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# PRODUCTION OF CHARCOAL BRIQUETTES FROM COTTON STALK IN MALAWI: METHODOLOGY FOR FEASIBILITY STUDIES USING EXPERIENCES IN SUDAN

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**Abstract**—The feasibility of charcoal production from cotton stalks in Malawi was studied based on experience from Sudan. The country relies considerably on biomass fuels. Of the total energy consumption in Malawi of 2.376 MTOE in 1989, 92% was met by biomass (fuelwood: 83.6% and charcoal: 8.3%). Petroleum fuels and ethanol contributed 5.4%; electricity, 1.6%; and coal, 1.0%. Most of the energy (84.8%) was consumed in the household sector. The "Malawi Charcoal Project", which is the main charcoal project carried out in the country, attempted to produce alternative softwood charcoal from the large resource of pine plantations but was not successful because of unacceptability of the product for household use, long transport distances and costs, and the equipment required for industrial uses. Briquetting of uncarbonized sawdust was also carried out by the Wood Industries Corporation (WICO), but failed due to unacceptability of the products and technical problems. The estimated total national demand for cotton stalk charcoal (CSC) briquettes is 15,000 t $yr^{-1}$ made up of 7000 and 8000 t $yr^{-1}$ for household and industrial sectors, respectively. The household demand is most substantial in Blantyre (3500 t $yr^{-1}$) and Lilongwe (2700 t $yr^{-1}$). Ngabu town was found to be the most appropriate location for a plant to supply the Blantyre market. Of the many plant options that were found financially and economically viable, four, using drum kilns for carbonization, were the most attractive. These were the 800 t $yr^{-1}$ agglomeration process with seasonal sun drying operation, 2- and 3-shifts, and the 3000 t $yr^{-1}$ roll process, year round operation, 2- and 3-shifts with financial internal rates of return of 28.1%, 38.3%, 26.6% and 40.0% respectively and a pay-back period of three years. The agglomeration process was overall the most attractive, though not significantly so financially.

**Keywords**—Charcoal, briquettes, cotton stalks, Malawi, Sudan.

## 1. INTRODUCTION

The energy consumption pattern of Malawi is characterized by considerable reliance on biomass fuels, predominantly fuelwood and charcoal. More than 90% of the energy needs of the country have been met by these woodfuels since 1981. This has put pressure on forest resources contributing to their depletion. In order to preserve the forests, the Government has banned the production of the much favoured hardwood charcoal from indigenous forests. However, the production continues illegally, largely due to inadequate enforcement of the law. An attempt to produce alternative softwood charcoal from the large resource of pine plantations has not been very successful, because of unacceptability of the product for household use, long transport distances and costs, and required equipment for industrial uses. There is thus the need to seek alternative energy sources. Cotton stalks and other agro-industrial and agricultural residues were shown in a preliminary survey by BTG in 1990[1] to have potential for this substitution.

The Biomass Technology Group (BTG) has carried out feasibility, market and pilot plant studies on and ultimately assisted in establishing an 800 t $yr^{-1}$ semi-centralized cotton stalk charcoal (CSC) briquetting plant in Sudan between 1985 and 1990,[2] has monitored and evaluated the operation of this plant[3] and carried out further market studies on it.[4] The process has been found technically feasible, and would be financially viable if management, organization and marketing were improved.

Based on the successful technical experience of BTG on CSC production in Sudan, BTG and

*List of abbreviations*—ADD: Agricultural Development Division; ADMARC: Agricultural Development and Marketing Corporation; BEV: Break Even Volume; BTG: Biomass Technology Group; CSC: Cotton Stalk Charcoal; FIRR: Financial Internal rate of Return; kgOE: Kilogram of Oil Equivalent; KTOE: Thousand Tonnes of Oil Equivalent; MTOE: Million Tonnes of Oil Equivalent; TOE: Tonnes of Oil Equivalent; WICO: Wood Industries Corporation.

Table 1. Summary of energy consumption of Malawi in 1989 by fuel and sector*

| Fuel | Coal | Petrol | Diesel | Paraffin | Jetfuel | Ethanol | Electricity | Hydro | Fuelwood | Charcoal | Total biomass | Grand total | Percentages: Commercial | Wood-fuel | Total biomass | Total energy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Final energy consumption | 24.5 | 47.3 | 70.7 | 0.0 | 9.9 | 0.0 | 38.8 | 0.0 | 1986.4 | 198.2 | 2184.6 | 2375.8 | 8.0 | 92.0 | 92.0 | 100.0 |
| Sector | | | | | | | | | | | | | | | | |
| Agriculture | 0.3 | 2.6 | 13.2 | 0.0 | 0.0 | 0.0 | 8.7 | 0.0 | 176.7 | 0.0 | 176.7 | 201.3 | 12.3 | 87.7 | 87.7 | 8.5 |
| Forestry | 0.0 | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 100.0 | 0.0 | 0.0 | 0.0 |
| Fishing | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 100.0 | 0.0 | 0.0 | 0.0 |
| Mining and quarrying | 0.0 | 0.1 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Manufacturing | 23.8 | 0.7 | 4.5 | 0.0 | 0.0 | 0.0 | 9.7 | 0.0 | 0.0 | 0.0 | 0.0 | 38.8 | 100.0 | 0.0 | 0.0 | 1.6 |
| Electricity generation | 0.0 | 0.3 | 1.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 100.0 | 0.0 | 0.0 | 0.1 |
| Water supply | 0.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 6.3 | 0.0 | 0.0 | 0.0 | 0.0 | 6.6 | 100.0 | 0.0 | 0.0 | 0.3 |
| Construction | 0.1 | 0.9 | 8.9 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 10.3 | 100.0 | 0.0 | 0.0 | 0.4 |
| Trade and distribution | 0.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 2.2 | 100.0 | 0.0 | 0.0 | 0.1 |
| Transport | 0.0 | 40.3 | 39.4 | 0.0 | 9.9 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 90.3 | 100.0 | 0.0 | 0.0 | 3.8 |
| Financial, prof. serv. | 0.0 | 0.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 100.0 | 0.0 | 0.0 | 0.1 |
| Government services | 0.0 | 3.6 | 2.9 | 0.0 | 0.0 | 0.0 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 9.3 | 100.0 | 0.0 | 0.0 | 0.4 |
| Private services | 0.2 | 1.3 | 1.3 | 0.0 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 5.3 | 100.0 | 0.0 | 0.0 | 0.2 |
| Households | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.8 | 0.0 | 1809.8 | 198.2 | 2007.9 | 2015.8 | 0.4 | 99.6 | 99.6 | 84.8 |
| Percent total consumption | 1.0 | 2.0 | 3.0 | 0.0 | 0.4 | 0.0 | 1.6 | 0.0 | 83.6 | 8.3 | 92.0 | 100.0 | 0.3 | | | |

*In KTOE unless otherwise stated; woodfuel = fuelwood and charcoal.

Source: Based on data from Department of Economic Planning and Development, Office of the President and Cabinet, Lilongwe.

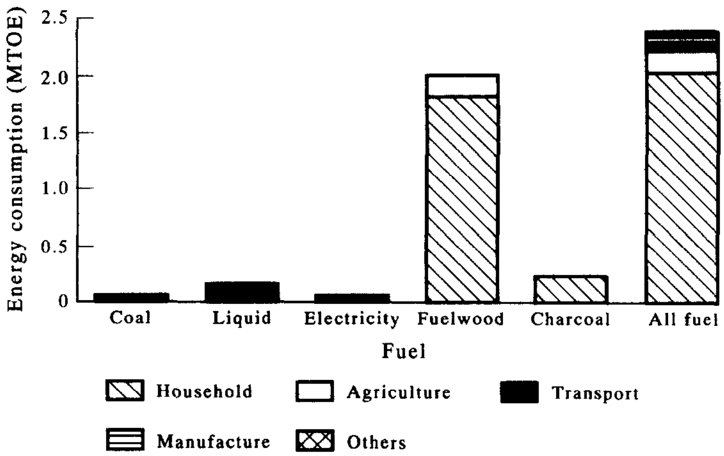


Fig. 1. Energy consumption of Malawi in 1989 by fuel and sector.

INDEBANK proposed the implementation of such a project in Malawi in a three-phase project. The findings of the first phase of the study, the feasibility study, have been reported in detail elsewhere[5] and are summarized in this paper.

## 2. METHODOLOGY

Information was gathered in Malawi in June 1991 on the potential market for the briquettes, the resource base, plant location and site conditions, the local manufacturing capacity, local implementing organizations, financial, economic and other relevant aspects. An appropriate market and plant location combination was selected and then suitable agglomeration and roll press plant options were designed and specified. It was sought to maximize the local content of machinery and equipment as a key to sustainable development of the technology. Quotations for the fixed capital investment items were received from both local and international sources. Finally, a financial/economic evaluation model of the processes was developed and used to assess the viability of various plant options varying in technology, briquetting scale, briquetting period (seasonal and year-round), carbonization period, and number of shifts.

## 3. RESULTS AND DISCUSSION

### 3.1. *Energy consumption patterns and trends*

With respect to energy consumption statistics, reliable historic data exist for commercial fuels, but not for biomass fuels, such as fuelwood, charcoal and bagasse and agricultural residues.[6] The available information is summarized in this section to give an idea of the energy consumption pattern of the country.

The most recent energy balance of Malawi (1989) is given elsewhere.[5] All biomass fuels,

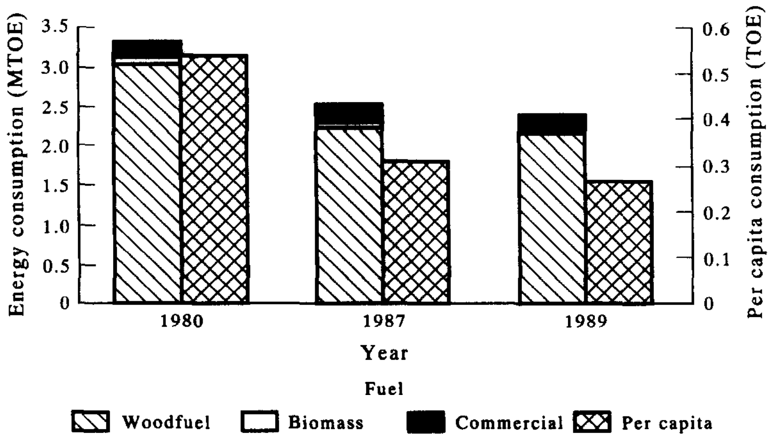


Fig. 2. Trend in energy consumption pattern of Malawi.

ethanol and hydro-electricity are produced and consumed in the country. All petroleum products and 33% of the coal requirements are imported. A summary of the energy consumption by fuel and sector is provided in Table 1 and also depicted in Fig. 1. Of the total consumption of 2.376 MTOE, 92% was met by biomass fuels. Fuelwood contributed 1.986 MTOE (83.6%), charcoal 0.198 MTOE (8.3%), liquid fuel (petroleum fuels and ethanol) 5.4%, electricity (including hydro-electricity) 1.6% and coal 1.0%. Most of the energy was consumed in the household sector (84.8%). The agricultural sector consumed 8.55%, transport 3.85%, manufacturing 1.6% and other sectors (fishing, mining and quarrying, electricity generation, water supply, construction, trade and distribution, financial and professional services, government, and private services) consumed 1.2%. All the charcoal was consumed in the household sector, although fuelwood was still the predominant fuel for this sector. There was a recent development to diversify the energy sources by producing ethanol from molasses at the Dwangwa Sugar mill in the Central Region. The ethanol is used primarily as a fuel extender in blends with gasoline, but as yet makes only a marginal contribution to the country's liquid fuel needs.

The per capita annual total energy consumption in 1989 was 265 kgOE. Energy consumption patterns of developing countries have been classified into low and high per capita total consumption on the one hand and low and high biomass consumption on the other hand.[7] On this classification basis, Malawi has a low per capita total consumption and high biomass consumption.

The trend in the energy consumption pattern of the country regarding total consumption, and proportion of fuelwood and charcoal since 1980 is depicted in Fig. 2. There has been little change over the years in spite of a relatively high population growth rate. The most obvious reasons for this are the declining economic performance, and rising fuel prices.

### 3.2. *Previous charcoal and briquetting projects in Malawi*

The main charcoal project that has been undertaken in the country is the "Malawi Charcoal project".[8,9] The project implemented the production of charcoal from the softwood wastes generated on large government plantations in Viphya in the Northern Region and sought ways to market this product. With a total capacity of 9500 t $yr^{-1}$, the project was described as the largest semi-industrial charcoal production program implemented in Sub-Saharan Africa. In terms of primary and secondary fuel properties, the softwood or pine charcoal has little in common with traditional hardwood charcoal. It has a much lower density and is relatively friable and thus composed of a greater proportion of fines. In spite of the demonstrated technical feasibility and considerable marketing efforts of the project, these disadvantages made penetration of the household charcoal market almost impossible. Other disadvantages were the large transport distances and handling difficulties. The urban household perceived the product as an inferior alternative to the traditional household variety.

The project attempted penetration of the industrial market. Combustion trials proved the technical feasibility for steam raising using pine charcoal in various industries. However, the use of pine charcoal required a number of modifications to equipment and operating procedure, these being:[9]

—the necessity for dry fuel storage, due to the hygroscopicity of the charcoal;
—the need for closer monitoring of the combustion process, thus increasing labour costs;
—the need for modification of the fuel feeding system.

Another potential user of the charcoal was Portland Cement Ltd, which expressed interest in the use of the fines produced by the project. The major advantage of the charcoal over currently used coal is its lower ash content which contributes to better cement quality and overcomes ash-related kiln operating problems. However, despite these advantages, Portland Cement has yet to begin using the charcoal.

Following the end of the charcoal project in August 1989, the Forestry Department took over the project and assumed the responsibility of disseminating the technology to private entrepreneurs and institutions. To that end, in 1990, there were two developments to address the main constraints to marketing of the charcoal: the acquisition of a special truck to transport the charcoal from Chikangawa to Lilongwe and Blantyre and the formation of an association of private entrepreneurs involved in the marketing of the charcoal. Funds have also been provided to the association for the construction of four storage sheds in Blantyre.[6]

While some interest has been shown in the charcoal, particularly by the tobacco industry, dissemination is still minimal.[10] No doubt, a cotton stalk charcoal briquette project conducted close to the urban areas can offer an additional viable and needed alternative to the charcoal needs of the country.

Briquetting of uncarbonized sawdust was carried out by the Wood Industries Corporation (WICO), albeit with little success. The project failed mainly because of (i) the unacceptability of the briquettes as a substitute for the preferred firewood, and (ii) technical problems with the machinery. Of the 12 briquetting machines imported from Taiwan, only two were operational at the time the company was visited. These two were being maintained with parts salvaged from the other machines and production of the briquettes had virtually stopped. This example emphasizes the significance of the success of such projects to local manufacturing and maintenance capabilities.[11,12]

### 3.3. *Potential market for CSC briquettes*

Estimations on the market size for wood charcoal are based on previous studies[8,9,13] and our own assessments. The lion's share of the urban household consumption is found in the four main cities: Blantyre (35,000 t $yr^{-1}$), Lilongwe (27,500 t $yr^{-1}$), Mzuzu (4300 t $yr^{-1}$) and Zomba (3700 t $yr^{-1}$).

Charcoal consumption in the industrial sector is presently low; fuelwood and coal are preferred alternatives. However, with increasing coal costs, chiefly due to transportation costs, charcoal is considered to be a viable alternative. The industrial sector may therefore be interesting for the penetration of charcoal briquettes especially as a substitute for coal. Coal is a scarce imported fuel that has to be transported over considerable distances. The coal consumption in industry during 1987 was assessed by the Malawi Charcoal Project.[7] A total of 39,900 t $yr^{-1}$ of coal was consumed nationally with 74% being consumed by two companies: Portland Cement Co (45%) and David Whitehead Textiles (29%). In Blantyre, the total consumption amounted to 16,350 t $yr^{-1}$ of which 70% was consumed by David Whitehead.

A market penetration of 10% was assumed for the briquettes based on previous market studies in Sudan and an analysis of the prevailing conditions in Malawi. The total national effective demand for CSC briquettes is 15,000 t $yr^{-1}$ made up of 7000 and 8000 t $yr^{-1}$ for the household and industrial sector respectively. The household demand is the highest in Blantyre (3500 t $yr^{-1}$) and Lilongwe (2700 t $yr^{-1}$) (minimum expected demand). The industrial demand is greatest in Blantyre, Zomba and Lilongwe. However, the figures are only tentative pending successful combustion trials. In total, the three cities have a tentative demand of 6800, 4000 and 3700 t $yr^{-1}$ for Blantyre, Zomba and Lilongwe respectively. Export options are not promising at the moment.

Historical charcoal consumption figures show an inclining or constant trend. Thus, in the medium-term, future demand can be expected to remain at least above the present level.

### 3.4. *Marketing strategy*

Suitable charcoal retailers should be found in Blantyre for distribution of the briquettes in the usual house-to-house and market outlets, where most of the consumers presently purchase their charcoal. A comparable approach to package the briquettes differently and deliver to supermarkets and filling stations can be useful, albeit at a higher price. This is supported by the fact that the briquettes are produced in a semi-centralized manner, different from the illegal hardwood charcoal production which is highly dispersed. Therefore, forward market integration is an attractive option. Especially at the initial stage, all the briquettes should be delivered to the retailers. A reliable transport company should be contracted to ship the briquettes to the retailers.

The briquettes should be packed in the 40 kg jute or polypropylene bags presently used for distribution of hardwood charcoal to the mainly low- and middle-income consumers. There is no need to use airtight and waterproof sacks, as the baked briquettes are resistant to moisture. For distribution through alternative channels, a smaller size of polypropylene sacks (16 kg) is recommended to fetch a higher price per unit weight.

Present prices of hardwood charcoal can be used as a basis for the briquette process. Thus, with a retail price of K413 $t^{-1}$ in Blantyre, a wholesale price or landed costs of the briquettes of K290 seems realistic, yielding a profit margin of 30% to the retailers compared to the present profit of 50% on hardwood charcoal. The same price should be offered to industrial consumers. There is no reason to lower the price of the briquettes below that of hardwood charcoal,

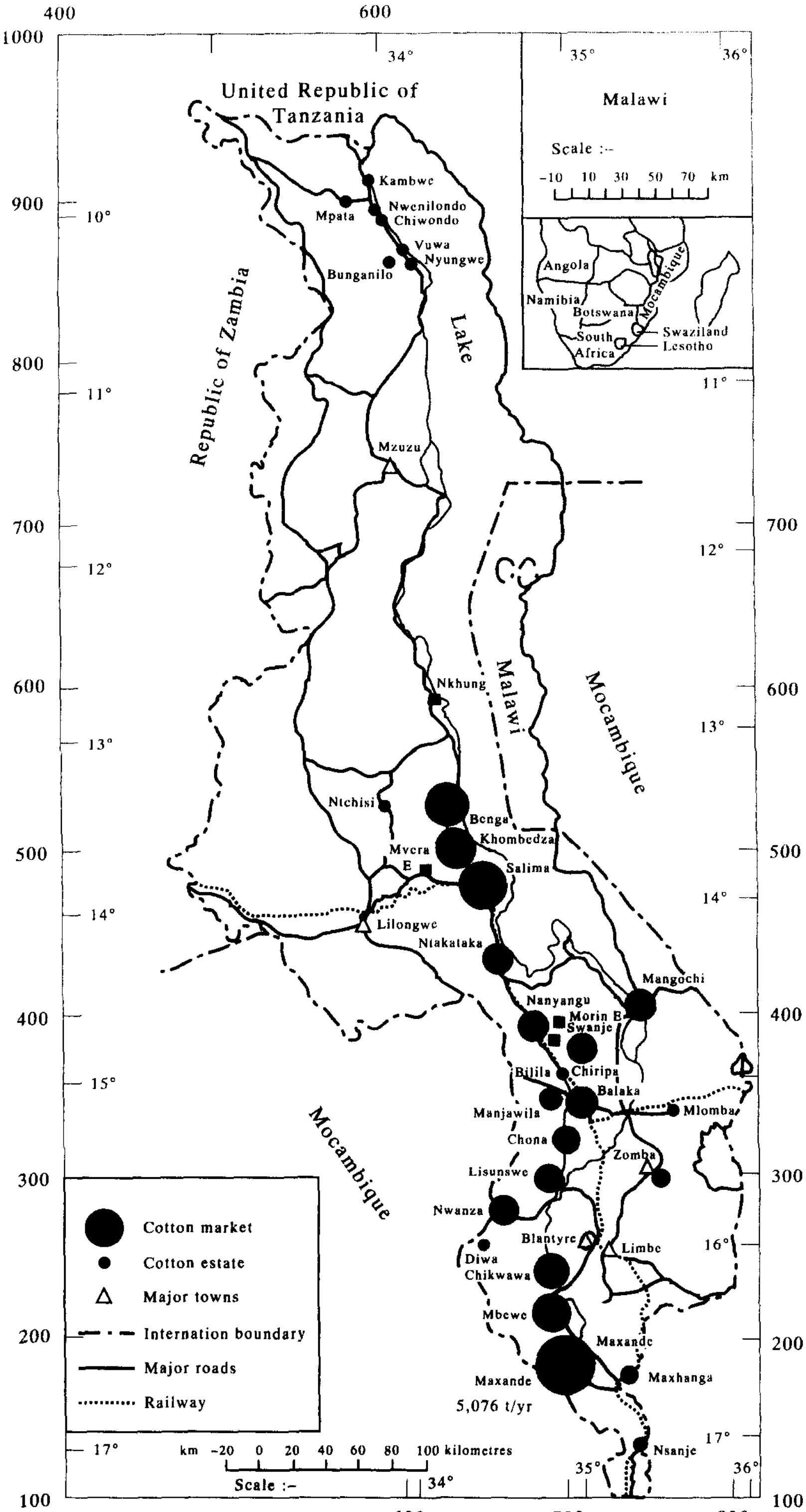


Fig. 3. Annual purchases of cotton in ADMARC markets and estimates in 1990/91. Source: based on data from ADMARC and David Whitehead and Sons Ltd, Malawi.

although such a lowering may be considered for industrial consumers if necessary. Instead, the higher prices could be charged because of the many advantages of the briquettes. Unfortunately, while the 30% profit margin may be quite attractive to market retailers and industrial users, it is low for traders who transport and retail the wood charcoal by themselves

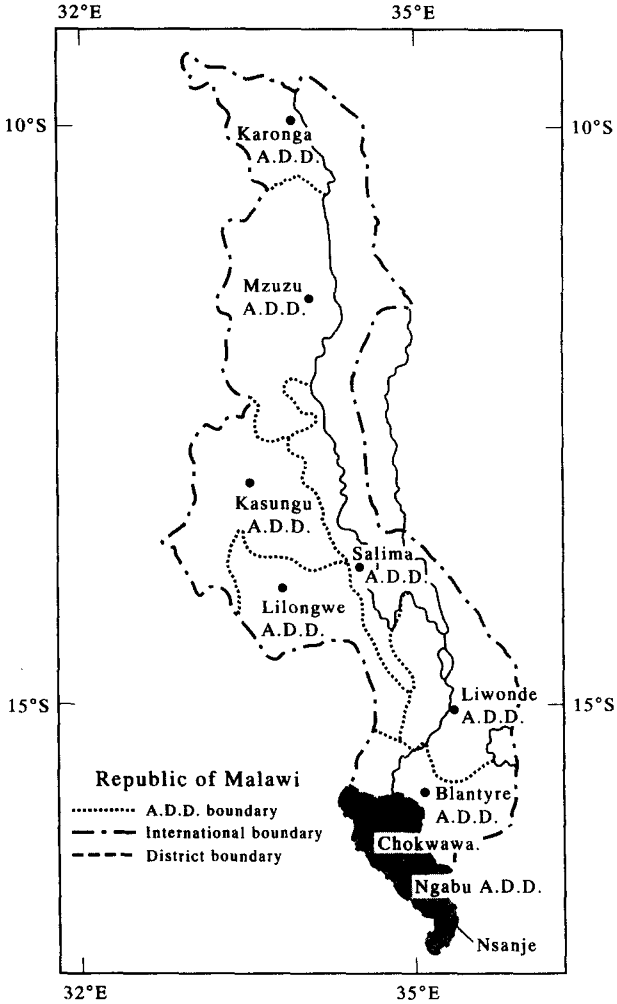


Fig. 4. Agricultural development divisions of Malawi.

and now obtain about 75–110% profit. Because this sector of the distribution channel is large, their continued support for the illegal charcoal business should be anticipated and can be a source of stiff competition for wood charcoal.

### 3.5. *Resource base and plant capacity*

Cotton is widely grown in Malawi, the production being concentrated, however, in a number of areas in the three regions. Over 90% of the total production of cotton in the country is by smallholder farmers and purchased by the Agricultural Development and Marketing Corporation (ADMARC). The distribution of cotton production can be seen from a detailed presentation of the growing areas as in Fig. 3. which gives the location of ADMARC purchasing markets and annual purchases in the markets in 1990/91 (a few are estimates for 1991/92). The Agricultural Development Divisions (ADD) of Malawi are shown in Fig. 4. Forty percent of the cotton production in Malawi is in the Ngabu ADD. In the densely growing area of the Shire Valley, production is concentrated around two major towns: Ngabu and Chikwawa. Forty-six percent of the cotton purchases in Ngabu ADMARC division in 1990 was from the Makende Market area, in which Ngabu town is more or less centred. The other important growing areas are the Salima division in the Central Region and the Balaka Division in the Southern Region, contributing 26% and 17% respectively.

The effective demand for the briquettes in Blantyre is tentatively estimated at 3500 t $yr^{-1}$ minimum and 6800 t $yr^{-1}$ if the industrial demand is included. However, the maximum stalk generation from the cotton production of 15,500 t $yr^{-1}$ in the Ngabu ADD is 54,250 t stalks $yr^{-1}$ which can yield a maximum of 14,240 t $yr^{-1}$ of CSC briquettes. However, not all the stalks can be collected because of the

Table 2. Technical characteristics of plant options (one-shift)

| Plant option designation* | Briquetting scale | Carbonization period (weeks $yr^{-1}$) | Briquetting period (weeks $yr^{-1}$) | Number of shifts |
|---|---|---|---|---|
| *Agglomeration* | | | | |
| A8HsS1 | medium | 8 | 24 | 1 |
| A8HlS1 | medium | 13 | 24 | 1 |
| A8HsY1 | medium | 8 | 49 | 1 |
| A8HlY1 | medium | 13 | 49 | 1 |
| *Roll press* | | | | |
| R3KsS1 | large | 8 | 24 | 1 |
| R3KlS1 | large | 13 | 24 | 1 |
| R3KsY1 | large | 8 | 49 | 1 |
| R3KlY1 | large | 13 | 49 | 1 |
| R6KsS1 | large | 8 | 24 | 1 |
| R6KlS1 | large | 13 | 24 | 1 |
| R6KsY1 | large | 8 | 49 | 1 |
| R6KlY1 | large | 13 | 49 | 1 |

*A = Agglomeration; R = Roll press; 8H = 800 t $yr^{-1}$; 3K = 3000 t $yr^{-1}$; 6K = 6000 t $yr^{-1}$; s and l = short and long carbonization periods respectively; S and Y = seasonal and year-round briquetting operations respectively; 1 = 1 shift.

dispersed nature of the sources and to some extent, alternative household uses. Collection of only about 50% of the stalks is considered realistic. Thus, the maximum capacity of the plant based on the resource base is estimated at 7000 t $yr^{-1}$ of briquettes.

The plant capacity is not limited by raw material supply. The sales to the household market can be confidentially estimated at 3000 t $yr^{-1}$. However, a capacity of up to 7000 t $yr^{-1}$ is possible if the briquettes are applicable in the industries based on a penetration of 10%.

### 3.6. *Local manufacturing capacity and implementing organizations*

It was observed that considerable manufacturing capability exists in the country for fabrication of most carbonization and briquetting equipment, although it could be further developed for the more specialized briquetting equipment. Enthusiasm for implementing the project was considerable both in the private and public sector; five organizations expressed interest.

### 3.7. *Plant location and site selection*

Two significant sources of raw materials were identified as the Ngabu and Salima ADDs. Briquette production in Ngabu ADD would target the Blantyre market, whereas that from the Salima area is only suitable for the Lilongwe market due to the transportation costs. The combination of the Ngabu cotton production area and the Blantyre market appears to be the most promising option and is considered for the present study. The potential of the Salima production area and Lilongwe market should be followed up in the future after the former option has been tested and economically proven successful. The most appropriate site for the plant is in Ngabu town in Ngabu ADD. The town is located in the centre of Ngabu ADD, would generate adequate stalks with minimum collection costs and has all the necessary infrastructure and good living conditions.

### 3.8. *Financial and economic evaluation*

3.8.1. *Plant options.* Two low pressure briquetting technologies using molasses binder are most suitable: the roll press, which is state-of-the-art industrial technology, and the agglomeration process. The agglomeration process uses a pan agglomerator, developed by BTG mainly because of its attractive features for application in a developing country: the capacity is

Table 3. Ranges of capital investment and production costs for plant options

| Plant option | Capital investment ($\times 10^3$ K) | Production costs (K $t^{-1}$) |
|---|---|---|
| Agglomeration, sun-drying | 289–477 | 133–181 |
| Agglomeration, forced draft drying | 459–578 | 152–245 |
| Roll press, 3000 t $yr^{-1}$ | 1399–1621 | 148–196 |
| Roll press, 6000 t $yr^{-1}$ | 2265 | 158 |

Table 4. Financial internal rate of return for promising plant options

| SN | Plant option | Normal kilns | Drum kilns | Subri-Fosse kilns |
|---|---|---|---|---|
| 1 | 800 l S 2-shift, sun drying | — | 28.0 | 17.9 |
| 2 | 800 l S 3-shift, sun drying | 10.3 | 38.5 | 24.0 |
| 3 | 800 l S 2-shift, forced draft drying | — | 15.9 | 10.7 |
| 4 | 800 l S 3-shift, forced draft drying | — | 26.1 | 17.5 |
| 5 | 800 l Y 2-shift, forced draft drying | — | 16.2 | 10.5 |
| 6 | 800 l Y 3-shift, forced draft drying | — | 27.7 | 17.8 |
| 7 | 3000 l S 2-shift | — | 26.2 | 17.7 |
| 8 | 3000 l S 3-shift | — | 38.6 | 25.3 |
| 9 | 3000 l Y 3-shift | — | 26.4 | 17.4 |
| 10 | 3000 l Y 3-shift | — | 40.4 | 25.7 |
| 11 | 6000 l S 1-shift | — | 16.9 | 12.0 |
| 12 | 6000 l Y 1-shift | — | 17.3 | 12.0 |

relatively small scale (50 kg $h^{-1}$ as compared to a minimum of about 2 t $h^{-1}$ for commercial roll presses), less complex, involves lower equipment cost and is less sensitive to equipment controls.[14]

A maximum plant capacity of 6000 t $yr^{-1}$ is selected for analysis, because of the economies of scale if the industrial coal market can be penetrated. This is a large-scale plant and should therefore use a roll press briquetting technique. It is also necessary to evaluate smaller plants for reasons such as unavailability of capital, simplicity of operations and logistics and labour/capital intensity. A smaller roll press plant of 3000 t $yr^{-1}$, is considered for this purpose. Penetration of the household market is guaranteed at this capacity. Next, a medium scale plant of 800 t $yr^{-1}$, similar to the Sudan plant, appears attractive. It would use the agglomeration technique with its different labour/capital intensity features and associated benefits. A small scale plant with capacity less than 500 t $yr^{-1}$ is not interesting in view of the large market potential. It would be forced to use the agglomeration technique and cannot benefit from economics of scale, such as the medium-size plant.

For the financial and economic evaluation, several production alternatives have been elaborated on the basis of the most important combinations of technology, scale, carbonization and briquetting period (Table 2). One-, two- or three-shift operations of 8 h $shift^{-1}$ are considered as alternatives for each plant option. The multiple shift options would improve capital utilization, although the benefits must be considerable to justify such a more complicated operation with its attendant organizational problems and risks. All the year-round operations are conducted with the use of forced draft dryers, while all seasonal operations are conducted with sun drying of the briquettes.

For each of the plant options, four types of kilns were investigated: (i) the normal open-ring kiln (cylindrical kiln with a conical top) of 2.2 $m^3$ capacity as used in Sudan, constructed from new steel sheets, (ii) the same kiln constructed from used drums, (iii) used drum kilns of 0.2 $m^3$ capacity, and (iv) the Subri-Fosse pit kiln (a modified rectangular pit kiln with metal cover fabricated from used drums) of 12 $m^3$ capacity.

3.8.2. *Capital investment and production costs.* For the more promising plant options (using drum kilns and long carbonization periods), the ranges of total capital investment and production costs, excluding distribution, are given in Table 3. The total capital investment costs range from K289,000 to K477,000 for sun drying agglomeration plant options; from K459,000 to K578,000 for the agglomeration options using forced draft drying; from K1,399,000 to 1,621,000 for the 3000 t $yr^{-1}$ roll press processes, and is K2,265,000 for the 6000 t $yr^{-1}$ roll press process. The items contributing most to the capital cost are the charcoal kilns, the agglomerators and the building for the agglomeration processes. For the roll press processes, the charcoal kilns, the hammer mill, the roll press and the forced draft dryer contribute most to the cost.

The chief production cost items are the charcoal, direct labour, maintenance, indirect labour, administration, capital and distribution costs. The production costs, excluding distribution, range from K133 $t^{-1}$ to K245 $t^{-1}$ for the agglomeration plants, K148 $t^{-1}$ to K196 $t^{-1}$ for the 3000 t $yr^{-1}$ role press plants and is K158 $t^{-1}$ for the 6000 t $yr^{-1}$ roll press plant. The components of the cost are further analyzed for the most promising option in the following section. The distribution cost is fixed at K55 $t^{-1}$ for transport of the briquettes to retailers.

Table 5. Investigation and feasibility parameters for the most promising plant options

| | Agglom. plant | | Roll press plant | |
|---|---|---|---|---|
| Parameter | A2 | A3 | R2 | R3 |
| Plant output, t $yr^{-1}$ | 1600 | 2400 | 6000 | 9000 |
| At interest rate: 10%, 1000% equity | | | | |
| Capital investment, K1000 | 383 | 477 | 1621 | 1844 |
| BEV, t $yr^{-1}$ | 611 | 775 | 2480 | 3100 |
| FIRR | 28.0 | 38.5 | 26.4 | 40.4 |
| Pay-back period, yrs | 3 | 3 | 3 | 3 |
| Direct value added, K1000 $yr^{-1}$ | 309 | 477 | 1049 | 1669 |
| Total briquett. workers/employees | 58 | 82 | 39 | 51 |
| At interest rate: 16.5%, 100% equity | | | | |
| Capital investment, K1000 | 386 | 481 | 1635 | 1860 |
| BEV | 690 | 871 | 2803 | 3458 |
| FIRR | 28.1 | 38.3 | 26.6 | 40.1 |
| Pay-back period, yrs | 3 | 3 | 3 | 3 |
| Direct value added, K1000 $yr^{-1}$ | 294 | 458 | 986 | 1598 |
| At interest rate: 16.5%, debt/equity: 60:40 | | | | |
| Capital investment, K1000 | 386 | 481 | 1635 | 1860 |
| BEV | 690 | 871 | 2803 | 3458 |
| FIRR | 25.8 | 35.9 | 24.3 | 37.7 |
| Pay-back period, yrs | 4 | 3 | 4 | 3 |
| Direct value added, K1000 $yr^{-1}$ | 294 | 458 | 986 | 1598 |

3.8.3. *Financial and economic parameters.* Detailed results of the financial and economic analysis for all the plant options are presented elsewhere.[5] They were considered for the normal open ring kiln, the drum kiln and the Subri Fosse pit kiln using an interest rate of 10% and a debt/equity ratio of 0:100 as a base case. The UNIDO guidelines[15] were applied. The financial internal rate of return (FIRR) for the most promising options are summarized in Table 4.

Options with FIRR of less than 10% have been omitted from the table. It has been found that several options are indeed financially viable with a FIRR ranging from 10.3 to 40.4. The use of the open ring kilns is however unattractive. The drum kilns give the best profitability in all cases because of the lower capital investment requirements. The Subri-Fosse kilns give an intermediate profitability. Four plant options using drum kilns are the most attractive: the 800 t $yr^{-1}$ agglomeration process with seasonal sun drying operation, operating at 2- and 3-shifts (options A2 and A3 with briquetting outputs of 1600 and 2400 t $yr^{-1}$ respectively) and the 3000 t $yr^{-1}$ roll process, with a year round operation at 2- or 3-shifts respectively (options R2 and R3 with outputs of 6000 and 9000 respectively). Their investment and feasibility parameters are summarized in Table 5. Options A2 and A3 had financial internal rates of return (FIRR) of 28.1% and 38% respectively at an interest rate of 10%, whereas options R2 and R3 had FIRR of 26.6% and 40.4%, respectively. All the options had a pay-back


Fig. 5. Production costs for agglomeration plant option A2 by components for various shifts.

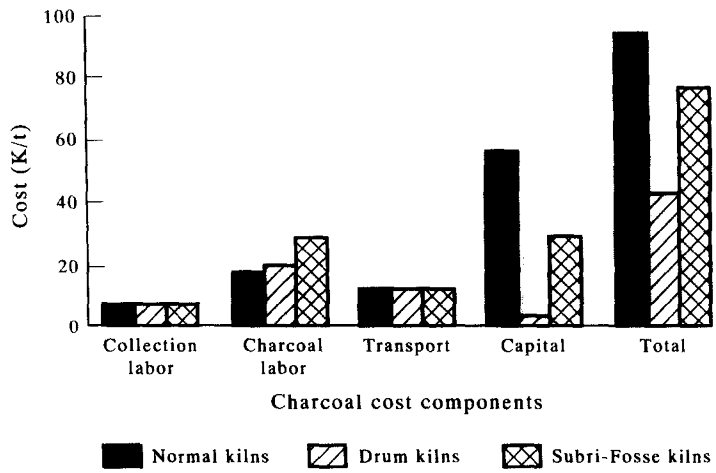


Fig. 6. Charcoal costs for agglomeration plant option A2 by cost components for various kiln types.

period of three years. The viability of the plants at commercial conditions of 16.5% interest and 0:100 and 60:40 debt/equity ratios are also similarly attractive (Table 5).

For these options, the subri-Fosse kilns yield an FIRR of 17.4% and 25.7% which is attractive and suggests the possibility of using combinations of drum kilns and the Subri-Fosse kilns where scaling down of kiln handling may be advisable.

From a socio-economic point of view all the options are favourable. The direct value added ranges from K294,000 for the agglomeration A2 option to 1,598,000 for the roll press R2 option, the plants employing 508 man-weeks of stalk collection labourers, 647 man-weeks of charcoalers and 35 briquetting workers and employees for the A2 option compared to 5714 man-weeks of stalk collection labourers, 7279 man-weeks of charcoalers and 51 briquetting workers/employees for the R3 option.

### 3.9. *Production cost and sensitivity analysis*

The production costs and charcoal costs are analyzed for two alternative plant options: A2 and R2. The major production costs components for the agglomeration plant are shown in Fig. 5 as a function of the number of shifts.

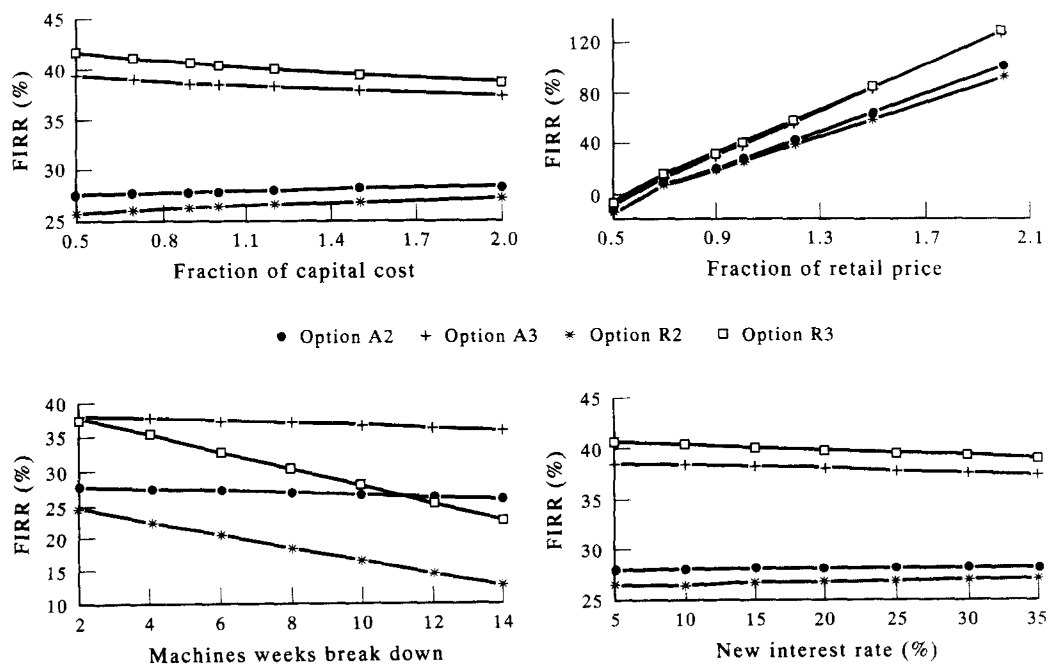


Fig. 7. Sensitivity of FIRR of plant options to changes in (a) capital costs; (b) charcoal retail prices; (c) weeks of machine breakdown; (d) interest rate.

The structure of the costs is quite similar for the two plants. The greatest contributions are from the capital and distribution costs. Benefit is derived from more shifts mainly from reduction in capital, maintenance and administration costs. Capital and charcoal labour costs are the major variants of the charcoal costs as shown in Fig. 6 for the agglomeration plant option A2. As expected, the considerable advantage of the drum kilns over the other types is due to the substantial reduction in capital costs.

An analysis of the sensitivity of the FIRR of plant options A2 and R2 to changes in capital cost, charcoal retail price, machine breakdown and interest are presented in Fig. 7. The 3-shift options decrease slightly in viability with increase in capital cost but the 2-shift options are generally insensitive or improve slightly in the range of changes tested because of the high tax regime. The sensitivity to charcoal retail price changes is the greatest for all plants. The profits increase sharply with increase in prices. The 3-shift options derive the most benefit from the price increases. The agglomeration processes are clearly superior to the roll press options regarding sensitivity to machine breakdown, while the profitability of the latter decreases sharply with increase in weeks of machine breakdown. The profitability of the roll press plants remains essentially constant within the 14 weeks of machine breakdown tested. This is because many machines are used in the agglomeration.

### 3.10. *Project selection*

The agglomeration process is the most attractive. Not so much financially, but from a technical, other financial, socio-economic and sensitivity points of view. It involves the lowest level of technology with low level of production organization and equipment that are easily fabricated locally, the lowest level of investment, and least energy consumption. It shows the least sensitivity to various changes in the conditions of the production and its more attractive employment and income distribution effects. It is recommended to implement the A2 option in the first instance and increase production by adopting the 3-shift option when the production system has been mastered.

The agglomeration process can be implemented immediately, because it meets the demand of the household sector. The output of the roll press plants exceeds that demand and their implementation will have to await the penetration of the industrial market. The R3 option is slightly over-sized for the total briquette market of 7000 t yr$^{-1}$, but the production program can be planned to supply the present demand and leave room for future growth of the market, for example through higher penetration of the industrial market.

## 4. CONCLUSIONS

The feasibility analysis shows that charcoal production from cotton stalks in Ngabu to supply the Blantyre market is financially and economically viable. Of the many plant options that are found viable, four, using drum kilns for carbonization, are the most attractive. These options are the 800 t yr$^{-1}$ agglomeration process with seasonal sun drying operation, 2- and 3-shifts, and the 3000 t yr$^{-1}$ roll press process, year round operation, 2- and 3-shifts; financial internal rates of return are 28.1%, 38.3%, 26.6% and 40.0%, respectively, with a pay-back period of three years. The agglomeration process is overall the most attractive alternative, though not significantly so financially.

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## REFERENCES

1. A. Williams, *The Potential for Rationalization of the Use of Agroindustrial and Agricultural Residues as Energy Sources in Malawi.* Biomass Technology Group, University of Twente, Enschede, The Netherlands (1990).
2. R. V. Siemons, A. M. Hood and T. Botterweg, *Feasibility Study on Semi-Centralized Charcoal Briquette Production from Cotton Stalks in the Republic of the Sudan.* Ministry of Foreign Affairs, De Hague (1987).
3. R. V. Siemons, J. Vos and A. Hood, *Evaluation of REPCO's Briquetting Activities: Cotton Stalk Carbonization and Briquetting Project, No. SD/89/048.* Biomass Technology Group, University of Twente, Enschede, The Netherlands (1990).
4. J. Vos and J. Heijndermands, *Marketing of Cotton Stalk Charcoal Briquettes in Sudan*, UNIDO XA/SUD/90/624. Biomass Technology Group, University of Twente, Enschede, The Netherlands (1991).
5. P. B. Onaji and R. V. Siemons, *Charcoal Production from Cotton Stalk in Malawi: A Feasibility Study.* Ministry of Foreign Affairs, The Hague, The Netherlands (1991).
6. Anon, *Economic Report.* EP & D, Department of Economic Planning and Development, Office of the President and Cabinet, Lilongwe.

7. H. E. M. Stassen and P. B. Onaji, *Woodfuel Activites of Some International/Donor Organizations, 1981–91.* A review prepared for the FAO, Rome, by the Biomass Technology Group, University of Twente, Enschede, The Netherlands (1991).
8. W. Teplitz-Sembitzky and G. Zierorth, *Solid Fuels in Malawi: Options and Constraints for Charcoal and Coal, Vol. II Charcoal.* Interdisciplinary Project Consult, Frankfurt (1988).
9. W. Teplitz-Sembitzky and G. Zieroth, *The Malawi Charcoal Project: Experience and Lessons.* Industry and Energy Department Working Paper, Energy Series Paper No. 20. World Bank, Washington DC.
10. H. Chitenji, Private communication. Energy Studies Unit, Ministry of Natural Resources, Lilongwe, Malawi (1991).
11. G. G. Stevenson, *Pre-Investment Analysis for Biomass Fuels.* A paper presented at the International Workshop on Biomass Fuel Briquetting in Developing Countries, Khartoum (1988).
12. S. Eriksson and M. Prior, *The Briquetting of Agricultural Wastes for Fuel.* FAO Energy and Environment Paper 11, FAO, Rome (1990).
13. Anon, *Malawi Urban Energy Survey*, Energy Studies Unit, Ministry of Natural Resources, Lilongwe, Malawi (1984).
14. R. V. Siemons, Cotton stalk charcoal agglomeration in the Sudan. In *Charcoal Production and Pyrolysis Technologies* (P. Thoresen, Ed.). REUR Technical Series 20, FAO, Rome (1991).
15. Anon, *Manual for the Preparation of Industrial Feasibility Studies.* UNIDO, Austria (1985).