Distr.
LIMITED 881
E/ESCWA/NR/WG.1/15
26 November 1988
ENGLISH
ORIGINAL: ENGLISH

UNITED NATIONS

ECONOMIC AND SOCIAL COUNCIL

ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

Seminar on Biogas Technology for Rural Areas
in Selected Arab Countries
26 November - 1 December 1988
Cairo

Biogas ...is it the Solution?

Country Paper
Yemen Arab Republic

Prepared by
Dr. M.K. Al-Motawakel
Department of Physics, Solar Energy Research LAB,
Faculty of Science, Sana´a University

بسم الله الرحمن الرحيم

الجمهوريه العربيه اليمنيه
جامعة صنعاء
كلية العلوم
قسم الفيزياء

الغاز الحيوى .... هل هو الحل ؟

دكتور/ محمد قاسم المتوكل
قسم الفيزياء - معمل ابحاث الطاقه الشمسيه
كلية العلوم - جامعة صنعاء - صنعاء الجمهوريه العربيه اليمنيه

المهندس / ضرار عبد الدائم
اتحاد المجالس المحليه للتعاون والتطوير
ص. ب ١١٠٦٩ - صنعاء - الجمهوريه العربيه اليمنيه

ملخص البحث

لا يزال الحرق المباشر لكل من الحطب - المخلافات الزراعيه والحيوانيه هو المصدر الأول لطاقة الطباخه فى المنزل اليمنى . هذا وتدل نتائج البحث ان المعدل المتوسط للاستهلاك الفردى قد وصل الى ١ر٧٧ كم من حطب الوقود فى اليوم .
وذلك يعادل (اذا ماكان المحتوى الطاقى ١٥ ميجاجول لكل كيلو جرام) حوالي ٢٦ر٦ ميجاجول من الطاقه فى اليوم (اى ٧ر٣٨كيلووات ساعه فى اليوم لكل شخص أو ٣٠٧ وات من الطاقه لكل ساعه من ساعات اليوم) . ان ذلك المعدل الأستهلاكى العالى يكلف رب المنزل يفرض ان السعر المتوسط للحطب ١ر٩ ريال لكل كيلو جرام) حوالى ٣ر٣٦ريال فى اليوم الواحد، ولكى نعرف اسباب ذلك الاستهلاك العالى يقدم البحث مناقشه شامله لصور الاستهلاك الطاقى فى المنزل اليمنى وذلك كمقدمه لمناقشة امكانية احلال مصادر الوقود الأحفورى (مثل الجاز - والغاز) محل الحطب .
ان المشهد الاول الذى يناقشه البحث يعالج امكانية استخدام الجاز والغاز بدلا من الحطب وقد اتضح ان ذلك ممكن ولن يكلف الشخص (عند مستويات الأستهلاك الحاليه) أكثر من ٣ ريال فى اليوم الواحد .
اما بالنسبة للغاز الحيوى (موضوع المشهد الثانى) فأن نتائج البحث تؤكد أن مصانع الغاز الحيوى التى يكون انتاجها اقل من ٥ متر مكعب فى اليوم لا تزال (بالنظر الى المنفعه الطاقيه فقط) نوع من انواع البذخ وان الترجمه العطيه لمثل تلك المصانع لن تكون ذا مردود مادى اما بالنسبه للمصانع التى تنتج أكثر من ٥ مستر مكعب من الغاز فى اليوم فأن الكلفه الماديه يمكن تبريرها بالعوائد الماديه المتوقعه بعد سنتين او ثلاث من انشاء المصنع . وعند مناقشة قدرة مصانع الغاز الحيوى فى تزويد منزل بالطاقه اللازمه للطباخه والأضاء ، اتضح ان ذلك ممكن اذا ماتوفرت كتله حيويه بمعدل قدرة ٤٥كيلوجرام فى اليوم (اى مايعادل انتاج ١٨ بقره كل منها ينتج ٢ر٥ كيلو جرام من المخلافات فى اليوم)، وكان رب المنزل مستعد لدفع أكثر من نصف دخله السنوى لأنشاء المصنع .

BIOGAS —— IS IT THE SOLUTION ?

M.K.AL-MOTAWAKEL
DEPARTMENT OF PHYSICS, SOLAR ENERGY RESEARCH LAB,
FACULTY OF SCIENCE, SANAA UNIVERSITY, SANAA, YAR

D.A.ALDAIN
CONFIDERATION OF LOCAL COUNCILS FOR COOPERATIVE DEVELOPMENT,
SANAA, P.O.BOX 11069, SANAA, Y.A.R.

SUMMARY

Fuelwood (the energy provided by the direct burning of wood, residues, dungs, and charcoal) is still the prime supplier for the cooking energy loads in the Yemeni houses. The results of the presented analysis show that the average daily consumption of fuelwood is about 1.77 Kg per day per person. This is equivalent (at fuelwood caloric value of 15 MJ/Kg) to about 26.6 MJ per day per person (i.e. 7.38 KWh per day per person or 307 W of continous thermal power). This consumption costs the house owner (at an average market price of 1.9 YR/Kg) about 3.36 YR per day per person (1 YR = 0.1 US$).

To study the reasons leading to such a high consumption rate, a detail discussions for the various patterns of energy uses is presented. After this introduction, the paper investigates the possibilities of replacing fuelwood with fossil fuels. In the first scenario, we consider the replacement of fuelwood with the locally available LPG. It turns out that a full replacement is possible and costs, at the current energy consumption rates, about 3 YR per day per person (i.e. 0.3 US$ per day per person).

As for biogas plants, the subject of the second scenario, it was found that biogas systems with production capacity less than 5 m^3 per day are still (considering the energy benefits alone) a luxury and implementing them is not realy a worthy investment. For biogas systems with production capacity greater than 5 m^3 per day the investment is relatively justified with payback period between 2 and 3 years. Add to this the practical difficulties involved in

finding a suitable practical setup. For example, replacing fuelwood consumption in a typical rural house demands an organic waste loading rate of 45 Kg of volatile solids per day. This would be possible if the farmer owns say 18 cows each producing 2.5 Kg of volatile solids per day.

Thus "IT WOULD BE PRUDENT FOR YEMEN TO PROCEED SLOWLY AND CAUTIOUSLY IN ADOPTING THE WASTE-TO-ENERGY CONVERSION PLANTS"...... YES DEMONSTRATIONS ARE NECESSARY BUT THE DEMONSTRATED SYSTEMS ARE NOT AFFORDABLE".

INTRODUCTION

Pattern Of Energy Uses In The Yemen Arab Republic

The fuels used in a typical Yemeni household vary in their types and quantities according to the daily functional uses of each fuel employed, foodhabits, availability of fuels, and to less extent the market prices of each fuel. The results of previous surveys [1, 2, 3] as well as the preliminary results of the 1987 household energy survey indicated that the functional uses of energy in a typical household are provided by the various fuels as listed in Table (1).

Table (1) : Functional Energy Uses Of The Various Fuels As Employed In The Yemeni Houses

Source	Order	Functional Energy Uses Urban	Rural
Electricity	1	Lighting	Lighting
	2	Operating Appl.	Operating Appl.
	3	Space Heating / cooling	
	4	Water heating	
	5	Cooking	
L P G	1	Cooking	Cooking
	2	Water heating	Water heating
Kerosene	1	Cooking	Lighting
	2	Water heating	Cooking
	3		Water heating
Charcoal	1	Smoking water pipe	Cooking
	2	Cooking	Smoking water pipe
	3	Water heating	Water heating
	4	Space heating	Space heating
Wood, Residues, Dung	1	Cooking	Cooking

The differences in the functional uses of energy come mainly from the differences in cooking habits, and the availability of employed fuels.

The current market prices of the various fuels, at least for the time being, do not control the choice of the type of fuel employed. Based on the prices per unit of energy, see Fig. (1), the use of LPG in say cooking is cheaper than the use of fuelwood but social values associated with the quality and smell of the baked bread are still the driving forces in choosing the type of fuel. This fact is reflected in the current geographical distribution of the annual per capita fuel consumptions plotted for both rural and urban areas in Fig. (2).

The data summarized in Fig. (2) were derived by interpretting the 1982 figures [2], adapted for 1988, together with the geographical availability of the various fuels as obtained from private communications. To compare the current situation with that of 1980 [4], Fig. (3) plots the ratio of the household cooking load as provided by the direct burning of wood-residues-dung-and charcoal to that provided by LPG and kerosene. It is clear that the current nationwide average of biomass-to-fossil fuel energy use ratio is higher than that of 1980. This is obvious because of the population increase and the weak penetration of fossil fuels particularly to rural areas.

The national rural and urban averages as well as the nationwide averages (mean of the national rural and urban averages) of the annual per capita fuel and energy consumptions and the corresponding biomass-to-fossil fuel energy use ratios are summarized, as obtained from Figs. (2 and 3), in Table (2).

Table (2) : National and Nationwide Annual Averages Of Per Capita Fuel and Energy Consumptions

Type Of Fuel	National Averages				Nationwide Averages	
	Fuel (Kg/P/Y)		Energy (GJ/P/Y)		Fuel (Kg/P/Y)	Energy (GJ/P/Y)
	Rural	Urban	Rural	Urban		
Wood+Residue+Dung+ Charcoal	798.0	498.0	11.48	6.92	648.0	9.20
Kerosene + LPG	46.7	46.1	2.10	2.23	46.4	2.15
Biomass-to-fossil fuels energy use ratios			5.54	3.24		4.39

Accordingly, the nationwide annual per capita fuelwood consumption, including that from charcoal, is 648 Kg (compared to 46.4 Kg from fossil fuels). Assuming a 3% annual growth in population and letting the fraction of the population using fuelwood be 0.7, then the total amount of fuelwood consumed in cooking in the whole country (as obtained by adapting the 1986 census for 1988 [5]) is 5.87 million cubic meter per year. This is exactly 4.7 times the current annual growth rate of tree planting (1.25 million cubic meters per year) and 0.87 greater than the figure of 1983 [6] .

There are a number of social and political difficulties which delayed the advancement of tree planting. Weber and others [7, 8, 9] have listed a number of difficulties. It seems like that the possibilities of increasing the green cover and consequently fuelwood are subject to increasing the political weight of the environmental issues, solving the problems associated with land ownership, and strengthening the ability of the Forestry Department so as to be able to tackle these issues from the technical and legal point of views. The third five-year plant (1987 - 1991) of Forestry Department did not mention the expected increase in tree planting compared to the reported rate (1.25 million cubic meters per year) but it is projected that the total area of tree planting will increase from 3.4 to 16.5 hectares during the period from 1987 to 1991 [6] . The practical implementation of such aims rests upon the availability of local and internationsl funds as well as on passing the Forestry Law.

Can We Replace Fuelwood With Fossil Fuels ?

There is no parameter one can use to describe the social acceptance of replacing fuelwood with fossil fuels. The biomass-to-fossil fuels energy use ratio relate the energy units provided by fuelwood to those provided by fossil fuels. This does not reflect the effect of social, economical, and energy conservation measures on consuming fuels. Such picture is reflected in Fig. (3) where the biomass-to-fossil fuel energy use ratios were greater, except for urban Sanaa and Al-Hodiedah, than one. Such exception has resulted from a number of factors. The shift from home baked to bakery bread

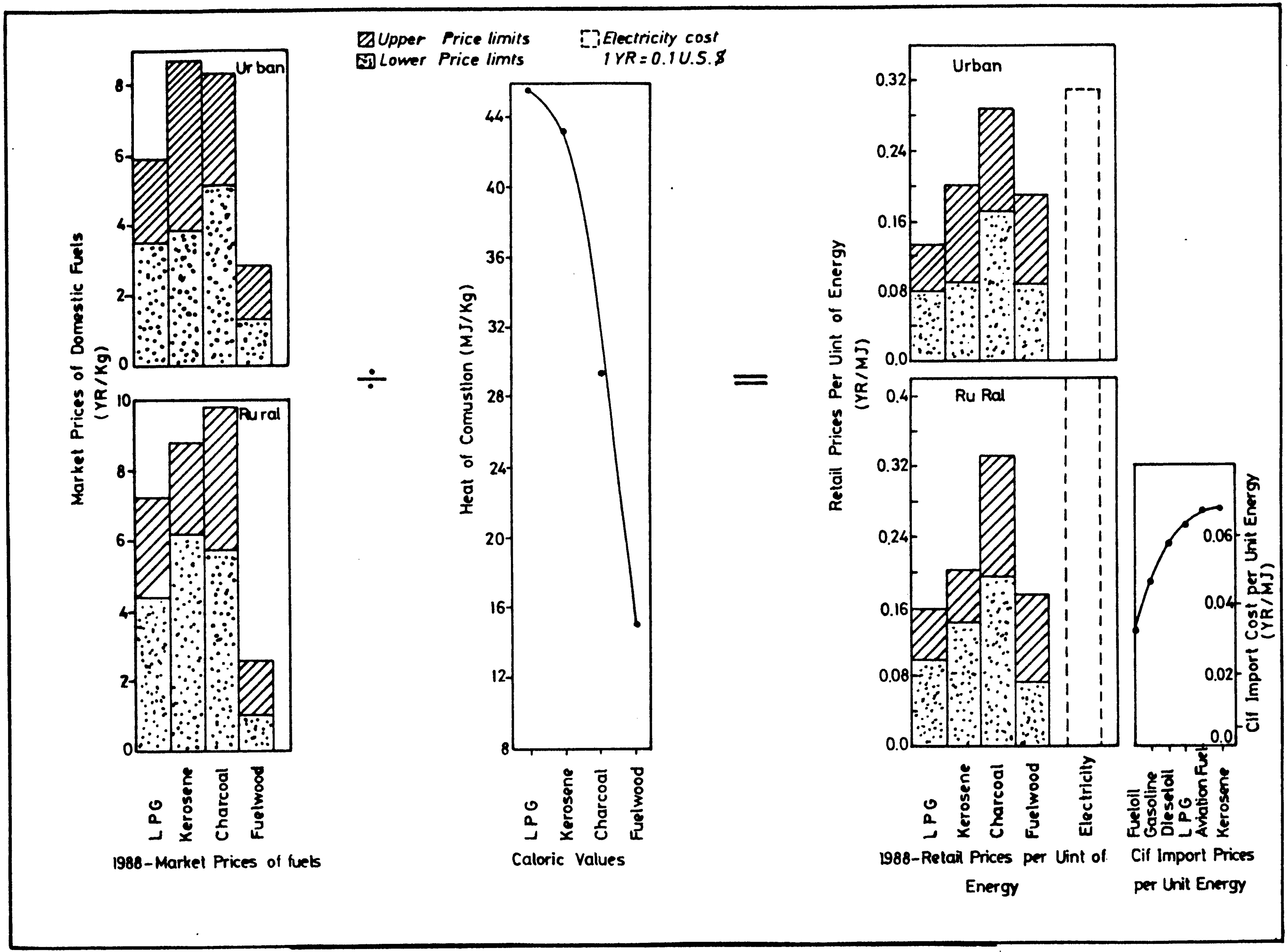

Fig. (1): 1988-Retail and Cif Import Prices Of Various Fuels As Used In The Yemen Arab Republic

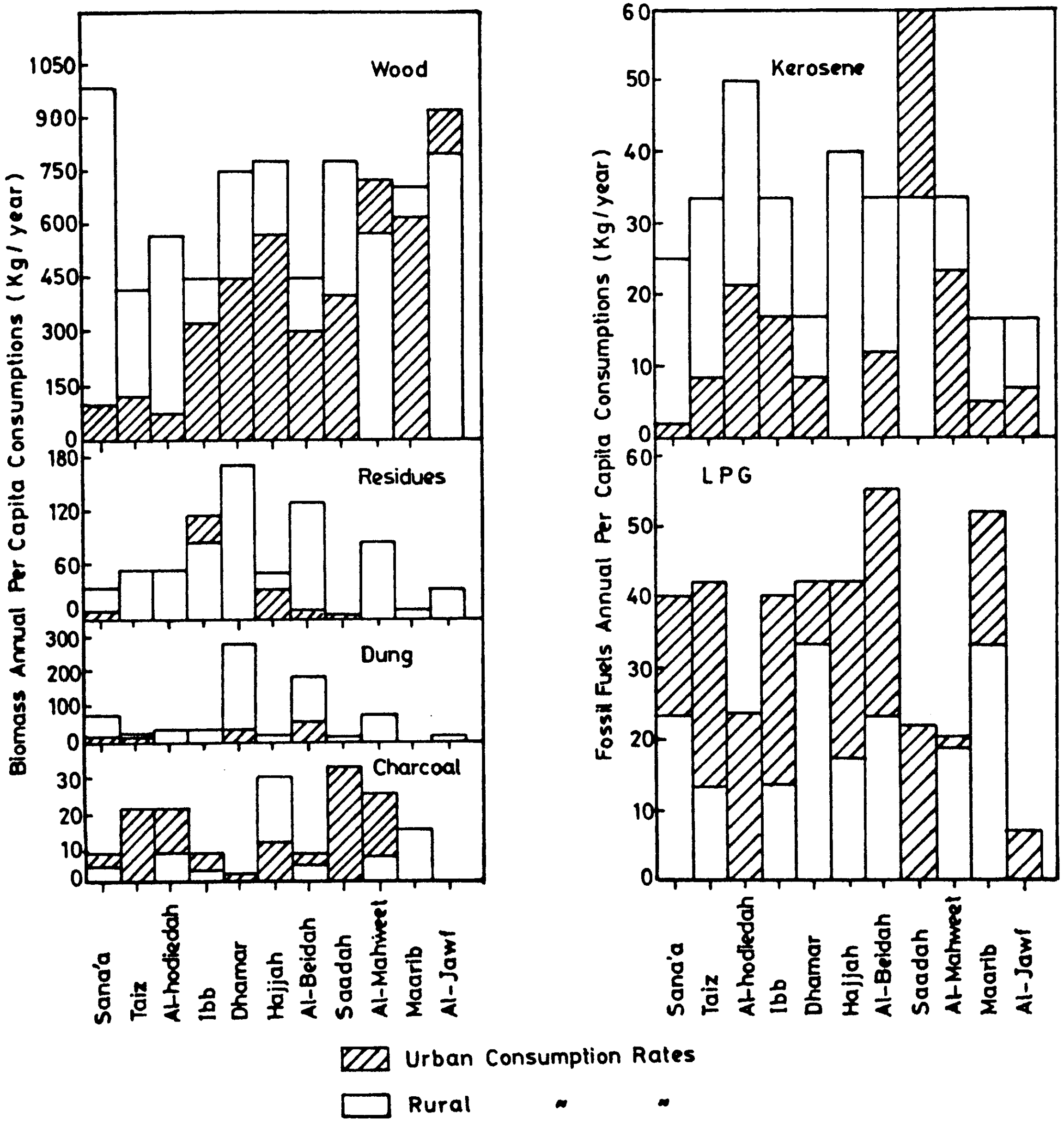

Fig. (2): Geographical Distribution Of The Annual Per Capita Fuel Consumptions

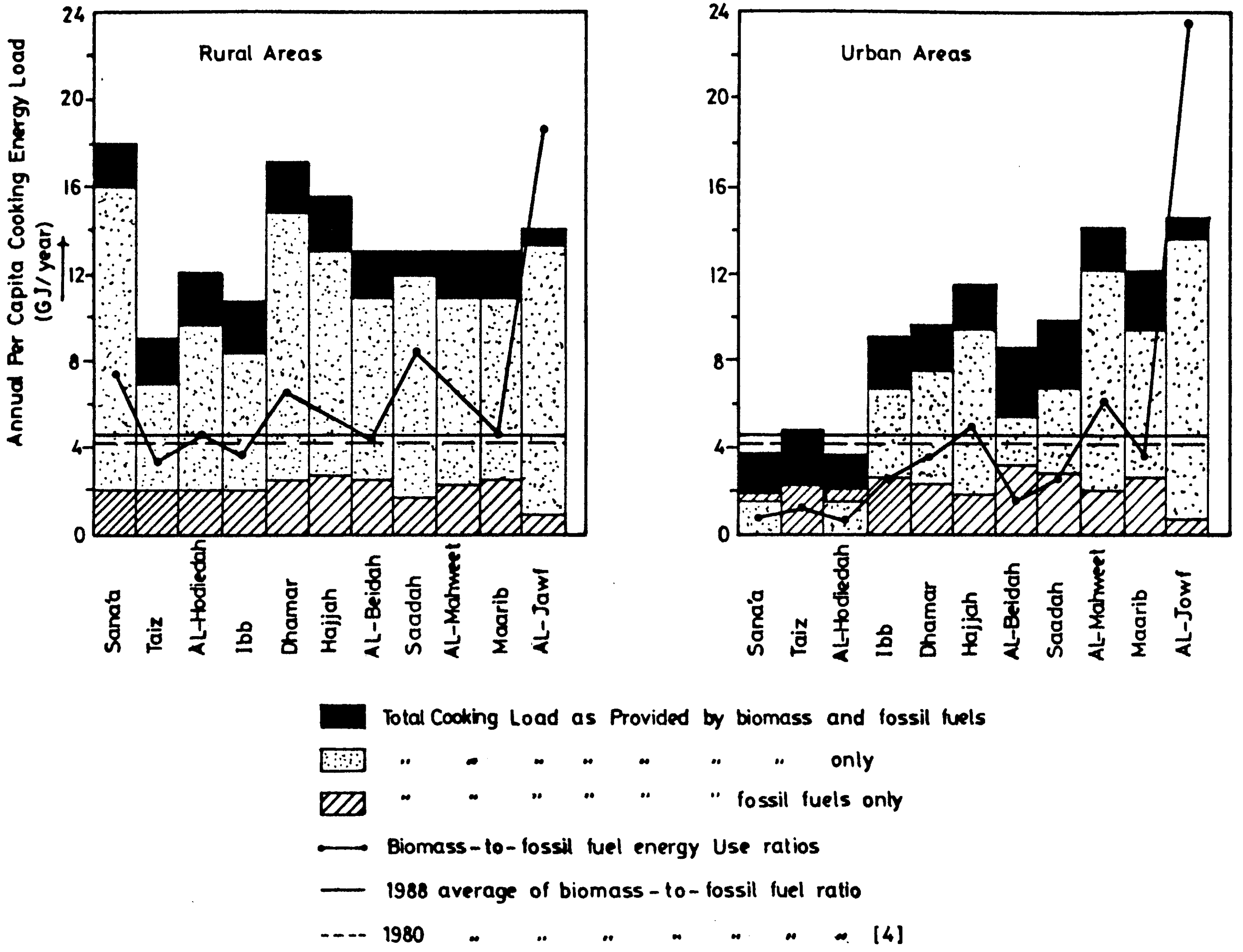

Fig. (3): Geographical Distribution Of The Annual Per Capita Cooking Energy Load and Biomass-to-Fossil Fuel Energy Use Ratio.

was one of the options employed by some urban houses in these two cities. Those who questioned the quality of bakery breads preferred to half their fuelwood consumption by baking every other day [2]. As for rural areas the storey is different. A large amount of the consumed fuelwood is collected for free rather than bought. This explains why the biomass-to-fossil fuel energy use ratio is greater than one in all rural areas. Add to these factors the fact that the currently used clay ''Tannur'' is an inefficient devise for baking bread. The results of the on-going tests at Sanaa University Solar Energy Research lab indicate that almost 60% of wood energy is lost to the surroundings. Only 8% of woodenergy is effectively used in baking bread. The rest of the energy goes in heating the clay Tannur to an average inside wall surface temperature of 300 °C. Another results confirm these findings. Peter Young [10] have reported that baking 1 Kg of bread requires 2.2 to 5 Kg of wood.

Assuming that all these difficulties will be overcomed, then the full replacement of fuelwood (i.e. energy provided by the direct burning of wood-residues-dungs-and charcoal) with fossil fuels (i.e. energy provided by Kerosene and LPG) demands the availability of 6.92 GJ (in the urban areas) to 11.48 GJ (in the rural areas) of fossil fuels per year per person.

Thus on the average we need 9.2 GJ of fossil fuels per year per person to fully replace the current consumptions of fuelwood. Assuming that 0.4 of the 9.6 million people in Yemen employ fuelwood, then the above figure translates into 0.78 MTOE (1MTOE=45.37 MGJ). It is projected that [11], the local LPG available from the national oil production as well as the planned piping of national natural gas would provide, after deducing the amount of natural gas employed in generating the thermal power, a maximum of 80% of the required fossil fuels. Accordingly, the shortfall of fuelwood substitution fuels demands supplementing the locally available LPG with 0.156 MTOE per year of imported or locally produced fuels.

SCENARIOS FOR THE FUTURE

Scenario I: Importing the Shortfall Of Wood Substitution Fuels

The current oil exports are of the order of 140000 barrel per day. There are plans to increase the oil exports to 240000 barrel per day [11]. The current as well as the planned oil exports are respectively equivalent to 7.41 and 12.71 MTOE per year. Thus importing 0.156 MTOE per year, about 2% of the current oil production and 1% of the planned oil production, will not pose a foreign exchange problem for the country. But

what fuels should we import ? and
how much would they cost ?

Fig.(1) shows the World Bank 1987 CIF prices of importing various fuels [12] . Using the caloric values of Fig.(1), the cif costs per unit of energy can be used as one of the measures for choosing the type of fuels to be imported. It is clear that importing LPG and Kerosene are the two realistic options. The current energy consumption patterns, see Figs.1,2, and 3, suggest importing both fuels. According to the import prices of Fig.(1), importing the supplement quantities would cost (0.8 LPG and 0.2 Kerosene) 457 million Yemeni Rial per year (i.e.45.7 million U.S.dollars per year).

Add to this sum the amount of money needed to:-

Cost
12 million YR/year: stop the decline of wood and rebuild the green cover [6]
2500 million YR/year: employ the national LPG [11]
4020 million YR/year: payment for the current and future use of fuels--estimated according to the current prices

then we arrive at a gross sum of 6989 million YR per year. This translates, assuming 0.7 of the 1988 population, to 3 YR per day per person. Thus each one of us is paying 3 YR per day to:

Cost	Function
1.725 YR/day	provide the house with the cooking energy at a rate of 0.026 GJ per day per person (i.e. 7.37 KWh/day/person)
1.074 YR/day	help in employing the national LPG
0.195 YR/day	help in importing the additional fuels
0.006 YR/day	help in rebuilding the green cover and development of forests

This is lower than the current prices of the cooking energy. In fact and based on the current consumption rates, each one of us pays 4.21 YR per day for utilizing LPG, kerosene, and fuelwood. Thus implementing the replacement is cost-effective but is it socially accepted ?. The answer to this question is difficult but the current consumption rates indicate that social values are still resisting the full replacement of fuelwood with fossil fuels.

SCENARIO II : PRODUCING THE SHORTFALL OF FUELWOOD SUBSTITITION FUELS LOCALLY —— THE BIOGAS OPTION

Before discussing the details of this option, let us reflect the views of the participants at the Nov. 1984 Cairo conference on biogas technology [13]. In that conference, participants agreed that :-

- The implementation of successful projects in biogas is very complicated and expensive despite the fact that biogas technology itself is clearly feasible and proven ; and
- Successful biogas projects must be part of on-going agricultural processing activities and emphasize both system efficiency and multi functionality such as fertilizer, animal feed, improved sanitation, and energy production.

In view of this message we choose to present biogas plants in two very different social and economic settings. The first considers the application of biogas plants in a chicken farm where they will serve as "fertilizer factories" and animal feed supplemenators while still serving as methane generators. In the framework of the individual cost-benefit approach, the second setting looks into family-sized biogas plants and concentrates on the question of whether a single rural family and/or community considers biogas plants as helpful and efficient investment. Before discussing each of these settings, let us consider the factors governing the sizing and costing of biogas plants.

FACTORS COVERING THE SIZING OF BIOGAS PLANTS

Sizing a biogas plants depends on the type of digester and its functionality. For example if health is the primary purpose then the reduction of the retention time (theoretical period during which solid particles or added volumes will remain inside the digester) and temperature are very important. If the plant is considered as a "fertilizer factory" then breakdown, stabilization, and storage of the organic and nutrients will govern the plants sizing. However if energy is the prime aim from constructing the plants then gas production should be optimized for the effect of concentration of feed, growth of microorganism, retention time, and the kinetic constants. All these factors have been combined in one equation which allows the prediction of gas yield [14] :-

$$\dot{V}_M = (Bg/\tau)\,\eta_T \qquad (1)$$

where

$\dot{V}_M$ = rate of methane yield (m^3 of CH$_4$/m^3 of digester per day)
B = ultimate methane yield (m^3/Kg)
g = influent volatile solids concentration (Kg/m^3)
τ = retention time (days)

The factor η_T expresses the reduction in methane yield due to the kinetic effect (expressed by the dimensionless parameter K) and the growth of microorganism (expressed by the factor U and measured in day^{-1}).

The factors K and U are defined as [14] :-

$$\begin{aligned} K &= 0.8 + 0.0016 * \mathrm{EXP}(0.06 * (g)) \\ U &= 0.013\,T - 0.129 \end{aligned} \qquad (2)$$

where T is the temperature inside the digester in °C. In terms of these two factors η_T is given by :

$$\eta_T = \left(1 - K/(\tau U - 1 + K)\right) \qquad (3)$$

Thus by projecting the quantities of matters that can be destroyed during a certain period and at a given temperature and for given values of B, one can use Eqns. 1 to 3 to predict the volumetric methane production.

The corresponding biogas ($\dot{V}_b$) and energy ($\dot{E}$) rates are given by :-

$$\begin{aligned} \dot{V}_b &= (\dot{V}_M / f_M)\, V_d \\ E &= \dot{V}_b H_b \eta_s \end{aligned} \qquad (4)$$

where

f_M is the proportion of methane in the produced biogas
H_b caloric value of biogas (23.1 MJ/m^3)
V_d volume of the digester ($V_d = \dot{m}\, \tau / g$) (m^3)
$\dot{m}$ rate of volatile solids production (Kg/day)
η_s conversion efficiency of the system

COST-BENEFIT ANALYSIS :

Looking at biogas technology from an economic point of view means calculating the investment per volume of gas produced or per unit of energy generated. The system cost, SC, (i.e. material, labor, administrative, and contractor benefit costs) was determined by correlating the daily rates of biogas production with the 1988 local market prices. The results of such correlation are plotted in Fig. (4) and can be formulated, to within ± 10%, as follows :

$$SC = C_r (\dot{V}_b)^{0.7} \qquad (5)$$

where

C_r is a correlation constant representing the system cost of producing 1 m^3 of biogas per day.

$\dot{V}_b$ is the rate of biogas production (m^3/day)

The annual operating expenses were calculated using the following assumptions : -

Depreciation	13 % of SC
Interest	7 % of SC
Maintenance	2 % of SC
Life time	7 years

The annual gross benefit considers only the energy benefit, evaluated at 155 YR/GJ, as an LPG displacement. It does not include the economic benefit from liquid or dried sludge with its organic fertilizer or soil conditioner value. The annual net benefit was defined as the difference between the annual gross benefit and the annual operating expenses. The payback period was then defined as the ratio of the system cost to the annual net benefit. The energy output of the plant was computed at a caloric value of 23.1 MJ/m^3 of biogas and a system conversion efficiency of 60 %. It is clear from Fig. (4) that biogas systems with $\dot{V}_b < 5\ m^3/$ day are still, considering the energy benefits alone, a luxury and implementing such systems is not realy a worthy investment. For biogas systems with $\dot{V}_b > 5\ m^3$/day, the investment is relatively justified with a payback period between 3.7 and 2 years.

APPLICATIONS :

SETTING I : This setting represents the condition of a typical rural chicken farm consisting of 4 large halls with total area of 600 m^2. Each of these halls houses 1000 heads of baby chicken for a period of 30 days. During one year the farm houses 36000 baby chicken divided equally between 9 (each 30-day) periods. Currently LPG and electricity respectively provide the space-heating and lighting loads.

The owner of the farm has indicated that the current energy consumption patterns, based on 365 days, look as follows : -

Source	Function	Daily rate (GJ/day)	Days per year	Total load (GJ/year)	Yearly cost (See Fig.1) (YR/year)
Electricity	lighting	0.0468	365	17.082	1774.44
L P G	space and	0.1430	365	52.092	8074.26
	water heating	0.0712	365	25.995	4029.18
	loads	0.0381	365	13.892	2153.26
Totals		0.2990		109.061	16031.14

As for the wastes, the owner claims that he is giving it for free as long as interested farmers are ready to transport the wastes on their expenses. When asked about his profit, he said it may amounts to 14% of the annual income from selling the chicken.

Biogas is seen as a substitute for both the lighting and space heating loads. The estimated manure, methane, and gas production rates (based on 6000 Kg live weight) are as follows [15] : -

Manure production	(Kg/day)	:	360.000
Total dry solids	(Kg/day)	:	105.300
Total volatile solids	(Kg/day)	:	77.300
Biogas production	(m^3/KgVS)	:	0.490
Methane proportion		:	0.600
Ultimate methane production	(m^3/KgVS)	:	0.294
Conversion efficiency		:	0.600

The energy requirements of the farm demand an average energy production rate of 0.299 GJ/day. 16% of this rate is for lighting, 48% for space heating during the winter period (Nov. to Feb.), 24% for space heating during the mild weather (April, and Aug. to Oct.), and 12% for space heating during the warm season (May to July). Accordingly an appropriate biogas plant should be designed to yield (taking $H = 23.1$ MJ/m^3) an average of 13 m^3 of biogas per day (i.e. 8 m^3 of methane per day). Optimizing Eqs. (1 to 3) indicates that if the temperature inside the digester can be maintained at 35 °C then an optimum design would be for an 18 m^3 digester and 20-day retention time. Such plant would produce (on the average) 20 m^3 of biogas per day (i.e. 12 m^3 of methane per day). The energy production rates of the optimum design are (based on 365 days) 0.039 GJ/day at 15 °C, 0.111 GJ/day at 20 °C, and 0.351 GJ/day at 35 °C.

These production rates are considered sufficient for the energy needs of the considered farm :-

Weather Conditions	Required Energy (GJ/day)			Produced Energy (GJ/day)	Excess (GJ/day)
	Space Heating	Lighting	Total		
Cold (15°< T<10°)	0.143	0.0154	0.1584	0.0390	-0.1194
Mild (20°< T<15°)	0.071	0.0196	0.0906	0.1110	0.0204
Warm (50°< T< 20°)	0.038	0.0118	0.0498	0.3150	0.2652
Total	0.252	0.0468	0.2988	0.4650	0.1662

Thus the sized plant would be able to cover the year round energy needs and there will be an excess of 0.1662 GJ/day. The system cost of such plant is, see Fig. (4), 22390 YR. The payback period and the unit energy production cost come respectively to 2 years and 81 YR/MJ/day. This unit energy production cost is higher by 27 YR/MJ/day than the current market price per unit of energy consumed. Despite of that, the annual benefit from considering the generated energy alone comes, see Fig. (4), to 48% of the system cost.

SETTING II : This setting is consernerned with the family-sized biogas plants. It is clear from Figs. (1 to 3) that fuelwood is still the prime supplier for the cooking energy needs in both rural and urban areas of the republic. The average annual per capita consumption of fuel, see Table (2), is 648 Kg. This is equivalent, at a caloric value of 15 MJ/Kg, to 26.6 MJ per day per person (i.e. about 307 W of continuous power).

The pattern of energy use and supply, adjusted on the basis of 365 days, is complex :-

Function	Daily Load (GJ/day/house)	Source	Retial Price (YR/GJ)	Daily Cost (YR/day/house)
Lighting	0.00288 [16]	National grid	420	1.2096
		Privately owned D.G.	55	0.1584
Cooking	0.15960	Fuelwood	170	27.1320
	0.01290	LPG	155	1.9990
Totals	0.17540			30.4990

Thus the per capita cost of energy (assuming that the average number of occupants per each house is 6) is 5.1 YR per day per person. This is equivalent at the current exchange rate (1 YR = 0.10 US dollar) to 0.51 U.S.$ per day per person (i.e. 36% of the average daily income [5]).

A biogas plant seen as a substitute for both the lighting and the cooking loads must be designed to produce at least 0.1754 GJ/day (i.e. 2.1 KW of continuous power). This will be beyond the money ability and the wastes availability of a typical rural Yemeni house. A typical rural community might own 18 cows that weigh 5400 Kg. Under such a case, the waste generation rates would be 56 Kg of dry solids and 45 Kg of volatile solids per day [15] . Taking the ultimate methane production as 0.2 m^3/Kg of VS [15] and optimizing Eqs. (1 to 3), then a 15 m^3 digester with retention time of 28-day would produce, at a temp. of 35 °C, 0.184 GJ per day. This is enough for displacing the cooking and lighting loads. But who can afford it ?. According to Fig. (4) the cost of such plant would come to 17443 YR. This is more than half the average annual per capita income of a typical Yemeni family. Add to this the fact that the above sized plant is only producing the energy needs of a single family. This complicate the situation of introducing biogas to rural areas not only because of the high cost but also because of the availability of wastes.

CONCLUSIONS AND RECOMMENDATIONS

In view of the presented results, it would be prudent for the Yemen Arab Republic to proceed slowly and cautiously in adopting waste-to-energy conversion plants and at the same time make funds available for :-

- Improving the current waste collection, transportation, and disposal system.
- Strengthening the present fossil fuel supply system by supporting the activities of manufacturing the pressurized gas cylinders locally.
- Improving the efficiency of the currently used cooking devices particularly the clay **Tannur** used for baking the Yemeni bread known as "Chobaz" and at the same time supporting the on-going research activities at Sanaa University regarding the development of a new clay Tannur design which can be fired by using a specially designed LPG burner rather than by the direct burning of wood, residues, dungs, and charcoal.
- Rebuilding the fuelwood resources
- Supporting the educational programs of increasing the people awareness towards the environmental issues.
- Investigating the potentiality of waste recycling trends.

REFERENCES : -

1) ANON, "FERTILITY SURVEY", DEPARTMENT OF STATISTICS, CENTRAL PLANNING ORGANIZATION, SANAA, YAR, 1977.

2) M.K.AL-MOTAWAKEL ET.AL., "ENERGY USED DOMESTICALLY IN THE YAR", APPLIED ENERGY, VOL.24, NO.3, PP.185-219, 1986.

3) N.A.AULAQUI, "HOUSEHOLD ENERGY AND TREE SEEDING DEMAND SURVEY IN THE SOUTHERN UPLANDS OF THE YAR", SANAA UNIVERSITY REPORT, JUNE, 1982.

4) L.PYLE, "BIOMASS ENERGY IN THE ARAB WORLD", CONSULTANCY REPORT, UNESCWA, NOV., 1980.

5) ANON, "1986 STATISTICAL YEAR BOOK", CENTRAL PLANNING ORGANIZATION, SANAA, Y.A.R.

6) ANON, "3RD FIVE-YEAR PLAN FOR TREE PLANTING AND FORESTS DEVELOPMENT PROJECT 1987-1991", MINISTRY OF AGRICULTURE AND FISHIERIES, GENERAL DEPARTMENT OF AGRICULTURE AFFAIRS, FOREST DEPARTMENT, SNAA, YAR, OCT.1986.

7) F.WEBER, "FORESTRY/CONSERVATION SITUATION AND POTENTIAL : MAHWEET PROVINCE-YAR", APPL. RESEARCH REPORT NO.3, AMERICAN SAVE THE CHILDREN/YEMEN, MARCH, 1980.

8) F.WEBER, "FORESTRY SECTOR PROGRAMMING : ISSUES, CONSTRAINTS, POTENTIAL-YAR", U.S. DEPARTMENT OF AGRICULTURE, JUNE, 1984.

9) ELS GEVERS, "STUDY INTO THE FIREDWOOD CONSUMPTION AND POSSIBILITIES FOR USE OF ALTERNATIVE ENERGY, RADA DISTRICT-YAR", RADA INTEGRATED RURAL DEVELOPMENT PROJECT, TECHNICAL NOTE NO.17, AUG., 1985.

10) P.YOUNG, "ASSISTANCE TO LOCAL STOVES AND OVENS IMPROVEMENTS", REPORT PREPARED FOR FAO, PROJECT GOP/YEM/018/SW1, 1986.

11) PRIVATE COMMUNICATIONS, "MINISTRY OF MINERAL AND OIL", SANAA, YAR, 1988.

12) WORLD BANK, "THE IMPACT OF RECENT OIL AND GAS DISCOVERIES ON THE MACROECONOMY AND ENERGY INVESTMENT OPTIONS", WORLD BANK REPORT 6376-YAR, FEB., 1987.

13) M.M.EL-HALWAGI, "BIOGAS TECHNOLOGY, TRANSFER AND DIFFUSION", PROC. OF THE CAIRO INTERNATIONAL CONFERENCE, NATIONAL RESEARCH CENTER, CAIRO, EGYPT, 17-24 NOV., 1984.

14) A.G.HASHIMOTO ET.AL., "ANAEROBIC FERMENTATION OF BEEF CATTLE MANNURE", REPORT TO U.S. DEPARTMENT OF ENERGY, 1978.

15) R.F.WARD, "ENGINEERING DESIGN OF BIOGAS UNITS FOR DEVELOPING COUNTRIES", PROC. OF THE CAIRO INTERNATIONAL CONFERENCE, NATIONAL RESEARCH CENTER, CAIRO, EGYPT, 17-24 NOV., 1984.

16) M.CROSETTI, "YAR : ASSESSMENT OF RURAL HOUSEHOLD ELECTRICITY SUPPLY OPTIONS", FIELD REPORT, WB/UNDP, ESMAP, 17 DEC., 1987.

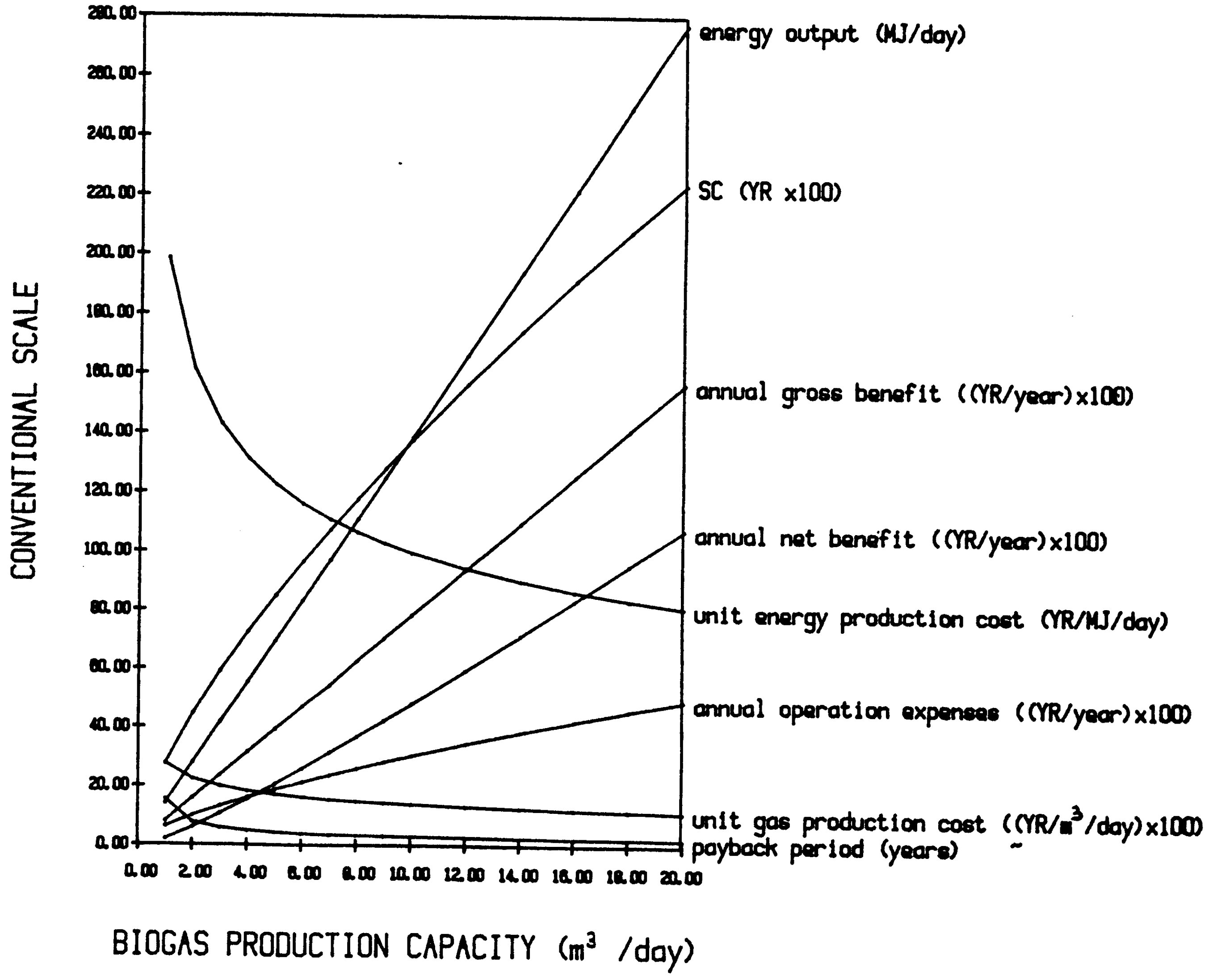

Fig. (4): Cost-Benefit Of Domestic Biogas Plants