam irradiance normal to the beam is determined by the following expression:

$$I_c = I_0 * K_d * \exp(-D_r * m * T_L)$$

where I_c = irradiance normal to the beam, watts per square metre
 I_0 = the solar constant, 1367 W/m^2
 K_d = the correction to mean solar distance
 D_r = the Rayleigh optical depth
 m = the air mass corrected to station height.

The higher the value of T_L , the greater the attenuation. The lower the sun, the greater the air mass, so the low sun is considerably attenuated if the value of T_L is high.

The key W.M.O. publication on solar radiation applications (4) in fact suggests a very useful way for estimating the clarity of the atmosphere from subjective assessments of sky colour. In the absence of measurements, this provides a very useful methodology for people closely associated with a specific area. It is less suitable for outsiders, as knowledge of typical sky colour is established by residence and by observation.

THE IMPORTANCE OF DIFFUSE RADIATION MEASUREMENTS

The estimation of slope irradiation can only be carried out if diffuse radiation data can be obtained, either by measurement or by estimation. The measurement of diffuse radiation may be done either by using a shading disc which is driven to follow the sun's path. The alternative, which eliminates the need for continuous mechanical movement is the shading band. The shading band position has to be adjusted periodically to allow for seasonal changes in the sun's position relative to the equator. The shading band however obscures some of the sky and corrections have to be applied. The simplest assumption to adopt in making this correction is that the brightness of the sky is uniform. This assumption produces relatively large errors. Considerable effort had to be given in the European Community program to finding better methods of correction. The correction depends on the relative clarity of the sky. It also depends on the type of instrument. A summary of the CEC work may be found in a recent CEC publication (6). It is desirable that scientific studies of such correctoins should be carried out at suitable scientific centres in Africa to check whether the same corrections are applicable as in Europe.

SIMPLE METHODS FOR ESTIMATING DIFFUSE RADIATION

It is possible to estimate diffuse radiation from both global radiation or from sunshine. The dimensionless equations take either the form:

$$\begin{aligned} D/G &= c+d*(G/Go) \\ \text{or} \quad D/G &= c'+d'(S/So) \end{aligned}$$

where D/G is the ratio daily diffuse/daily global horizontal surface radiation
 G/Go is the ratio of the daily global horizontal surface irradiation/global irradiation outside the atmosphere
 S/So is the relative daily duration of bright sunshine
 c, c', d and d' are linear regression coefficients.

The author studied the data from several African stations in 1960 (7). The values of the constants c and d were found to vary with site, Table 1. This paper has just been independently reappraised against results of many other more recent formula and appears still to be a very reliable method at the monthly mean daily level (8) (9).

ADDITIONAL SOURCES OF DATA RELATING TO SOLAR RADIATION

While very limited records may be available of actual radiation measurements, much more information exists on other relevant variables like sunshine and cloudiness. Today sophisticated information about cloudiness is available from

satellites. Considerable work has already been carried out on this in many countries, for example in the Commission of the European Communities' program on Solar Radiation Data, Project F, Action 4.3. A book dealing with European work in this field is about to be published (10). European work is continuing in this area with an emphasis on the Northern half of Africa. The few ground stations are very important in providing reference points of calibration to improve the reliability of a difficult technique. Difficulties in inadequate spatial coverage exist in Europe as well, and considerable expertise has been built up in developing the two European Solar Radiation Atlases, one for horizontal surfaces, the other for inclined surfaces (11), (12). A summary of the achievements of the first two four-year CEC programs may be found in reference (13). The experience built up in this program in Europe is clearly applicable to other areas of the world, and steps have already been taken through the initiatives of the Commonwealth Science Council to organise programs evolving from this European experience in two major regions, Africa and the Caribbean.

THE EUROPEAN SOLAR RADIATION ATLASES

The production of these Atlases took considerable time. The broad decision to process essentially daily data was the basis of the horizontal surface Atlas. The raw data had to be reduced to a common pyrheliometric scale. All data was first converted to the World Radiation Reference scale (WRR). Next a quality control process was applied to eliminate obviously unsuitable data. Problems of a systematic nature were found with some of the data for example, the Italian data measured with Robitzsch pyranographs were not in line with data from adjacent countries using more reliable instruments. Adjustments which varied from season to season had to be applied. This instrument, which is robust and independent of power supplies, is known to overrecord under conditions of high irradiation.

Tables were then prepared, on a month by month basis, of global mean irradiation, monthly mean maximum global irradiation, the extraterrestrial daily radiation averaged over the month, monthly mean daily sunshine, monthly mean astronomical daylength. Two dimensionless ratios were also included, G/Go and S/So.

The next stage was to systematically study the relationship on month by month basis of daily values of G/Go and S/So using the standard Angstrom linear regression formula:

$$G/Go = a + b(S/So)$$

where a and b are regression coefficients, which depend on atmospheric clarity.

This process provided, for each site where observed data was available, values of a and b. These values were found to link fairly closely with the clarity of the atmosphere at different sites. Important new methods for estimating the clarity of the atmosphere from the sum of the Angstrom regression coefficients (a and b) have been evolved (14). The values were subsequently used as an important part of the methodology for developing the inclined surface Atlas.

The next stage in the mapping process was to use the values of a and b in conjunction with sunshine data for a number of additional sites to estimate, from the sunshine data, values of the global irradiation again on a month by month

basis. Values for several hundred sites were produced, and used to supplement the observed radiation data in the production of the horizontal surface irradiation maps.

Diagrams showing the annual mean course of global radiation for 124 stations for which observed data existed were extracted. Finally frequency distributions of global radiation for 49 stations were compiled. These give the mean monthly cumulative frequency distribution of daily irradiation above given thresholds, and also the mean monthly maximum number of consecutive days with daily irradiation above given thresholds.

This Atlas provides a model which should be of considerable value to others attempting to achieve similar goals in other parts of the world, like Africa. Inter country collaboration proved very important, as radiation patterns are not related to geographic boundaries. The CEC Atlas contains data for a number of countries in the Soviet block, and successfully crosses the barriers too easily set by accepted contemporary politics. The same crossing of barriers will be necessary to produce appropriate maps of solar radiation in Africa.

DEVELOPING A METHODOLOGY FOR INCLINED SURFACE RADIATION PREDICTIONS

A substantial research effort had to go into the development of the European Solar Radiation Atlas for Inclined Surfaces. There are few centres where measured inclined surface radiation data are available. Furthermore, if such measurements are made, the results are limited to surfaces of specific tilt and orientation. Solar designers require data for any slope and orientation they may wish to specify. Considerable difficulties therefore stood in the way of the development of an inclined surface radiation Atlas for Europe.

Any method evolved had to accept the limitations of the input data base. This input data base was the data in the CEC European Solar Radiation Atlas Vol I.

The input data used to develop by numerical modelling the inclined surface Atlas were:

1. Monthly mean daily global radiation on a horizontal surface
2. Monthly mean values of the daily duration of bright sunshine
3. Monthly mean values of the monthly maximum values of daily global radiation on the horizontal surface
4. Monthly mean maximum duration of bright sunshine
5. Values of the monthly Angstrom regression coefficients a and b, taken out at the daily level.

Observed monthly mean daily data were available for 102 sites in Europe. In order to perform the slope calculations, a method had first to be evolved to convert the daily horizontal surface data to the hourly level, and the diffuse radiation had to be separated from the beam, also at the hourly level. Then a model had to be developed to estimate slope irradiances from horizontal surface values. The limited number of observed inclined data sets data available were used to check the accuracy of the modelling process.

The problem of the non uniformity of the radiance of the sky had to be addressed in the slope modelling process. A clear sky model was developed first and then an overcast sky model. The monthly mean slope model was derived from them, using the relative duration of bright sunshine as the basis for splitting the sky irradiation contribution into a clear sky and grey sky component in the computational process. The actual relationships are quite complex, but the steps involved are described in full detail in the specially published CEC book (15).

CLEAR SKY RADIANCE MODEL

A turbidity sensitive radiance model was evolved, which described the main features of the brightness pattern of the clear sky, the aureole around the sun, the ring brightening effect around the horizon, the point of low radiance at 90° to the solar position on the solar azimuth. Once a radiance model has been established, by numerical integration it is possible to determine the relationships between slope diffuse irradiance and horizontal surface diffuse irradiance for any slope and orientation (16).

OVERCAST DAY RADIANCE AND RADIATION MODEL

The work on this part of the project was carried out by Professor Krochmann and his colleagues in Berlin (17). The Moon and Spencer formulation, long standard in daylighting studies for estimating mean overcast sky luminance distributions, was verified as also appropriate for overcast sky radiance distribution prediction. Statistical relationships between horizontal surface overcast day irradiation and solar altitude were established. Once again, making suitable allowances for ground reflected energy, a complete solution could be obtained. There appears to be no reason why the Moon and Spencer overcast day formula should not hold in the African continent. However, it is likely, because of the different types of cloud associated with overcast days in Africa, especially in the Equatorial region, that the European overcast day radiation formula may need modification.

MONTHLY MEAN HOURLY SLOPE IRRADIATION MODEL

The hourly slope irradiation model has three components, the beam, the sky diffuse and the ground reflected diffuse. The first component is easily determined by simple trigonometry from the horizontal surface beam values. Estimation of the ground reflected component is based on the global horizontal surface irradiation. The key decision is the choice of ground albedo. In Europe a value of 0.20 was adopted as standard. However, in Africa, the strong seasonality of rainfall has to be considered, and the ground albedo in drier areas could be substantially higher for a significant part of the year.

The modelling difficulties are centred on the diffuse radiation estimates for slopes. In preparing the CEC Inclined Surface Radiation Atlas, it was assumed that the diffuse sky contribution could be split into two parts, by using the relative sunshine duration. The blue part was assumed to be proportional to the product of the 4° relative sunshine duration and the clear sky value. This part was converted to the slope values using the clear sky model. The clear sky horizontal blue component was subtracted from the hourly horizontal diffuse to give the overcast/partially cloudy sky grey component. This was converted to the slope value using the Moon and Spencer radiance formula. The sum of the two components is the mean sky component on the slope. It was assumed there were no directional effects for the overcast sky contribution, but further studies are showing that this assumption is not entirely satisfactory (18) (19).

THE EUROPEAN SOLAR RADIATION ATLAS VOL. II INCLINED SURFACES

The final production of the Atlas itself was a team effort. Inclined surface radiation tables were first prepared in the Department of Building Science, University of Sheffield for 102 sites in Europe. These tables give monthly mean values of daily global radiation and diffuse radiation on a range of inclined planes. The tables, which are published in the Atlas, also give the estimated clear day daily global and diffuse radiation on the same slopes. The input data is included in the Tables and also the normalisation factors used to match the theoretical horizontal values to the observed values. These Tables were then used by R DOgniaux and G Preuveneers (Institut Royal Meteorologique de Belgique), together with associated information, like the Horizontal Surface maps in Volume I, to draw monthly maps for the European region covered by the tables drawing isolines of inclined surface irradiation. The Atlas also provides information about the radiation transmitted through single and double vertical clear glazing for the 102 sites. Data on solar radiation on overcast days is also provided for a range of slopes. This was assumed to be independent of orientation. A brief explanatory text is provided at the beginning. The detailed computational methodology however is not provided in the Atlas itself, which is primarily a source of data.

ASSOCIATED BOOK AND SCIENTIFIC COMPUTING PROGRAMS

The full scientific studies together with all the detailed computational procedures are being published in book form by the CEC. The book also contains additional prediction procedures for daylighting studies. It also enables radiance studies of the overcast, clear and monthly mean skies to be carried out. A manual method for computing hourly solar radiation using the CEC Atlas procedure is provided. The Department of Building Science in the University of Sheffield has developed a series of colloquial programs for systematically carrying out the computations. This contains an input base for 101 European sites. This makes it a simple process to carry out predictions for any site in the data base for any slope and orientation. Facilities for interposing one or two sheets of glass of any required normal incidence transmittance are included. These allow all the directional characteristics of glass on solar radiation transmission to be assessed.

An alternative version of the program suitable for African conditions has been developed. This uses the WMO technique described in reference 4 to estimate the turbidity. A sample output for Bulawayo is attached as Table 3 showing the estimated slope irradiance on an equator facing surface.

STATISTICAL STUDIES OF THE DISTRIBUTION OF SOLAR RADIATION

Another practical requirement for solar energy application is knowledge of the statistical distributions of solar energy in different months of the year. Liu and Jordan developed a simple but widely adopted method that enables estimates of the statistical distribution of daily global radiation to be estimated from the monthly mean values of the atmospheric transmittance (20). The method is however based on American observations. The author has studied the validity of the US method for the UK and found important differences (21). He has been able to show that better predictions can result if proper attention is paid to the clarity of the atmosphere using the sum of the Angstrom (a+b) as a simple measure of turbidity. He has also been able to show how reasonably accurate

statistical distributions for sloping surfaces can be derived very simply, using the inclined surface European Solar Radiation Atlas tables as inputs. There is no space to discuss these issues further here, but clearly study of the statistical distributions of daily radiation data in different parts of Africa merits considerable further study.

ADAPTING THE METHODS TO AFRICA

By extensive and positive collaborative effort involving many different groups of scientists from different countries in the European Community, an entirely new type of Atlas has been successfully evolved. The scientific procedures involved have been fully documented and a start has been made on making more widely available the detailed computational procedures using the techniques of modern information technology.

The program of the Commonwealth Science Council for solar radiation data studies in Africa is essentially trying to build on the experience of the European project described in outline above. It is clear a two stage program is required. The development of the work on horizontal surfaces has to come first, because the estimation of inclined surface radiation is dependent on the availability of horizontal surface data on which to base the slope estimates. Detailed slope studies at appropriate centres can follow. There should be many benefits from such a program of collaboration. Reaching an understanding of the most appropriate physical parameters to adopt for variables like the Linke Turbidity Factor should emerge. A better understanding should be reached concerning the diffuse radiation climate of Africa. There should be improved knowledge of the statistics of solar radiation, with improved formulae for making estimates in the absence of detailed measurements. This should lay the foundation for more reliable assessments of the economics of solar energy applications. It should also provide designers with the information they really need.

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**METHODS FOR ESTIMATING DAILY SOLAR RADIATION USING
CLIMATOLOGICAL DATA**

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ABSTRACT

Techniques for estimating daily insolation by determining extra terrestrial sunshine and data on sunshine hours or cloud cover are discussed. Using one year of fairly good records of global radiation and sunshine hours for two stations in The Gambia, at Basse (Lat. 13° 33', Long. 14° 54') and Sapu (Lat. 13° 33', Long. 14° 54') correlation coefficients are derived for the Prescott equation using regression analysis and a computer program. These "constants" are shown to undergo slight variations with location and according to the prevailing season, ie rainy and dry seasons. These are compared with other estimates for West Africa, other parts of Africa, Europe, Asia, USA and Australia.

DETERMINING EXTRA-TERRESTRIAL RADIATION

The total amount of energy radiated by the sun can be determined if the effective absolute temperature of the sun is known. From various research results, this can be assumed to be about 5800 °K (Haltiner and Martin, 1957) and the total energy flux (F) has been calculated as 3.9169×10^{26} watts or 56.146×10^{26} cal min⁻¹. Since this amount of energy is also at normal incidence on a sphere concentric with the sun and at a radius equal to the mean sun-earth's atmosphere, it can also be determined by:

$$F = 4\pi R_0^2 I_0 \quad (1)$$

Where R_0 is the mean sun-earth distance of 1.5×10^{13} cm and I_0 is the so called solar constant defined in watts cm⁻² or cal min⁻². Thus from equation (1) the solar constant can be determined, ie

The solar constant was first introduced by A Pouillet in 1837. Its estimated value varies between 1.946 and 2.0 cal min⁻¹ cm⁻² according to the work of various researchers. In this paper a figure of 1.98 cal min⁻¹ cm⁻² will be assumed in the subsequent calculations.

By use of I_0 , the total amount of energy received by the part of the earth/atmosphere system facing the sun can be determined according to the following formula

$$E_s = \pi r_e^2 I_0 \quad (2)$$

Where r_e is the radius of the earth equal to 6.37×10^8 cm. This gives the total energy received as 2.55×10^{18} cal min⁻¹. At the top of the earth's atmosphere the amount of radiation, more specifically, depends on the orientation of a

receiving surface in relation to the sun's normal incident radiation. This in turn depends on the time of the year, time of the day and the latitude over which the surface is located. From Figure 1, it is clear that the amount of radiated energy through a surface A_n is equal to the energy through A_h since no attenuation of this energy took place before it enters the earth's atmosphere, thus;

$$I_0 A_n = R_s^1 A_h \quad (3)$$

Where R_s^1 is regarded as the instantaneous extra-terrestrial radiation. It is to be noted also from this figure that

$$\frac{A_n}{A_h} = \cos Z \quad (4)$$

Where Z is the solar zenith angle, ie the angle subtended by the local vertical originating from the centre of the earth and the line parallel to the normal rays of the sun. Since the earth follows an ellipse in its movement around the sun, the value of I_0 is modified according to the square of the ratio between the mean sun-earth distance (R_0) and the instantaneous sun-earth distance (R). Equation (3) can therefore be revised accordingly, ie

$$R_s^1 = I_0 \left(\frac{R_0}{R} \right)^2 \cos Z \quad (5)$$

From figure R and by use of spherical geometry, it can be proven that

$$\cos Z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h \quad (6)$$

Where ϕ is the latitude of the point of observation, δ is the solar declination and h the hour angle or the angle through which the earth rotates to bring the point p under the direct rays of the sun. The hour angle is defined to be zero at solar noon and exactly 90° at sunrise or sunset during equinoxes. Substituting equation (6) in equation (5) and integrating over a period of 24 hours ie complete rotation of the earth, R_s can be defined as follows;

$$R_s = I_0 \left(\frac{R_0}{R} \right)^2 \int_{-h}^h (\sin \phi \sin \delta + \cos \phi \cos \delta \cos h) dt \quad (7)$$

Since $\frac{dh}{dt} = W$, which is the angular velocity of the earth given in radians such that 2π radians is covered in a day, equation (7) can now be rewritten as;

$$R_s = I_0 \left(\frac{R_0}{R} \right)^2 \int_{-h}^h (\sin \phi \sin \delta + \cos \phi \cos \delta \cos h) \frac{dh}{W} \quad (8)$$

Which yields after integration

$$R_s = \frac{1440}{11} I_0 \left(\frac{R_0}{R} \right)^2 (h \sin \phi \sin \delta + \cos \phi \cos \delta \sin h) \text{ cal cm}^{-2} \text{ day}^{-1}$$

In which h is expressed in radians (0.5 radians = 90°) in the first term of the equation. From equation (6) and by definition of h , it can be shown that at sunrise or sunset for all latitudes $\cos h = 0$, which means that

$$\cos h = \frac{-\sin \phi \sin \delta}{\cos \phi \cos \delta} = -\tan \phi \tan \delta \quad (10)$$

In solving equation (9), the solar declination can be estimated by various methods. A series solution (Paltridge and Platt, 1976) has been derived as follows;

$$\delta = 0.006918 - 0.399912 \cos \theta_0 + 0.0702575 \sin \theta_0 - 0.006758 \cos 2\theta_0 + \quad (11)$$

$$0.000907 \sin 2\theta_0 - 0.002697 \cos 3\theta_0 + 0.001480 \sin 3\theta_0$$

Where $\theta_0 = 2\pi d/365(6)$ and d being the number of the day in the year from 1 to 365(6). Equation (11) estimates δ with a maximum error of 0.0006 radians ().

δ can also be estimated using the following relationships developed by the US Department of Energy, Division of Solar Energy, ie

$$\begin{aligned} \delta &= 23.45 \sin(1.008(n-80)) \quad 1 \leq n \leq 80 \\ &= 23.45 \sin(0.965(n-80)) \quad 81 \leq n \leq 266 \\ &= -23.45 \sin(0.975(n-266)) \quad 267 \leq n \leq 365(6) \end{aligned} \quad (12)$$

where n is the number of the day in year from 1 to 365(6). The day given against a particular declination may vary by one or two days given this approach. The solar constant modifier () can also be calculated using a series expansion (Paltridge and Platt, 1976);

$$\begin{aligned} \left(\frac{R_0}{R}\right)^2 &= 1.000110 + 0.034221 \cos \theta_0 + 0.001280 \sin \theta_0 + \quad (13) \\ &0.000719 \cos 2\theta_0 + 0.000077 \sin 2\theta_0 \end{aligned}$$

ESTIMATING GLOBAL RADIATION AT THE EARTH'S SURFACE

The solar constant term I_0 is only useful for estimating extra-terrestrial radiation. At the surface of the earth, the energy received is largely attenuated. The attenuation of solar radiation by the earth's atmosphere is complex and depends on parameters that are not only difficult to estimate but also subject to considerable spatial and temporal variations. Furthermore, the situation is complicated by the presence of clouds which readily reflect back into space a portion of the incoming radiation.

Because direct measurement data are not always available, certain semi-empirical approaches have been suggested. One which is of interest is the Prescott Equation (1940). This employs calculated extra-terrestrial radiation values and a ratio of measured sunshine hours (n) and the daily possible sunshine hours (N) obtainable from equation (10). Prescott's equation is in the form

$$R_E = R_S (a + b \frac{n}{N}) \quad (14)$$

where R_E is the estimated global radiation, a and b are empirical constants which are obtained from regression analysis between the ratios R_E/R_S and n/N where R_E is measured global radiation.

When daily sunshine hours data are not available, mean fractional cloud cover data can be used. Black (1956) using cloud cover values for 88 European stations established a quadratic relationship between cloud cover (C in oktas) and the

ratio of measured global radiation and calculated extra-terrestrial radiation, in the following form, ie

$$R_g/R_s = 0.803 - 0.340 (C/8) - 0.458 (C/8)^2 \quad (15)$$

Davies (1965, 1967) derived the constants of equation (14) for some stations in West Africa (Table 1). He found that both the values of a and b vary with location and time of the year; a decreases and b increases toward higher latitudes. He observed that in general a depends only on the displacement of the regression line which in turn depends on the scatter of the plotted points. There were more scattered points during the wet season than during the dry season. Coefficient b defines the rate of change of R_g/R_s with changes in cloudiness and this declined from a December maximum to a September minimum. Other researchers have derived Prescott's constants for other locations around the world (Table 2).

DERIVING THE CONSTANTS OF THE PRESCOTT'S EQUATION FOR STATIONS IN THE GAMBIA

As noted earlier, the use of equation (14) for estimating incoming global radiation requires prior determination of a and b for a given location. For the Gambia, data of global radiation and sunshine hours from two stations, viz Sapu and Basse, have been used in a computer program for the derivation of these constants. The data covered a period of one year.

By determining extra-terrestrial radiation from equation (9) and total possible sunshine hours from equation (10), regression analyses on the ratios R_g/R_s and n/N were performed and thus produced the values as indicated in Table 3. In general, a relatively high correlation coefficient resulted between daily values. The values of a are higher during the wet season (June to October) while the values of b attain their minimum during this same season. In general, better correlation coefficients resulted during the dry season (November to May).

After determining the Prescott constants based on correlation for a monthly period, global radiation for each day of that month was then estimated by using equation (14) (Table 4). The cloud cover and equation (15) were also used to estimate global radiation for comparative reasons.

CONCLUSIONS

In Table 4 is reproduced a sample of the computer results for the station of Sapu for the month of January. The estimated results of global radiation R_g and R_c , respectively using sunshine hours and cloud cover, both provided good estimates of the actual measured values. The values estimated with cloud cover on average were higher by about 5%. In general, it is to be recommended that the Prescott constants be determined for each month so as to accommodate likely climatic variations during the course of the year.

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TABLE 1: R_G/R_S versus n/N for different data groupings (Davies, 1965)

GROUPINGS	a	b	r (Correlation Coefficient)
All data	0.19	1.60	0.86
By station			
Benin	0.28	0.33	0.84
Kano	0.26	0.54	0.83
Accra	0.30	0.37	0.82
Fort Lamy	0.43	0.32	0.72
Niamey	0.11	0.72	0.82
By month			
January	-0.04	0.88	0.99
February	-0.04	0.88	0.92
March	0.07	0.80	0.96
April	0.08	0.82	0.97
May	0.12	0.73	0.93
June	0.19	0.61	0.87
July	0.20	0.64	0.93
August	0.20	0.60	0.86
September	0.26	0.50	0.92
October	0.17	0.62	0.92
November	0.07	0.74	0.94
December	-0.12	0.99	0.88

**TABLE 2: Some values of the constants in Prescott's Equation
for different locations (Brutsaert, 1982)**

Location	Latitude	Period	a	b
Accra (Ghana)	6°	Monthly	0.30	0.37
Kano (Nigeria)	12°	Monthly	0.26	0.54
Kunammura (W. Australia)	16°	Daily	0.334	0.431
Delhi (India)	29°	Weekly	0.31	0.46
Tateno (Japan)	36°	Monthly	0.25	0.54
Dodge City (Kansas, USA)	38°	Daily	0.230	0.542
Cleveland (Ohio, USA)	41°	Daily	0.188	0.539
Madison (Wisc. USA)	43°	Daily	0.208	0.530
De Bilt (Netherlands)	52°	Daily	0.22	0.50
Rothamsted (England)	52°	Monthly	0.18	0.55
Matanuska-Anchorage (Alaska, USA)	61°	Daily	0.261	0.465

TABLE 3: Computed constants of the Prescott's equation and correlation coefficients based on 1980 data

Station	Month	a	b	r	(correlation coefficient)
Sapu (Lat. 13.55° Long. 14.96°)	January	0.250	0.399	0.91	
	February	0.264	0.387	0.90	
	March	0.277	0.432	0.86	
	April	0.237	0.392	0.90	
	May	0.288	0.393	0.87	
	June	0.276	0.380	0.90	
	July	0.302	0.360	0.89	
	August	0.303	0.362	0.88	
	September	0.288	0.371	0.89	
	October	0.316	0.379	0.83	
	November	0.280	0.384	0.89	
	December	0.238	0.405	0.91	
Basse (Lat. 13.332° Long. 14.22°)	January	0.255	0.380	0.87	
	February	0.315	0.326	0.84	
	March	0.269	0.398	0.86	
	April	0.328	0.359	0.75	
	May	0.325	0.368	0.75	
	June	0.384	0.271	0.71	
	July	0.293	0.347	0.88	
	August	0.337	0.303	0.85	
	September	0.477	0.148	0.53	
	October	0.332	0.369	0.73	
	November	0.270	0.369	0.87	
	December	0.125	0.476	0.84	

TABLE 4: Sample of the computation results, Sapru, Lat. 13.55°, January 1980

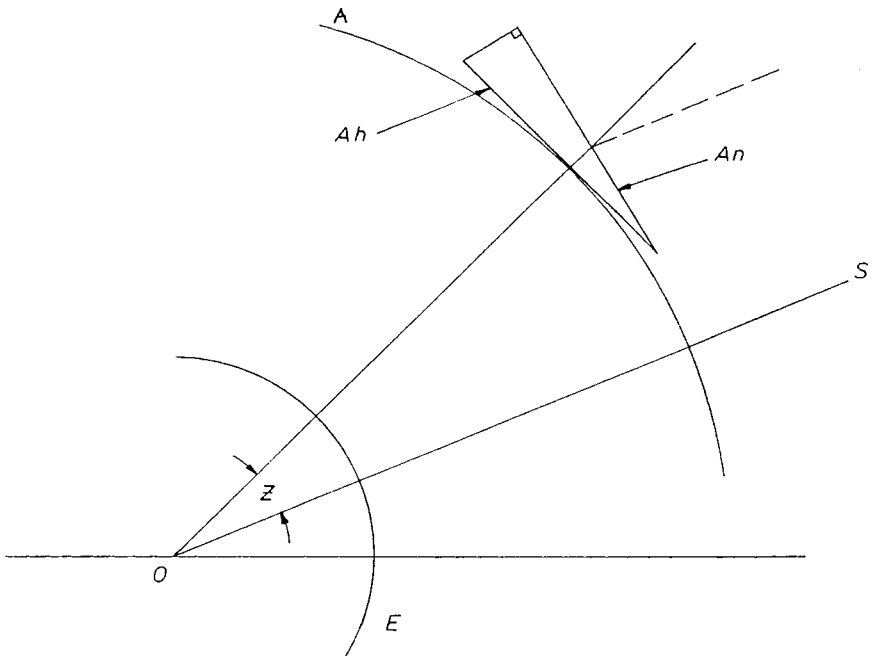
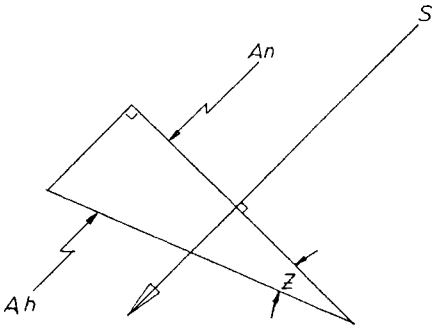
Day	δ Radians	RS		Rg		N hrs	n hrs	n/N	Rg/RS	RC cals/cm ² day	RE cals/cm ² day
		cals/cm ² day	cals/cm ² day	cals/cm ² day	cals/cm ² day						
1	-.401069	710.192	418	11.2179	9	.802291	.588573	547	404		
2	-.399557	711.183	404	11.2212	8.9	.793143	.568068	536	402		
3	-.397913	712.251	355	11.2248	7.3	.650348	.498420	348	362		
4	-.396138	713.394	80	11.2286	0	0	11.12140	80	178		
5	-.394233	714.613	364	11.2328	.9	.080123	.509367	111	201		
6	-.392199	715.904	225	11.2372	2.5	.222476	.314288	111	242		
7	-.390037	717.268	243	11.2419	2.6	.231279	.318785	141	245		
8	-.387747	718.704	158	11.2468	.4	.035566	.219840	111	190		
9	-.385331	720.209	293	11.252	3.5	.311056	.406826	142	269		
10	-.382790	721.783	487	11.2575	10.3	.914947	.674718	544	443		
11	-.380125	723.424	446	11.2632	10.2	.905604	.616513	483	442		
12	-.377337	725.130	413	11.2692	9.4	.834134	.569553	424	422		
13	-.374427	726.901	424	11.2754	9.7	.860280	.583298	574	431		
14	-.371397	728.734	402	11.2819	9.8	.868651	.551641	502	434		
15	-.368249	730.628	371	11.2886	8.5	.752975	.507782	325	401		
16	-.364983	732.581	352	11.2955	7.1	.628570	.480493	276	366		
17	-.361600	734.592	418	11.3026	9.7	.858207	.556923	506	435		
18	-.358104	736.658	409	11.3100	9.7	.857647	.552210	592	436		
19	-.354494	738.778	436	11.3176	9.8	.865906	.590164	569	439		
20	-.350773	740.950	430	11.3254	10.2	.900628	.580336	453	451		
21	-.346942	743.172	430	11.3334	10.2	.899991	.578601	363	452		
22	-.343002	745.442	465	11.3417	10.2	.899339	.623791	408	453		
23	-.338957	747.757	493	11.3501	10.9	.960345	.653305	516	472		
24	-.334807	750.117	480	11.3587	10.5	.924402	.639900	533	464		
25	-.330553	752.518	474	11.3675	10.4	.914890	.629885	479	462		
26	-.326199	754.960	388	11.3765	8.1	.711996	.513935	391	403		
27	-.321745	757.439	421	11.3856	9.9	.869518	.555821	337	452		
28	-.317194	759.953	493	11.3949	10.4	.912685	.648724	584	466		
29	-.312547	762.501	486	11.4044	10.5	.920694	.637376	574	470		
30	-.307806	765.081	486	11.4141	10.6	.928676	.635227	614	474		
31	-.302973	767.689	487	11.4239	10.2	.892864	.634371	590	465		

(δ : solar declination; RS: extra-terrestrial radiation; Rg: measured global radiation; N: possible hours of sunshine; n: measured sunshine hours; RC: radiation determined with ground sensor)

b=0.250
b=0.399
r=0.91

FIGURE 1: Radiation at the top of the atmosphere

(A_n : surface normal to the sun's rays; A_h : surface parallel with the earth's surface; S: direct radiation from the sun; E: earth's surface; A: top of the atmosphere; Z: solar zenith angle).



ESTIMATION OF SOLAR RADIATION FOR NIGERIA AND CAMEROON

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ABSTRACT

Data are presented for global solar radiation on a horizontal plane, H and of duration of sunshine, n , on a monthly basis and their regression coefficients, for various stations in Nigeria and the Republic of Cameroon. It is concluded that the individual station regression equations would be reasonably accurate for most applications particularly when the raw data are not available. Overall regression equations, while giving general average values do not accurately predict the insolation in a particular area.

INTRODUCTION

In order to appraise the economics of a proposed solar-energy application in a particular area and to design a conversion device which will meet a potential demand, it is necessary to know the amount of solar radiation obtainable at the pertinent location. There are other uses of such information such as a meteorological forecasting, determination of agricultural potential and estimates of evaporation rates from bodies of water. Thus solar energy, like any other national resource, demands detailed information on its availability.

Previous surveys of the availability of solar energy in various areas of the world have been based on data available in the more developed countries. While these items of information have been of some use, they do not provide a complete picture particularly for developing countries. Since the availability of the solar resource is essentially site-specific so too must monitoring of the resource. Unfortunately, the less-developed countries have very few monitoring stations which is attributable to the high costs of monitoring devices. In recent times, however, many new stations have been started throughout the world, thus increasing the amount of data available. In addition to these are the more extensive meteorological stations which routinely measure other useful parameters such as air temperature, relative humidity, sunshine hours, rainfall etc. which can be used, selectively in estimating solar radiation intensities.

The present paper describes part of a project which aims to provide an extensive study of solar energy economics for Nigeria and Cameroon and in particular to provide solar-radiation maps for the two countries. Specifically, this paper provides a means of estimating solar radiation on horizontal surfaces for several areas of Nigeria and Cameroon. While there are several types of solar radiation data, each with its own particular utility, the form of data most readily available and most frequently reported is global radiation on a horizontal surface. It is also the most useful form in that methods are available for estimating other types of data from them.

The present project is motivated by the near total absence of accurate solar radiation data bases for Nigeria and Cameroon and also the need to develop solar energy conversion devices particularly for rural application. Within Nigeria, there are five stations with a reasonably reliable record of insolation - Lagos, Ibadan, Benin, Nsukka and Kano. In Cameroon, there are ten - Yaounde, Yoko,

Ambam, Batouri, Douala, Mafe, Koundja, Ngaoundere, Garoua and Maroua-Salak. The Nigerian stations have data for up to five years, the Cameroonian stations for less than one year with the exception of Yaounde and Garoua which have data for nearly two years. Instruments used are predominantly Kipp and Zonen and Eppley pyranometers for global radiation and the Campbell-Stokes Sunshine Recorder for sunshine hours. Details of all stations are shown in Table 1.

PROCEDURE

Various empirical relations have been developed for estimating solar radiation using common meteorological variables such as air temperature, relative humidity, duration of bright sunshine, altitude and latitude. The degrees of successes have been equally varied.

To obtain a survey of solar economics in Nigeria and Cameroon and to prepare solar radiation maps based on good estimates, the following forms of the empirical relations were examined:

$$H' = a \exp (b(S-R)) \quad (1)$$

$$H' = AS^a R^b \quad (2)$$

$$H' = a + bS \quad (3)$$

$$H' = a + bR \quad (4)$$

$$H' = a + bT \quad (5)$$

$$H' = a bS + cR \quad (6)$$

$$H' = a + Bs + cR + dT \quad (7)$$

where H' is the ratio of the observed insolation H to its extraterrestrial value H_0 , R is the relative humidity, T is the ratio of the observed air temperature to its local maximum value and A , a , b , c , d are constants of the regression equations. The various meteorological parameters being readily available, the task was to determine the regression constants and hence deduce the best and the simplest of the equations. All these relations have been used by previous authors with the exception of equation 7 which is relatively new.

Data were sought from the appropriate institutions and from the literature. Those from the Cameroon, albeit few, were used to examine the problems.

The regression equation

As noted above, solar radiation and other data obtained from the Republic of Cameroon were used to test equations 1-7 above and hence to determine the regression equations for that country. Results obtained are shown in Table 2. Values for H_0 here are the local maximum global radiation as measured. The correlation coefficient for equation 7 is in the form of a 3 x 3 matrix.

To determine the appropriateness of the equations, results were obtained of values of H/H_0 as predicted by the equations and compared with actual values for each of the 10 stations in the Cameroon (Table 3).

TABLE 1: Details of stations

Stations		Latitude	Longitude	Altitude (metres)	Duration (months)
<u>NIGERIA</u>					
Lagos	1973 - 76	6° 27'N	3° 24'E	3	48
Ibadan	1973 - 78	7° 26'N	3° 54'E	228	72
Benin	1958 - 62	6° 33'N	5° 37'E	78	60
Nsukka	1975 - 78	6° 52'N	7° 24'E	488	45
Kano	1953 - 57	12° 3'N	8° 32'E	472	81
<u>CAMEROON</u>					
Yaounde	1982 - 83	3° 52'N	11° 32'E	753	24
Yoko	1982 - 83	5° 33'N	12° 22'E	1028	24
Ambam	1982 - 83	2° 23'N	11° 17'E	602	24
Batouri	1982 - 83	4° 25'N	14° 14'E	650	24
Douala	1982 - 83	4° 1'N	9° 44'E	5	24
Mamfe	1982 - 83	5° 43'N	9° 17'E	126	24
Koundja	1982 - 83	5° 37'N	10° 45'E	1208	24
Ngaoundere	1982 - 83	7° 17'N	13° 19'E	1115	24
Garoua	1982 - 83	9° 20'N	13° 23'E	241	24
Marouwa-Salak	1982 - 83	10° 28'N	14° 16'E	423	24

TABLE 2: Regression equations for Cameroon Republic

Equation	Regression equation	Correlation index
1.	$H/H_0 = 0.713 \exp(-0.142(S-R))$	0.626
2.	$H/H_0 = 0.885 R^{-0.77} S^{0.582}$	0.778
3.	$H/H_0 = 0.62 + 0.26S$	0.992
4.	$H/H_0 = 0.806 - 0.09R$	-0.863
5.	$H/H_0 = 0.849 - 0.136T$	-0.01
6.	$H/H_0 = 0.571 + 0.019R + 0.336T$	0.0992
7.	$H/H_0 = 1.19S + 0.567R + 3.0T - 2.46$	

TABLE 3: Estimates of solar radiation from tested equation

Station	H/Ho							
	Actual	Eqn.1	Eqn.2	Eqn.3	Eqn.4	Eqn.5	Eqn.6	Eqn.7
Yaounde	0.718	0.759	0.580	0.713	0.735	0.745	0.676	0.632
Garoua	0.805	0.706	1.06	0.780	0.757	0.745	0.768	0.833
Ambam	0.700	0.758	0.588	0.715	0.735	0.745	0.678	0.645
Nkoundja	0.725	0.733	0.784	0.760	0.740	0.749	0.739	0.725
Ngaoundere	0.791	0.716	0.929	0.785	0.752	0.749	0.772	0.807
Maroua	0.784	0.697	1.21	0.783	0.764	0.748	0.772	0.760
Mamfe	0.730	0.758	0.575	0.709	0.736	0.741	0.671	0.687
Batouri	0.709	0.749	0.661	0.732	0.736	0.743	0.702	0.750
Douala	0.702	0.764	0.541	0.706	0.732	0.738	0.666	0.776
Yoko	0.776	0.735	0.768	0.756	0.740	0.743	0.732	0.854

The following conclusions may be drawn:

1. Equation 4 shows that relative humidity has negative correlation as earlier reported by Ahmad et al (1983) which is high in absolute value and hence may be used for solar radiation estimation.
2. Air temperature, on its own, cannot be used for solar radiation estimation since it is insensitive to location (Table 3).
3. Equation 2 appears to predict rather high values for solar radiation in the northern areas (arid and semi-arid) while giving correspondingly lower figures for the southern or rain-forest areas.

From the present analysis the modified Angstrom relation (Equation 3) is as good as any, for the prediction of global solar radiation in a tropical area like Cameroon and Nigeria. It is simpler to use than either Equations 6 or 7. Hence, it is used for the rest of the work described here.

Global solar radiation for Nigeria and Cameroon

In the Angstrom-type of regression equation, mean daily insolation for monthly periods, H is derived from the amount of extraterrestrial solar radiation, H_0 , the number of measured sunshine hours at a station, n, and the maximum number of sunshine hours possible at the station, N, from the expression

$$H = H_0 (a + b n/N) \quad (8)$$

where a and b are coefficients of the regression equation. H_0 is obtained from the equation

$$H_0 = \frac{24}{\pi} G_{sc} (1 + 0.33 \cos (360 \delta / 365)) (\cos \phi \cos \delta \sin W_S + 2 \pi W_S \sin \phi \sin \delta / 360) \quad (9)$$

where $G_{sc} = 1370 \text{ W/m}^2$, the solar constant

$$\delta = 23.45 \sin (360(284 + d)/365), \text{ the declination} \quad (10)$$

d = day of the year

ϕ = latitude (north positive)

w = hour angle

$$W_S = -\tan \phi \tan \delta, \text{ the sunset hour angle} \quad (11)$$

$$N = \frac{2}{15} \cos^{-1} W_S \quad (12)$$

In the above, all angles are in degrees. Equation 8 is based on a development of Angstrom and used in modified forms by Fritz and MacDonald (1949), Black et al (1954), Mateer (1955) and Page (1961) among others. With particular reference to West Africa, the Angstrom relation has also been used by Davies (1965), Swartman and Ogunlade (1967), Akinsete (1974), Harry (1978), Ezekwe and Ezeilo (1981), Bamiro (1983) and Neba-Fabs (1984). Davies worked on data from two Nigerian stations (Kano and Benin) while supplementing his work with data from

Niamey (Niger Republic), Accra (Ghana) and Fort Lamy. Swartman and Ogunlade obtained relationships in dimensional form for Nigeria from data from Ikeja (Lagos), Benin and Kano. The other local investigations have been for definite locations - Nsukka (Ezekwe and Ezeilo 1981), Ibadan (Bamiro 1983) and Lagos (Harry 1978). Neba-Fabs (1984) dealt entirely with the Cameroon.

As with the work by Davies (1965) the present study takes a broad view of the Nigerian and Cameroonian solar climate. Regression coefficients a and b are determined for the two countries and for specific locations within them. - Lagos, Ibadan, Benin, Nsukka, Kano and Yaounde and Garoua.

RESULTS

Results of the analyses are shown in Tables 4 and 5 as well as those obtained by Bamiro (1983) for Ibadan and Ezekwe and Ezeilo (1981) for Nsukka.

The figures obtained for Nigeria as a whole underestimate the solar radiation for the northern areas and the south. Thus, estimates from this equation can, at best, be said to give an average for the country. For more serious work, the regression equation for each station must be used. The coefficients obtained for Kano, Northern Nigeria ($a = 0.11$, $b = 0.67$) are rather different from those quoted by Davies (1965) ($a = 0.26$, $b = 0.54$). This may be attributed to the progressive change and a more arid climate in Kano. For Nigeria, there continues to be a latitudinal trend with values of a decreasing and b increasing as one moves from south to north.

The values of $a = 0.62$ and $b = 0.26$ obtained for Cameroon are rather puzzling. There is no valid explanation for this behaviour. Values obtained from the regression equation are in good agreement with these values. Generally, data for the Cameroon are few in number thus prompting further investigation in the future.

ACKNOWLEDGEMENT

The authors wish to thank the Meteorological Departments of Nigeria and the Cameroon Republic, and DGRST, Yaounde for their cooperation in providing some of the data used for this work. Most of the computation was done on the University of Lagos, Mechanical Engineering Department computer.

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TABLE 4: Regression coefficients for Nigeria and Cameroon and for individual stations

Grouping	a	b	r	t	Lat.
Nigeria	.20	.52	.81	.70	
Cameroon	.62	.26	.99	.88	
Individual stations					
Lagos	.29	.33	.86	.62	6° 27'N
* Ibadan	.35	.37		.72	7° 26'N
Benin	.28	.33	.84	.61	6° 33'N
+ Nsukka	.28	.65		.93	6° 52'N
Kano	.11	.67	.89	.79	12° 3'N
Yaounde	.27	.30	.86	.57	3° 52'N
Garoua	.28	.43	.78	.71	9° 20'N

* Bamiro (1983); + Ezekwe & Ezeilo (1982).

TABLE 5: Regression coefficients for Lagos by months

Month	a	b	t
January	.29	.24	.53
February	.24	.34	.58
March	.23	.36	.59
April	.25	.26	.51
May	.42	.12	.54
June	.36	.01	.37
July	.32	.09	.41
August	.31	.14	.45
September	.33	.11	.44
October	.48	-.13	.35
November	.05	.68	.73
December	.39	-.02	.37

RECENT DEVELOPMENTS IN THE ACQUISITION AND PROCESSING OF SOLAR RADIATION DATA IN CYPRUS. RESULTS AND FUTURE ACTIVITIES

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ABSTRACT

The work of the Meteorological Service to set up a network of stations to collect radiation data is described. Data on the radiation characteristics of Cyprus are presented.

THE ACTIVITIES AND CONTRIBUTION OF THE METEOROLOGICAL SERVICE IN THE SECTOR OF RENEWABLE ENERGIES

The Meteorological Service of the Ministry of Agriculture and Natural Resources is actively involved in national programmes on the development of solar and wind energy. Its main responsibility is to secure the collection of the relevant meteorological data and the processing of these data for various applications and studies.

The Service plays an important part in the selection of suitable instruments and their proper installation, operation and maintenance, including calibration of radiation instruments.

At the beginning of 1985 the Meteorological Service was collecting radiation data at seven locations, sunshine duration data at 12 locations and wind data at 17 locations. Further improvements in this network of stations are under consideration.

The data collected at these stations are processed and published regularly and statistical summaries prepared.

THE RADIATION CENTRE

Early in 1984 a key prerequisite for the collection of reliable solar radiation data had been fulfilled. A radiation centre was established near Nicosia. It includes the necessary instrumentation for establishing national standards for calibration purposes.

There are three pyranometers for global and diffuse irradiation on a horizontal surface and global irradiation on an inclined surface, one net radiometer for radiation balance on a horizontal surface and one sunshine recorder. The reference instruments are a pyranometer and a net radiometer.

The various radiation components are measured hourly. Other meteorological parameters are measured at the site of the centre. Robitzsch bimetallic actinographs are operated at six locations recording daily global irradiation on a horizontal surface.

In 1984 a schedule for the testing and calibration of the radiation instruments was introduced. Radiation equipment is at the radiation centre and instruments at the outstations are tested and calibrated once a year against the standard instruments at the radiation centre. The calibration period for each instrument is at least two weeks.

The existing network of radiation stations is considered satisfactory for the basic needs. However, for special applications and studies additional data are required.

PROCESSING OF THE RADIATION DATA

The radiation components measured at the radiation centre are integrated and printed on an hourly basis. The hourly values are entered into special forms and the daily totals and the hourly means are extracted manually. Sunshine duration records are analysed on an hourly basis.

Planimetric computation of data from the bimetallic actinographs is done manually. The relevant data are fed into an electronic computer for the calculation of the daily totals and means.

RESULTS AND OTHER RELEVANT CALCULATIONS

Existing radiation data and other relevant parameters are summarised in Table 1. Calculated parameters were produced using the guide lines provided during the training workshop held in Seychelles in 1983.

Clear days

Using an Angstrom Compensation Pyrheliometer the hourly values of direct irradiance at normal incidence in Nicosia were measured on carefully selected clear days in each month. Subsequently the hourly values of direct irradiation on a horizontal surface and on surfaces inclined 35° and 50° to the horizontal and a vertical surface facing the Equator were calculated.

The daily diffuse irradiation on a horizontal surface was found from the known values of the global and direct irradiation. Using isotropic approximation for the diffuse irradiation the daily totals of the diffuse and global irradiation were calculated for the above mentioned inclined surfaces. Their ratios were calculated in relation to those on a horizontal surface.

Using measured values of direct irradiance at normal incidence on clear days and the algorithm relating these values to the extraterrestrial irradiance at normal incidence, the Linke turbidity factor was calculated. The arithmetic mean of the calculated hourly Linke turbidity factor varies from 2.7 in January (mid-winter) to 4.0 in July (mid-summer).

The global irradiation on a horizontal surface on clear days varies from 3.2 KW.H/m^2 (11.5 MJ/m^2) in December to 7.9 KW.H/m^2 (28.6 MJ/m^2) in June.

The diffuse irradiation on a horizontal surface on clear days varies from 13% of the global in June to 21% of the global in December.

The ratio of the global irradiation on horizontal surface on clear days to the irradiation at the top of the atmosphere is about 0.70, defining in this way the value of the sum of the regression constants a and b in the Angstrom formula for this set of data.

The calculated amounts of global irradiation falling on various inclined surfaces facing the Equator (using isotropic approximation for the diffuse irradiation and not taking into account the ground reflected radiation) showed that for Cyprus,

at latitude 35°N , the optimum tilt angle, in the sense that a surface receives the maximum possible global irradiation, varied from nearly zero degrees in June and July to 55° in December.

For the cold period of the year an inclination of 50° to the horizontal is the best angle for fixing flat plate solar collectors, which are widely used in Cyprus for water heating. On clear days in December the amount of the global irradiation on a surface inclined 50° to the horizontal and facing south is nearly 6 KW.H/m^2 (21 MJ/m^2) and corresponds to 184% of the global on a horizontal surface. In June the corresponding value is 69%.

A vertical surface facing the Equator receives global irradiation which varies from about 162% of that received on a horizontal surface in winter to about 17% of that received on a horizontal surface in summer.

For vertical surface facing the Pole the corresponding values are about 10% in winter and 15% in summer and for vertical surfaces facing East or West these are about 52% in winter and 42% in summer.

Overcast days

The amount of overcast sky diffuse irradiation on a horizontal surface was calculated at about 0.7 KW.H/m^2 (2.5 MJ/m^2) in mid-winter to 1.6 KW.H/m^2 in mid-summer. This accounts for 14% of the irradiation at the top of the atmosphere. The value of 0.14 corresponds to the regression constant a in the Angstrom formula.

From this value and from what has been mentioned about the sum of the constants a and b it is concluded that the regression constants in the Angstrom formula for this set of data are $a = 0.14$ and $b = 0.56$.

Average weather conditions

In the plain areas of Cyprus the mean daily sunshine duration varies from about 5.5 hours in mid-winter to 12.5 hours in mid-summer or 55% to 85% of the astronomical day length, respectively.

With these climatic conditions the mean daily global irradiation on a horizontal surface varies from about 2.2 KW.H/m^2 (7.9 MJ/m^2) in mid-winter to 7.2 KW.H/m^2 (25.9 MJ/m^2) in mid-summer.

On high ground the corresponding values for sunshine duration are about 4 hours and 11 hours, respectively and for global irradiation 1.8 KW.H/m^2 (6.5 MJ/m^2) and 6.4 KW.H/m^2 (23.0 MJ/m^2), respectively.

Measurements carried out during 1984 at the radiation centre in Nicosia gave the following results. Global irradiation varied from 2.1 KW.H/m^2 (7.5 MJ/m^2) in November to 7.4 KW.H/m^2 (26.6 MJ/m^2) in June. Diffuse irradiation was as low as 13% of the global in September and as high as 46% of the global in March when hazy conditions prevailed. Global irradiation by a pyranometer inclined at 50° to the horizontal and facing the Equator varied from 77% of the global on a horizontal surface in June to 186% of the global on a horizontal surface in December. Radiation balance on a horizontal surface measured with a net radiometer varied from 1.4 KW.H/m^2 (5.0 MJ/m^2) in mid-winter to 4.0 KW.H/m^2 (14.4 MJ/m^2) in mid-summer. The radiation balance was about 60% of the global irradiation on a horizontal surface.

The regression analysis of the radiation data collected at a coastal station at an elevation of 45m in the period May 1982 to April 1983 gave the following values for the regression constants in the Angstrom formula:

$$a=0.16, b=0.56, a+b=0.72, \text{corr.} = 0.966$$

The analysis of data collected during 1984 gave the following results. For the radiation centre, an inland station in the central plain at an elevation of 155m:

$$a=0.19, b=0.49, a+b=0.68, \text{corr.} = 0.883$$

For an inland station on the mountains at an elevation of 640m:

$$a=0.15, b=0.55, a+b=0.70, \text{corr.} = 0.985$$

For another inland station in the mountains at an elevation of 1380m:

$$a=0.10, b=0.67, a+b=0.77, \text{corr.} = 0.978$$

APPLICATIONS AND FUTURE ACTIVITIES

Solar radiation data and other relevant information are extensively used in developing flat plate solar collectors which are widely used in Cyprus for water heating for domestic purposes, for pre-heating/heating of water for boilers in hotels and for heating the water in swimming pools. Passive architecture is another sector in which information on solar radiation are applied. Radiation data are also applied in the methods for estimation of the water requirements of crops.

Future activities include the improvement of the network of radiation stations and the systematic development of radiation statistics including radiation on inclined surfaces. The Meteorological Service will participate in a government project on renewable energy/energy conservation.

CONCLUSIONS

The radiation centre has now been established and the calibration of the radiation instruments are carried out regularly. Through measurements at the centre itself and a basic network of radiation stations routine data are made available on solar radiation in Cyprus on a daily and monthly basis. Achievements have been satisfactory and provide the basis for the further development and improvement of radiation statistics for Cyprus.

TABLE 1 - Solar radiation data for Cyprus (based on data for 1984)

<u>Parameter</u>	<u>Mid-Winter</u>		<u>Mid-summer</u>	
<u>On clear days</u>				
Global	11.5	MJ/m ²	28.6	MJ/m ²
Diffuse/Global	21%		13%	
Global/Extraterrestrial	0.70		0.70	
Global (Incl. 50 ⁰ , S)/Global	1.84		0.69	
Linke Turbidity Factor	2.7		4.0	
<u>On overcast days</u>				
Diffuse (calculated)	2.5	MJ/M ²	5.8	MJ/m ²
Diffuse/Extraterrestrial	0.14		0.14	
<u>Average weather</u>				
Global	7.9	MJ/m ²	25.9	MJ/m ²
Sunshine Duration	5.5 hr	(55%)	12.5 hr	(85%)

Regression analysis

<u>Station</u>	<u>Elevation</u> (m)	<u>a</u>	<u>b</u>	<u>a+b</u>	<u>Corr.</u>
Akhelia-Western coast	45	0.16	0.56	0.72	0.966
Nicosia-Inland, plain	155	0.19	0.49	0.68	0.883
Saittas-Inland, mount.	640	0.15	0.55	0.70	0.985
Prodhromos-Inland, mount.	1380	0.10	0.67	0.77	0.978

THE USE OF LOW COST MICROCOMPUTERS IN SOLAR AND WIND ENERGY DATA MANAGEMENT

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ABSTRACT

Site-specific, assessment of solar and wind energy and data analysis can be a tedious and costly task. However, the recent advent of low cost "home" computers can provide solutions to both tedium and high cost. This paper describes a low cost data acquisition and processing system presently being assembled around a small, inexpensive "home" computer.

INTRODUCTION

Growing interest in alternative energy usage has resulted in an increase in the number of locations worldwide at which solar radiation intensity, wind speed and related parameters are measured. The major requirements of a suitable recording system are accuracy and reliability and especially in the case of developing countries, low cost.

Many types of data recording instruments are currently on the market and these may be placed into two broad categories - those which store data as recorded and those which process data before storing. The former type requires that the data be fed into a computer for analysis. The latter type also requires another instruments to access the data (Wyatt 1983).

Huge quantities of data accumulate in a relatively short time (Munroe, 1978), making it necessary to exercise some degree of control over what data are actually stored. The advent in recent years of relatively inexpensive "home" computers has opened up possibilities for completely computerised data collection and reduction systems with efficient data storage capabilities and at a low cost.

This paper describes the organisation of a small data acquisition and processing system built around a low-cost "home" computer. It illustrates how an important research tool can be assembled at relatively low cost.

DATA ACQUISITION AND PROCESSING SYSTEM

System organisation

The organisation of a typical data acquisition and processing system is illustrated in Figure 1. The system consists of three major sub-systems:

1. Instrument sub system
2. Data management sub-system
3. Power sub-system

Instrument sub-system

The World Meteorological Association (1971) has comprehensively reviewed the types and accuracy of the various instruments available for measuring solar

radiation and wind energy parameters. This will not be repeated here. However, as would be expected, all instruments would need to have a computer compatible output. The Kipp and Zonen or Licor range of pyranometers would thus be quite suitable for solar radiation intensity measurement. Similarly, for wind speed measurement, a suitable instrument would give as output either a voltage or a train of pulses proportional to wind speed. For the wind direction indicator, the sensor should give a voltage output which is proportional to wind direction.

Data management sub-system

The microcomputer

The microcomputer is the most important component in the data management sub-system. Of the several microcomputers available at prices below £150, the Sinclair ZX Spectrum was the one chosen. Reasons for choosing the Spectrum included:

1. Low cost - around £130
2. Excellent software support - programs for statistical analysis, linear regression etc. are readily available commercially.
3. Excellent hardware support - peripherals which are readily available include floppy disc drives for mass storage of data, analog-to-digital interfaces, real-time clock, etc.
4. Good literature support - several books are available on the Sinclair range of computers, for programs, hints and tips, etc.
5. Good "technical" support - there are books and at least one magazine devoted to projects for the Sinclair computers. Those handy in electronics can build and calibrate their own wind speed and direction indicators etc.
6. Data storage capability - the computer can store data alone, without having to store the entire program. This increases the storage efficiency of any storage medium chosen.
7. Can be operated from a single voltage source - unlike some others which require three separate voltage sources. The computer can thus be efficiently operated from a single 12-volt battery.

The ZX Spectrum is an 8-bit microcomputer designed around the Z80A, 8-bit microprocessor. The unexpanded machine with 16 kilobytes (16K) of memory would be quite adequate for this application. However, a 48K machine is currently being used, to allow extra space for program development. The computer is reasonably easy to program and simple programs are required for control of instruments, data channel selection and data capture, analysis and reduction. In operation, the computer reads all the channels every five minutes and processes the data in the time interval between successive readings. Storage of the summary of the results takes place once each hour.

Analog-to-digital converter/multiplexer

The analog-to-digital converter (A/D converter) converts the voltage output of the sensors to a form which is acceptable to the computer. This is available as an off-the-shelf item for the Spectrum, but may be assembled from scratch using any of several designs available. The system should have facilities for channel selection or multiplexing, so that only one A/D converter is required for all the channels used. One channel is required for each sensor and the multiplexer switches the A/D converter to any channel selected for measurement. The unit plugs into the computer and is powered from the computer's power supply.

Data processing and storage

Data storage can be on an ordinary cassette tape recorder. However, problems can arise when trying to run the computer and the tape recorder from the same set of batteries. A better solution would be to use floppy discs for storage. While this can cost from four to ten times as much as a tape recorder, it offers the following advantages:

1. It can be plugged into the expansion port of the computer and receive power from the computer.
2. Information stored on the disc can be accessed in a random manner, rather than only the serial or first-in, first-out basis of the cassette.
3. The system is very fast and a large amount of data may be read (or stored) in seconds, as compared to minutes on the cassette recorder. If the cassette recorder is used, then some additional circuitry would be required to start and stop the recorder by computer, so that the system can be completely automatic.

To cut down on the amount of storage required per channel, some control should be exercised over what information is stored. If information is required hourly, then the following data is stored each hour for each data channel.

1. Maximum value
2. Minimum value
3. Mean value
4. Standard deviation
5. Total (if applicable)
6. Cumulative frequency distribution (ie what percentage is greater or less than a given value).
7. Hour of the day

This procedure would drastically reduce the amount of information to be stored. Values for any given day may be synthesised from the hourly values. The computer is quite suitable for this task and would perform the required calculations rapidly and accurately though only within the limits of accuracy of the original data.

Real-time clock

The real-time clock can be read and set by the computer. If measurements are to be made every five minutes, then the computer will take its time from the clock which it frequently reads. Data is then processed once each hour on the hour and stored.

The clock would have its own rechargeable nickel-cadmium battery and once set, would continue running independent of the rest of the system.

Visual display unit

An ordinary television set is adequate for this purpose. This does not need to be operating continuously when the system is fully operational but is necessary for monitoring any communication with the computer.

Power sub-system

The power sub-system is quite straight forward, and consists of a 12-volt battery and a battery charger connected to the mains supply. In operation, the mains charges the batteries as well as supplying power to the computer. In the event of a power failure, the batteries take over automatically and system operation continues unaffected, since the power sub-system constitutes an uninterruptible power supply. The size of the battery determines how long the system can continue operating after a prolonged mains failure.

Sealed nickel cadmium or lead-acid rechargeable batteries are ideal for this application, since they require virtually no maintenance, eg topping up with distilled water, etc.

SYSTEM PERFORMANCE

It is not possible to give a report on the performance of the system as it is not yet finished. It has undergone some design modifications which are still to be acquired. For example, when the system was first conceived in 1983, there was no floppy disc drive compatible with the Spectrum. Now there are several to choose from.

Sensors for solar radiation monitoring have been acquired and will shortly be mounted. Sensors for wind speed and direction are being designed and built locally. They are to be calibrated against a meteorological instrument which is expected to be located at the University in the very near future. It is hoped that a report on system performance, cost and component availability can be given soon after the system is completed.

CONCLUSION

The system described here demonstrates that an inexpensive "home" computer can be converted at relatively low cost to a data management system for solar and wind energy studies.

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ASSESSMENT OF SIERRA LEONE'S ENERGY POTENTIAL FROM AGRICULTURAL WASTES

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ABSTRACT

A survey has been conducted to estimate the energy potential of agricultural and forestry wastes available in Sierra Leone, to provide the necessary information base for policy makers. The preliminary results which covered nine types of crop wastes, three different animal wastes and two types of forestry wastes are presented. Examples are discussed of how the different agricultural wastes can be used to supply the energy required in most of the post-harvest operations that are carried out at village level.

INTRODUCTION

Sierra Leone does not have a large pool of conventional energy resources. To become energy self-sufficient, non-conventional sources of energy must be developed, including biomass. At present in Sierra Leone, most of the biomass used for energy is in the form of wood or charcoal. There is potential to exploit a much broader range of biomass resources. However, it is necessary first to assess the amount available nationally.

The project described in this paper has been carried out to determine the national energy potential from agricultural and forestry wastes.

BACKGROUND ON AGRICULTURE AND FORESTRY

Agriculture (crops)

Agriculture plays a major role in the economy of Sierra Leone, contributing about 28.6% of the total export earning and 32% of the gross domestic product. Rice is the staple crop and is produced all over the country. Other food crops include cassava, maize and millet. Among the cash crops are: coffee, cocoa and palm kernel which are produced mainly in the southern and eastern region; groundnut and sugar cane which are produced in the north; and citrus fruits which are produced all over the country on a very small scale. Of these, coffee and cocoa rank high with 16.1% and 13.4% of the total annual export earnings respectively. Together, these crops represent only 10% of the GDP.

Agriculture (Livestock)

In Sierra Leone, the main source of meat is beef. But cattle rearing is not very organised and most farms average only 10-50 head of cattle. Most of the cattle are in the northern province. Goats and sheep are reared in large numbers all over the country. The combined population of sheep and goats is greater than that of cattle. Goats, sheep and cattle are seldom housed or confined. Piggeries exist only in the urban centres and their adjacent rural communities. The average size is about thirty (half of which may be piglets). There are several poultry farms in the country, with from 500-50,000 chickens.

Forestry

About five percent of the total area of the country (mainly south-eastern region) is covered with high tropical forest. There are several forestry plantations whose total area is approximately 10,000 ha.

METHODOLOGY

Following an initial identification of the different wastes produced in the various farming operations, two parallel investigations were undertaken to characterise the wastes and to determine the total resources using data from field tests and statistical records.

Identification of agricultural and forestry wastes

Wastes have been classified into five groups: crop wastes produced in farming operations such as harvesting and milling; firewood produced as a result of the bush fallow farming system; animal wastes; wastes from forestry operations; and wastes from agro-industries.

Three criteria were identified for selecting a particular plant crop waste as a possible source of energy. Firstly, the crop should have an annual production in excess of 10,000 tons. Second, the moisture content of wastes is less than 20% making them good candidates for thermochemical conversion. However, wet wastes are suitable for bacteriological conversion. Third, the ratio of waste to crop should be high. For instance, cassava stems were not considered because of the low ratio of stem to root.

As far as animal wastes are concerned only confined animals and larger animals were selected. Goat and sheep wastes were not considered suitable. Although cattle are not confined in most cases, the size of their droppings and the limited distances over which they roam makes the collection of cowdung a potentially economic exercise. Poultry and piggery wastes were also considered in this study.

In the case of agro-industrial wastes only solid wastes were considered since most liquid wastes tend to be very dilute. Two forestry wastes were considered; sawdust and wood cut-offs.

It is widely believed that deforestation is caused by clearing of forest for firewood. However in most developing countries like Sierra Leone, forests are not cleared for firewood. Firewood is a waste product of the land preparation in the bush fallow farming system. Thus the quantity of firewood available depends on the extent of the food crop farming operations. In this study, firewood is considered as a waste from the farming work.

Laboratory experiments

Laboratory tests were carried out to determine some of the relevant physical characteristics of the wastes. The properties measured were: moisture content; calorific value; bulk density and ash content. The energy content, the thermochemical conversion prospects, and problems involved in transporting large quantities away from the point of production were determined.

Determination of waste factors

Total production of various crops was obtained from statistical records. The proportion it was to crop produced was estimated in field experiments. The method for the collection of field data varied from crop to crop. Below the methods used to determine the waste factor which is defined as the ratio of the waste to the primary products are described. Two broad categories of wastes have been defined: those produced on farms and those produced during processing off the farms.

Wastes left on farm land

Only rice straw and the natural vegetation removed during land preparation for farming, can be considered as a farm waste.

- a. Determination of waste factor for rice straw: In Sierra Leone during harvesting most of the straw is left on the farm and only the stems containing the seeds are cut-off. Straw from a measured area was collected and weighed and the ratio of straw to paddy produced, thus calculated. The waste factor thus obtained was estimated at various locations and for both upland rice farms and boliland swamps.
- b. Natural vegetation: During land preparation for farming the natural vegetation is cleared. Most is burnt and serves as a soil fertiliser. The larger trees are traditionally used for firewood. Available statistics on the volume of wood per acre of forest land in Sierra Leone (Alanta 1979) and on the total acreage of upland rice farm developed annually, was used to calculate the tonnage of firewood available annually from rice farming.

Wastes produced off-farm

This group includes all the wastes in the post-harvest operations such as milling and threshing, as well as those generated by agro-industries.

- a. Rice husk, peanut shells and coffee husk: All these wastes are generated during the milling (or shelling) of the primary product. A measured quantity of the uncleaned product (i.e. paddy rice, unshelled peanut etc) was milled (or shelled) and the weight of the waste and the primary product recorded separately. The ratio of the waste to the primary product is the waste factor.
- b. Cocoa pods: Cocoa-bean production statistics are normally quoted for dried beans. The waste factor was therefore based on dried beans. A weighed sample of the podded cocoa was taken and processed by the traditional method. The dried beans and the dried pods were weighed and the waste factor computed.
- c. Palm fruit fibres: This type of waste is produced on a large scale in three main oil mills processing palm fruits. A known quantity of palm fruit was processed. The ratio of palm fruit fibres to the quantity of palm oil produced gave the waste factor.
- d. Woody remains of palm fruit bunches: The palm fruits are loosely attached to a thorny mass which is disintegrated during processing for palm oil. The woody remains are a useful source of energy. The waste

factors for this waste was estimated from a mass balance taken over the total crop.

- e. Palm kernel shells: To determine the quantity of shell generated per unit weight of palm kernel produced, a known quantity of the unshelled units was cracked and the weight distribution between the kernel and the shell recorded.
- f. Bagasse: There is only one sugar mill in the country. The factory provided information on the quantity of bagasse to sugar produced.
- g. Livestock (poultry, piggery and cattle waste): Animal compounds (eg a poultry, a piggery) were visited once a day (early in the morning) to collect all wastes of the previous day. The total waste was divided by the number of animals present to give the waste per animal. The average weight of the animals involved in the experiment was also recorded.

Forestry wastes

Two types of wastes are generated by the forest industry: sawdust and wood cut-off. Some of the latter is usually left on the forest floor by the logging team. The quantity of wood cut-off produced depends on company practice and hence the waste factor will vary with the company. These industries were visited and interviewed on the quantity of waste they produced. An average of the estimates was used as waste factor for the industry.

Data on primary products

To gain regional and national estimates for waste products information on the annual production of the primary products was obtained. Three main sources of information were used: published reports or data, communications with industries and government departments, and visits to industries. The Agricultural Statistical Bulletin (PEMSU 1983) proved the most useful source of published data. Published by the Planning, Evaluation, Monitoring, and Services Unit (PEMSU) of the Sierra Leone Government's Ministry of Agriculture and Forestry, it has information on the annual production of nearly all major crops produced in the country. It also has information on the nature and size of both natural and plantation forests.

RESULTS AND DISCUSSION

Physical characteristics of the wastes

The results of the experiments to determine the bulk density, moisture content, ash content and calorific value of the wastes are given in Table 1. With the exception of palm kernel shells, all waste products are very bulky (bulk density less than that of water). This has very unfavourable implications for the transportation, particularly of rice husks. Thus these wastes will have to be used locally.

The moisture content of most of the crop wastes (with the exception of bagasse) ranged from 11-20%. Hence they can readily be converted to other forms of energy through any of the thermo-chemical routes such as combustion, pyrolysis and gasification. Biological conversion will require the addition of a lot of water, and bacteria, and will have a long retention time. The moisture content

of animal wastes was fairly high - varying between 16% and 86%. The lower figure represents cowdung which was usually dropped in open fields where they dried before collection. The average moisture of forestry wastes was 30%, which corresponds to that of wet wood.

The ash content of most of the wastes is fairly low. The only exceptions are rice husk and straw which have very high ash content (approximately 20%). The ash contents of palm fruit fibres, palm kernel shells, sawdust and other forestry wastes are negligible.

Gross energy values are inversely correlated with ash content, as would be expected, since ash represents weight contributing zero energy.

Waste factors

Tables 2-4 give the waste factors for all the crop wastes considered in this work. Table 5 summarises the daily droppings of animals. Table 6 contains information on the percentage of logs that is wasted in sawmills.

These data are similar to published work especially in the case of rice husk (Pitakarnnop et al 1983). Rice straw to grain ratio is very high because of the low grain yield per hectare. Paddy production is 1.3 tonne per hectare compared with 3-5 tonnes per hectare reported in some literature (Dunn et al 1983). The larger yield corresponds with improved farming methods.

Daily droppings per animal are also very much lower than those reported in the literature because of the lower average weight of the animals. In the case of cattle, the dung was dry when collected and explains the low value for the daily droppings.

Total energy from agricultural and forestry wastes

Tables 7-9 give the total wastes associated with each of the major crops. Wastes associated with rice are the most abundant. Rice straw tops the list in quantity, followed by wastes from clearing for rice farming and then rice husk. Among the forestry wastes, wood cut-off is the most abundant and in the livestock cowdung dominates.

The total energy available nationally from all major agricultural and forestry wastes is given in Table 10. By far, the most important waste is dry wood collected during clearing of natural vegetation in the bush fallow farming system. Some of this waste, especially that generated on farms close to urban areas, is already being used as firewood.

Other major potential energy sources are rice straw and husk. However because of their high ash content and low bulk density, these fuels will have a very short radius of economic usefulness. The largest energy potential from agro-industries is bagasse produced by the sugar mills. This and other wastes like palm fruit fibres and palm kernel shells are currently being used by the industries that produce them. In addition, a small number of farmers who process oil palm by traditional methods also use palm fruit fibres as energy sources in some parts of the country.

The estimated total energy available annually from wastes produced on farms and in agro-industries is about 1.5 million tonnes oil equivalent. This is very

significant since the annual import of crude oil to Sierra Leone is approximately 300,000 tonnes.

Mode of utilisation of wastes

Most of the wastes produced by industries are used in those factories as a source of energy. Palm oil mills use the palm fruit fibres and the nut shells to fire their boilers, and bagasse produced by sugar mills is similarly used. Recently, the forest industries corporation of Kenema in the eastern region started using their wastes to generate electricity to run all their machines. Sawdust can also be used for cooking or baking in specially designed stoves and ovens (Massaquoi 1985; Bassey 1983).

Other wastes evaluated here have not yet been recognised by farmers as potential energy sources. In order to promote the utilisation of these waste, notice must be made of the fact that their low bulk density requires them to be used at or near the point where they are generated. Promotional efforts, should aim at augmenting existing energy sources for farm activities and providing energy for other work currently been undertaken by human labour.

Thus, efforts to utilise rice husk or straw should concentrate on using them in some form in drying, milling or parboiling. The use of rice husk in stoves to parboil paddy are currently underway. Similar efforts should be made in converting rice husk to gas which could be used to run rice mills.

Farm wastes should be considered individually. All the processing and farming operations associated with a particular waste should be examined to identify those steps that could be energised.

CONCLUSION

A survey of Sierra Leone's energy potential from agricultural and forestry wastes has been carried out. From the results of the survey the following conclusions can be drawn.

- i. The total energy from plant wastes, which is estimated at 1.5 million tonnes of oil equivalent per annum, is about five times the total annual crude oil import.
- ii. The total energy from crop wastes alone is more than double that of the annual crude oil import.
- iii. The total energy from the dead remains of the natural vegetation which is cleared in the bush fallow system, is estimated at 23,852 TJ/annum or 542,000 T.O.E.
- iv. The total energy from crops associated with rice farming is about 700,000 tonnes oil equivalent.
- v. The low bulk density of the wastes means that they are best used in the communities in which they are produced.
- vi. It is possible to use the energy available from some crop wastes to energise the operations leading to the production of the waste. An example is the use of rice husk stoves to parboil rice.

- vii. The energy available from forestry wastes is not substantial but exist in large quantities in a few locations.
- viii. Among the livestock wastes, cowdung has the largest energy potential but since most of the cattle are not housed it is difficult to use this waste.
- ix. All waste from agro-industries are currently been used by the producers to run their boilers.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to the Commonwealth Science Council for the financial support of this project. The presentation of this work at the International conference on Research and Development of Renewable Energy Technologies in Africa, has been made possible through a travel grant by the International Development Research Centre of Canada. Their sponsorship is gratefully acknowledged.

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TABLE 1: Physical characteristics of major agricultural and forestry waste

Waste	Bulk density (kg/m³)	Moisture content (% wet basis)	Ash content (%)	Calorific value (MJ/Kg)
<u>CROP</u>				
Rice husk	107	11.87	20.3	12.75
Rice straw	320	17.91	17.9	13.5
Firewood (average)	650	17.5	Neg.	16.5*
Cocoa pods	-	19.27	10.2	14.2
Coffee husks	575.5	17.35	9.4	15.35
Peanut shells	429	16.35	14.2	15.46
Palm kernel shells	1315.56	12.02	1.31	16.4
Palm fruit fibres	826	11.48	Neg.	23.21
Woody remains of palm fruit bunches	-	10.2	Neg.	18.2
Bagasse	-	50	11.3	9.3+
<u>FORESTRY</u>				
Sawdust	200-220	50	Neg.	10.5
Wood cut-offs (Green)	690	50	10.5	
<u>ANIMAL</u>				
Piggery	-	90	-	1.8
Poultry	-	85	-	4.4
Cowdung	-	16.8	-	14.5

* Menyonga (1983); + National Academy of Science

TABLE 2: Waste factor of some crops wastes

Waste (primary product)	Average weight of sample (Kg)	Average weight of primary (Kg)	Average weight of waste (Kg)	Waste factor = $\frac{\text{wt of wst}}{\text{wt of pri}}$
Rice husk (rice paddy)	20	20	6.5	0.325
Rice husk (cleaned rice)	20	13.5	6.5	0.482
Dry cocoa pods (beans)	11	1.5	1.5	1 *
Coffee husks (coffee seeds)	5.5	1.25	1.25	1 *
Peanut shells (peanut)	28.0	14.0	14.0	1
Palm kernel shells (kernel)	16.0	5.6	10.4	1.85
Palm fruit fibres (oil)	24	3.6	3.5	0.97
Woody remains of palm fruit bunches (oil)	-	-	-	1.48 **
Bagasse (sugar)	60,000	6,000	20,000	3.3 ***

* In the case of cocoa pods and coffee husk, the difference between the sample weight and the sum of that of the primary and waste is due to moisture which was removed after drying the waste and the primary product.

** Estimated by this work.

*** Magbass Sugar Factory (personal communication).

TABLE 3: Computation of waste factor for rice straw

	Swamp rice	Upland rice
Area of farms brushed (3.85 x 3.45)	13.30 m ²	13.30 m ²
Quantity of rice straw gathered (Kg)	10	6
Straw/hectare (kg/ha)	7520.0	4511
Paddy/hectare (kg/ha)	1500	1340 (PEMSU 1982)
Waste factor = $\frac{\text{wt of straw}}{\text{wt of paddy}}$	5.013	3.37

N.B. The ratio of upland rice to swamp rice is 3.254/1.263. Hence the average waste factor for straw is given by

$$\frac{1}{4.5} (3.254 \times 3.37) + (1.263 \times 5.013) = 3.78$$

TABLE 4: Weight of dead wood generated from bush fallow farming system

Average volume of wood/hectare	5.48	m ³ /ha	PEMSU (1982)
Quantity of paddy/hectare	1.35	tone/ha	
Volume of wood/tonne paddy	4.06	m ³ /tonne	
Approximate density	0.650	tonne/m ³	
Weight of wood/tonne of paddy	2.6	tonnes/tone of paddy	

TABLE 5

No of animals		Total daily droppings (kg/day)	Average droppings per animal per day kg/animal/day	Annual droppings tonnes/animal/year	Average weight of animal (kg)	Daily dropping % of live wt
Poultry	1000	60	0.06	0.0216	1	6
Piggery (Unit waste)	49	90	1.83	0.66	60	3.05
Cowdung (air dried)	23	80.5	3.5	1.26	200	1.75

TABLE 6: Statistics on forestry wastes

<u>Industry</u>	<u>Percentage of logs wasted as</u>		Total
	sawdust	wood cut-off	
Panguma Sawmills	4	36	40
Forest Industries Corporation	3	30	33
SILETI	Not applicable	50	50
Average	3.5	38.7	41

TABLE 7: Computation of total wastes generated annually (crops)

Wastes (primary product)	Waste factors (tonne/tonnes)	Total annual primary production (tonnes)	Total waste (tonnes)
Rice husk (paddy rice)	0.325	556,000	180,700
Rice straw (paddy rice)	3.78	556,000	2,101,680
Dead natural vegetation (paddy rice)	2.6	556,000	1,445,600
Cocoa pods (cocoa beans)	1.0	8,600	8,600
Coffee husks (coffee seeds)	1.0	30,500	30,500
Peanut shells (peanut)	1.0	10,100	10,100
Palm kernel shells (palm kernel)	1.85	41,000	75,850
Palm fruit fibres (palm oil)	0.97	49,000	47,530
Woody remains of palm fruit (oil) bunches	1.48	49,000	72,520
Bagasses (sugar)	3.3	6,000	20,000

TABLE 8: Computation of total wastes (forestry)

Waste	Waste as % of log	Annual quantity of logs handled		Total waste (tonnes)
		(m³)	tonnes	
Sawdust	3.5	71,000	46,150	1615.75
Wood cut-offs	38.7	71,000	46,150	17,860
Total Forestry Wastes				<u><u>19475.3</u></u>

TABLE 9: Computation of total wastes (animals)

Waste	Waste per animal per year tonnes/animal year	Total animal population	Total annual waste (tonnes)
Cowdung	1.26	333,181	420,000
Poultry	0.0216	3973,000	85,817
Piggery	0.66	15,000	9,900
Total Animal Waste			515,717

TABLE 10: Total energy potential from wastes

Type of waste	Total waste produced annually (tonnes)	Calorific value GJ/tonne	Total energy potential (GJ)	Total energy in tonnes oil equivalent*
Rice husk	180,700	12.75	2,303,925	52,362
Rice straw	2,101,680	13.5	28,372,680	644,833
Cocoa pods	8600	14.2	122,120	2775
Coffee husk	30,500	15.35	468,175	10,640
Peanut shells	10,100	15.46	156,146	3548
Palm kernel shells	75,850	16.4	1,243,940	28,271
Palm fruit fibres	47,530	23.2	1,102,696	25,061
Woody remains of palm fruit bunches	72,520	18.2	1,319,864	29,996
Bagasse	20,000	9.4	188,000	4272
A. Total Crop Waste			<u>35,277,352</u>	<u>801,758</u>
B. Clearing of natural vegetation for farming	1,445,600	16.5	<u>23,852,400</u>	<u>542,100</u>
Sawdust	1615	10.5	16,957	385
Wood cut-offs	17,860	10.5	187,530	4262
C. Total Forestry Waste			<u>204,497</u>	<u>4647</u>
Cowdung	420,000	14.5	6,090,000	138,409
Poultry	85,817	4.4	377,594	8581
Piggery	9900	1.8	17,820	405
D. Total Animal Waste			<u>6,485,414</u>	<u>147,385</u>
Grand Total (A+B+C+D)			<u>65,819,160</u>	<u>1,495,890</u>

* tonne of oil = 44 GJ

MEASURING FAMILY FUEL CONSUMPTION

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ABSTRACT

Planning for family fuel saving requires measurement of total family cooking fuel consumption as a basis for comparison. Two simple methods of comparing fuel consumption are described to: (1) test acceptability of a charcoal cooking stove in low-income urban homes; and (2) measure fuel saving produced by woodstoves in rural homes. The charcoal stove offered savings as compared to cooking with electricity and in some cases as compared with wood. Users who are charged a flat rate electricity tariff for a limited load found the charcoal stove more convenient as their maximum allowance of electricity did not provide sufficient cooking power. New charcoal stoves proved more efficient than traditional cooking methods with fuel savings of the order of 70%.

INTRODUCTION

Refined laboratory methods of testing the efficiency of a cooking stove tell us little about the acceptability of that stove in every situation (Foley *et al* 1984). Nor do they give an accurate indication of fuel savings in practice. Assessment of how a proposed new stove will serve the needs of a given group of people would be extremely difficult in the laboratory.

We describe here approaches to determining whether a proposed new stove saves wood or money for real housewives. In answering this question, we hope to provide some indication of what other factors might affect choices as to whether to change or not to change from traditional to new cooking methods.

Reflecting the financial and manpower constraints of a non-government training centre engaged in rural development by motivating groups in the field, the projects described are designed to gain the maximum participation of potential client households in making measurements in their own domestic situation. Only a few of the most significant parameters can be included and their measurement must be as simple as possible.

Two methods will be described, as applied in different situations. The first attempts to determine whether use of a specific new technology, a charcoal cooker, would save money for urban households. The second tests whether new styles of wood-burning stoves would reduce rural families' overall fuel wood consumption.

TESTING CHARCOAL STOVE

The question

Charcoal is not used by lower income urban families in Zimbabwe and deforestation due to heavy urban demand for fuelwood is becoming a national problem. Poorer urban dwellers complain of the cost of other cooking fuels, mainly paraffin and electricity. Thus, a recently developed charcoal stove seemed to offer a new alternative. Charcoal is readily available in the country, from wattle plantations where charcoal is a by-product for which there is at present insufficient commercial demand.

The stove in question was manufactured by a local firm and we obtained three free samples for use in our tests.

Testing method

We selected volunteers from the residents of Harare's lower-income suburbs through personal contacts: either parish churches or members of our own staff living in the suburbs in question, and their friends. Each selected family was lent a charcoal stove and given a 5kg bag of charcoal. We explained how the stove worked and obtained their agreement that they would do all their cooking on the charcoal stove from a specified morning until the bag of charcoal was consumed. They were not told the retail price of either the stove or the charcoal.

When the charcoal was finished, each household was visited again. Information was obtained on how long the charcoal lasted, how much was spent per week or per month on their present method of cooking and the price of their present stove and the cost of repairs and maintenance. We also requested any other comments on the relative merits of charcoal and other methods of cooking.

This procedure was followed in different types of household in different suburbs, from widows with children to large and fairly prosperous families.

Results

In the examples below, the price of a 5kg bag of charcoal is Z\$2.00; a two-pot charcoal cooker, \$36.00; and a three-pot charcoal cooker, \$50.00. Prices of other stoves and fuels are listed in each case. For each household, the location and number of family members are indicated.

Households using wood only

Household (1); Tafara; 2 adults, 3 children, spending \$2.50/week for wood which lasts 4 days; wood for the other 3 days is collected from rapidly thinning woodland nearby.

	Fuel/month	Stove	Comments
Charcoal	\$ 4.00	\$36.00	Clean and quick
Wood	\$10.00	\$ 5.00	

Charcoal break-even: 5 months

Other households in Tafara and nearby Mabvuku estimate wood should cost \$4-\$5/week if it was all bought, which no one can afford.

Household (2); Mbare; widow and 5 children; buys wood as offcuts from a carpentry shop 75c/each, which lasts 3 weeks;

	Fuel/month	Stove	Comments
Charcoal	\$ 4.00	\$36.00	
Wood	\$ 1.00	\$ 5.00	Wood always cheaper

Households cooking with paraffin only

Household (3); Tafara; 2 adults and 4 children;

	Fuel/month	Stove	Stove maintenance per year	Comments
Charcoal	\$12.00	\$50.00		Want to keep the cooker
Paraffin	\$10.00	\$ 7.00	4.50	

No break-even

Household (4); Mbare; widow and 2 children;

	Fuel/month	Stove	Comments
Charcoal	\$13.00	\$36.00	
Paraffin	\$ 5.25	\$ 7.00/year	Needs replacing as spares are not available

No break-even

Household (5); Mbare; lone widow;

	Fuel/month	Stove	Comments
Charcoal	\$ 2.00	\$36.00	
Paraffin	\$ 1.05	\$ 5.00	Used same stove for 5 years

No break-even

Households using both wood and paraffin

Household (6); Glen View; 2 adults and 7 children;

	Fuel/month	Stove	Stove maintenance	Comments
Charcoal	\$20.00	\$50.00		
Wood	\$ 4.00	\$ 5.00		
Paraffin	\$ 8.00	\$ 7.00	\$4.50/year	
Total w & p	\$12.00	\$12.00	\$4.50	

No break-even

Household (7); Tafara; 3 adults, 7 children;

	Fuel/month	Stove	Stove maintenance	Comments
Charcoal	\$ 8.00	\$50.00		Includes heating iron for clothes
Others (total)	\$17.00	\$12.00	\$3.00/year	

Break-even 4 months

Households with electricity

Household (8); Tafara; 2 adults and 2 children;
electricity charged per kWh

	Fuel/month	Stove	Comments
Charcoal	\$ 8.00	\$ 36.00	Satisfactory
Electricity	\$ 6.00	\$420.00	

Electricity break even: 16 years

Household (9); Mabvuku; 2 adults, 6 children: electricity: flat rate \$7.00/month, max. 5A. Electric stove cost approx. \$400.00.

Charcoal cost \$4.00/month; using \$36.00 stove cooking is quicker than with electricity, easier than with paraffin: would buy charcoal stove at this price, even though they would still pay for electricity for lights, radio and refrigerator.

Household (10); Mbare; widow and 3 children: electricity included in rent. Charcoal \$2.70/month in \$36.00 cooker - too expensive, as here electric hot plate cost less than this cooker.

Household (11); Mabvuku; 3 adults, 5 children:
Electricity; flat rate \$7.00/month, 5A max. Charcoal cost \$12.00/month in \$50.00 stove. Electric stove cost about \$400.00 - electricity break-even: 3 years. Would buy charcoal stove if it cost \$15.00.

Household (12); Mabvuku; 8 adults, 7 children.
Electricity: \$10.00/month flat rate; can only use one hot plate of a \$400.00 stove at a time. Charcoal cost \$8.00/month in a \$50.00 stove: They want to buy stove at this price.

Comments

These families regard their fire or stove almost exclusively as a means of cooking. If it also heats the house this is incidental. These preliminary results show that the charcoal stove can offer savings within a reasonable period for some who now use wood fuel; these represent a growing potential user group as wood fuel becomes scarcer.

Electricity is more expensive than charcoal for most families, at least within the time scale most people would consider. Paraffin, although the cheapest alternative, is subject to interruptions in supply, so one family listed here is now trying to change to electricity from paraffin.

This sample is small and testing continues. It is necessarily slow because a certain trust in the questioner is required as well as a knowledge of the testing method.

TESTING WOOD STOVES

The question

Working with groups of rural people we had produced what we hoped were improved wood burning stoves. Our two main types of stoves, and the iron grate which most rural people in the provinces of Mashonaland, Manicaland and Masvingo use, are illustrated in Figure 1.

The mud stove is carved and moulded out of a solid block of anthill clay, a material which rural housewives are familiar with. The design owes something to the lorena stove (Evans 1979) and something to the new Nepali Chulo (Bachmann and Saubolle 1980). These two designs and the existing grate have been described elsewhere (MacGarry 1983).

Here we are not concerned only with cooking efficiency. An open fire in the central fireplace (choto) of a rural Shona kitchen serves many purposes besides cooking including: heating, provision of a social focus, smoking meat to preserve it, and drying clothes in wet weather. It is unlikely that any new method of heating will outperform the existing fire and hearth in all these areas. Hence

households that use a lorena-type stove, sometimes also light a fire in the central choto.

Our question is therefore; by how much (if at all) does use of a new stove reduce a family's weekly or monthly fire-wood consumption?

Gill (1982) has pointed out that the grate now used superseded the previously used three-stone hearth because it saved cooking time but not wood. Thus, our assessment must also consider these other factors that influence the housewife's decision, although fuel saving carries more weight than it did 20 or even 10 years ago.

Even so, a saving in firewood consumption will only seem important to users if it is sufficient for them to notice without using highly sophisticated measuring techniques. We have therefore developed techniques which they can easily use but are still adequate for our purpose.

Method

Wood is usually collected by women and in the season when there is less agricultural work to do. Traditionally, only dead wood was collected, or wood cut when clearing fields was used when it had dried. Now more green wood is cut, but it is still allowed to dry before use. The users test moisture content by the way the wood breaks and its general appearance. For the purpose of our measurements, we assumed that this method ensures a reasonably consistent moisture content in fuel used.

We aimed to measure the perceived overall fuel saving of a kitchen, ie not just stove (which may not be used all the time) vs traditional hearth, but stove/hearth combinations as used vs hearth alone. This can be done by asking housewives who use new stoves two simple questions:

- a. How long did a headload of wood last when you had only the old hearth?
- b. How long does it last now?

We asked these questions frequently over two or three years of all stove users. Six within 5km of our centre were visited monthly for the first year. We assumed that each woman's "head load" would be a fairly constant mass of wood as long as she was collecting from the same place, which they usually do for at least a number of months at a time. We have recently made a few measurements to test this assumption.

Results

Every enquiry showed an appreciable saving of wood using the new stoves. The women we questioned most regularly all reported that a head-load lasted about two days in the old hearth and fire to seven days when using either type of stove. This is significant even if we assume a total error of -20% in relating this to an actual mass of wood of standard heat of combustion.

The measurements summarised in Table 1 justify the assumption that a "normal head load" for the same woman will have a mass that varies less than 10%. The exceptions in the table are recognised as large loads or small ones. It is interesting to note the close agreement between sizes of loads collected by

women who gather wood together. The variation in size of load with distance is clear (compare loads carried 1-2km with those carried 4km). This is only a small sample and further measurements are to be made.

The users report variations in fuelwood use through the seasons although we have not succeeded in measuring these exactly.

- a. During late rainy season, February-May, a variety of foods are cooked even between meals, so cooking fuel consumption rises.
- b. During cold weather, June-August, more fuel is used to warm the house. Mudstove users often have a fire in the old hearth at night in this season, so their fuel consumption rises considerably.
- c. During the post-harvest season, June onwards, users of either kind of closed stove burn dry maize cobs which are a more efficient source of heat in a stove than in an open hearth.

It was estimated that a good harvest could give cobs for two months cooking, but the three years of this programme have been years of drought and harvests have been poor.

CONCLUSIONS

The comparison of charcoal with other cooking fuels has shown that it could offer a saving for many urban families. Our figures only begin to show the variety of situations that exist and more work is planned.

Measurement of the effect of introducing new stoves on rural firewood consumption showed a large saving due to using the stoves under test, as compared with the very wasteful open hearth that is commonly used. Such dramatic improvements cannot be expected in many situations.

To observe seasonal effects on fuel consumption we need to define more closely the range of error to be expected from: a. variable size of a normal head-load and b. variations in moisture content of wood. Differences between different species of wood will need to be considered in some situations. However, if these refinements go much beyond what the users normally observe for themselves they would also go beyond the purpose for which this work was undertaken, which was to help the users find the best stoves for their own use.

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TABLE 1: Head-load mass measurements

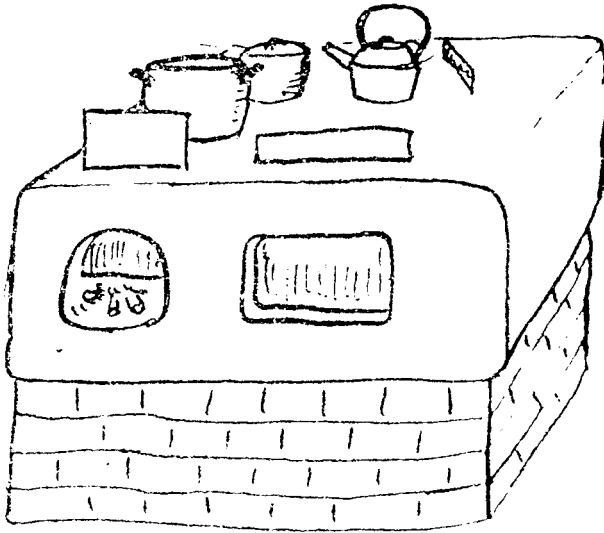
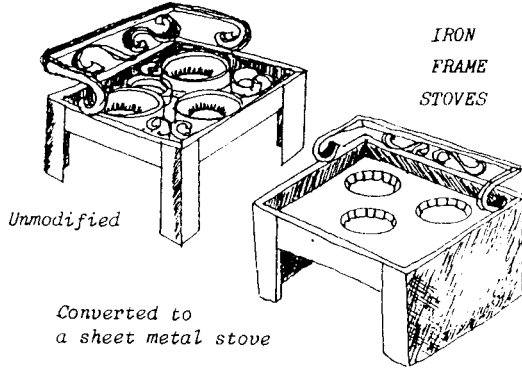
Collected by:	Age Yrs	Distance (km)	Mass (Kg)			Comments
			A	B	C	
Mrs B Chamboko	+ 50	4	28)
Mrs M Chamboko	+ 30	4	27			) collect
Ms M Chamboko	+ 50	4	30			) wood
Mrs R Chamboko	+ 25	4	29			) together
Mrs C Chamboko	20?	4	27)
Mrs S Takadiyi	46	1	39	43	42	
Mrs G Tembo	36	1	42	42	40	
Mrs C Muchabaiwa	39	1.5	37	39	39	
Mrs L Chirau	45	2	49	37	47	
Mrs C Tapfumanei	37	1	27	39	32	
Mrs T Mandaza	39	1.5	42	38	43	
Mrs C Dick	49	1	32	28	30	- weak health
Mrs A Tembo	+ 46	2	30	33	26	
Mrs E Mutizwa	37	2	39	42	41	
Mrs E Mandaza	43	1.5	40	42	42	
Mrs J Muzanenhamo	19	2	-	22	25	
Mrs H Mutasa	+ 45	1.5	20	-	22	

Distance: women's estimates roughly checked by enquirer.

Age: Chamboko family and Mrs Mutasa: enquirer's estimate
Others - own statements.

A,B,C represent loads collected on different days.

Figure 1: Wood-burning 'stoves'



mud stove

METHODOLOGIES FOR MODELLING OF BIOMASS RESOURCES AND USES

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ABSTRACT

The application of dynamic systems analysis to the selection of renewable energy technologies and their mode of integration within a village system are described. The concept and methodology for adopting systems analysis for this purpose are explained by reference to a technocratic simulation model, MERDA (Model for Energy and Resource Development Analysis). This feedback model was initially used to monitor the effects of various technocratic scenarios on a rural community in southern India. However it can be utilised for other locations including villages, towns, districts and islands in Africa for instance, with the minimum of modification. Also described is a preliminary economic feedback model, ECONOMERDA, designed to investigate whether biomass-based technologies, notably the biogas plant, can develop within the village system purely under economic forces, and a system dynamics model, ECCO (Enhancement of Carrying Capacity Options) which operates at the national level and has been used to assess the carrying capacity potential of Kenya. Particular emphasis is placed upon the forest biomass sector of the model.

INTRODUCTION

Through a lack of adequate financial and energy investment, and despite the acquisition of foreign aid ostensibly earmarked for the purpose, progress in agricultural and rural development in many developing countries in general remains disappointingly slow. Clearly the present state of affairs cannot be allowed to continue. The UN estimates Africa's population growing by 206% from 1984 to 2025 (Pearce 1984) while FAO, the Food and Agriculture Organisation of the United Nations, contends that even with only moderate population growth there will be 65 countries, largely African, unable to feed themselves at present levels of agricultural inputs without external assistance by the end of the century (Marshall 1984).

What can be achieved by such countries through more effective deployment of their natural, mainly biomass, resources via the implementation of integrated technological systems, in turn capturing and conserving devices and contemporary advances made in the biological sciences? This raises questions of social acceptability which in turn requires the education of the recipients of these technologies. To what extent are the proposed integrated systems truly synergistic? Are there likely to be any deleterious side-effects? Is output necessarily always improved? What are the dynamics of the system -does it required one agricultural season to become effectively established, or several?

One rigorous means of establishing the outcome of a certain set of interventions is to test the proposal by its introduction within a dynamic simulation model of a rural community. This paper explains how this may be done and presents as its principal example, a highly detailed study made of a small village in Tamil Nadu State, southern India, called Injambakkam for which a comprehensive data base had been acquired (MCRC 1980). The methodology is equally applicable to communities in Africa.

SYSTEMS ANALYSIS

Systems analysis is, in essence, the scientific analysis of real life interactions. The product of this analysis is a reduction of the complex entities and interactions of the real system to a set of cause and effect observations that adequately describe the system under study, but which is nevertheless sufficiently simple to be understandable to the observer or decisionmaker.

This model should ideally answer only one question. In the work carried out on Injambakkam village this question was judged to be "How much solar energy can be captured in photosynthetic activity (that is, as biomass resources) and put to use within the village system?" In practice however, by the inclusion of some subsidiary relationships, models can answer many questions.

The process of model formulation is known as simulation. Continuous simulation, applied here is concerned with flows and levels in which each individual entity in the flow is not differentiated from the others, but all are aggravated together; for example the village rice stock, the harvest and daily consumption. An aggregated model, while less informative than a disaggregated, is more robust and reliable.

Systems analysis considers all facets of a situation simultaneously; the interrelationships between component parts of a system rather than the parts themselves. It is therefore an ideal tool for evaluating the merits and demerits of implanting a particular set of biomass oriented technologies aimed at improving the output of a Third World village, district, island or country.

Four crucial issues need to be resolved: What is the best use of bio- and agricultural technologies to raise output? What are the dynamics of change? What level of productivity may be ultimately attainable? What social or economical changes may be needed to make such a self-reliant development possible? To answer these questions, systems modelling has the two merits of versatility and speed. It allows for the examination of a large number of scenarios, each with a different set of initial and/or ensuing conditions.

The process of change over decades can be monitored by the systems modeller in a matter of seconds. To achieve the same spread using solely experimental work in the field would require the setting up and monitoring of a very large number of rural communities, each implanted with a different technological mix. Data collation might take as long as 20 years and the degree of organisation and cooperation sought would be difficult to obtain in the extreme.

DYNAMIC SYSTEMS ANALYSIS METHODOLOGY

To gain some insight into the technique of modelling consider a hypothetical Third World village community (Figure 1). Crops are cultivated on fertile soil. There is woodland, grassland, fallow land, and wasteland plus roads, houses and ponds etc. Some of this waste land has potential for upgrading. In Figure 2 the village layout is stylised, without reference to spatial factors, with all areas of land of the same type being aggregated.

Since the object of the study is to find how a rural community may prosper within a larger system, we have to decide on the boundary between the two. This is called the system boundary, and we can choose, if we wish, to aggregate within or without of that boundary. Within the boundary, flows can be recorded

as money, as mass and energy (kilograms of protein, gigajoules of fuel energy, kilocalories of food energy and so on), and as human labour and animal hours of work. In a rural community where much is done without money changing hands it is more useful to ignore money flows. However, if a material good or an activity passes through the system boundary to the outside world it is useful to convert it into money values, and consider the revenue to be spent on purchases. For example, exported rice generates money to buy fertilisers, kitchen utensils, transistor radios, etc.

To project into the future we need to employ a dynamic model in which stocks and flows are linked by a system of differential equations solvable by numerical analysis. Solution of the differential equations is made accessible by the development of specialised computer languages such as DYNAMO and ND TRAN 2 and is given a more mathematical treatment in a subsequent section.

The first step in an analysis is to identify the relevant parts of the system and how they interact. The direction of the arrow indicates the direction of the causation. The sign adjacent to the arrowhead shows whether this is a positive or negative effect. Thus



demonstrates that increasing fertiliser application increases crop yields. This is simple statement presupposes a high level of knowledge, which if not available must be researched.

Frequently, the relationship is non-linear. An increasing death rate decreases population. Since a change in population must affect subsequent death rate, we can represent the latter by a causal loop diagram (Figure 3). Causal loops may be positive (+) or negative (-). In Figure 3 the effect of increasing death rate on population is negative. Increasing birth rate resulting in increasing population size leading to increasing birth rate is a positive causal loop.

The next analytical step is to decide which elements are flows (called "rates" in system dynamics terminology) and which are state variables (known as "levels"). Levels can be likened to a tank containing a quantity (stock) of water, as opposed to a flow of water through a pipe that enters the tank, which is a rate. Rates have the dimension of units/time whereas levels are measured without reference to time. The flow of water into a tank is illustrated in system dynamics symbols in Figure 4.

It is most important to note the difference between the directions of the arrow in the causal loop diagram and the system dynamics diagram. In the former it shows the direction of the causation, in the latter the direction of flow of material (or information).

Turning to a hypothetical Third World village community we can develop a model for the use of a community biogas generator operating on cattle dung. Nitrogen rich soil conditioner, in the form of the biogas plant effluent will increase rice production. The extra rice straw can be fed to cattle, thus raising dung yields which in turn means more soil conditioner (and of course more biogas) from the biogas generator. The circle is completed. Thus rice productivity is further enhanced. We have therefore identified a positive feedback loop as depicted in Figure 5.

Output does not go on rising forever. Each addition of nitrogen yields less and less increase in output and eventually, after several cycles (seasons) a new level of output is stabilised. It is a simple step from the causal loop diagram to the system dynamics diagram once the level variable has been identified. The digester is the only level variable, to which is associated two rates - the rate of loading dung (IN) and the rate of removal of soil conditioner (OUT). This is illustrated in Figure 6. Here there are some new symbols:

 represents a constant



represents an auxiliary variable - an identifiable variable that is used in the calculation of rate equations

The rice is only harvested once a year so this is represented by a sample procedure illustrated thus:

SAMPLE	
	1 yr

An important part of the system dynamics diagram is the relationship between nitrogen in soil conditioner and rice yield. This model was translated into a DYNAMO program and the results of the simulation are shown in Figure 7.

The biogas plant is brought into production in year 1. Initially the dung is put into the biogas generator instead of being spread on the fields. This has an adverse effect on the next rice crop. In the third year the soil conditioner output, which has approximately twice the usable nitrogen content of directly spread dung, produces an increased rice yield. The positive feedback loop previously described boosts the rice yield in subsequent years until a new equilibrium level is reached (around year 7). The rice yield has increased by a factor of 42%. One should note that a calculation which did not take account of the feedback would have shown only a 12% increase!

One interesting conclusion is that imported fertiliser would have a greater effect than might be imagined. Importing 1.8kg N/ha per year would initially increase the yield by 7% but again, the positive feed-back loop comes into effect and this extra yield produced more soil conditioner for the next year's crop, until a new equilibrium is attained. We can now consider with the aid of a model how one could improve on the performance of the village agriculture.

THE ACQUISITION OF A DATABASE

A simulation model of a real system such as a Third World rural community and its biomass resources can accurately reflect that system only when sufficient relevant data have been acquired. Before projecting into the future via the dynamic systems analysis methodology described above, details of the major parameters of the system (village) must be obtained so that the steady-state village can be modelled at time zero.

These data will include physical, economic and social characteristics of the village and also land area use and distribution pattern, climatic information, demographic details, agricultural practice, crop productivities, livestock

ownership, food consumption, energy productivities, livestock ownership, food consumption, energy production and levels and distribution, village imports (such as fertilisers, kerosene and consumer durables) and exports (for example, food surpluses, wood and handicrafts). Ancillary data might consist of occupational patterns, medical information, social organisation and so forth.

The acquisition of such data is often a laborious task, generally entailing personal contact with a large cross-section of individuals from the community, though a village "accountant" may have some of the demographic data. A village survey is most easily accomplished by interviewers who are already known in the village and who have obtained the people's confidence. It is therefore important that the systems modeller makes known his precise requirements to those carrying out the survey in the village. The fact must also be taken into account that some villagers are often unwilling or unable to supply accurate data. Thus the importance of conducting, at least initially, a comprehensive survey is reinforced so that any misleading information which cannot obviously be detected as such is outweighed by the responses nearer to the truth.

Once a model has been constructed for a particular village and any problems in the simulation have been ironed out, then the level of data requirements for similar work on other villages is reduced. This was borne out by the systems modelling experience of the Energy Studies Unit, University of Strathelyde. Initially a highly detailed survey of the Indian village of Injambakkam was conducted by the Murugappa Chettiar Research Centre (MCRC), Madras. The survey consisted of general data on the 211 constituent households of the village to provide a broad perspective followed by a more detailed questioning of 70 selected households (MCRC 1980). Using these data a technocratic model was utilised to simulate the activities of Injambakkam and then used successfully for the simulation of two Nepalese hill villages, Salme and Tarevir, where the data bases provided were considerably less detailed.

THE MERDA MODEL

The basic model described previously was expanded and implemented using the database for Injambakkam village, Tamil Nadu, India. The model was named MERDA (an acronym for Model for Energy and Resource Development Analysis) and is now a generic dynamic feedback simulation model realised for the computer in ND TRAN 2 language. The ND TRAN 2 package was obtained from Notre Dame University, Indiana, USA and is similar though not identical to DYNAMO software. ND TRAN 2 can be implemented on any computer with an ANSI standard FORTRAN compiler and at least 28 k bytes of store. Hence MERDA could be run on virtually any machine equal to or bigger than a PDP11. In fact MERDA runs on the ICL computer and takes up approximately 15 seconds of computer time at a cost of US\$2 each run.

It consists of 111 equations plus 63 data constants and tables and is divided into six major sectors: rice production, legume production, fertilisers, biogas production, financial and the energy sector, to which others can be added if required. The causal loop diagram, Figure 8, illustrates the interactions between the various parameters, including introduced technologies, and Figure 9 the system dynamics diagrams. The numbers and other scenario details are not spelled out here; instead the options available to the model user are given.

Within the rice production sector, two crops of rice are grown each year. It is convenient to look at these separately and then sum the relevant quantities. A

stock of rice for each harvest is maintained but depleted by consumption. Each year at the appropriate times each stock is updated by the amount of the harvest according to the yield. Consumption is then calculated to deplete the stock in one year. The yield per hectare is a function of the fertiliser applied by hectare and the total yield is obtained by multiplying this by the rice growing area, taking into account that the whole area need not be used. The total consumption is obtained by summation and accounting for post-harvest losses.

The legume production sector is almost identical to that of rice production except that there is only one crop per year. The production of legumes is initially zero and the modeller provides the starting year.

The stock of fertilisers is provided by dung or digester sludge output; legume leaves; Casuarina leaves; algae; and imports. Fertiliser is counted as its nitrogen content; the other nutrients are assumed to be available in non-limited quantities.

Dung is calculated as a function of the cattle fodder available (crop wastes and grazing). Initially a proportion of this is collected and spread on the fields. When the biogas plant starts operation the dung instead is put in the digester; provision has been made for a different collection efficiency to be used. The digested sludge is then spread on the fields.

Leaves containing nitrogen from the food legumes and Casuarina trees are used as fertiliser when they are brought into production. Algae are started in small ponds and then over a period of time established on the fields, where they fix nitrogen from the atmosphere.

Import levels can be switched on or off at times chosen by the modeller. In the financial sector, the difference between village earnings and expenditure is put in a bank account where it earns a real 2% per annum interest when the balance is positive. When they are in debt the villagers pay a 2% real annual interest rate. Village expenditure for imports includes: fertiliser; wood (can be earnings if there is an export); work energy; biogas plant capital; clothing; extra food, eg fish, milk, eggs, etc. Pumps, both capital and running costs; windmills; Totem (Total energy module for electricity generation and heat reclamation).

The energy sector, as distinct from the biogas production sector, is more closely concerned with heat energy, furnished by fuelwood. The demand for primary energy in the form of heat is calculated as a function of population, with provision for a higher end-use efficiency to be incorporated over a time period chosen by the modeller. Wood harvest is given by the forested area multiplied by the yield per unit area. A change may be made to an energy crop plantation at any time in the simulation. Any deficit in the supply and demand equation is imported and any surplus is exported. If a biogas plant is operating any surplus gas can be used as heat energy (eg for cooking). A limited amount of waste heat from the Totem plant can be utilised here, for heating water only. These last two supplies, if implemented by the modeller, would force an increase in the wood export.

The biogas production sector is more closely related to work energy. The demand for work energy for irrigation is added to that for lighting. Before the biogas plant comes on stream all of this energy must be imported. These imports are reduced by gas production but can never go negative, in which case the excess gas is used in the heat energy sector to substitute for wood. When biogas

becomes available the fraction of rice growing area is increased by extra irrigation until 100% is utilised. The number of new pump sets required for this is calculated in this sector.

If windmills are required in a scenario the energy saved by using this method for irrigation is subtracted from the demand. A Totem system, if selected by the modeller, reduces the supply of gas but produces some electricity which is then added to the supply. Some waste heat is transferred to the heat energy sector.

Other sectors can also be included, for instance, population growth can be catered for in scenarios if required - the modeller provides the net annual rate of increase in population. The spatial layout of the village is handled separately here for convenience. All the areas can be altered by the modeller. Indicators of village wellbeing (eg protein intake, solar capture, etc) are calculated for the model output.

The scenarios, sensitivity testing of the model, and results of model simulations have been published elsewhere (Lewis 1984; Slessor *et al* 1982). Briefly the results indicate that Injambakkam has the potential to utilise its biomass resources to become self-reliant in food and fuel within 5-7 years.

AN ECONOMIC ASSESSMENT OF BIOMASS BASED DEVELOPMENT IN INJAMBAKKAM VILLAGE

Having established the technical feasibility of self-reliant development for the village, a more rigorous economic analysis was made than that performed by MERDA, using a feedback model called ECONOMERDA. Its purpose was to investigate whether biotechnologies such as the biogas plant could develop within Injambakkam and villages like it purely under economic forces, with the rate of introduction controlled by the mechanism of price.

ECONOMERDA is essentially an extension of the MERDA model in which the economic driving force is the desire to have an economic return on capital investment (Figure 10). The opportunity for production and distribution of biogas is vested in an entrepreneur who develops the system only where it is advantageous to him, and if it is viable for him to do so then it should be viable to a village cooperative also.

Essentially livestock dung is bought from the villagers and the post-digestion gas and sludge fertiliser are sold back to them, with the capital required for construction of plant borrowed from a bank at commercial interest rates. The digester has an annual dung throughput of 17.5t. It is assumed that the higher the price paid for dung (base price of Rs 0.1/kg dry wt) then the greater the proportion of available dung will be sold (Figure 11) and when the amount available for digestion exceeds the current throughput capacity another plant is built. The price offered to the villagers for dung is determined by the profitability of the whole operation (Figure 12), while the price at which biogas is sold is notionally 80% of the price of imported diesel fuel. Similarly the price of sludge fertiliser is set at 80% of the price of nitrogen equivalent of imported chemical fertiliser. Profitability is monitored by maintaining a financial balance for incomings and outgoings. Thus the money accruing from the sale of gas and sludge fertiliser increases the balance while the cost of dung purchase, labour and maintenance, interest and repayments of capital decreases the balance.

The biogas is used initially for irrigation until two rice crops per year can be grown on all the available paddy area. Some of the resulting increase in rice production is exported so that the farmers may buy new biogas-operable pump sets without the community going into debt. When the technocratic scenario used for MERDA is incorporated into ECONOMERDA, equilibrium levels for the parameters monitored are reached by year 15.

Over 15 years rice production increases by 240% to improve nutritional standards and export potential. Biogas production, at over 1TJ per annum, is sufficient to irrigate biannual rice crops, with 320 GJ/y surplus for other uses. Solar energy capture more than doubles, the entrepreneur's profit is Rs12,000 (US \$1500) per annum, and his return on investment is 40%. However, while this approach to assessing economic viability is clearly a useful one, further hard cost data are needed to improve its credibility.

In addition to the above approach a more conventional cost benefit analysis (CBA) was used to investigate the feasibility of introducing biogas plants into a rural community such as Injambakkam (Armstrong 1983). Essentially CBA is a method of assessing the desirability of public projects where future, as well as current, returns are considered, as are potential side-effects on society. It is based on the notion that an allocation of resources to an investment project should increase social welfare and involves the enumeration and evaluation of all relevant costs and benefits to assess the effect of carrying out projects (in this case the introduction of biogas plants) on the welfare of society as a whole. A favourable verdict is returned where total benefits exceed total costs.

However, many of the assumptions made about social costs and benefits within a CBA are necessarily subjective (value judgements), and are difficult to quantify. Financial analyses of a project aimed at introducing biogas plants to the village indicate that an entrepreneur, or indeed village cooperative, would benefit from such a venture on strictly market price terms. However, a final appraisal using such values does not adequately indicate changes in the villagers' economic welfare. This requires the estimation and use of shadow prices whereby inputs and outputs are valued according to their true resource costs and values to the village, which is the essence of a CBA. Furthermore, CBAs include externalities such as the reduction in pollution caused by burning biogas rather than wood and the reduction in time spent looking for woodfuel, whereas financial analyses take no account of such factors.

In general, the results of the various CBAs were favourable in that the installation of biogas plants in Injambakkam would indeed increase social welfare. Nevertheless these results are highly sensitive to parameters such as the rice yield (since the post-digested sludge acts as a fertiliser in the paddy fields), to biogas yields and to labour costs and so the values placed on these parameters are critically important to the outcome of the CBA undertaken. As in the approach to economic feasibility adopted by utilising the ECONOMERDA model, further hard cost data are also required to increase the credibility of cost benefit analyses.

THE ECCO MODEL - BIOMASS SECTOR

ECCO (Enhancement of Carrying Capacity Options) is a feedback system dynamics model operating at the national level and in such a way that accounting is made in energy rather than money terms. It maintains at all times the essential resource elements of the economy, of which the biomass/woodfuel

sector is one. ECCO can be used to explore many policy options amongst which are trade offs between land for biomass energy or food, or between food and cash crops, and has been applied to the case of Kenya.

Carrying capacity is defined as that population, at any moment in time, which can be indefinitely sustained at a given standard of living. It is not a threshold, and can be enhanced by appropriate national development using physical and human resources. The model assesses the overall scale and trend of the economy, sector by sector (eg water, non biomass energy, agriculture, biomass, industry etc) in such a way that each sector grows so as to satisfy the overall resource needs of all the other sectors. Thus if the domestic demand for energy cannot be met by fuelwood from the biomass sector, any shortfall must be made good by the non-biomass energy sector. If it cannot do so then material standard of living falls. Once the long-term physical profile is known conventional economic methods may be used to plan the implementation of each sector.

Figure 13 presents an influence (causal loop) diagram of the model's biomass sector, while Figure 14 is the system dynamics diagram. Data are provided for Kenya by Mwenge International Associates Ltd (MIAL 1984):

Average natural forest yield	1.05t/ha.y; 70 y growing period
Average plantation yield	9.2t/ha.y; 7y rotation
Woodfuel demand	25.5GJ/ha.y

In a country like Kenya the harvesting of biomass by collecting firewood from the forests and woodland is a very important source of fuel to the population. Eighty per cent of Kenya's energy accrues from biomass. In this sector, the harvesting of the natural forest is gradually augmented by the introduction of fast growing energy crop plantations.

Capital formation in this sector is not allowed until after 1985. The desired capital stock is calculated either as that required to meet the household sector energy demand, or to plant the entire forest area, whichever is smaller. A check is made to ensure that the area cleared for new plantations does not provide more than the demand for woodfuel. Capital has to be replaced after the plantation is harvested, so the lifetime of capital stock is set equal to the plantation growing time. Capital is allocated to the harvesting sector sufficient to always maintain the necessary stock to meet the full harvesting level anticipated.

The area to be planted is decided according to the actual capital stock available for planting. This is calculated by dividing this by the capital necessary to plant one hectare. Through a seven year delay, corresponding to the time for the forest to mature, one-seventh of the planted area is harvested.

The biomass stock of the plantation is calculated as the time integral of the growth rate minus harvesting. The growth rate in mass terms is simply a function of the area planted. The harvesting rate is given by the area harvested times the mass per hectare of the mature trees obtained.

All of the forest area currently allocated to energy supply that is not planted is allocated to natural forest. The biomass of this forest is calculated in the same way as for the plantation. The rate of harvesting, though, is determined by the

demand for energy in the domestic sector that is not met by the plantation and clearing operations. There is a check made to ensure that if there is no biomass left none is harvested. The yield of biomass from the outside forest area, that is from trees grown on agricultural land, is accounted.

The data for yields and energy inputs will depend on the tree species chosen. If the domestic demand for energy cannot be met from the biomass sector any shortfall must be made good by the (non-biomass) energy sector. The energy and water demands for forestry are calculated under the appropriate sectors of energy and water.

What has been presented here is a methodology for dealing with the biomass (specifically fuelwood) resource of a country, in this case Kenya. It could be applied with equal facility to any African country with a sufficient database upon which to draw. The results are dependent on the data inputs and assumptions made in all other sectors of the ECCO model as well as the biomass sector, and so for this purpose are less important than the methodology used.

DISCUSSION

While this paper has tried to focus on methodologies for the modelling of biomass resources and technologies for their use, the MERDA, ECONOMERDA and ECCO models are policy making tools for development in all aspects of economic activity, whether at the rural community or national level. Indeed to model biomass in isolation from other sectors would be of little use since they are all interconnected in the systems methodology adopted. It would not be profitable for example to attempt to measure biomass energy production to the exclusion of everything else since then there would be no land for food crops nor investment for other activities, and no opportunity for a balanced development strategy. [An exploratory biomass production systems model, BIOMET has recently been developed at the University of Florida with the boundary of the production process taken as the system boundary (Mishoe et al. 1984)]

Clearly, in the African situation, continuous deforestation and falling food production per capita are trends which need to be arrested and reversed. However, investment here may take investment away from the urban/industrial sector of an economy which is why the overall system has to be researched, not merely the agricultural and biomass sectors. It is then left to the politicians and policymakers to decide the priorities for their particular country, such as whether to attempt more food and self-reliance or export-led growth of manufactured goods rather than adopting import substitution strategies.

The models described in this paper can aid the decision process, but they themselves require hard data, data which in many countries are not yet obtainable. Nowhere is hard data more unobtainable than in the production and consumption of the biomass resources so crucial to the economies of developing countries. Modelling is a very useful tool, but as a prerequisite data collection is absolutely vital.

Finally, to fully explain the system dynamics methodology adopted has not been possible in a paper such as this, but interested readers are referred to the texts now available on the subject, particularly to that by Forrester (1973), for a more complete treatment. System dynamics is potentially a very rewarding approach to the process of decision-making not only concerning biomass resources, but in attempting to achieve development goals in all areas of an economy.

ACKNOWLEDGEMENTS

The author would like to thank Professor Malcolm Slesser and the International Federation of Institutes for Advanced Study (IFIAS), Sweden, especially Executive Director, Dr Sam Nilsson for both encouragement and financial support. The people of Injambakkam village, Tamil Nadu, India deserve a special mention since without their cooperation, much of this work would not have been possible, as does Prof C-G Heden in initiating the IFIAS Self-Reliant Development programme. To Dr C V Seshadri and his colleagues at the Murugappa Chettiar Research Centre, Madras go both my thanks and respect for their pioneering and devoted labours in the villages themselves. Jane King, Population Division, UNESCO, Paris is thanked for her involvement in the UNESCO carrying capacity project out of which the ECCO model as applied to Kenya arose. My colleague Mr Ian Hounam deserves special congratulations for his work on the systems analysis aspects of the programme, while I must also thank the Royal Society of London and the Carnegie Trust for the Universities of Scotland for much needed travel support.

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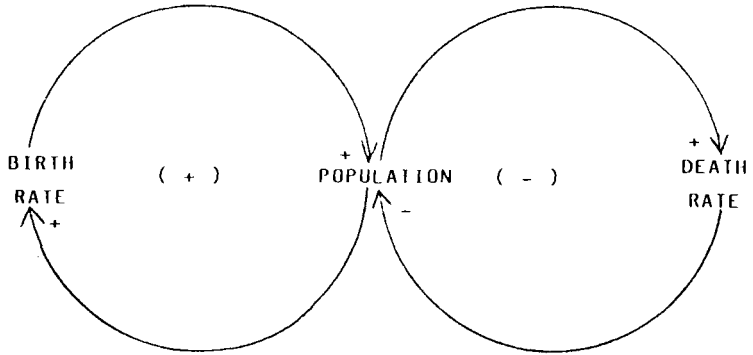


Fig. 3 Causal Loop Diagram of Simple Population Model

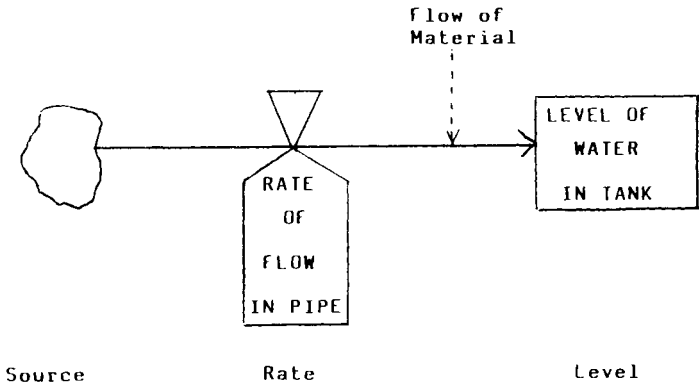


Fig. 4 System Dynamics Diagram

Fig. 5 Rice Production - Causal Loop Diagram

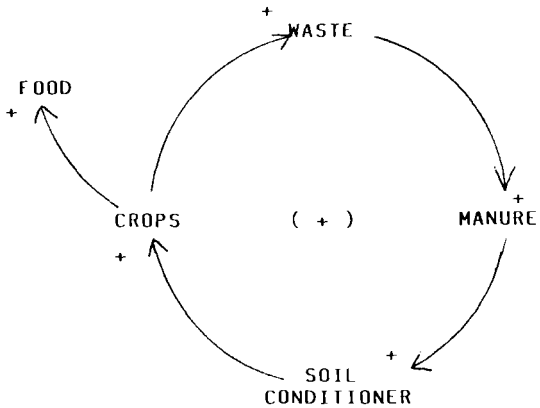


Fig 6. System Dynamics Diagram of Simple Village Model

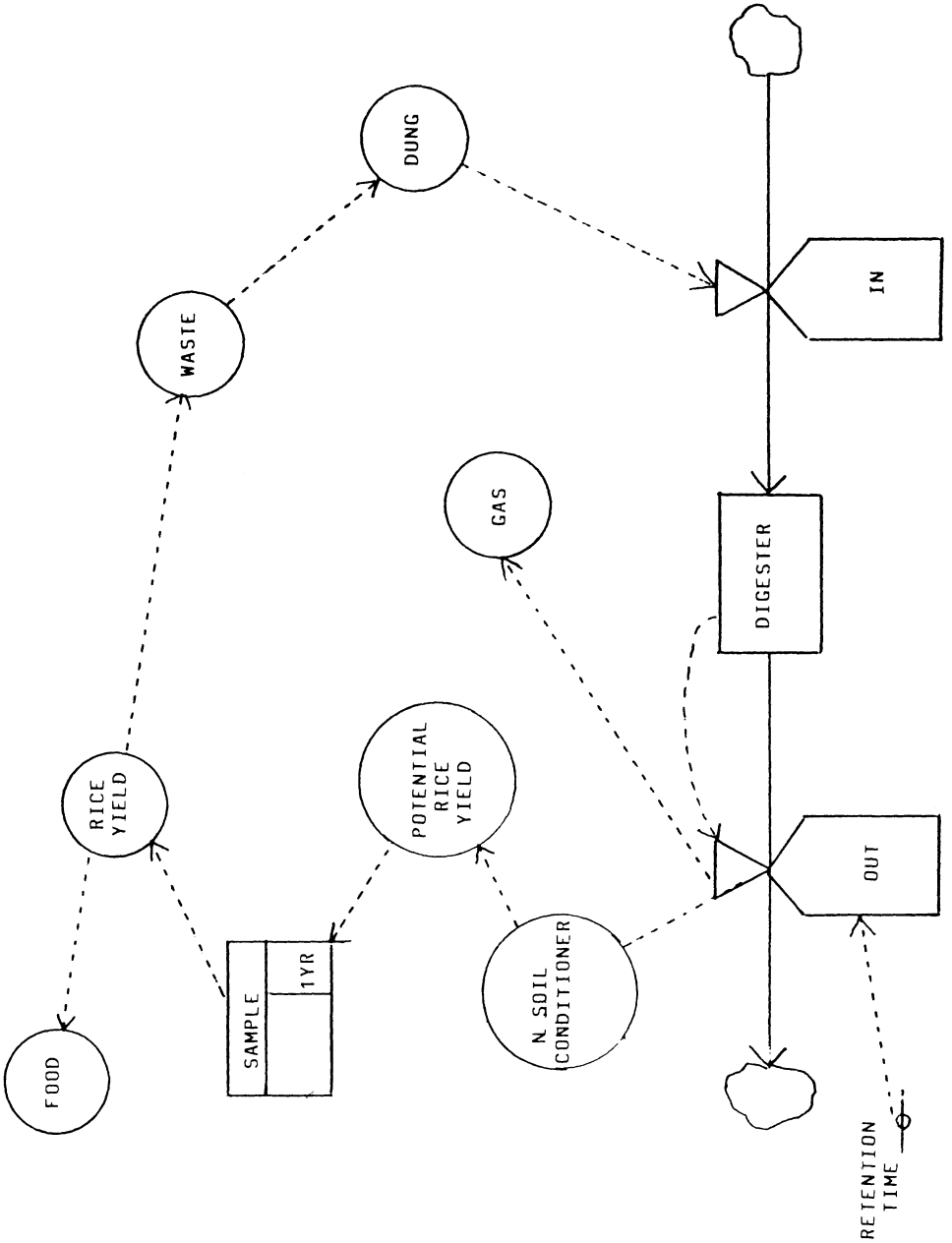
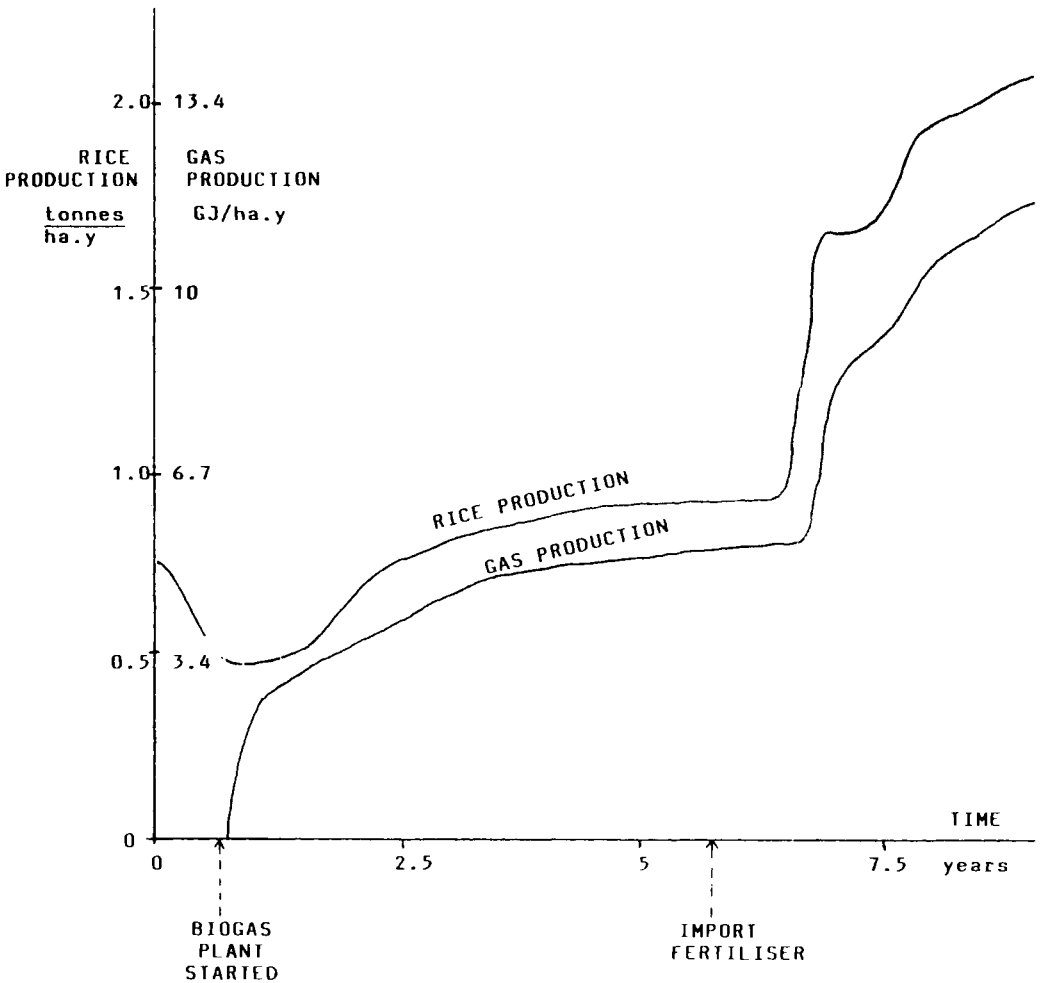


Fig 7. Output of Simple Village Model - Scenario 2:
Biogas Plant and Imported Fertiliser



EXPLANATION OF SYMBOLS (Fig 9)

ALGAE	Algae Production
ANINT	Annual Real Rate of Interest
BGOUT	Total Soil Conditioner Output
BGRT	Biogas Plant Retention time
BG1IN	Input to 1st Biogas Plant
BG1OUT	Output of 1st Biogas Plant
BG2IN	Input to 2nd Biogas Plant
BG2OUT	Output of 2nd Biogas Plant
BKBAL	Bank Balance
CBGEN	Cost of Biogas Generator
CNP	Cost of New Pumps
CTM	Cost of TOTEM
DUNG	Cow Dung
EARN	Village Earnings
ETM	Electricity Production from TOTEM
FERT	Total Fertiliser Available
FERTI	Fertiliser Imports
FOODC	Food for Cattle
FOODH	Food for Humans
FR1PH	Fertiliser for Winter Rice Crop per ha
FR2PH	Fertiliser for Summer Rice Crop per ha
GA	Grazing Area
GAS	Total Gas Production
GC	Grass for Cattle
GTM	Gas to TOTEM
HEXC	Human Excrement
INTIN	Interest on Bank Account
LBG1	Level in Biogas Plant No 1
LBG2	Level in Biogas Plant No 2
LEG	Legume Production
LUF1	Land Utilisation Factor Winter crop
LUF2	Land Utilisation Factor Summer crop
NWM	Number of New Pumps
POP	Population
RC1	Rice Consumption from Winter Crop
RC2	Rice Consumption from Summer Crop
RHT1	Rice Harvest Time Winter Crop (fraction of year)
RHT2	Rice Harvest Time Summer Crop (fraction of year)
RICEA	Rice Growing Area (potential)
RICEC	Total Rice Consumption
RMIN	Money into Bank Account
RMOUT	Money out of Bank Account
RWH	Wood Harvest
RY1PH	Rice Yield per ha in Winter
RY2PH	Rice Yield per ha in Summer
WASTE	Waste from Rice for Cattle Fodder
WDDEM	Wood Demand
WDIM	Wood Import
WKDEM	Work Energy Demand
WKIM	Work Energy Import
WW	Water Weed Production
WY	Wood Yield per ha

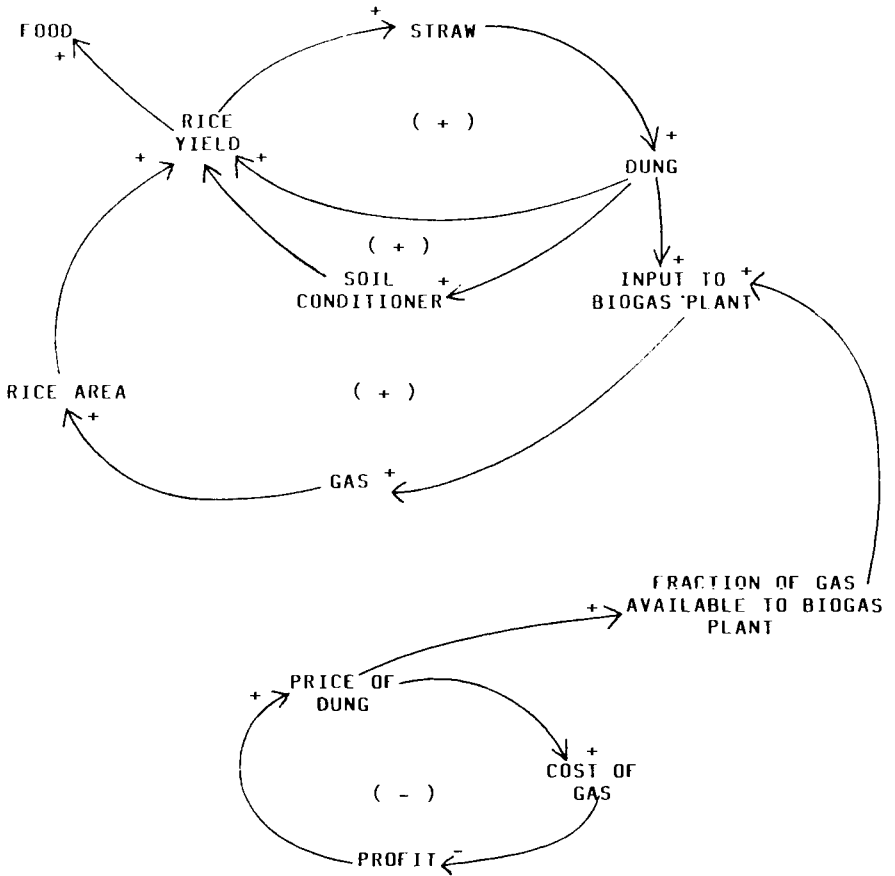


Fig 10. Causal Loop Diagram of ECONOMERDA

Fig 11. ECONMERDA : Dung Price vs Dung Availability

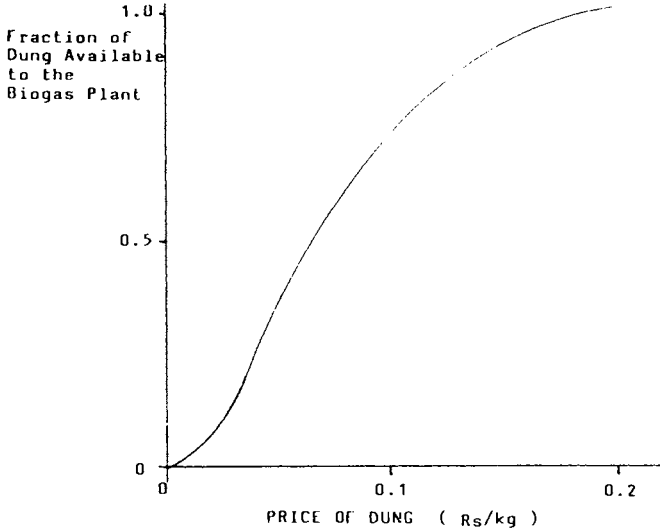
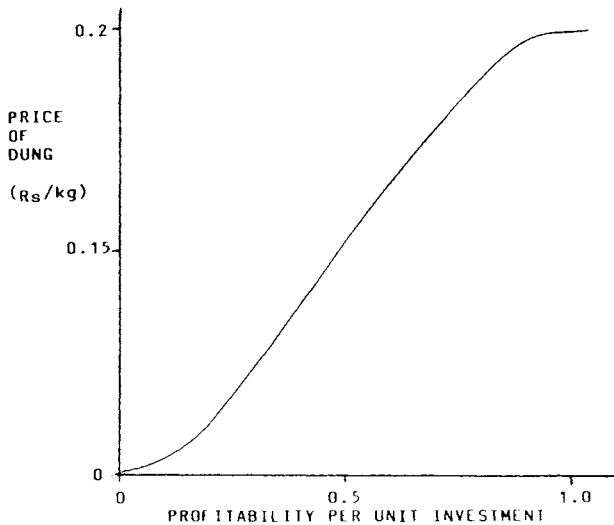
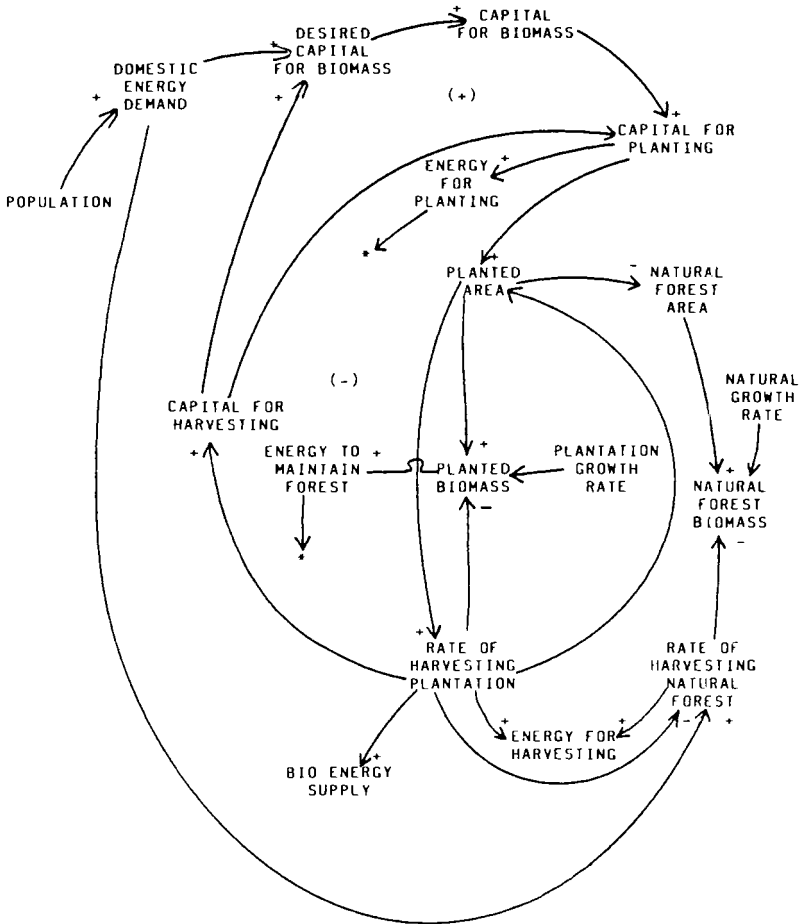


Fig 12. ECONMERDA : Dung Price vs Profitability





* = Link to main model - Energy Demand

Fig 13. Influence Diagram of ECCO Biomass Sector

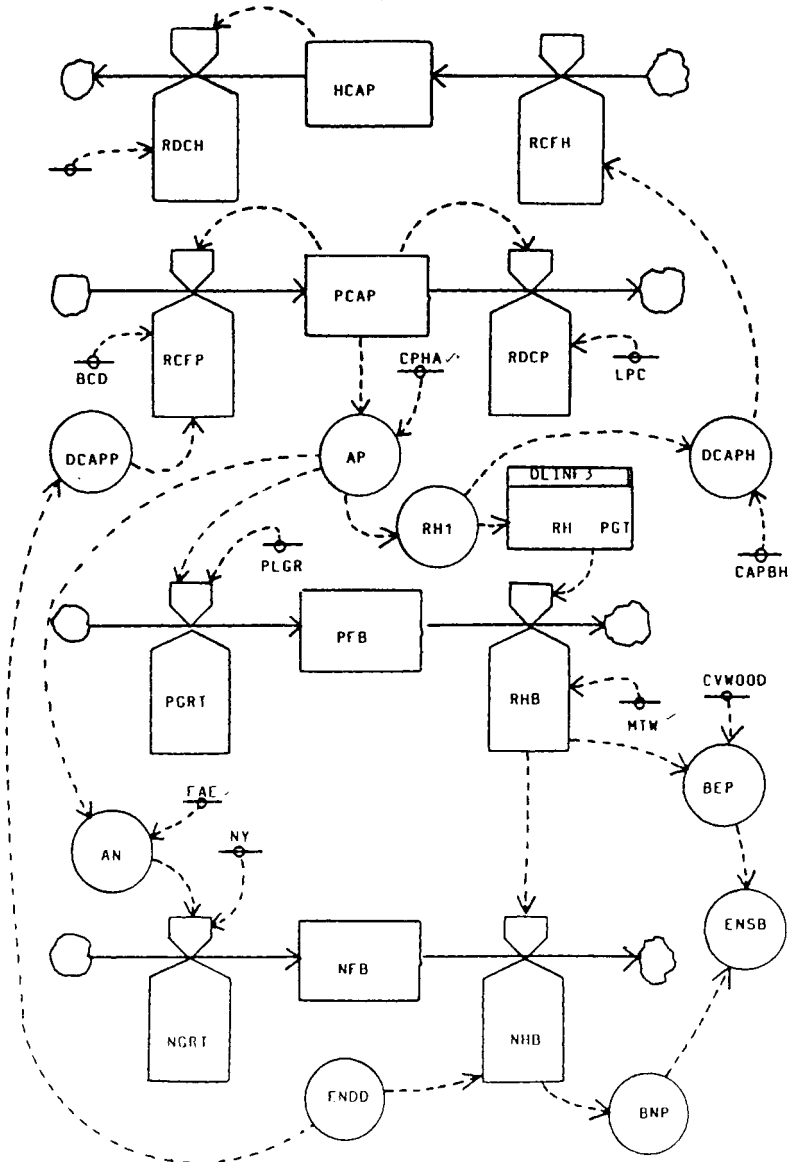


Fig 14. System Dynamics Diagram of ECCO Biomass Sector

EXPLANATION OF SYMBOLS - FIGURE 14

AN	Area of natural forest for bioenergy
AP	Actual area planted
BCD	Desired capital for biomass
BEP	Bioenergy production of plantation
BNP	Bioenergy from natural forest
CAPBH	Capital required for planting
CPHA	Capital required for unit area planted
CVWOOD	Calorific value of wood
DCAPH	Desired capital stock for harvesting
DCAPP	Desired capital for planting
ENDD	Household energy demand
ENSB	Energy shortage in biomass sector
FAE	Total forest area for bioenergy
HCAP	Capital stock for harvesting
LPC	Lifetime of plantation capital
MTW	Mature tree mass per unit area
NFB	Natural forest biomass
NGRT	Natural forest growth rate
NHB	Rate of harvesting natural forest
NY	Natural forest yield per unit area
PCAP	Planting capital stock
PFB	Proportion of forest area for bioenergy
PGRT	Plantation growth rate
PGT	Plantation maturation time
PLGR	Plantation growth rate per unit area
RCFH	Rate of capital formation for harvest
RCFP	Rate of capital formation for planting
RDCH	Rate of capital depreciation
RDCP	Rate of depreciation of planting capital
RH	Actual rate of harvesting
RH1	Future rate of harvesting
RHB	Rate of harvesting biomass

C. NATIONAL PROGRAMMES

**GENERAL CONSIDERATIONS AND PLAN OF ACTION
FOR MASS INTRODUCTION OF RENEWABLE ENERGY
TECHNOLOGIES IN NEXT MALI 5 YEAR
DEVELOPMENT PLAN**

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ABSTRACT

A major programme is now underway to promote greater use of renewable energy resources in Mali. Current activities to assess the potential for using solar, wind and biomass resources and to develop technologies are described. The Mali National Solar Energy Laboratory has designed and now manufactures various pieces of equipment. The current Mali five year plan includes a comprehensive renewable energy programme within its overall plan to promote self-reliance and economic and social development.

INTRODUCTION

In addition to hydroelectric power, renewable energies (RE) are the only national energy resources in Mali. Over 50% of Mali's export receipts go towards oil imports. There are a number of constraints beyond governmental control that limit the exploitation of hydroelectric power. However, there is much potential for exploiting other RE resources. The following sections indicate directions for integrating RE into the most recent five year plan for the economic and social development of Mali.

ENERGY

Petroleum products

The country is entirely dependent on imports. Because of the steady increase in oil prices since 1973, the country cannot meet its needs in accordance with the desired development. From the 1960-70's to 1981, the percentage of imported energy costs compared to Mali export receipts increased from 25% to nearly 50%. The total consumption of these products was about 190,000 tons in 1980 for an annual consumption per head of 28Kgs (one of the lowest rate in the World) compared to respectively 1,100,000 t and 134 kgs in the Republic of Ivory Coast for example.

Hydroelectric power

Mali has at least 17 sites with potential capacities of over 1100 MW, but the possibilities of exploitation are limited because of technical constraints and the high costs. The highly centralised nature of production is incompatible with the decentralised nature and generally low needs of a vast country with a largely (90%) rural population. The Selingue hydroelectric power station illustrates this. In service since 1980 only about one third of its 44 MW power is presently utilised.

Renewable energies

Solar energy

The level of insolation in Mali is one of the highest in the world (on average 4.8 to 6 kwh/sq m/day). For instance, about 20 sq km of photovoltaic cells displayed to such an insolation are sufficient to provide about the equivalent of the country's general consumption of petroleum products and about 1 sq km the equivalent of the total electric energy consumption.

Wind power

Wind speeds average 4-5m/s in areas north of the 14th-15th parallel (Mopti - Timbuctu - San-Nioro). In the centre of the country (including Bamako - the capital city - area) with speeds of 2 to 3 m/s, it can still be exploited. The speeds reach their highest in January and their lowest in October. This distribution, which is the opposite of that of the solar energy, allows a certain complementarity between these two sources.

Biomass energy

In general, the areas where this form of energy would be important are the north of the country and the "Delta Du Niger" (from Macina to Timbuctu). The estimated reserves are quite large, in the range of 1,300,000 TEC/year (TON - Equivalent - Oil). The sole bridge of Manantali is expected to supply 250,000 TEO of wood.

Wood

Wood meets over 90% of the population energy needs. The pressure on the forests due to population growth (2.7% in 1980), coupled with the low rates of regeneration mainly caused by the draught, have led to large scale deforestation. This may become irreversible if the next Mali development plan were not directed towards radical solution. The need for wood for Bamako (BKO) alone will increase from 200,000 in 1982 to 500,000 tons in 1990, whereas prices will go up by 15% a year.

General features of renewable energy

The nature and the considerable potential of R.E make them a major source of national wealth. Their exploitation is appropriate to national development which is directed towards two main targets: self-reliance in food and the fight against desert encroachment. The uses already made of these energies in Mali show the role that they can and must play in achieving these targets.

USAGE OF RENEWABLE ENERGIES IN MALI

Solar photovoltaic power

Solar cells are in use for lighting systems in BKO, Kati, Niore and in some schools and rural sanitary units. Solar fridges (in some dispensaries, including Niore, Ouelessebougou, Gao) are used for the preservation of vaccines. In the hospital in San, sterilisation of material and pumping rely on solar energy. Solar pumping is the most common usage of solar energy in Mali. About 100 solar pumps are already operating with a peak power output of over 100 KW. The first

has been in operation since 1977. The equipment is reliable and economic to run. Two grinding solar mills are operating in Bourem in Aly and in Tonfa (200kgs ground millet/day with a power of 2.6 KW).

Solar chargers of rechargeable batteries designed and made in the Mali National Solar Energy Laboratory (SEL) are available for sale. The wide availability of this product will lead to a reduction of household costs especially in rural areas and to a fall in the considerable importation of dry cell batteries.

At least 25 telecommunication and signalisation systems are already operating in Mali (at R C F M - Railway Company - Police Headquarters, airport). The Post Office has been using solar energy to supply all its isolated stations with energy for some time.

Solar heat

Solar drying sheds for many kinds of products (fish, meat, vegetables, fruit, gypsum etc) are being used in many localities (Mopti, San, Gao, Bamako) as well as solar distillers (San, Gao, Niore, Bougouni).

A solar water heater was the first solar device produce by the SEL. It has been on the market since 1975. Its wider availability could result in a twofold advantage: fall in currency export as a result of the end of importing electrical water heaters and then reduction in electricity consumption.

Solar stoves are a radical solution to the problem of deforestation. Action must be taken especially to ensure its acceptance by the population. It is already being used in some rural training centres (CAR).

Wind power

A windmill used for pumping (4 m diameter wheel) has been operating for some months on a well of 25m in a field in the vicinity of Bamako. It produces 2 to 3 cubic metres/h. Five others are being made entirely by the Solar Energy Laboratory for needy areas. Aerogenerators yield power from wind. It is an excellent solution for isolated and windy areas. Investigations are in progress at the SEL, and there is a possibility of cooperation (for local production) with foreign companies specially one Belgian firm.

Bioconversion

Improved wood stoves

More than 1000 portable improved woodstoves (PIS) have been diffused by SEL in the areas of Gao, San, Bougouni and Bamako. Others have been distributed by the Peace Corps and volunteers from other countries, in other regions, particularly in Bandiagara. The wider availability of PIS is a problem of strategy: to mobilise the population; to organise production; to find better ways of selling and financing all the steps of an operation at national level. Finance has been secured for a project in Bamako. This will be the first step towards solving the numerous problems and lead to systematic and quick popularisation of this product.

Biogas digestors

About 20 are already operating in BKO and Koutiala. SEL is about to install six more in other localities of the country. The gas is used for lighting, cooking, refrigeration, pumping, grinding of grain etc.

Gasogenes

Four generators are already in use producing gas to be converted to power (at the office du Niger at Dogofry). These installations use waste materials from agriculture or agro-industrial production. The generators have reached a level of reliability which allows the popularisation of the process. This opens up important prospects for energy saving in the agro-industry. Mali is participating in the World Bank programme on evaluation of the existing gasogenes, for precise recommendations for diffusion.

Renewable energy is already being developed and exploited in Mali. Mali is one of the leading developing countries as far as efficient use of these energies is concerned. In many cases RE solutions have proved more reliable and profitable (pumping, telecommunications, signalisation). In other cases, only vast diffusion, technical improvements and conditions for a large scale production will bring down costs and make these energies competitive.

At present, RE represents the only possible solution to the energy crisis in many countries. For instance, for the preservation of vaccines in several sanitary units, mechanisation (solar mills) for villages. Can we estimate the number of human lives saved, of alleviated suffering, of time saved and being more efficiently used by women for more productive activities (economical, cultural, social - children education for example) through appropriate introduction of RES?

EXTENSION PROSPECTS OF RENEWABLE ENERGY

All the information given earlier, have accounted for the political decisions of the CEAO (West African Economic Community) to create CRES (Solar Energy Regional Centre) with its production firm and to launch under the supervision of this institution a regional programme for R E equipment.

The elaboration of the national Malian part of this programme has mobilised all the country's sectors of development. The national R E equipment programme has been worked out at a highly appropriate time in order to contribute to the next five years' plan for economic and social development.

The R E programme has been designed within the framework of the Mali national strategy for integrated development from the bottom up and on the basis of national priorities which are:

- In the economic field: self-reliance in food, mastery of water and the strengthening of experience in the reconstitution of cattle; the fight against desert encroachment; the fight to overcome the problems of a land-locked country; the association of the private sector with national industrial development.
- In the social field: to facilitate access to basic education for the majority of the population at school age; to improve and develop health.

- In the energy field: to promote to the optimum development of local energy resources (hydro-power and R E) and that of a better utilisation of energy in all its forms.

In order to reach the targets of this development policy, it will be necessary to consider the possibility of a significant contribution of R E towards meeting development needs. The proposed measures in order to reach these results involve not only local mastery of R E technologies, but also the implementation of all the necessary accompanying actions in motivating, training and maintenance.

The national R E equipment programme (15 well designed, well studied and costed projects) involves all sectors of the economy, as well as all the usages mentioned earlier.

Provisions are being made to equip 1700 villages with RE technology to promote self-reliance in food and the master of water. Against desert encroachment, the programme wants to promote the development of the PIS and the massive introduction of solar and biogas stoves. To overcome problems associated with being a land locked country, independent energy systems are to be installed for telecommunications, the beaconing of airports, radio communications and sign posts on railways. Other targets include:

- Energy savings in the agro-industries of the Office du Niger through the substitution of imported oil by locally produced products, eg alcohol, thus saving 1 million litres of oil per year.
- Saving by households on the cost of wood by using the PIS.
- Job creation to assure the production and the popularisation of the PIS and other R E equipment and their maintenance.
- The improvement of social and economic well-being of populations: (health, education, cultural activities).

The national R E equipment programme which was published as a document, gives detailed information about the projects which have been considered and given priority. It lasts from 1984 to 1989. Its total cost is 13,321,500,000 F CFA, including 11,015,700,000 for R E equipment. The financing needs are estimated at 12,462,600,000 F CFA while the population is expected to contribute 329,050,000 F and the government 529,850,000 F.

CONCLUSION

The national R E equipment programme is the result of a planning study of energy devoted mainly to R E. In energy planning, the philosophy, the approach and the methods differ. The introduced programme will be appropriate for the needs of a land-locked developing country which suffers permanent drought.

The exploitation of national renewable energy resources is one of the objectives in the overall national strategy for economic and social development. It lies with the government to ensure its effective implementation. Only imagination and a political will to develop in the first instance our local resources can give the right and long-lasting solutions.

**THE UNIVERSITY ROLE IN ENERGY STUDIES, MODELLING AND
PLANNING POLICY FOR MAURITIUS**

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ABSTRACT

The current and projected energy situation in Mauritius, including data on energy sectors, supply, and demand, is presented. The role of the University of Mauritius in energy studies, modelling and planning policy is discussed with respect to identified energy research projects, and the need for a technical resource, the University, to be used by both the government and private sectors in Mauritius.

CURRENT ENERGY PICTURE AND ENERGY SECTOR DEVELOPMENT

With the exception of around 11% of the total energy consumption, which is produced locally by hydro electric power stations and through the use of excess bagasse at the sugar factories, the remaining 89% of primary energy consumed is imported petroleum products ie gasoline, diesel, kerosine, fuel oil and LPG (Baguant and Grimmer). (Excluded from this primary energy consumption is bunkering fuels for ships and aircraft and bagasse utilisation for sugar processing.) Imported petroleum products are in the refined form, since the total consumption is not enough to justify setting up a refinery.

Table 1 gives the estimated current primary energy consumption by fuel types and consuming economic sectors for 1980 (Baguant 1982a). Wood and charcoal consumption in the residential sector has not been considered, due to the difficulty of obtaining good data. But, as much as 40% of families may use wood and charcoal for domestic purposes representing approximately 1786×10^9 Btu/yr. If families switched from wood and charcoal use to electricity and fossil fuels for cooking, the increase of fossil fuel importation could be sizeable.

Programmes for developing locally available alternative energy sources have already been initiated. The alternative energy sources, which could have a significant impact on the energy balance of Mauritius in the short term are hydro power and electricity from excess sugar cane bagasse.

In addition to existing hydro power stations (23 MW installed capacity producing an average of 70 GWH of electricity per year), a 30 MW hydro station (Champagne Project) has recently been completed and is expected to produce up to 40 GWH of electricity annually. Thus, the average annual hydroelectricity production is expected to reach 110 GWH representing a fuel oil saving of around 26,000 ton oil equivalent (TOE) computed at 35% thermal conversion efficiency. However, there may yet be difficulties with the availability of water at this new hydro station.

The sugar factories in Mauritius, by making use of excess bagasse and steam, already produce on average 25 GWH of exportable electricity. The fuel oil saving here to the Mauritian Central Electricity Board (C E B) is 6000 TOE.

In the past, bagasse has been viewed as a waste product disposal problem and the bagasse-fired boilers were not designed with high efficiency in mind. It has been shown that, by using steam more efficiently for raw sugar manufacture and by making use of high pressure boilers and condensing turbines as opposed to low pressure boilers and counter pressure turbo alternators, exportable electricity production can be increased 10 fold (Baguant). Such a high pressure steam facility has been installed at the largest of the 21 sugar factories. It is expected in the short term that the total contribution of the sugar industry will be around 80 GWH, representing a fuel oil saving of 19,000 TOE.

FUTURE ENERGY DEMAND AND POTENTIAL ENERGY SECTOR DEVELOPMENT

During the period 1950-80, the total energy consumption in Mauritius, excluding energy in the sugar cane bagasse used by the sugar factories for manufacture of raw sugar, has increased at an average rate of 7-8% per annum. This increase has been in line with increase in GNP (Baguant 1982b).

Based on the results of the analyses of energy/GNP elasticity and assuming that GNP would grow at 3% per annum in real terms, three energy demand levels have been worked out - high, medium and low (Fig. 1). By the year 2010 the energy demand is expected to be in the range 21,000 to 25,000 x 10⁹ Btu (518,000 to 622,650 TOE) representing a 2.5 to 3-fold increase compared to the 1980 level of demand.

The completion of the new hydro power and bagasse power stations will almost double the percentage contribution of local, renewable energy resources to the energy needs of Mauritius. However, to further close the gap between energy demand and energy supply from local resources, and to avoid foreign exchange drainage and sustain the economic development process, efforts to develop locally available alternative energy sources must be reinforced.

The biomass, direct solar energy and other alternative energy sources, which could have a significant impact on the energy balance of Mauritius in the short, medium and long term are listed in Figure 2. The energy end uses where those energy sources are already making a substantial input are indicated as are those areas offering potential for further development.

The role of the University of Mauritius as a major research institution in energy sector development, are discussed in the remainder of the paper.

THE UNIVERSITY RESEARCH ROLE

The role of the University of Mauritius in energy research is discussed here in terms of specific University projects.

Energy systems studies

- a. The University proposed to establish a programme in energy modelling and policy planning for Mauritius. A computerised energy database and spreadsheet software will be used to create computer models of energy

projections. Present university publications on energy sources and demand will be continuously updated.

- b. Assessment of the minimum modular-size unit needed to establish a petroleum refinery in Mauritius should be addressed. The infrastructure for a refinery-based chemical industry would be considered in the economic study, whereby the refinery supplies the by-products of gasoline, diesel, and fuel oil production as chemical feedstocks.
- c. Within the local context, it is necessary to identify local industries (eg sheet metal tank fabrication) that can construct energy and conservation devices. Also, the availability of imported materials (eg glass, plastic film, insulation) needs to be documented.

Hydroelectricity

In view of difficulties with the availability of water at hydroelectric plants for release of water for power production, it may be both desirable and necessary to construct a pumped hydropower system at certain sites, using the existing upper reservoir, and a new daily storage reservoir below the power generating station. Such a pumped hydropower system makes sense only if cheap baseload is available, provided by improved steam utilisation efficiency at sugar factories and economic bagasse storage for year-round bagasse burning. The University proposes to investigate possible hydroelectric sites (eg Champagne Project) where pumped hydro may be feasible, depending on the lower reservoir size and soil properties.

Bagasse

- a. The University proposed to examine whether reduced income from growing high-fibre content cane is offset by the sale of electricity generated by burning bagasse from that cane. (Of course, to give the proper incentives to the sugar factories to generate excess electricity, credit for bagasse-generated electricity at the marginal or replacement cost of C E B electricity would be required. This is another analysis problem).
- b. Methods of bagasse storage during intercrop needs examining. These methods might include baling, pelletising and briquetting. Economically viable strategies need to be developed, and to that effect efforts already initiated at the University must be reinforced and maintained.
- c. Regarding the use of bagasse as a substitute for fuel oil and/or diesel in the tobacco and tea industries, preliminary investigations have already been initiated at the University (Baguant and Grimmer) and it is proposed to extend this analysis to other industries.
- d. The University proposed to examine the use of bagasse in the residential sector. This will include briquetting, pelletisation, carbonisation of bagasse as a substitute for firewood, and the testing of specially designed stoves, in cooperation with the private sector.
- e. In addition to buffering baseload electrical power generated from bagasse through energy storage systems (eg pumped hydro), another way that bagasse could be used for peaking is to transform it into another fuel to

be burned in rapid start-up and shut-down engines and turbines. Bagasse could be transformed into methanol, or carbonised into micron-sized particles and mixed with fuel oil, and burned in engines. Fuel transformation tends to be prohibitive both economically and energywise, and the University proposed to study this problem.

Woody biomass

In order to make use of the woody biomass resource available it is essential to undertake or maintain the following investigations:

- a. Assess the various quantities and qualities of wood that are being used or could be made available for energy purposes.
- b. Identify and assess the techniques which are available for using woody biomass as an energy source in the industrial sector.
- c. In the domestic sector, an ongoing project on the design of various models of wood/charcoal/bagasse pellet stoves must be reinforced. (See parallel plans under "Bagasse").
- d. Based on the resource data findings, an integrated woody biomass strategy for the island needs to be formulated.
- e. International developments on uses and conversion processes of woody biomass need to be continually reviewed.
- f. Systematic forestry management must be maintained in order to avoid deforestation.
- g. Air pollution problems would need to be identified, particularly in urban areas.

Cane Tops and Leaves

- a. A project is in progress at the University to increase the economic value of CTL through production of energy and food. The various aspects being investigated are:
 - The extraction of leaf protein
 - SCP and ethanol production from CTL juice
 - Biogas production through anaerobic digestion of the fibrous residue
 - Synthesis gas production using pyrolysis
 - Electricity production by burning the fibrous residue and raising steam.

Based on results to date, it has been concluded that CTL is an attractive biomass for co-production of energy and food.
- b. More detailed investigations of:
 - Electricity generation from the fibrous residue

- Ethanol or SCP production from the juice have been planned. Some of the aspects identified for further investigations are:
 - Cheaper means of CTL handling and preparation
 - Storing of the fibrous residue during intercrop through baling, etc. (see parallel plans under "Bagasse").
 - Possibility of making low grade ethanol for cooking purposes as opposed to high grade ethanol for gasohol production.
- c. The long term effects of not directly returning CTL to the sugar cane fields as a soil condition, mulch and anti-erosion practice will be examined. The possibility must be examined that the by-product of energy/food processing could be returned to the fields as a sprayed organic emulsion, similar to the way the residues of molasses production are returned to the cane fields.

Molasses

- a. Problems with gasohol such as modifications of existing storage and distribution points, overall energy balance of the strategy ratio of ethanol to gasoline mixture for gasohol and long term effect on engines have yet to be properly investigated in the local context. Most important of all the tradeoff between a lower gasoline import bill on the one hand and a reduction in molasses revenue on the other needs careful consideration.
- b. The use and economics of 94° G L hydrous alcohol needs to be examined. For example, molasses could be diluted with cane juice (containing 5% fermentables) to achieve 10% beer for fermentation, while conserving fresh water. Anhydrous alcohol will operate in engines with only minor modification, and could power irrigation engines, as well as vehicular engines.
- c. Other alternative uses of molasses and/or ethanol need to be investigated:
 - Ethanol as a cooking fuel, to replace kerosene
 - Yeast production as feed for the livestock industry
 - The various ways of using vinasse, an ethanol production by-product, need to be investigated.

Other agricultural and municipal wastes

- a. Given the potential of biogas an energy source, the following work already initiated needs to be reinforced:
 - Improve digester performance through stirring the raw material and controlling its temperature.
 - Improve already designed biogas burners.
 - Demonstrate the fertiliser value of slurry.

- Improve performance of a diesel engine already modified to run on biogas.
 - Possibility of cutting down capital investment by using other materials for construction of the digester and gas holder.
- b. Currently 15% of Port-Louis municipal expense (as an example) is refuse disposal. It would be worthwhile to examine the conversion of municipal wastes into
- Recoverable recyclable materials
 - Combustible fuels

Conversion of municipal wastes into fuels would also reduce the use of petroleum fuels to burn the waste.

Plant oils

Possible plants to provide oil would have to be cyclone resistant or grow in non-cyclone seasons. Such plants would hopefully be suitable for marginally arable land. For example, in the US South-West, the jojoba plant has been found to flourish in extremely harsh climatic conditions, while producing a large quantity of oil. Although suitable for dry, wind blown areas, its resistance to cyclones is unknown.

Solar water heaters

Batch solar water heaters would deliver the most energy for the unit cost. Such heaters have been popular in mild climates with no freezing problems. Mauritius might present an ideal place for their use. Several proposed designs will be studied under CSC funding.

Solar dryers

Additional applications of solar dryers eg drying of tobacco leaves, fish and salt, need to be investigated. Subsequently economic analyses of the various models within the local context need to be carried out.

Solar ponds

- a. For an economically viable solar salt gradient pond, the following conditions are desirable:
- cheap salt
 - impermeable soil
 - soil with low thermal conductivity
 - fresh water for surface flushing
 - minimal rainfall disturbance
 - minimal wind disturbance.

The last two conditions would indicate that solar salt gradient ponds may not be feasible in Mauritius, due to its cyclones. If the thermal gradient is destroyed, the entire pond must be drained, losing the stored heat, and the gradient reinitialised. However, solar salt gradient ponds can be very stable against disturbances. Also, alternative pond designs, such as gel ponds, are a possibility, although very much in an experimental stage.

The University proposes to study solar salt gradient ponds with a small scale (perhaps 10 m²) solar pond to investigate the problems of wind and rain disturbance and the general problems of salt pond stability.

- b. Shallow solar ponds (non-salt-gradient) are also a possibility for batch heaters, particularly in the industrial sector.

Photovoltaic (PV)

- a. In order to be ready for any development in PVs in Mauritius, it is essential that the University staff should be familiar with such aspects as the PV modules available on the market, their characteristic efficiency, proper installation techniques, etc. Demonstration units are to be set up at the University to identify and investigate the possible applications of PV's for small irrigation projects, domestic water supply, and solar cooling. Economic analysis and comparative cost of this energy source would have to be taken into account.
- b. Rodrigues Island is the best site for PV in Mauritius where small scale PV systems could replace the use of diesel generators. (Use of PV on the island of Mauritius does not make much sense at present. There is an extensive utility grid and since peak demands are in the evening and morning solar PV is not a reasonable match to the load peak.)

The University proposes to study the use of PV systems on Rodrigues, paying careful attention to the water-pumping application, problems with salt-infusion to wells, etc. and the general hydrology of Rodrigues, as well as the more straight forward technical aspects of PV water-pumping systems, eg size of array, type of pumps, economics of delivered water, and integration with existing diesel generating systems.

- c. The possibility of setting up a PV module assembly industry in the Export Processing Zone (EPZ) in Mauritius is to be explored. Present PV module construction is quite labour intensive. Inexpensive Mauritian labour could significantly lower costs for modules exported to Australia and African Commonwealth nations. The study will be carried out by the Schools of Industrial Technology and Administration in cooperation with the EPZ Association of the private sector.

Wind energy

- a. There is a need to expand wind resource prospecting with a large number of inexpensive anemometer data loggers. Wind resources are quite site-specific. The University propose to use wind data accumulators with the cooperation of the Meteorological Department, to improve the wind data grid for both Mauritius and Rodrigues.

- b. The mechanism for collaboration that already exists between the Meteorological Department and the University should be reinforced for the benefit of the wind energy programme development.
- c. Underground water pumping and electricity generation for the national grid appear to be an attractive proposition at this stage. However, the effects of underground water removal on ocean salt water infusion needs to be examined carefully.
- d. Problems posed by risk of cyclones, corrosion due to high salt content of the atmosphere, especially in the coastal areas, need to be given careful consideration when designing or selecting wind generators. The University proposes to conduct research on these above problems.

Wave energy

Several problems associated with the wave project have been identified:

- Proper siting of the turbines
- Permeability and strength of the reef
- Ecological impacts of the wave-ramp on the reef and coastal areas (salt water infusion)
- The effect of seasonal variation on the electrical output.

Though it is recognised that wave power will most probably not have an impact on the energy balance of Mauritius during this century, continual monitoring and reviewing of development elsewhere must be maintained.

O T E C

At this stage it is proposed that the University, in collaboration with the Meteorological Department collect appropriate data to evaluate the potential of OTEC systems in Mauritius. Future developments elsewhere need to be properly documented and systematically updated. Eventually, such work will be used in feasibility studies at the appropriate time.

Geothermal energy

The possibility of obtaining assistance from international institutions would appear to be the appropriate strategy for completing the technical work necessary before actually getting into the drilling stage. An academic institution such as the University is in a good position to obtain such assistance and to analyse the geothermal energy potential, for the public and private sectors.

Energy conservation

- a. Conservation efforts should be complemented and reinforced by the development of a more active and systematic conservation programme. Within such a programme, energy consuming sectors need to be identified where conservation could have significant impact in the immediate and long term.

- b. For example, conservation in the transportation sector, which consumes almost 50% of the total primary energy, would have a significant impact on energy savings. One third of the population consumes four-fifths of the fuel, while two thirds consumes one-fifth of it. Approaches to increasing the use of public transport, in particular buses, and away from use of private cars are to be investigated.
- c. In the industrial sector, introduction of systematic energy auditing schemes would help to identify the potential for substantial energy savings. Even at the sugar factories, such schemes would help in saving process steam.
- d. In the residential sector, introduction of new cooking fuels and stoves will reduce the demand for imported kerosine for cooking. Also, the introduction of new housing design based on possible heating/cooling concepts could increase the comfort factor of housing on Mauritius.
- e. Substitution in energy carriers also leads to energy and foreign exchange savings; eg it has been shown that shifting from kerosine to LPG would lead to a decrease in total BTU importation. Policies should therefore be geared towards encouraging such substitution. The University proposes to study these effects, in collaboration with other public and private sector organisations.
- f. The University will continue to participate in energy conservation programmes mounting seminars, workshops, and energy conservation campaigns in close collaboration with the private and government sectors. Training courses in energy management could also be conducted at the University to upgrade the skill of policy makers, planners and plant managers.

CONCLUSION

We have examined various energy sources and uses. Figure 2 shows a matrix diagram linking alternative energy sources (including energy conservation) and energy end uses in the Mauritian energy sectors. The dots indicate possible areas of contribution of the various alternative energy/conservation technologies to the identified energy end uses. (Check marks indicate areas where substantial contribution are already being made). It should be noted that in many areas, the total amount of a given energy source cannot provide enough energy for all the end uses identified. In such cases, the use of an energy source will be dictated by the economics of the situation. Also, it is important not to double-count fuel energy inputs to the electrical generation sector and electrical energy inputs into the remaining sectors.

It is only by overall systems analysis of the energy situation, in a comprehensive Energy studies programme, that the proper development and use of Mauritian energy resources can be undertaken. The University of Mauritius, as the leading technical resource on the island, would be the ideal focus for such energy studies conducted in an apolitical atmosphere for the benefit of both private and government sectors.

ACKNOWLEDGEMENTS

One of the authors (DPG) would like to thank the US Department of State (the Us Information Agency) for its support to him as a Visiting Professor of Energy Studies under the US Fulbright Program. Both authors gratefully acknowledge the cooperation of individuals in the private and government sectors in obtaining the information presented in this paper.

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TABLE 1: Sectoral Energy Consumption, Mauritius - 1980

Consuming Sector	FUEL TYPES							Total	Per cent
	Gasoline Regular	Gasoline Premium	Diesel	Kerosene	Fuel Oil	LPG	Electricity		
Transportation	119	1516	2481	-	-	-	-	4116	47.4
Residential	-	-	-	877	-	76	447 (131)	1400	16.1
Commercial	-	-	-	-	-	-	225 (66)	225	2.6
Industrial	-	-	-	-	514	-	300 (88)	814	9.4
CEB - Internal Uses	-	-	-	-	-	-	14 (4)	14	0.2
Line and Other Losses	-	-	-	-	-	-	225 (66)	225	2.6
TOTAL CONSUMPTION	119	1516	2481	877	514	76	1211 (355)	6794	78.3
CONVERSION LOSSES - CEB									
TOTAL PRIMARY ENERGY INPUT									
NOTE:	(i)	With the exception of figures in () which are in million KWH, all the other figures are in 10 ⁹ BTU.							
	(ii)	The electricity consumed by the individual sectors do not include the portion of energy lost during the electricity generation process. All such conversion losses are indicated separately.							
	(iii)	Percentages are based on the total primary energy consumed.							
	(iv)	The blanks " ____ " indicate that the fuel type is not consumed directly by the economic sector concerned.							

FIGURE 1: Total Energy Demand (1950-2010)

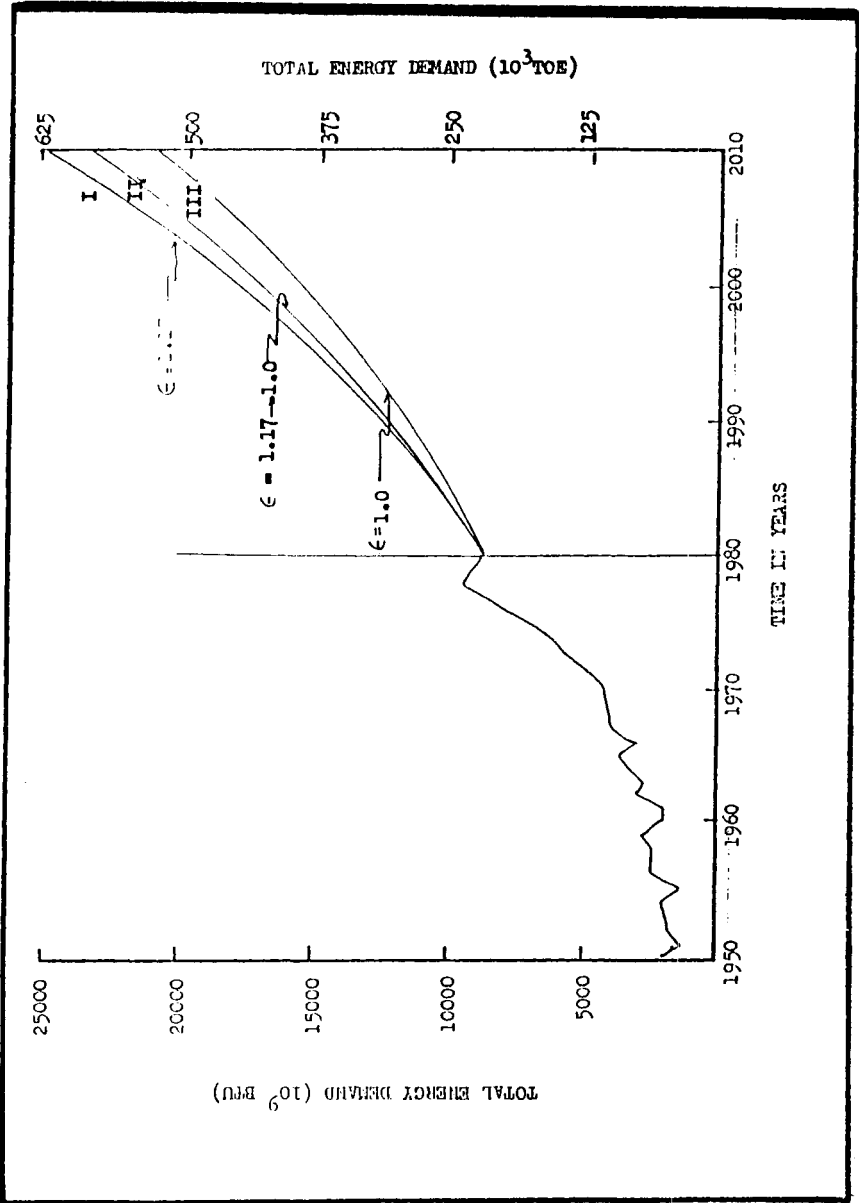
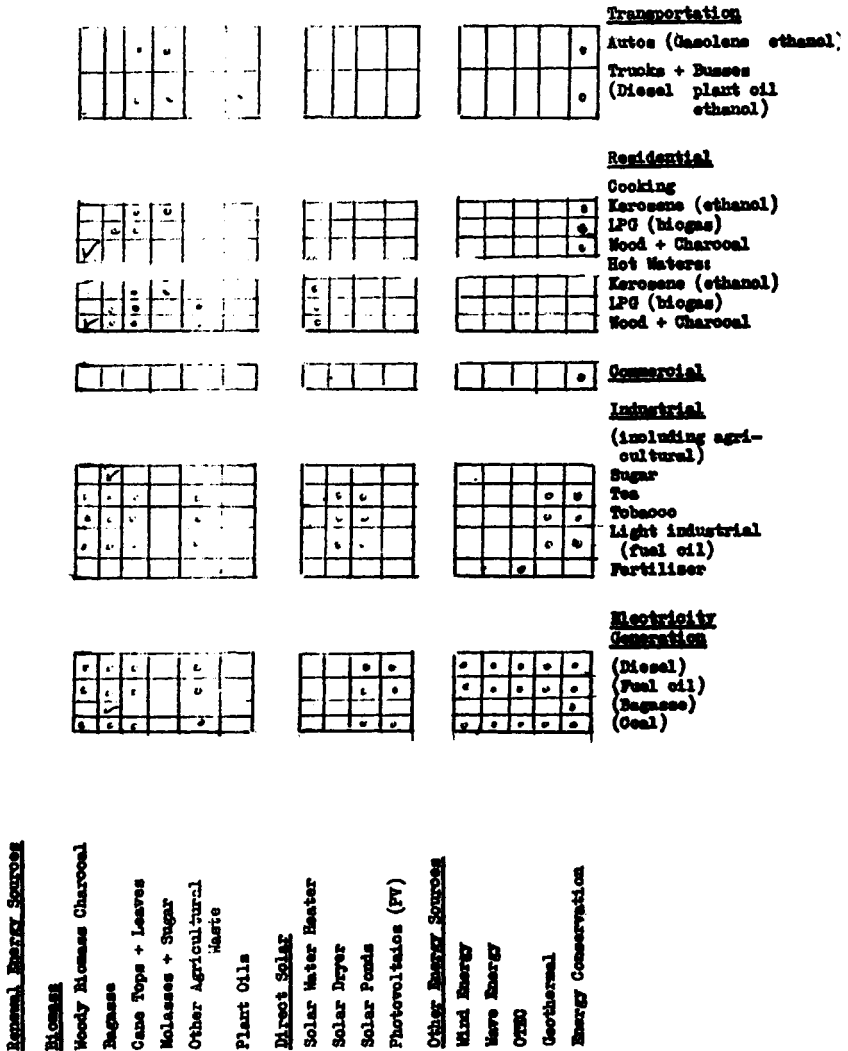


FIGURE 2: Matrix of Energy Sources versus Energy End uses



A MODEL FOR THE PROJECTION OF ENERGY DEMAND IN MAURITIUS

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ABSTRACT

This study sets out to develop a simple econometric model, using electronic spreadsheet analysis, to predict the sectoral and aggregate energy demand of Mauritius until the year 2000. The model is tested for an activity annual growth rate of 3 to 4% and an annual rate of fuel price increase of 5 to 8%. The results indicate that, excluding the sugar sector, some 350,000 TOE of primary energy input would be required annually by the year 2000, a figure far lower than most, if not all, previous estimates. The implications for investment in new capacity are quite important.

INTRODUCTION

Energy planning requires a reasonable knowledge of past energy consumption and a projection of likely future consumption. The most powerful tool for studying energy demand is econometric modelling. This approach uses statistical methods to estimate demand functions in accordance with the economic theory of demand. Econometric methods may be applied at any level of disaggregation, for example total demand, demand for each fuel, and sectoral demand.

This study is concerned with long-term forecasts of energy demand using the econometric approach. The economic parameters income and price elasticities, to be used in the energy demand functions, are derived from historical data. Thus the first part of this study is devoted to the establishment of the energy balance of Mauritius for the period of 1975 to 1983.

THE ENERGY BALANCE

Units

In an energy balance table, it is necessary to convert measurement of all the different fuels to a common basis. Tonnes oil equivalent (TOE) is used in the present study, not only because it is becoming the most universally used energy unit, but also because the primary concern of energy planners in the non-oil producing developing world is to minimise oil imports.

The sugar sector

In Mauritius, the sugar industry, which consumes more than half of the primary energy input, is self-sufficient energy-wise, using bagasse, a by-product of sugar-processing, for all its energy requirements. Energy production and consumption in the sugar sector have been excluded from the energy balance here. However, provision is made for the electricity purchased from the sugar factories for the national grid.

Level of disaggregation

An energy balance is a set of equilibrium relationships to describe the energy supply, conversion and consumption at a point in time. The energy balance is

represented as a matrix or table. The data for different fuel types are disaggregated and the energy consumption is considered separately for the industrial, transport, domestic and commercial sectors.

The primary energy supply is broadly sub-divided into indigenous products and imports, the latter consisting of petroleum products and coal, whereas hydro and bagasse make up the bulk of the indigenous products. The primary energy content of the hydro and bagasse is evaluated on an oil equivalent basis, assuming a conversion efficiency of 33%. The contribution of fuel wood and wood charcoal, which, according to Gillett (1981), accounts for only about 0.5% of the total primary energy input has not been considered because of lack of reliable data. It has also not been possible to obtain consistent data for stock exchange of petroleum products.

Assumptions and computerisation

With the available data, sets of equilibrium relationships are established on the basis of certain assumptions. For example, it is assumed that:

- a. Kerosene and LPG are used exclusively for domestic purposes
- b. Gasoline is used exclusively for transportation
- c. Diesel is used for electricity generation and transportation
- d. Fuel oil is used for electricity generation and industry
- e. Electricity is the only energy input in the commercial sector.

An Electronic Spreadsheet - Multiplan - is used for tabulation and computation. By properly "linking" the various "cells" of the spreadsheet with the appropriate formulae, it only becomes necessary to enter the data, and the computer takes care of all the calculations and displays the values in the appropriate places.

General comments on the energy balance

The energy balance for Mauritius for 1975-83 was computed largely following the format recommended by Meier (1983). A summary of sectoral energy consumption, 1975-83, is presented in Table 1.

Excluding the sugar sector, imported petroleum products account for about 90% of the total primary energy input. This figure has remained virtually constant for the past decade.

The total primary energy supply, increased annually by about 10% during the period 1975 to 1979, and has since declined gradually by about 3% annually.

The production of electricity for the national grid has only been growing at a rate of about 1% annually since 1979.

The transport sector has been by far the largest consumer of energy, accounting for about 60% of total final energy use. The transport sector uses only petroleum products, while all other sectors use at least a certain proportion of high grade energy in the form of electricity. Had the comparison been done instead on the basis of primary energy inputs, the transport sector could have been shown to consume about 50% of the total primary energy input.

THE ECONOMETRIC MODEL

The econometric equation

Energy demand for a particular fuel, i, can be assumed to be a function of:

- a. Economic activity, A, (eg GDP).
- b. Price of the fuel i, P_i .
- c. Price of other substitutes to fuel i, $P_j \neq i$.
- d. A time factor $\phi(t)$.
- e. Physical factors (eg temperature).

As we are here dealing with only one country, the physical factors are ignored. Further, in the present study, the time factor and the effect of fuel substitutes are not considered. With these assumptions, the demand function, D_i , of fuel, i, becomes

$$D_i = f(A, P_i) \tag{1}$$

A widely used demand function is of the log-linear type. Thus

$$D_i = K A^\alpha P_i^\beta \tag{2}$$

where α is the income elasticity and β the price elasticity coefficient of energy demand.

If the activity growth rate is r and the annual increase in fuel price p, then the energy demand after one year, D_1 , relative to the energy consumption, D_0 , for a base year is given by

$$D_1 = D_0 (1+r)^\alpha (1+p)^\beta \tag{3}$$

thus energy demand after the nth year is

$$D_n = D_0 \left\{ (1+r_1) (1+r_2) \dots (1+r_n) \right\}^\alpha \left\{ (1+p_1) (1+p_2) \dots (1+p_n) \right\}^\beta \tag{4}$$

The income elasticity, α , and price elasticity, β , are derived from the historical data contained in Table 1, using the ratio of GDP to consumer price index as a measure of activity, A. The actual values of A, r and p used for the calculation of α and β by linear regression methods are shown in Table 2.

Sectoral energy demand forecast

Energy demand forecasts to 2000 are summarised in Table 3 and Figure 1, taking 1983 as the base year.

For the transport and industrial sectors α and β were calculated at 1.15 and -0.20 respectively. It was assumed that there would be an activity annual growth rate of 3% until 1990, 3.5% until 1995 and finally 4% until the year 2000, as well as a rate of fuel price increase of 5% annually until 1990 and 8% thereafter.

Given these assumptions it is forecast that the transport sector will require some 143,000 toe annually as primary energy input by the year 2000 and the industrial sector will have a two-fold increase in energy requirements by the year 2000 (Table 3, Figure 1).

The projection of energy demand for the commercial and domestic sectors has been computed on the assumption that $\alpha = 1$.

Projection of total energy demand

The sectoral energy demand for each year is aggregated to the total energy demand as illustrated in Figure 1. The model indicates that the aggregate energy demand for the year 2000 would be slightly less than 250,000 TOE. When allowance is made for conversion losses, the total primary energy input required would be of the order 250,000 TOE for 1990 and about 340,000 TOE for the year 2000. These figures are very low when compared to previous estimates; for example, a World Bank/UNDP study (Ahmed *et al* 1981) indicates that the primary energy requirements for the year 1990 would be of the order of 295,000 to 330,000 TOE, which far exceeds our estimate.

A rough estimate also indicates that petroleum requirements for the year 2000 would be about 290,000 TOE.

CONCLUSIONS

Any forecast will be at best an approximation to an unforeseeable future. However, provided there is a reasonable amount of accurate data, econometric methods have been known to yield fairly accurate forecasts.

In the present study, it can be argued that the econometric parameters such as income and price elasticity coefficients derived from historical data may not be appropriate for the projection model. Similarly, the assumptions regarding activity growth rate and estimated increases in fuel price may be questioned. However, the beauty of electronic spread-sheet analysis is that all computed values of the energy balance table automatically adjust themselves once any parameter (or any other data) is changed. The above exercise can therefore be carried out for any other assumptions or scenarios, without sacrificing time. In fact this method lends itself very appropriately to "what-if" analysis and close monitoring.

Despite the uncertainties inherent in any projection exercise, our estimates of energy demand fall far short of all previous estimates. The far-reaching implications of heavy investment in new capital equipment should therefore be looked into more judiciously.

With the exception of the sugar industry, the transport sector will remain the main consumer of energy. In order to reduce our dependence on imported fuel appreciably, the production of indigenous substitutes should be seriously considered.

Although the present econometric model has been applied specifically to Mauritius, it can be easily adapted to any other country.

ACKNOWLEDGEMENT

I wish to place on record the valuable contribution of Dr Ray Tomkins, of the Management Science Department, Imperial College of Science and Technology, University of London, for his advice and suggestions to use electronic spreadsheet analysis.

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TABLE 1: Sectoral Energy Consumption - 1975 to 1983

(All units in TOE)

Energy Sector	1975	1976	1977	1978	1979	1980	1981	1982	1983
Industrial	14,215	21,030	22,930	24,960	23,263	22,865	22,250	21,740	21,140
Domestic	24,890	29,465	34,625	38,560	39,451	36,614	30,410	30,480	29,650
Commercial	4770	4795	4950	5480	6060	5865	6060	6430	6480
Transport	80,810	90,680	100,105	104,120	102,123	91,040	97,970	90,780	91,995
Total energy use	124,685	145,970	162,610	173,120	170,897	156,384	156,690	149,430	149,265
Total primary energy supply	163,925	192,910	216,640	230,560	232,940	214,505	213,880	207,590	206,145

TABLE 2: Some Economic Parameters used to evaluate
Income elasticity (α) and price elasticity (β)

Year	GDP (at factor cost) Rs Million	A = $\frac{\text{GDP}}{\text{CPI}}$	Growth Rate r	Rate of fuel price increase p
1975	3090	2687	-	-
1976	3666	2864	0.066	0.21
1977	4357	3090	0.079	0.05
1978	4875	3186	0.031	0.02
1979	6540	3737	0.173	0.37
1980	7389	2979	-0.203	0.95
1981	8765	3086	0.036	-
1982	10,050	3160	0.024	-
1983	10,650	3170	0.003	-

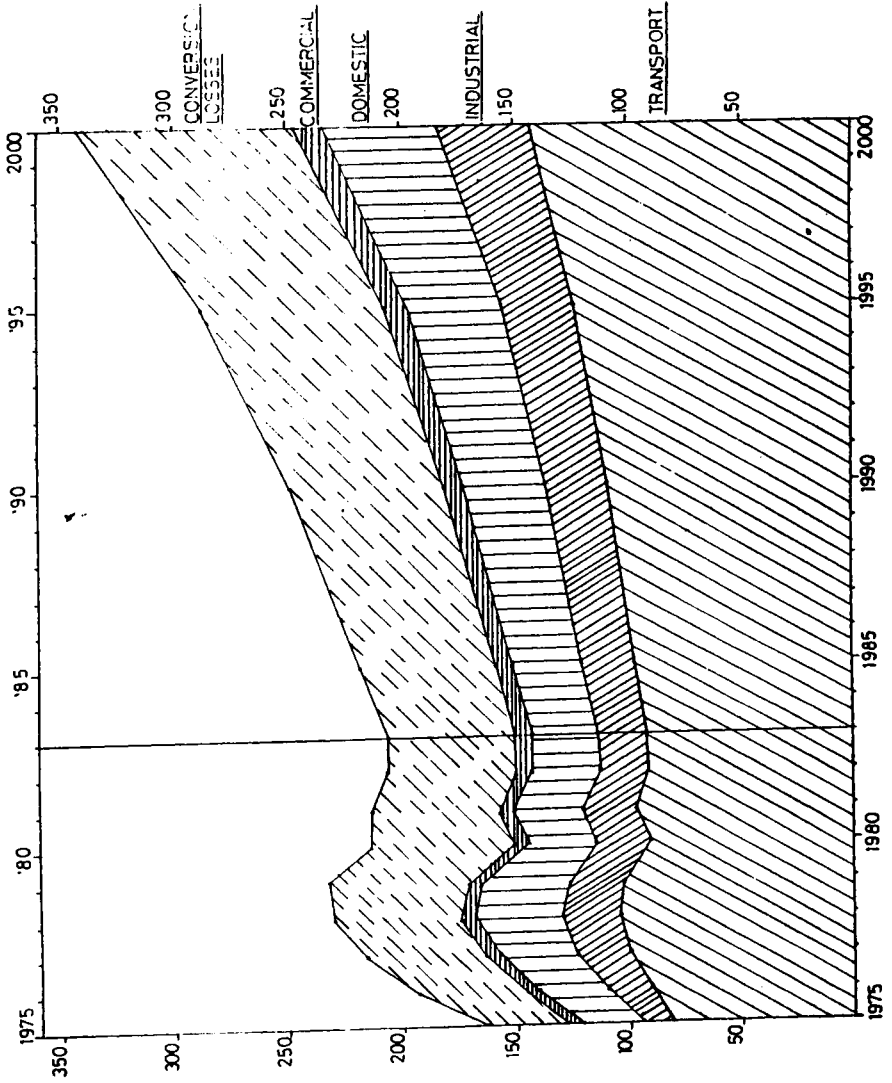
TABLE 3: Sectoral Energy Demand Forecast until the Year 2000

(All Units in TOE)

Sector	1983	1985	1990	1995	2000
Industrial	21,140	22,600	26,800	32,000	40,000
Domestic	29,650	31,400	36,400	43,000	52,000
Commercial	6480	6900	8000	9500	11500
Transport	91,995	97,500	109,000	123,000	143,000
Total energy demand	149,265	158,400	180,200	207,500	246,500
Required total Primary Energy Supply (incl. conversion losses)	206,000	218,600	248,600	288,400	342,600
Total energy supply* UNDP/WB (1981) AEP Scenario		255,000	295,000		
BC Scenario		270,000	330,000		
Required petroleum products	189,000	186,000	211,000	245,000	290,000

* Figures given for comparison purposes
From Ahmed et al (1981).

FIGURE 1: Sectoral Energy Demand Forecast



**RESEARCH AND DEVELOPMENT EFFORTS IN
RENEWABLE ENERGY TECHNOLOGIES IN NIGERIA**

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ABSTRACT

Despite Nigeria's position as an oil exporting country, there is an important role for renewable energy in the present and future. Nigeria has enormous renewable energy resources. These could adequately supplement conventional energy. But this will require the development of efficient and economical indigenous technological. Renewable energy activities in Nigeria over the last 15-20 years are reviewed. This rather slow (compared to many other African countries) development of renewable energy technologies is attributed to the lack of a comprehensive energy policy in the past.

INTRODUCTION

At present Nigeria is mainly dependent on conventional energy sources (coal, oil, gas, and hydropower) except for firewood which has been the major source of energy in rural areas for a long time. The role of renewable energy sources in Nigeria can be defined as supplementary for the present with great potential for meeting a much more substantial part of the future energy needs of the country.

The renewable energy technologies are at various stages of development in many countries of the world. This paper reports on the research and development efforts made in Nigeria in various renewable energy technologies. Information given here has been obtained through various Nigerian and international publications on renewable energy technologies and related areas, and personal communications of the authors with other researchers in the country.

RESEARCH AND DEVELOPMENT EFFORTS IN RENEWABLE ENERGY TECHNOLOGIES

Renewable energy research and development activities have been going on for the last 15-20 years. Participation of private sector in renewable energy research and development has been negligible. There are only a few multinational companies in this field, and they have only been interested in commercialising some imported renewable energy systems. Most research emanates from research institutes, universities, polytechnics and colleges of technology.

Activities in renewable energy technologies

Solar radiation and wind data

A considerable amount of effort has been directed to the collection of solar radiation and wind data for various locations in the country. The International Institute for Tropical Research, Ibadan has collected such data for Ibadan for the last 15 years or so. Similarly, the Road and Building Research Institute, Lagos has installed a number of recording units at various locations in the federation, recently. Many research institutes and universities have also tried to collect the data for their geographical areas.

Various empirical relations and models have been worked out. Sun tables and charts are being evolved. The effect of the period of harmattan when the atmosphere is filled with suspended dust particles has been assessed. Such a period last for about 3-4 months in the northern part of the country.

Some attempts to find the optimum angle of tilt for various locations have been made. Elementary approaches towards the construction of radiation measuring instruments and sunfinders have also been explored. A preliminary attempt to plot a solar map of Nigeria has been made (Figure 1).

Solar Thermal Systems

A number of systems have been designed and constructed in various institutions.

Flat plate collectors A number of flat plate collectors have been made, designed and constructed, usually from locally available materials. However, there has been little follow-up to improve their performances. Imported flat plate collectors have been used in solar water heaters, dryers and refrigeration systems and their performance evaluated. Locally constructed spiral-type collectors have also been tested.

Concentrating collectors Various concentrating techniques have been tried at a number of places using mainly parabolic, cylindrical, conical and fresnel type collectors.

Selective coatings University of Nigeria, Nsukka and University of Sokoto have reported some efforts towards the development of selective coatings. Studies on spectral emissivity of layered systems have been conducted.

Tracking systems Because of the abundance of solar radiation in Nigeria, little importance has been attached to developing tracking systems. Studies on tracking versus non-tracking have been undertaken at a few locations. A photovoltaic powered tracker has been developed at the University of Lagos.

Solar water heaters A number of low cost solar water heaters have been designed and evaluated. Solar water heaters have considerable potential in both the domestic and industrial sectors, but only a few are actually in use in the country.

Solar cookers and ovens Solar cookers and ovens have attracted a lot of interest in Nigeria particularly by researchers at Bida, Sokoto and Enuga. Various types - parabolic, box-type with or without boosters, and fresnel-type solar cookers and ovens - have been fabricated. Temperatures up to 200°C have been achieved. Several types of local food items have been cooked in reasonable times in these solar cookers and ovens. Figure 2 shows a locally fabricated box-type solar oven with two boosters. Indoor solar kitchens with a roof that directs solar radiation onto the cooking area are being designed. Studies on the possible assistance of solar energy in baking and other purposes have also been reported.

Solar dryers Hot box and separate collector solar dryers have been fabricated for drying grain, fruit, fish and vegetables. Studies of performance and economics aspects have been undertaken. Researchers at Nsukka, Ife, Lagos, Ibadan, Kano, Bida and Zaria for example, have made considerable efforts to develop dryers to minimise the spoilage of agricultural produce. Recently, the Institute of Oceanography and Marine Research, Lagos has developed a commercially feasible solar dryer for fish.

Solar stills Proto-type solar stills have been constructed at Lagos, Bida, Kaduna and Sokoto. Predicted and actual performance studies, and mass-energy balance studies of some of the solar stills have been undertaken. Large-scale solar distillation plants for rural areas where the water supplies are unhygienic have been suggested. Distillation rates of the order of 0.8kg/m^2 to 1.2kg/m^2 have been obtained in places with average sunshine.

Solar refrigeration and air conditioning Solar refrigeration and air conditioning has enormous potential in rural Nigeria particularly for storage of food, and drugs. Unfortunately, there have been few break-throughs. Attempts have been made to fabricate aqua-ammonia refrigerating systems powered with solar energy at Zaria, Nsukka, Lagos, Bida, Ife and Port Harcourt. Studies on solar-driven organic jet ejectors have also been reported. The possibility of distributing centrally-generated chilled fluid for solar cooling systems has been considered.

Solar thermal powered engines Only some theoretical studies have been reported in this area. No practical development has taken place so far.

Integration of solar thermal systems into agro and other industrial setups Apart from the studies on solar thermal energy applications in agricultural and industrial processes mentioned above, only a few theoretical studies on other aspects such as seed germinators, incubators, large-scale distillation units, process heat units, and solar ponds have been carried out. No practical results have so far emerged.

Solar Photovoltaic Systems

Very little effort has been made to develop indigenous photovoltaic technology. This may be due to the capital intensive nature of the technology.

Solar cells Photovoltaic studies in organic dyes and $(\text{pbl}_2)_{1-x}(\text{KI})_x$ alloys have been undertaken and attempts made recently to fabricate wide band solar cells. There are plans at various universities including the Sokoto Energy Research Centre to construct various types of solar cells.

Characterisation of solar cells and modules Attempts have been made to characterise solar cells and modules manufactured overseas. Studies on I-V curves at various insolation levels, effect of temperature on power output, matching of load with modules, effect of environmental conditions on the output, efficiency, spectral sensitivity and optimum angle of tilt of modules have been carried out. Most cells and modules being studied are mono-crystal silicon solar cells. Theoretical studies have been carried out on the possible performance of other types of solar cells in local climatic conditions. Some theoretical studies on the application of microprocessors for automatic control of modules have been carried out at Sokoto.

Photovoltaic pumps A demonstration project at Tungar Buzu, Sokoto State for the supply of drinking water to a small rural community has been set up. In addition, photovoltaic pumps have been installed in some individuals' houses. Much has been written about the potential of photovoltaic pumps for micro-irrigation and rural water supplies. Plans are underway to install imported pumps in rural and remote locations and study the feasibility of their use in local conditions. A number of multinational companies have attempted to commercialise photovoltaic pumps in Nigeria. Success has been limited due to

their inability to recognise the need to evaluate their technologies under local conditions.

Photovoltaic powered televisions There is an important role for photovoltaic powered televisions for education and enlightenment in rural and remote areas not connected to the national electricity grid. A community TV viewing centre at Zauro, Sokoto State has been set up and studies have been reported on matching a household television with photovoltaic modules.

Photovoltaic powered communication systems There is much potential for using photovoltaic power especially in remote places. These include railway signalling, transmitting and booster stations and road traffic control. The Sokoto Energy Research Centre has initiated a project to power its intercom systems with photovoltaic modules.

Photovoltaic powered cathodic protection systems Nigeria has long oil pipe lines and there is scope for introducing photovoltaic powered cathodic protection systems. No practical projects or studies have as yet been proposed.

Remote home power systems At Birnin-Kebbi, a proto-type house has been powered with photovoltaic modules for all its electricity requirements and the results have been encouraging.

Passive solar systems

Although passive solar technology has tremendous scope, particularly for keeping buildings cool, in Nigeria, little research has been directed to the field.

Solar passive architectural buildings Studies on energy consumption in residential buildings, thermal performances and thermal comfort levels in traditional and modern buildings etc. have been reported. Proto-type solar passive houses have been constructed at Ife and Birnin-Kebbi. A number of passive and integrated energy houses are being conceived at a number of locations. The integration of such architecture in the national and states housing programmes is being recommended.

Passive cooling systems Two passive coolers have been developed at Sokoto and Maiduguri. Concepts of evaporative cooling, roof ponds etc. are being considered. Such passive coolers when fully developed might reduce the electricity demands in urban areas by substituting for air conditioners. They will also be very useful in rural areas where there are no cooling systems.

Wind Energy Systems A number of windmills have been installed for pumping water. Some were installed more than two decades ago and the majority are now broken and abandoned. Studies on the potential of windpower for different locations have been carried out. The Sokoto Energy Research Centre is presently involved in reactivating some of these old windmills.

Biomass Biomass has not been given enough attention and it is only recently that the potentials of biomass in Nigeria has started to be appreciated.

Biogas systems The biogas potential in Nigeria has been estimated. Prototype biogas digesters (continuous and batch feeding types) have been fabricated at Ife, Zaria, Birnin Kebbi and Sokoto. Production of biogas from different animal manures, Eupatorium odoratum, algae and other agricultural wastes has been

studied. Analytical studies of biogas produced and its end-use systems are at developmental stages. Figure 4 shows a locally fabricated prototype biogas plant.

Fuelwood This area requires immediate attention. Shortage of fuelwood, draught and desertification are major problems in Nigeria. Patterns of supply and consumption of fuelwood have been studied and various exotic and indigenous tree species have been identified for fuelwood production. Community woodlots, shelterbelts, agroforestry etc. are the major focus of research. Studies on combustion-related characteristics of various plant species concerning their suitability as domestic fuel have been carried out at Ibadan. The Federal Department of Forestry has been involved in this area for a long time. Various State Governments and the Federal Government have planned tree-plantation programmes. The Sokoto Energy Research Centre in conjunction with the Faculty of Agriculture of the University of Sokoto is planning a long-term research programme on fuelwood for the sudan savanna region of Nigeria.

Woodstoves Most of rural population in this country uses fuelwood for cooking and water heating. The traditional three-stone type of stove is very wasteful of energy. The Sokoto Energy Research Centre is developing more efficient woodstoves. Three types of such stoves to suit different sizes of families have been fabricated (Figure 3) and are presently being tested for further improvements and popularisation.

Other biomass utilisation technologies Other potential technologies include combustible gases and liquid fuels, pyrolysis, aerobic fermentation etc. No practical applications have been reported so far.

Energy Storage Systems Thermal energy storage systems studies on thermochemical storage have been carried out at Sokoto and Zaria and are being considered at various other places.

Electrical energy storage systems Commonly available lead-acid batteries have been used for storing electrical energy in most of the photovoltaic installations. There is a need for developing suitable electrical energy storage systems. Such developments will broaden the scope of photovoltaics, particularly where electricity is required for night-use such as street and home lights etc.

Energy conservation

Interest in energy conservation is growing. The potential for conserving conventional energy in different sectors of the economy and the possibility of integrating them with renewable energy systems have been considered. Some energy conservation monitoring devices have been reported.

Integrated and rural energy systems

Integrated and rural energy projects are underway at Ife, Ibadan and Sokoto. The energy supply and consumption patterns of some rural communities are being studied and the possibilities of incorporating renewable energy systems to improve the living conditions are being explored.

Training and manpower development programmes

The availability of suitable manpower is essential to the success of any programme. Plans are underway to start high level training programmes in renewable energy technologies at the Sokoto Energy Research Centre of the University of Sokoto, Solar Energy Research Centre of the University of Nigeria, Nsukka, and the Yola Campus of the University of Maiduguri. Training programmes for middle-level manpower are being set up at the Federal Polytechnic, Bida and the Sokoto State Polytechnic, Birnin-Kebbi. A proposal for an integrated approach to training and manpower development in renewable energy technologies has been put forward by the authors of this paper at a recent national conference.

CONCLUSIONS AND FUTURE PROSPECTS

- a) Nigeria has an enormous potential of renewable energy sources. Conventional energy sources are finite and are likely to be exhaustible in the not too distant future.
 - b) To harness these renewable energy sources particularly in rural areas, considerable research and development efforts are necessary.
 - c) Research and development activities have been in progress for some time. But in most cases with no defined goals and the "development" aspect of renewable energy technology has not been considered. Private sector involvement in these activities has been negligible.
 - d) The Federal Government has started supporting these activities recently. It has established two energy research centres at Sokoto and Nsukka for training, research and development in solar and other renewable energy technologies.
 - e) There is a need for a more collaborative and cooperative approach among the organisations involved in renewable energy technologies development. A comprehensive national renewable energy programme has to be evolved to coordinate and streamline these activities.
 - f) We believe that with the present backing of various governments and with the active participation of the private sector, the future will see the mass adaptation of renewable energy systems in various sectors of Nigerian economy.
- * A bibliography of published papers on renewable energy research in Nigeria is available from the authors.

FIGURE 1: Preliminary solar radiation map of Nigeria.

(Year averages for the ration of measured solar radiation on a horizontal surface on ground in a day, H, and extra-terrestrial irradiation in the day, H₀)

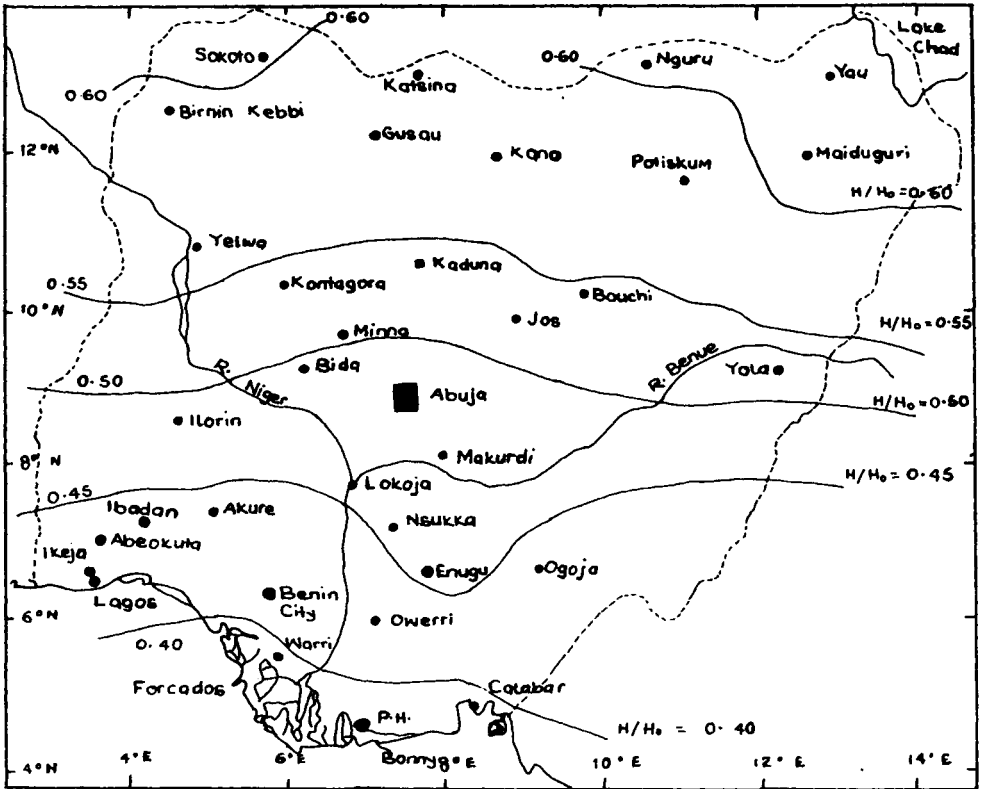


FIGURE 2: A locally fabricated solar oven

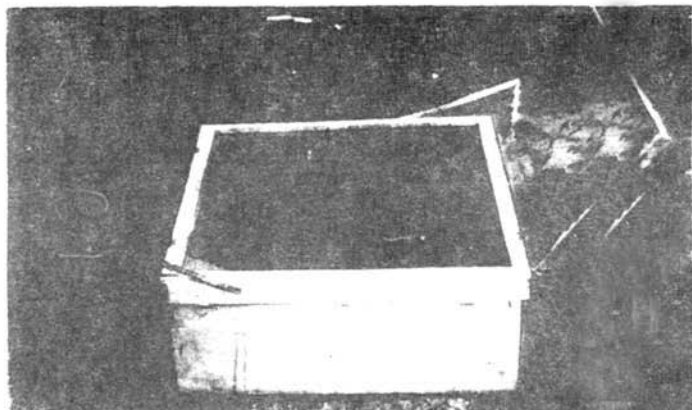


FIGURE 3: Woodstoves under testing

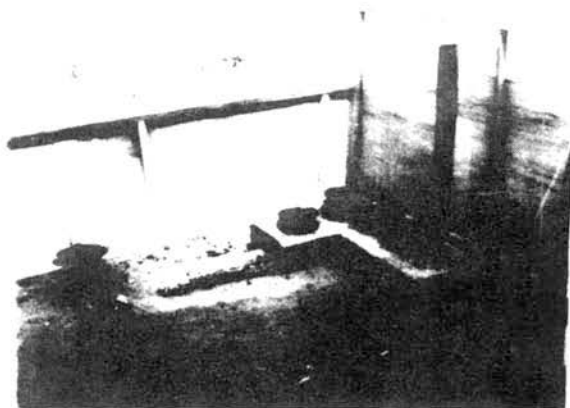
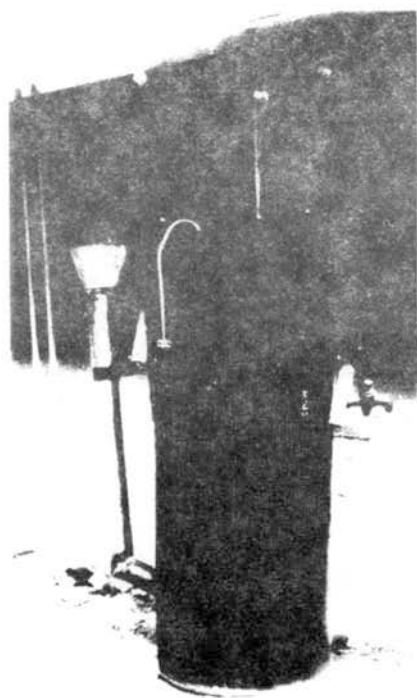


FIGURE 4: A prototype biogas plant



RENEWABLE ENERGY ACTIVITIES IN SENEGAL

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ABSTRACT

Available data suggest that Senegal has considerable potential new and renewable energy resources, including solar, wind, biomass, hydro and peat and lignite. This sector has only recently become established. Existing programmes are discussed. Government and organisational involvement, financing and manpower training are outlined.

INTRODUCTION

Senegal faces two major energy problems: the rising cost of petroleum (CFA francs 81 billion in 1983) which consumes more than 50% of the export earnings and accelerating deforestation (120,000 ha forest destroyed each year).

A programme known as "RENES" (Energy Redeployment in Senegal) has been established which at present constitutes the only reference and guide for action in the energy field until a national strategy has been formulated. Through the RENES programme, Senegal aims to halve its import of petroleum products by 1990 and replace them by local energy resources.

This paper describes the activities and organisations established to promote the development of new and renewable energy resources in Senegal.

AVAILABLE NEW AND RENEWABLE ENERGY

Solar energy

Solar energy has been used for more than 20 years in Dakar where the levels of radiation are recorded routinely. Average values for the area are:

- global radiation : 5.8 kWh/ m²/d
- horizontal diffuse radiation : 2.07 kWh/m²/d

Solar intensities are less well known for the rest of the country. In cooperation with the national meteorological services 9 measuring stations have recently been set up in the interior (Podor, Louga, Linguere, Bambey, Tambacounda, Kedougou, Ziguinchor) in order to evaluate the potential solar energy. However accurate up-to-date solar data are not yet available in these regions.

Wind energy

A dozen national meteorology stations set up at airports measure wind speed and direction. Analysis of data over a period of five years shows that the wind potential which can be exploited in Senegal is limited to a 30-40km wide coastal strip going from Saint-Louis to Sine-Saloum, as well as along the river Senegal from its mouth to Rosso. The average maximum speeds are from 5 to 6 m/s. Further data have been obtained by a network of measuring stations established in recent years throughout the country.

Biomass

Potential sources of biomass in Senegal include: forests and natural vegetation; waste and agricultural by-products; and seaweeds collected on the coast. To these products can be added plants designed to produce domestic fuel. This source is still insufficiently developed in particular for the cultivation of fast growing species such as eucalyptus and graminaceous plants.

A recent study, funded by the Danish government and conducted by GOWICONSULT-ORGATES, on the efficient use of agricultural by-products as domestic fuel has shown the existence of an important biomass potential south of the Kaolack-Tambacounda line whereas biomass resources are rarer north of this line. Projections over 10 years of the available agricultural waste and by-products give estimates of 762,000 tons biomass for 1984-85 and 1,345,000 tons for 1993-94.

Hydroelectricity

In addition to the large hydroelectric power stations (eg Manantali, Kekreti, Sambagalou) important possibilities for mini and micro power stations exist on the Senegal and Gambia rivers. A study financed by CEE and carried out by ORGATEC has made an inventory on the rivers of a certain number of sites that may be equipped with micro water power stations.

Other sources

Although the newly found peat and lignite resources are not renewable they are a an indigenous source of energy. The Nyayes peat bed estimated at 50 million m³, is now undergoing an important development programme. Lignite and mangrove peat deposits are currently being evaluated and exploration is now under way.

Energy conservation measures must be taken into account in defining any coherent energy policy. In a study by a Canadian company Gaucher Pringle, it was estimated that Senegal could save 63,000 TEP in the industrial and transport sectors.

PROGRAMMES

In addition to the solar and wind potential evaluation programme, other programmes have already been implemented or are in the process of being set up by various bodies and institutions.

Heat and thermodynamics programmes

Water heating

The water heater currently marketed in Senegal will be assembled by the Industrial Company for Solar Energy Applications (SINAES) industrial unit now being built in Thies. It is well designed but expensive. SINAES is working to develop a cheaper water-heater made with local materials.

Solar drying

Two types of dryers have been developed for the processing of fish: one at the food technology institute (ITA) and another at CERER. They are respectively:

- a cheap individual small scale construction in the form of a drying tent,
- a semi industrial type with plane collectors designed for cooperative use. A 100 m² model that can dry 750 kg of fish in two days has been in operations at Guet Ndar (Saint-Louis) since November 1983.

Model dryers have also been designed for agricultural products and fodder.

Solar distillation

A modular distiller with a surface of 2.3 m² has been developed. An 80 m² distiller, designed for the CNRA at Bambey, is to be constructed once the tests have led to reliable conclusions.

Pumping

In 1976, four thermodynamic solar pumps manufactured by SOFRETES were installed to provide the concerned villagers with drinking water. Nine years later, none of these pumps are in good working order. More reliable equipment has been designed and will replace these.

Generation of electricity by means of thermo-dynamics line

Design faults have also been a problem in thermo-dynamic projects. The Diakhao power generation station never worked satisfactorily. The project to build a 100 kw generating station in the Fleuve Region has been modified. The thermo-dynamics source initially chosen was abandoned in favour of a photovoltaic option.

Photovoltaic line

Basic research on photocells

The Faculty of Science of the University of Dakar has been carrying out basic research on semiconductors.

Pumping

Several experimental and pilot plants have proved more successful than thermo-dynamic pumps. A programme to develop a pumping system to supply medium range power (25-50 kw) is currently being planned and negotiations for external funding are underway.

Rural electrification

Only one application exists in this area at the moment: the experimental centre for energy in rural areas at Niaga Wolof, where a 5 kw photovoltaic generator coupled to a 4.6 kv aero generator provides the village with electrical energy.

Other applications

Within the programme known as "use of new and renewable energy" a pilot experiment is successfully supplying photocell electrical energy to a health centre at Mont-Rolland.

The Post Office and Telecommunications of Senegal has "solarised" the North axis Hertzian beams situated between Bakel and Matam and plans to do the same with the Hertzian relays between Kaolack and Ziguinchor.

Biomass

Production of vegetable briquettes

A study on the use of agricultural byproducts as domestic fuel was completed in July 1984. This study, carried out by COWICONSULT-ORGATEC, proposed a ten year master plan to use rationally agricultural byproducts. The programme will explore the production of briquettes from agricultural products and their use as domestic fuels.

Fermentation

Various types of methane fermentors are under study, eg at the Senegalese Institute for Agricultural Research (ISRA), the University Institute of Technology (ENSUT) and CERER. These studies are oriented towards the production of methane and promotion of the widespread use of equipment adapted to locally available raw materials and to the social and cultural habits of the rural population.

A feasibility study on the building of a bagasse or sugar molasses alcohol production unit is to be conducted by a Brazilian company.

Gasification and Pyrolysis

A feasibility study of a pyrolysis plant was begun by SONACOS, but abandoned due to the unavailability of the raw materials, groundnut shells. In compliance with the fifth programme of development for Senegal, FED has agreed to finance the construction of a biomass power station. A feasibility study is underway.

The problem of the availability of raw materials, could be solved by the increased production of ground nuts resulting from the completion of dams currently under construction.

Energy conservation activities

Improved Stoves

CERER has developed two types of improved stoves. For rural communities, a wood-burning stove called Ban Ak Suuf has been perfected. This stove, made from clay and sand, consumed 30-40% less wood than traditional open-fire cooking. Moreover, the model currently being encouraged throughout the country has been adapted to local socio-cultural traditions. More than 12,000 stoves have already been constructed. Funding has just been granted to continue the programme, whose objective is to construct 300,000-500,000 stoves.

For urban areas, a charcoal burning stove called Sakanal has been perfected. This metal stove consumes 40-50% less charcoal than traditional malgache stoves.

Peat Development

Combustion tests on briquettes made of a mixture of peat and charcoal have given satisfactory results. Also, feasibility studies conducted by the Senegalese Peat Company on the use of peat as a domestic fuel substitute for charcoal have revealed very interesting conclusions. A plan for the construction of a production centre for peat briquettes has been formulated and presented to financial backers who have already expressed interest in the project. However, the peat plant programme is moving slowly. A counter-evaluation, already underway, has been asked for by the World Bank.

Wind Energy

Research into the development of wind energy has been divided between the Ecole Polytechnique of Thies (EPT) and ENSUT. In the first phase EPT conducted research on rapid rotation windmills (aerogenerators), while ENSUT concentrated on problems with slow rotation windmills and coupling of photovoltaic cells to aerogenerators for pumping.

Upkeep and maintenance of new and renewable energy equipment

The majority of equipment installed in Senegal to date has been for purposes of research and experimentation and therefore, provisions for maintenance have been overlooked during the initial planning stages. Unfortunately, this has often led to difficulties.

To rectify this oversight, 25 million CFA francs was released by the National Energy Fund to SINAES to provide for the upkeep and maintenance of new and renewable energy installations.

Negotiations with France are currently in progress to find a means of repairing new and renewable energy equipment already installed in Senegal.

COORDINATION, STRUCTURE AND RESOURCES

Coordination and structure

Government ministries, institutes and research centres, private industry, and extension organisations, are all involved in the development of policies, research, and exploitation of renewable and alternative energy resources.

Government ministries

The ministries concerned include:

- Ministry for Scientific and Technical Research (MRST)
- Ministry of Industrial Development and Handicraft - responsible for the energy policy of Senegal.

- Ministry of Environmental Protection - which promotes the use of new and renewable energy resources and, in particular, the development of biomass energy.
- Ministry of Rural Development - which supervises the training of personnel selected to operate new and renewable energy equipment in rural areas, as well as promoting the use and development of biomass energy.
- Ministry of Social Development - which supervises the training of users and promotes consumer awareness.

Institutes and research centres

CERER (formerly IPM) was created in 1960 as an Institut de Faculte. Since 1980, it has had the status of Institut d'Universite. Its activities have centered primarily on the evaluation of solar and wind potential, thermal and thermodynamic transformations of solar radiation, follow-up investigations of solar and wind installations, methane fermentation, and finally energy conservation in the areas of improved stoves and building insulation.

ENSUT, besides its intermediate and advanced training programmes, conducts research in a variety of areas: 1) photovoltaic conversion; 2) wind energy machines adaptable to and constructible in Senegal; 3) wind generators; 4) fermentation for methane production; and 5) the biotechnologies of fermentation.

The Senegalese Institute of Agricultural Research (ISRA) is primarily interested in biogas, conducting experiments with various prototypes of methane digesters at its centre in Bambey. The CRODT also examines the fuel potential of algae.

The Institute of Food Technology is responsible for the development of new transformation and preservation methods suited to Senegalese food production. Its efforts have centered on the perfection of solar tents designed for drying fish.

The Faculte de Sciences of the University of Dakar has contributed to two areas of research. Its laboratory for semi-conductors performed fundamental studies on thin-layered photovoltaic material.

Private industry

SINAES was created in August 1976 by the Government of Senegal - which furnished 50% of the capital - and by various partners from the Senegalese and French private sector. It has been responsible for the construction, installation, marketing, and maintenance of solar and wind equipment, and thus has assembled and installed nearly all of the new and renewable energy equipment in Senegal.

Extension of organisations for non-renewable energy resources

SENELEC, as a producer of electricity, is interested in the use of new and renewable energies and participates together with MRST in the implementation of various projects, notably those with an electricity generation component, provided that SENELEC controls the management of these projects.

Personnel

Although important efforts have been made to train local personnel, their numbers remain insufficient to promote a rapid mastery of the development of the sub-sector. They may even be decreasing in number.

To correct this tendency, measures have been examined to promote employment and avoid the desertion of trained personnel. The 1985-89 four year plan will give a prominent place to the fields of new and renewable energies, as did the previous four-year plan (1981-85).

Financing

In order to support the development of new and renewable energies in Senegal, foreign money lenders have agreed to a relatively significant financial contribution. Thus, over the last ten years, more than five thousand million CFA francs have been invested in the sub-sector. Exterior financing, which represents more than 75% of this amount, has been received by Senegal, principally in the form of grants.

Regulations and institutions

In order to encourage the development of the sub-sector, which is still in its initial stages, the government has taken various measures.

Law 81-22 of 25 June 1981 allows purchasers of solar and wind equipment to deduct from their taxes the total amount of money spent to this end.

Circular from the Prime Minister, 10.226 PM/SGG/ECT of 24 December 1972 recommended that all government buildings and certain types of houses built by SICAP and by OHLM should be equipped when needed with solar water heaters.

To support its policy of the voluntary development of new and renewable energy resources, the Government of Senegal created SINAES in 1976. In 1980 SINAES was granted certain tax advantages in order to fulfill its new and renewable energy objectives.

The interest that Senegal accords to the development of new and renewable energies is illustrated on a regional scale by the participation of Senegal, along with eight other countries of the CEAO and the CILSS, in the implementation of the Regional Centre for Solar Energy, headquartered at Bamako.

PERSPECTIVES AND CONCLUSION

The years to come will undoubtedly see the further development of new and renewable energy resources. Its impact on rural life will become increasingly important.

Senegal is a developing country with an agriculturally-based economy, confronted moreover by severe energy and food problems. The exploitation of new and renewable energy resources must become a leading priority in its economic and social development if these problems are to be resolved.

There must be a continuing evaluation of potential new and renewable energy resources and design of practical and economically feasible systems for their application throughout Senegal.

The following priority objectives for the renewable energy programme have been identified:

- Decreased consumption of wood and charcoal
- Pumping of water in rural regions
- Conservation of foodstuff and medicine
- Rural electrification
- Heated water
- Production of petroleum substitutes.

Considering the innovative character and the advanced technical potential of the sub-sector, an effective training policy must be followed to provide skilled personnel to continue developing the sub-sector.

Concerning the transfer of technology and financial support for national programmes, bi and multi-lateral cooperation must be reinforced and diversified as much as possible. These programmes will be formulated exclusively in regard to previously defined objectives.

The problems to overcome are immense. However, past experience has established tested and effective procedures, and Senegal, with the help of friendly countries is better equipped to take up the challenge.

POLICY OPTIONS FOR FUTURE ENERGY USE IN SIERRA LEONE

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ABSTRACT

The paradox in Africa is that the continent does not lack energy sources but has failed to demonstrate proper energy management and planning regarding the exploitation and utilisation of these resources. This paper discusses the various policy options for the future energy use in Sierra Leone. The current energy balance sheet is presented. This provides the basis for predicting future consumption up to the year 2000 using socio-economic, political, institutional and demographic factors. Various policy options are investigated that match the computed future demand. This analysis provides concrete suggestions for policy formulation relating to future consumption, source exploitations and utilisation in Sierra Leone. Results obtained can be applied to other African countries.

INTRODUCTION

Oil-importing developing countries of Africa are plagued with huge balance of payment deficits, mounting external debts, dwindling export figures, and foreign exchange scarcity. To this is added the severe implications on the social fabric of their societies as the rate of utilisation of the most important traditional energy source, fuelwood increases.

This situation will persist unless drastic policy changes are made. The most plausible line of approach in securing an adequate energy supply both for survival and development is to formulate a comprehensive energy policy. Such a policy requires not only baseline information regarding resources, consumption patterns, pricing structure etc., but also the predicted demand and various policy options to satisfy this demand. The latter aspect will be the focus of this paper discussed in relation to Sierra Leone.

The energy sources are briefly outlined to provide the background to the present consumption and future supply. Various policy options are analysed from which concrete suggestions are made to satisfy the future demand.

ENERGY SOURCES

Sierra Leone does not have a detailed energy source map at present. But certain ad hoc studies provide preliminary estimates for the various energy sources in the country. These studies form the basis for the discussion in this section.

The energy sources of Sierra Leone can be classified into renewable and non-renewable sources. The former are hydro, direct solar, biomass and to a limited extent wind. The latter are lignite and crude oil.

Lignite deposits are found 70 km from the capital and the north eastern part of the country. Though there are no precise estimates, UNDP (1980) suggests a figure of 740,000 tons of proven and indicated quantities. These deposits have significant clay with them. The south western coastal areas of the country are presently being prospected for crude oil. Though work has been going on for the past two years there has been no government report regarding their findings.

Due to the geographical position of the country, solar energy is a very attractive energy source. Sherriff (1982) computed the horizontal radiation for various areas of the country for the different months of the year. The country average was estimated to be 395 cal/m²/day. Wind energy is less attractive. Proximity to the equator results in very low average wind speeds.

Hydro sources are the greatest energy resource. Present potential is estimated at over 600 MW of both large and mini units. Inadequate funds and source data have prohibited the exploitation of this source. Another problem is the major seasonal variation in water levels. These fall to as low as 10% of the maximum during the dry season.

Biomass is a major energy source in the country. Forms available include fuelwood, ethanol from a sugar refinery, and agricultural and animal wastes. Atlanta (1979) estimated the high forests to be 5% and secondary forests 4% of the total land area of 72,000 km². Up to 90% of the total wood used in Sierra Leone is for fuelwood. Agricultural wastes include groundnut shells, coconut husks, sawdust etc. In addition to human waste, there are significant quantities of cattle waste in selected regions of the country.

ENERGY CONSUMPTION

The inadequacy of data and poor quality data collection makes it difficult to evaluate the energy consumption levels in Sierra Leone. Data regarding non-commercial energy are non-existent and those for commercial energy are not properly organised. The situation is improving. Davidson (1983) conducted a nation-wide survey of all the energy consuming sectors for the year 1982. Data from this study forms the basis for computing the current energy balance sheet below.

Survey

The energy economy was divided into sub-sectors that were classified as follows:

- residential, households of urban and rural areas
- commercial, operations and premises of commercial centres
- industrial, all formal and informal activities, mining, manufacturing, factories etc.
- agriculture, directly farming and indirect activities
- transportation, all modes of transport passengers and freight
- services, government institutions, hospitals, schools and public corporations.

Methods employed included examination of existing records, personal interviews and observation, and administration of questionnaires. Various sampling techniques depending on the sub-sector studies. In several cases new techniques to extract information had to be introduced.

Energy balance sheet

The overall energy balance is shown in Table 1. Over 50% of the commercial energy is used by the transportation sector. For non-commercial sources, the domestic sector becomes dominant. This is mainly due to the prominence of fuelwood which is used mostly for cooking. The relatively low efficiency of the devices in domestic use account for the high energy used by the domestic sector. There is greater diversity in fuel sources used in urban households than rural households. Travel by road is significant because of the volume of cars and the absence of a rail system. Sea transport is very limited and not as organised as road. The high value for sea transport is mainly due to the high value for bunkering. Industrial activities are quite low in Sierra Leone. Mining, which produces its own electricity, is by far the most important industrial activity.

These results now form the basis for future energy use to be computed.

FUTURE ENERGY USE

The national economies of most developing countries are weak national economies. This reduces their control over future trends. Usually their policies are largely dictated by outside forces. This increases their vulnerability to the pitfalls of the international economic system. This makes it difficult to predict energy use since there is a strong interaction between economic development and energy use. The local factors such as erratic performance and disorder normally experienced in various sectors of the national economy only reinforces this point.

Ideally to make reliable forecasts for future energy use demands the development of techno-economic computer models based on consistent and realistic assumptions of the various consuming sectors of the energy. Presently, we are developing a computer model that will be capable of predicting future energy use in LDC's. However, using currently available data a set of consistent and realistic assumptions have been used here to evaluate the future energy use. These assumptions can be summarised as:

- economic - income, trade patterns, global trends, debt involvements, etc.
- political - policy change, structural change, etc.
- technological - technology imports, local capability, technical changes, etc
- institutional - social systems, infrastructure etc.
- demographic - population change and distribution, household size, urbanisation etc.

Since these factors are not entirely independent they will not be discussed separately. This work is concentrated on the end-use of energy hence the analysis will be discussed in terms of demand by the various sub-sectors. Though not the only way of looking at future use, this provides one approach to evaluating future demand.

Using the present consumption as the baseline the future energy demand is predicted up to the end of the century using 1990 as the intermediate point.

Apart from various assumptions for the specific sub-sectors, some general ones were made regarding the factors outlined above. These assumptions were arrived at after discussions with the relevant government authorities, the assessment and observation by the author in specific areas, and government records.

The most important economic factor used in this analysis is the gross domestic product (GDP) and an annual rate of 4.1% is used. The effect of the parallel market due to smuggling was also considered. It was assumed that with time smuggling will decline and the GDP will be more reflective of the national economy.

The expected major shift in policy calls for more efficient management of the country's resources. This will show up as an overall improvement of the economy. Due to foreign exchange restrictions the country will be forced to increase local production of basic equipment using local materials as best as possible. This will assist in improvement in domestic appliances.

The trend for technical changes in global perspective will also affect the technology imports and better energy efficient devices will be used in various industries. There will be a time lag between the development of technology and its use in developing countries.

The expected changes in demographic factors will have serious implications on the total energy use. The population is growing at 2.8% per year. But with the present campaign for family planning, increased urbanisation, better health facilities, and literacy improvements population growth is expected to fall to about 2.6% per year. Improvement in the overall development of a nation reduces the rate of population increase. Rates were also assumed for shift between the urban and rural population. The fact that as humans become economically better off they move to more energy intensive activities was considered by looking at the movement between income groups at both urban and rural sectors. A summary of the demographic and economic assumptions made in analysis are given in Table 2.

Sectoral assumptions

The differences in the energy demands of the various sub-sectors necessitates that they are discussed separately.

Household

The projected household profile is shown in Table 3 for the years 1990 and 2000. Estimates are given for the various income groups as identified by Davidson (1983). The various end-uses were considered as significant changes are expected to occur for the different end-uses. Though there are likely to be substantial changes in cooking it is expected that more efficient devices will be introduced. This will have more impact on the people using firewood and charcoal. The change in the distribution between the different income groups in rural and urban areas is expected to change in the 1990s and 2000. This will also affect energy demand. The expected drift in population from rural to urban explains the reduction seen in Table 3 for rural areas.

Industrial

Table 4 presents predicted changes in energy demand within the industrial sector. Mining, the most important industrial activity is expected to increase in the coming years. It is assumed that a second bauxite company will start and that kimberlite mining in the present diamond mining site will be on-stream. Intense gold mining activity and rutile and iron ore mines will continue. These activities account for the increase observed in the mining section. Food processing is also expected to increase significantly due to the growth in agro-based industries and the present call for food processing in the country. Construction is expected to increase due to improvements in infrastructure especially road building.

Transportation

Only moderate growth is expected in the transportation sector based on expected improvement in the economy (Table 4). The expected shift to high income earners will contribute to the increase in car travel. Government participation and also congestion in urban travel will force more people to travel by mini-buses.

Agriculture

An increase in mechanised agriculture is expected due to the current food shortages and the involvement of more sophisticated business operators in farming. Also the fruits of the various government projects are expected to have yielded results. Hence, agriculture and its support services will become more energy intensive (Table 4).

Only moderate growth is expected in the commercial and services sector. They are very dependent on the nature of the economy (Table 4).

Table 5 summarises the predicted changes in energy consumption within all the sectors including the percentage contribution to total consumption.

POLICY OPTIONS

The summary of the future use of energy shows that a 7.5% increase is expected by the year 1990 and 12.0% by the end of the century. The existing source of supply cannot support such requirements. This section discusses various policy options that are aimed at solving this problem using as much locally available resources as possible.

Four possible policy options are:

- increased fuelwood
- improved fuelwood stoves and kilns
- introduction of new and renewable energies
- conservation measures.

They are interdependent but will be discussed separately.

Increased fuelwood supply

There is a high demand for fuelwood which will escalate unless measures are taken to counteract this. People especially in rural areas, do not have alternative to fuelwood. Therefore it is very important that adequate arrangements are made to assure the supply of wood.

Agroforestry, ie combining selected tree species with existing food crops, is an attractive option for many reasons. It is estimated that 50% of present fuelwood comes from land preparation for farming. Selected trees can be intercropped with certain food crops and this means fuelwood is close to the farm. An added advantage is that trees help to prevent soil erosion. Davidson (1985) recommends *Albizzia adianthifolia* and *A. zygia*. They have calorific values over 4000 kcal/kg and are high yielding and fast growing.

Another method of increasing fuelwood supply is by plantation programmes to replant depleted forest areas, and develop plantation farms in forest or periurban areas. Trees for such programmes would include *Albizzia* and *Luceana*. An added advantage of these trees is that they fix nitrogen in the soil as well.

The expected potential of this supply option: **Tree yields of 10-15 tonnes/ha in 2000-5000 ha producing 39000 tonnes/ha by 1990 and twice that in 2000.**

Improved fuelwood stoves and kilns

One method of conserving fuelwood is to introduce improved stoves that can use both charcoal and firewood. Efficiency of existing stoves are under 15% and the three stone stoves is as low as 9%. Improved stoves are now available with efficiencies up to 25% (Davidson 1985).

The inefficiency of charcoal production in which 75% of useful heat is lost (Davidson 1983), compounds the problem. Metal kilns or pyrolysis in industrial process can improve the situation. More convenient cooking does not necessarily save fuel and large scale introduction will definitely have an effect.

Expected potential: **Using 25% efficient stoves and more efficient charcoal will reduce energy demand for cooking by 10-15%.**

New and renewable sources

New and renewable energy sources in Sierra Leone are likely to have an impact on the overall energy picture and include:

- Biogas for rural application in individual houses
- Biogas for selected industrial activities
- Producer gas for selected industrial purposes
- Direct solar for water heating, water pumping, crop drying, and to a limited extent communications
- use of ethanol both as a fuel or as additive in the transport sector
- agricultural wastes in improved stoves, ovens, smokers etc.

Expected impact: **Biogas will have greatest impact mainly in northern provinces; ethanol could save 15% of transport costs; other sources would provide for 5% of domestic demand.**

Conservation measures

This option will prove very useful for the industrial sector in two ways. Firstly by achieving very low running costs and in certain cases no costs at all by improving performance of existing equipment through proper auditing and close monitoring. This might involve introducing some retrofitting but at cost that can be afforded by the industries. Secondly introducing more efficient devices. Technology presently available in developing countries can cut production energy consumption by a factor of 5 to 10 (Davidson 1985). It will be very useful because of the stage of industrialisation of many developing countries means they need to purchase new machines.

Expected gains: **10% of industrial needs by 1990 and 20% by 2000.**

All these policy options call for strong political will and a comprehensive study on energy pricing. This mechanism can also be used to stabilise the energy situation but this issue is not considered here.

CONCLUSIONS

This study shows that significant savings can be made by taking certain policies. These are:

- Increase fuelwood supply by adopting measures suggested
- Subsidise programmes to introduce stoves and kilns in both urban and rural areas
- Create schemes for utilising biogas in the northern province. Use tax incentives for industrial purposes. Producer gas can be utilised as well. Encourage solar water heating for urban areas and crop dryers for rural areas
- Encourage fuel switching in transportation sector between diesel and petrol. Use ethanol produced locally as additive
- Encourage intense conservation programmes
- Existing programme for electricity by hydro should be intensified.

These policies along with political will can go a great way to solving the imminent energy crisis.

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to the various government and other agencies in providing information for this work. The funds from the University and the International Development Research Centre (IDRC) of Canada are deeply appreciated. The work of the research team is acknowledged.

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TABLE 1: Energy consumption by sectors 1982 (TJ)

Source	Domestic	Commercial	Industrial	Agriculture	Transportation	Services	Electricity Production
Gasoline	-	-	-	-	1988.0	-	-
Diesel	-	7.0	1236.35	8.04	1992.0	7.9	1.96
Kerosene	1263.0	-	37.97	-	592.0	-	-
Fuel oil	-	-	106.79	-	1499.0	-	1134.8
LPG	377.5	-	0.14	-	-	-	-
Lignite	-	-	0.55	-	-	-	-
Sub-total	1640.5	7.0	1678.75	8.04	5971.0	7.9	1136.76
Commercial (%)	(16.6)	(0.07)	(17.03)	(0.08)	(54.6)	(0.08)	(11.5)
Firewood	31,588.0	84.51	76.9	-	-	4.43	-
Charcoal	4441.0	13.03	103.5	-	-	-	-
Agric. waste	12.1	-	88.6	-	-	-	-
TOTAL ENERGY	37,681.0	104.5	1947.75	8.04	5971.0	12.17	1136.76
(%)	(81.4)	(0.2)	(4.2)	(0.02)	(11.6)	(0.03)	(2.5)

TABLE 2: Summary of demographic and economic assumptions used in the analysis

Variable	1982 base year	1990	2000	Average Annual Growth (%)
<u>Population (Millions)</u>				
Total	3.356	4.124	5.341	2.6
Urban	0.839	1.32	2.136	7.0
Rural	2.517	2.804	3.205	2.1
<u>Persons/Household</u>				
Total	7.94	7.4	7.0	
Urban	7.0	6.6	6.1	
Rural	8.3	7.9	7.5	
<u>Income Distribution %</u>				
Urban				
Group 1	56	49	40	
" 2	24	27	31	
" 3	15	17	19	
" 4	5	7	10	
Rural				
Group 1	100	95	90	
" 2	negl.	5	10	
Gross Domestic Product (Lem)	1264.5	1743.8	2606.1	4.1
GDP/Capita (Le)	376.8	422.8	487.9	1

TABLE 3: Household end-use energy predictions

Income Group	End Use	Energy Demand TJX10 ³		
		1982	1990	2000
URBAN				
1	Cooking/heating	3.35	3.39	4.03
	Lighting	0.37	0.38	0.46
	Ironing	1.19	1.21	1.44
	Others	0.07	0.08	0.08
	Sub-Total	4.98	5.05	6.01
2	Cooking/heating	2.25	2.66	4.45
	Lighting	0.20	0.24	0.39
	Ironing	0.62	0.73	1.23
	Others	0.06	0.06	0.11
	Sub-Total	3.13	3.69	6.18
3	Cooking/heating	1.06	1.69	2.76
	Lighting	0.12	0.20	0.32
	Ironing	0.32	0.51	0.83
	Others	0.05	0.07	0.12
	Sub-Total	1.55	2.47	4.03
4	Cooking/heating	0.31	0.72	1.50
	Lighting	0.04	0.07	0.18
	Ironing	0.09	0.20	0.42
	Others	0.02	0.05	0.42
	Sub-Total	0.46	1.06	2.21
TOTAL		10.12	12.27	18.43
RURAL				
1	Cooking	25.48	24.00	17.88
	Ironing	1.85	1.74	1.3
	Lighting	0.68	0.68	0.47
	Sub-Total	28.01	26.42	19.65
2	Cooking	-	1.09	2.24
	Ironing	-	0.22	0.45
	Lighting	-	0.14	0.30
	Sub-Total	negl.	1.45	2.99
TOTAL		28.01	27.87	22.64

TABLE 4: Energy demand for other sub-sectors

Sub-Sector	DEMAND (TJ)		
	1982	1990	2000
<u>Industrial</u>			
Mining	1193.65	1392.96	1851.26
Construction	152.30	197.99	251.39
Eng. metal	98.70	138.18	193.45
Food Procs	53.73	73.85	159.69
Others	449.87	494.86	544.34
<u>Transportation</u>			
Cars	1100.20	1613.40	2218.40
Buses	814.10	932.40	1242.10
Freight	1189.70	1308.67	1439.54
Air	592.00	651.20	716.32
Sea	2135.68	2345.25	2584.17
Others	139.32	153.25	168.57
<u>Agriculture</u>			
Machines	8.02	16.04	24.06
Services	0.74	1.11	1.55
<u>Services</u>			
<u>Commercial</u>	116.67	128.37	141.21

TABLE 5: Summary of energy productions

Sub-Sector	1982		1990		2000	
	TJ	%	TJ	%	TJ	%
Domestic	38,130.00	81.40	40,140.00	78.90	41,070.00	77.30
Industrial	1947.75	4.20	2297.84	4.50	3000.13	5.70
Transportation	5971.00	11.10	7008.17	13.8	7482.10	14.10
Agriculture	8.76	0.02	17.15	0.03	25.61	0.03
Services & Commercial	116.67	0.23	128.37	0.28	141.21	0.27
Electricity Production	113.00	2.50	1250.31	2.50	1375.34	2.60
TOTAL	47,310.89	100	50,841.80	100	53,094.39	100

ENERGY PLANNING ACTIVITIES IN ZAMBIA

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INTRODUCTION

Zambia like most other African countries achieved her independence during the early 1960s and embarked on major development plans to increase industrial output and also to exploit the vast untapped resources in rural areas. This involved massive investments in plant and equipment requiring large amounts of energy and capital. Like most other countries Zambia was and is still a mono-economy and during those days the price of copper (the most important foreign exchange earner) was high enough to support these development plans. The price of oil at that time was reasonably cheap.

Since 1973, the cost of oil imports to Zambia increased dramatically from nearly 50 million kwacha in 1975 to 225 million kwacha in 1983 – an increase of nearly 450%. In 1975, these imports only accounted for 8.2% of the total imports. In 1983 this figure had risen three times to 25.6%. At the same time oil use has actually gone down due to the slowed industrial capacity (Table 1).

Between 1964 and 1983, the urban population has increased from 20% to 43% and is rising. This means that more commercial energy is going to be used.

In 1982, a World Bank team visited Zambia to carry out an energy assessment programme. One of their recommendations was that Zambia should re-examine its energy programmes and potential so that long term investment, and other facilities could be planned. They also reinforced the government view that the nation should through careful planning reduce this overdependence on petroleum products which have to be imported.

SCENARIO

According to preliminary data shown in Table 2, among the three major commercial fuel supplies, hydroelectricity contributed 67.8%, coal 11.6% and oil 18.5% in 1983. In the same year the major consumers were industrial processes such as mining. Because of the emphasis placed on the agricultural sector by the government the energy consumption in agriculture has been increasing steadily.

In 1984 the University of Zambia in conjunction with the government Department of Energy and the National Energy Council instituted an energy plan of action to study the pattern of energy supply and demand in the country and to make projections up to 1995.

The objectives were:

- a. To develop a diversified energy supply system which will reduce dependence on oil.
- b. To maximise the use of renewable resources.
- c. To maximise the use of indigenous resources.
- d. To provide energy for optimum industrial development.

- e. To reduce non commercial fuel use and resulting deforestation.

The first step was to collect demand and supply data for 1970-84. About 4000 questionnaires were sent out during August-October 1984. The data are still being evaluated. Some difficulties in the balancing of supply and demand figures were experienced but this is still being checked, and where possible data are being recollected.

THE MODEL

The model being developed for the analysis of data, particularly for future predictions and rationalisation, is based on experiences in Zambia. But some of the features in other models like the Energy Supply and Planning Model and the Argonne Energy Model are also incorporated.

The model is a network representing the energy-producing sector and energy prices based on the relative costs of various energy supply alternatives. All the energy resource production, conversion, transport and demand activities in existence as well as those having potential for use are incorporated in the network as nodes and referred to as processes. The network links represent energy flows between processes. The network can be used to project future energy flows and prices on the links. Projection based on engineering cost, technological availability and acceptability can be made. These energy demands are then matched with supplies with least cost. The model can be used also to analyse effects of government policy. Details of the model will be available when it is fully developed.

RENEWABLE ENERGY RESOURCES - THEIR ROLE

From the scenario it is quite clear that some measures are needed immediately:

- a. A comprehensive energy conservation programme must be instituted. Conservation is widely regarded as a resource and its encouragement if possible by legislation, will save a lot of investment. This is already being done under the 2nd phase of the National Energy Plan of Action.
- b. A systematic study of renewable energy resources in the country and their possible exploitation particularly in the substitution of commercial fuels.

Because one cannot wait for the energy plan to be completed, work is already in progress in a number of areas, some of which have been reported at this meeting by other colleagues from Zambia. These include:

- a. hydropower
- b. solar heating and cooling
- c. solar pumping
- d. wood stoves and their improvement
- e. alcohol production for fuel
- f. wind energy
- g. coal utilisation

Although the main aim is to reduce the commercial fuel consumption, traditional fuels such as wood which constitute an improvement in the quality of life and a major part of the fuel supply for the rural areas still form quite a significant portion of current studies. Only by proper monitoring of this fuel consumption can deforestation be arrested.

Preliminary findings indicate that apart from conservation in most of the industries there will be a need for proven renewable technologies to save even more power. Options such as process steam by utilising solar energy preheaters, biomass and other forms of renewable energy, are being actively considered.

FUTURE WORK

- a. Since demand projections will have to be met by adequate supply of energy; it is important to take stock of the amount of renewable energy resources available in the country.
- b. Analysis of the current demand and supply patterns is in progress and it is hoped that this will be available to the government in the near future.

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TABLE 1: Oil importation in Zambia

Year	Quantity tons	Value K'000	% total imports
1975	852,075	49,228	8.2
1976	907,615	63,540	13.6
1977	776,926	67,388	12.6
1978	780,154	68,107	13.8
1979	699,328	97,144	16.3
1980	761,832	153,963	17.6
1981	750,543	185,000	21.0
1982	748,150	198,000	21.6
1983	608,228	225,189	25.6

TABLE 2: Supply and demand contributions of the various energy types

<u>SUPPLY</u>	% Contribution to commercial energy supply
Hydroelectricity	67.8
Coal	11.6
Oil	18.5
<u>DEMAND</u>	% Contribution of sector
Mining	47.5
Commerce and services	23.0
Transport	11.7
Manufacturing and construction	10.6

APPENDIX I

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Renewable Energy Development in Africa

Proceedings of the International Conference on Research and Development of Renewable Energy Technologies in Africa

The first international conference on research and development of renewable energy in Africa was held in Mauritius from the 25-29 March 1985.

The Conference, held under the auspices of the African Energy Programme of the Commonwealth Science Council, was attended by 100 scientists, researchers, policy makers from 30 countries, and representatives of international organisations.

The Conference had three main objectives:

- * to report the results of research projects on renewable energy technologies in Africa covering both the activities of the African Energy Programme and other institutions/agencies;
- * to provide an opportunity for international exchange of research ideas and information between African scientists and colleagues from elsewhere;
- * to provide a forum for scientists and potential donors to explore modalities for future collaboration on energy research and development in Africa.

Over 70 technical papers were presented on research and development programmes in Africa and contributions from international collaborators. These papers, presented under four generic themes, have been edited and produced into a 2-volume set of conference proceedings. The proceedings provide the most comprehensive single assembly of renewable energy research progress in Africa.

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Printed and published by
The Commonwealth Secretariat
Marlborough House
Pall Mall, London SW1Y 5HX
Volume 1 ISBN 0 85092 291 7
Published in 2 volumes

