INTEGRATED MODELING OF A RURAL ENERGY SYSTEM : A SYSTEM DYNAMICS APPROACH

BY

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A THESIS

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ABSTRACT

This thesis attempts to analyse the structural mechanisms of a rural energy system contributing to the physical quality of life (PQLI) of the people, which indicates the degree of development in the rural sector, and to examine the effects of various development policies affecting energy and rural development. Bangladesh is used as a case study.

This thesis presents initially an integrated model (qualitative) of a rural energy system based on Huq's Model interrelating quality of life and per-capita energy consumption. This model forms the basis for the development of a computer model based on the system dynamics methodology developed by Forrester for policy planning purpose. The model has been developed by integrating a number of sub-systems such as, population, cattle production, crop production, rural house-hold fuel consumption, bio-gas production, and agro-based industries for status projection and/or optimizing edible, salable, and combustible outputs to improve the physical quality of life.

With a view to opertionalize the qualitative model with quantitative data, empirical equations have been developed by correlating the physical quality of life (PQLI) and different type of energy consumption (kWhr/cap) (e.g. Electrical energy, Commercial energy, and Total energy).

In developing countries major share of total energy is contributed by biomass fuels, as a results, contributions of electrical energy and commercial energy are small. Considering

this energy consumption pattern, it has been considered appropriate to use PQLI vs. TE equation (5.14) for operationalization of the model. At the time of operationalizing the model, it has been observed that the per-capita energy consumption data for Bangladesh (1003 to 1933 kWhr/cap) is less than the lower limit for which the equation (5.14) is valid. Based on the Forrester's concept, a modified Quality of Life Indicator (QLI) has been proposed to interrelate the energy consumption data for Bangladesh.

At the final stage, the integrated model for a rural energy system has been operationalized at micro as well as in macro level by using the data available for Bangladesh. The simulated results (1981-2010) lead the following observations:

i) The food production system is unstable. Population growth rate is higher than that of growth rate of food production.

ii) Average draft power shortage has been estimated as 0.14 kW/ha.

iii) Tree biomass fuels are gradually taking larger share of total biomass fuel consumption which is responsible for increasing the rate of deforestation.

iv) Fuel burning efficiency is sensitive to tree biomass consumption as well as deforestation.

v) Quality of Life is declining.

The modified concept for interrelating QLI with per-capita total energy consumption developed by this study may be applicable to low energy consuming developing countries like Bangladesh.

Suggestions have been made to under-take future studies with a view to utilize this model for specific policy prescription.

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CHAPTER-I

INTRODUCTION

1.1 The Role of Energy

Each human need has two aspects - the physical and spiritual. Physical needs can be easily listed as [1]

1) Food of adequate quantity and quality
2) Clean domestic water
3) Shelter including ventilation and protection from extreme weather.
4) Clothing
5) Sanitation.
6) Light.

Energy is needed to meet these physical necessities. The practical energy needs that correspond to the human needs are as follows [1]

1) Agricultural inputs as energy (irrigation, draught power, fertilizer, manufacture of implements, crop processing, transport, food, storage of seed, pest-control).
2) Energy for cooking and lighting.
3) In cold countries, energy for space heating; in hot countries, energy for cooling (air-conditioning).
4) Energy for clean domestic water supply which in some places includes energy for boiling and freezing of drinking water.
5) Energy for transport.

6) Energy for processing and fabricating materials needed for the construction of houses, making of pots, pans, clothes, tools, vehicles etc.; energy is also needed to run local health services, schools, government and other community uses.

Therefore, energy is needed to meet the subsistence requirement as well as to meet the demand of economic growth and development.

In the well-off nations of Europe, Australia, Newzealand and Japan, the energy consumption per capita exceeds five tons of coal equivalent per year and the people in these countries enjoy a better quality of life than people of most other countries. In North America it is more than double of this [2]. In many developing countries measured (i.e. modern commercial) energy consumption is barely a quarter ton of coal equivalent per capita annually. The people of the third world fulfill their energy need in many cases by using solar energy. This use of solar energy is dominated by photosynthetic conversion. The energy captured through agriculture in crops and crop residues provides food for people and fodder for draft animals. In some areas dung and crop residues are used for cooking and heating. In the past two decades these traditional energy sources have been supplemented by the use of coal, oil, and electricity in agriculture, transport, industry and domestic sectors [3,4,5]. As for example, in Bangladesh in 1973-74 traditional fuels supplied 73% of total Primary energy [6]. The shares of traditional fuels in 1990 and 1995 are estimated as 65.4% of and 58.4% of total primary energy respectively [9]. However, this commercial energy supplement is used almost exclusively by the upper 20 per cent of the wealthy people in poor countries.[1] It is evident that the energy need of a great number of people in these countries are not being met properly and adequately. The most striking feature of energy used in the third world is that the amount of energy consumed by the poor people for obtaining useful work is small.

Actually, when inputs to agriculture are increased properly, the number of jobs and the energy output per worker and per unit of land increases. In other words, with appropriate inputs the plants can capture solar energy more efficiently to produce more. Energy is needed to increase as an input to the agriculture to raise the crop yields, extend the irrigated land, increase multicropping, mechanize construction, repair water projects, build modern roads and hence ultimately improve the quality of life of the peasants. Regardless of how fast and with what real success the developing countries move toward the still distant goal of rural modernization, direct and indirect energy flow into farming sector will have to take up a much larger share of the future energy consumption.

In the developing countries vast rural areas depend on energy derived from human and animal muscle power, biomass and farm and animal waste (farming sector) and rarely, if at all, directly or indirectly from sun and wind power [7]. It must be realized that the quantity of electrical energy consumed per person in the fortunate electrified areas is not the only or any reliable indication of overall "human condition" in a region or country; rather the total energy produced and obtained from all possible sources found available and existing in the particular area can be a valid index for measurements in this connection,[8] i,e the "physical quality of life index" (PQLI).

The energy situation is specially complex in Bangladesh because of the lack of abundant quantities of commercial energy resources, a large population density and predominantly traditional ancient way of agriculture primarily dependent on the nature. The fact is that Bangladesh has a very limited quantity of commercial energy resources available, with the traditional energy resources constituting about two third of the supply base. Known reserves of commercial energy sources are: natural gas, 13×10^{12} cft; coal, 1650×10^{6} tons; peat, 600×10^{6} tons; hydro electricity, 1500 GWH/annum and oil, 5.47×10^{6} tons. [9].

Therefore, rural farming sector is the source of bio-mass fuel as well as the main energy consuming sector of the rural area. In this modeling, stress will be given on the integrated use of these local and traditional sources of energy for status projection and assessment of implication of policy changes in the rural energy system.

1.2 Definition of Urban and Rural Areas in Bagladesh

In 1974 and 1981 population censuses the following definition of urban area was adopted. The term "Urban-area" will normally include places having a Municipality (Pourashava), Town Committee (Shahar Committee) or a cantonment Board. In general an urban area will be a concentration of population of at least 5000 persons in continuous collection of houses where the community sense is well developed and community maintains public utilities, such as, street lightings, water supply arrangements, etc. In Bangladesh, according to 1974 & 1981 population Censuses, except urban area rest of the habitation is to be treated as rural area.

Rural Electrification Board (REB) established in 1977 is responsible to provide electricity beyond the PDB service area (i.e Upazila Head-quarters, rural areas). It may be noted that the area covered by REB includes both urban area (according to 1974 & 1981 Censuses) and rural areas. The scope of this thesis is limited to rural areas of 1974 & 1981 population censuses.

1.3 Rural Energy System in Bangladesh

In Bangladesh about 85% of the population live in rural areas, agriculture is virtually the only form of employment. There are large seasonal variations in demand for labour and there is much underemployment and unemployment. There are a few middle class farmers and some large farmers, but the majority of population are small, marginal farmers and landless labourers. Every year a large quantity of biomass sources are produced in this area to meet the food, fodder, fuel and other physical needs of both rural and urban population. Because of increasing population pressure and to improve the physical quality of life a flow of some commercial fuels into the rural energy system has become essential to maintain a biomass production process on a sustainable basis. Qualitative energy demand in different sectors of rural energetics in Bangladesh are shown in Tab. 1.1 which reflects commercial energy demand in rural energetics. It is to be remembered that the commercial energy is essential as an input indirect use to the rural energetics for fertilizer and pesticide and direct use in machinery and transport to ensure higher output of crop, fuel and fertilizer. Biomass fuel in industries is mainly used for the processing of agricultural crops. Commercial energy is also directly used in lighting and small amount in industry.

In Bangladesh the major share of the total energy is consumed in rural areas. Thus it is imperative that the problem of assuring a reasonable supply be recognized and an effective plan for this be formulated, particularly for the majority of the consumers, maintaining their growing demand for both traditional and commercial energy.

Table 1.1

Qualitative energy demand in different sectors in rural energetics.

Sector	End-use	Form of energy	Supply source
1. Domestic	i) Cooking	Biomass: Tree biomass, Agriculture residue, Animal dung	Local
	ii) Lighting	Kerosine, Electricity	External
2. Agriculture	i) Tillage operation	Human & Animal Muscle power, Diesel power	Local External
	ii) Irrigation	Muscle power, Diesel, Electricity	local External
	iii) Fertilizer	Biomass, Chemical energy	Local External
	iv) Pesticide	Chemical energy	External
3. Transportation	i) Head load, Rickshaw-van	Human muscle power	Local
	ii) Boat, Mechanized Boat	Human muscle power, Diesel	Local External
	iii) Bullock cart	Muscle power	Local
4. Rural industry	i) Heat & Light	Biomass, coal, electricity, kerosine	Local External
	ii) Shaft power	Muscle power, diesel, electricity	Local External
5. Rural trade	i) Lighting	Kerosine and Electricity	External
	ii) Man power	Muscle power	Local

A subsistence economy of consumption and production forms a cycle. Food must be produced for people and cattle; people and animals have to eat food and fodder in order to have the strength to take care of the next corp. The cycle is balanced as long as production [food, fodder, fuel, fertilizer etc.] is sufficient for the population. Therefore a sustainable energy flow through different energetics (human, animal, cropping, domestic, etc.) linking with each other forming a closed loop provides desirable quality of life. However, when the population grows quickly and it is not possible to settle elsewhere through migration or extend the crop areas, it is necessary to increase production by intensification. The potential increase of agricultural production is limited however, if no additional energy other than a higher amount of human and animal labour is available. Total input into agriculture has to be increased considerably if higher yields are to be achieved. This is the situation which Bangladesh faces today. This situation will lead to an increase in the energy intensity of the economy and particularly to greater requirement for commercial fuels. Increase in energy supply for meeting subsistence and productive need is considered an important aspect for achieving the development objectives.

In one hand it would be necessary to maintain the supply of traditional fuels at a regenerative rate through proper planning. On the other hand input of commercial fuel is also to be increased to meet the energy need for production and overall development.

1.4 Need for Rural Energy System Modeling

There is no doubt that overall energy planning is a vital activity for all countries, especially, for those with limited energy resources but having great development needs. What is not always appreciated is the importance of rural energy system modeling as a major element of the overall energy planning task.

An indication of the importance of rural energy is given by the size of the contribution of biomass fuels to the total primary energy supply of the nation. In 1990, the GOB [9] estimates show that biomass fuels (i.e. agricultural residues, wood fuels and dung) from farming sector provided over 75% of final energy consumption. The possibilities for increasing the supply of biomass fuel in future are limited and, hence the anticipated additional energy demand in the rural areas must be met by commercial fuels and/or through conservation. This will require careful modeling in view of the financial and infrastructural limitations in the rural sector.

The problem of traditional fuel supplies in the rural sector has very recently attracted wide public attention, but it poses a threat to the future prospects of developing countries like Bangladesh. This 'second' energy crisis is evidently closely related to high rate of population growth and the pressure that this puts on the environment to provide food and traditional fuel.

Widespread deforestation and its consequences (increased flooding, erosion and siltation) are the most visible symptom of the problem. There are other less obvious symptoms, such as the removal of tree cover within agricultural areas (rarely recorded in statistics) and the gradual shift to more ecological damaging fuel collection practices (i.e. increased use of crop residues and dung as fuel) which divert valuable nutrients and organic matter away from the soil.

In human terms, the efforts required to collect fuel for basic needs already constitute a major burden on a large part of the rural population. It is not uncommon for members of households to spend three to five hours daily gathering fuel. The worry about cooking fuel is common to many areas of the developing world. For instance, peasants in the central Chinese province of Hunan have a saying very similar to the African one: "It's not what's in the pot, but which is under it, that worries you"[1].

Energy demand in the rural areas has to be considered mainly in four sectors: domestic households, agriculture, agro-industry and transport (farming sectors) as well as nonfarming sectors. Agriculture is the important productive sector and will in future require increasing inputs of energy for fertilizer, irrigation, machinery and transport to ensure increased output of food. Industrial activities in the rural areas are at present limited but are planned to grow in future, needing more energy.

It is clearly vital for the well-being of any nation, specially the least developed nations that effective steps be taken to improve the arrangements for energy planning in general, and rural energy modeling in particular, and to ensure that appropriate policies are developed and projects implemented. Only in this way can adequate fuel and energy supplies be assured for the major part of the population that lives in the rural areas. Therefore, modeling for rural energy system must be integrated with overall energy planning to ensure consistency.

1.5 Importance of Mathematical Modeling

The optimal development and management of an integrated energy system is a complex, dynamic and multi-faceted problem depending not only on available technology but also upon economic, agricultural and social factors.

Experimentation with an actually existing energy system may be costly and time consuming or totally unrealistic. Substituting energy flow system models can conduct a series of experiments towards this aim. The mathematical models clearly are of great value to understand and the system approach is the most appropriate technique to handle such problems. By developing such dynamic models on a quantitative basis for the rural energy system integrating with its essential components (human energetics, animal energetics, cropping energetics, cooking energetics, physical quality of life etc.). With a view to test the validation of this model, this may be applied at micro as well as in macro level for the different developing countries. Bangladesh is used here as a case study.

1.6 The Objective of the Research

The main objective of this research work is to develop a system dynamic model of a rural energy system with a view to evaluating the system performance interms of physical quality of life as a system performance indicator, for status projection and policy analysis. The specific objectives in this approach are:

i) To develop a structural framework of a rural energy system contributing the physical quality of life.

ii) To develop a supporting mathematical model for the physical quality of life as a function of per-capita energy consumption to quantize the physical quality of life.

iii) To develop a simulation model of a rural energy system based on system dynamics for status projection interms of physical quality of life and analysis of alternative courses of actions.

iv) To apply this model at micro and in macro level in Bangladesh for validation of the adopted technique, and to use this model as computer laboratory for policy analysis.

1.7 Brief Description of the Procedure/Methodology

In this research, attempt has been made to develop a quantitative dynamic model of rural energy systems to facilitate study of farm activities as production enterprises which are intended for providing livelihood and other basic necessities to rural sector in micro and macro level. This attempt is based on Forrester's system dynamics methodology[12,13].

The following steps have been followed :

i) Review the investigations of energy system globally, regionally, nationally, and locally.

ii) Investigate the mathematical modeling methodology.

iii) Development of the model-structure for describing the rural energy system qualitatively, particularly for developing countries like Bangladesh.

iv) Development of a mathematical model for physical quality of life based on energy consumption (kwhr/capita).

v) Micro level analysis of rural energy situation in some typical villages of Bangladesh.

vi) Development of a model-structure of rural energy system at micro and in macro level in the form of verbal description and convert them to form of the system dynamics flow diagram.

vii) Conversion of the flow diagram into a set of simulationeous difference equations.

viii) Determination of the different parameters of the proposed model using aggregate and unaggregate data of some rural areas.

ix) Simulation of the system for status projection and determining alternative courses of action for policy analysis.

1.8 Scope of This Research

The scope of the research is limited to developing a system dynamics laboratory for performing integrated rural energy system analysis and demonstrating its potential value to policy planners by examining the impact of certain specific policies. The model does not make policy recommendations. It is only a tool to evaluate various alternative policies which is expected to provide guidelines to decision-makers. The Problems of implementing particular policies is beyond the scope of this research. Only the probable consequences of adopting a specified strategy can be examined.

Since the result depends in various way on the concepts of sectoral interaction that are built into a model, confidence in the results depends on one's confidence in the structure of the model and the quality of data. Therefore, each variable, corresponding relationship and assumptions used in developing the model, is made explicit and the model user can examine, and if necessary revise these assumptions on the basis of more reliable information. These will continually improve the model and the results obtained will be increasingly reliable. The conceptual model structure is such that it is believed that the model could be used for analyzing other rural energy systems in developing countries with minor modifications.

One specific feature of the model is that it is designed to serve as a development planning laboratory to perform policy formulation and testing by evaluating performance and behavior of significant variables.

CHAPTER-II

REVIEW OF LITERATURES

2.1 Introduction

Rural energy is a subject of deep concern to researchers and planners of energy system. A vast literature is available on this important issue. These studies can be classified into two categories:-(1) Survey of rural energy resources and consumption pattern, and assessment of rural energy demand (2) energy modeling.

2.2 Survey of Rural Energy Resource and Consumption

A brief review of different energy studies carried out in Bangladesh have been presented in the following sections with a view to conceptualize the mental model of the rural energy system.

It has been mentioned in previous chapter that more than two third of the total energy consumed in Bangladesh is supplied by biomass fuel resources. The largest share of biomass fuel consumed in domestic sector is for cooking, and therefore it is important to consider the structure and the amount and pattern of energy consumption in rural domestic sector. Both commercial and non commercial energies are used in this sector. Biomass fuel serve generally for cooking and crop processing while kerosene is used for lighting. Small number of households have electricity for lighting. Per capita consumption of biomass fuel is an important factor in estimating rural energy demand.

In Bangladesh, percapita consumptiom of biomass fuel is an important factor in estimating rural energy demand. Consumption of biomass fuels in Bangladesh is estimated by different studies is presented in Table 2.1.

In Four studies for macro level (GOB [6], Tyers[15], Hughart [16], BEPP [10) energy coefficients were estimated on the basis of secondary data and the values varied from 2.8 -7.6 GJ/capita/yr. In four village level studies (Brisco [17], Islam [18], Quader & Omar [19], Islam [20]) energy coefficients were estimated by location specific micro level rural energy survey and the values varied from 4.46 - 8.81 GJ/capita/yr. A value of 4.44 GJ/capita/yr reported by Douglas [21] was estimated on the basis of a countrywide rural energy survey. It may be seen that the value of 1.6 GJ/person/yr estimated by Rahman [14] was inconsistent in comparison to the values of the coefficient estimated by other studies.

Wide variation of percapita consumption of biomass fuels reported in Table 2.1 may due to variation of study methodologies, location specific, socio-economic and cultural factors. Location specific nature of supply and demand of biomass fuels was reported by Doglus and seen in Table 2.2. Per-capita consumption of biomass fuel was lowest (2.45 GJ /yr and was attributed to its location in a poorly forested area.

Table 2.1

Estimated biomass fuel use/yr. for cooking by other studies

Reference	Composition of source of biomass fuel %			Percapita Fuel consumption (GJ/yr
	Tree	Agriculture residues	animal residues	
GOB [6]	12.5	62.5	25.0	2.8
Tyers [15]	7.0	66.0	27.0	5.0
Brisco [17]	36.0	61.0	3.0	6.8
Hugart [16]	-	-	-	4.3-7.6
Islam [18]	71.0	24.0	5.0	4.9
Douglas [21]	63.0	37.0	+	4.44
Rahman [14]	57.0	38.0	5.0	1.6
Quader, Omar [19]	59.0	38.0	3.0	8.1
Islam [20]	74.0	10.0	16.0	4.46
BEPP [10]	10.0	66.0	24.0	4.93 (rural)

Source: Islam [22, 23], BEEP [10]

Consumption of biomass fuel according to land holding size (covering the whole country) was estimated by Doglus [21] and is shown in Table 2.3. Lower percapita fuel consumption by higher land holding group has been attributed [21] to economy of scale of cooking, variation of type of food cooked by different land holding size and higher technical heat utilization efficiency of the type of fuel used by higher income group households.

For a particular village in Rangpur district, variation of per capita consumption of biomass fuels according to the landholding size was estimated by Quader and Omar [19]. It is reported that per capita consumption of total household cooking fuels increases as size of landholding increases (6.91 GJ/yr for landless to 16.9 GJ/yr for landholding of 10 acres). Higher per capita fuel consumption by households with large landholding was attributed [23] to higher amount of food cooked and to increased fuel consumed for parboiling and gur making. The per capita consumption of fuel for only food cooking for landless household and household with landholding size of 10 acres varied from 6.64 GJ/yr to 10.52 GJ/yr respectively. Caloric food intake per capita also increased with increase of landholding size from 1910 kcal/day (2.9 GJ/yr) for landless to 3800 kcal/day (5.8 GJ/yr) for landholding of 10 acres. Islam [23] opined that the higher per capita food consumption by households with larger landholding may be due to better accessibility as well as to the

Table 2.2

Location specific supply and demand of biomass fuel

Resion	Sample Districts	GJ/cap/yr
North West	Bogra, Dinajpur, Rajshahi, Rangpur	5.05
West	Faridpur, Jessore, Pabna, Kushtia	2.95
North Central	Comilla, Dhaka Mymensingh	4.49
South	Barisal, Patuakhali	3.77
Forest fringe	Khulna, Sylhet	4.85
Urban fringe	Dhaka, Khulna	5.23

Source: Douglas [21]

Table 2.3

Consumption of biomass fuel according to land holding size

Land holding size (acres)	GJ/cap/yr
0 - 1	5.41
1 - 2	5.08
2 - 3	4.85
3 - 4	4.32
4 - 5	4.23
5 - 6	4.37
6 - 7	4.14
7 - +	3.81

Source: Douglas [21]

indigenous system of payment to agriculture labourers. In Bangladesh, agriculture labours traditionally and predominantly are paid partly cash and partly with food.

Annual percapita consumption of biomass fuels by different socio-economic groups was estimated by Hughart [16] for a village in Bangladesh as follows: landless, 4.3 GJ; poor, 4.7 GJ; middle, 5.8 GJ; rich, 7.6 GJ. Supply of cooking energy for different groups were estimated as: landless, 0.7 GJ; poor, 4.6 GJ; middle, 5.2 GJ; rich, 13.8 GJ. A wide gap between the demand and supply of cooking fuel for land-less families indicates the scarcity of their cooking fuel.

In Bangladesh in addition to domestic cooking, some biomass fuels are consumed for processing of crops (e.g. paddy parboiling and gur making from date palm juice). In 1981, total production of rice was estimated by BEPP as 13.92 million tons of which 60% was processed at household level. Biomass fuels requirements have been estimated as 0.4 ton residues per ton of rice, giving a total annual fuel use of 2.81 million tons.

Lighting energy

Islam [18] reported that in rural survey area 81% of lighting appliances were open wick lamps and 19% hurricane lanterns (fitted with chimney). In an Indian rural energy study [24] the estimated percentage of open wick lamp, hurricane lanterns and other lamp types used in the survey area were 76%, 19% and 5% respectively. In 1981, BEPP [10] estimated that out of total 12.739 million rural households, only 2000 had electricity connections for lighting while the remainder used kerosene for lighting. Total consumption of kerosene for rural domestic lighting is estimated as 0.229 million tons (0.83 GJ/household/year).

<u>Human muscie power</u>

In rural energetics, energy input to the human energetics is either in terms of calorific intake or/and in terms of potential work and output is the labour force. BEPP [10] estimated that during the agricultural slack season 62% of the rural employed males and 77% of employed females are underemployed. The extent of underemployment among non-agricultural workers was assessed at 21% for employed male and 60% for employed females. On the other hand, during agricultural peak seasons, over 65% of the employed males and 30% of employed females work more than normal hours. Because of this seasonal effect there is an imbalance between demand and supply of the labour force.

<u>Draft power</u>

Livestock plays an important role in providing energy for agriculture: over 98% of draught power for crop production, a substantial amount of power for transportation of harvested crop and also for post harvest processing of crops. According to the estimate of the planning commission [25], the overall shortage of draught power in 1981 was 18.8%. According to the analytical criteria of Gill [26] there was no overall shortage of animal draught power but localized shortage was identified in the district of Noakhali and Kushtia. An overall shortage of 27% was estimated on the basis of the MeColly study [27]. Moreover, available animal power was insufficient to meet the demand in all the districts. The shortage is most acute in the districts of Chittagong Hill Tracts, Noakhali, Faridpur, Jamalpur and Kushtia. According to BEPP estimate, the maximum daily shortage of draught power in the range of 51% - 60% was identified in the districts of Comilla, Faridpur, Jamalpur, and Patuakhali in the dry season and in Noakhali in the wet season. The prospective number of mechanical devices are required to meet the draught animal power shortage. Alam [28] has reported that in 1980 there were 3454 tractors and 4180 power tillers in Bangladesh. It is not however known what percentage of the machines were actually in operation for cultivating land. Agricultural Census [26] reported that 41,000 farm households (0.66% of the total) used mechanized devices for cultivation. No separate information is available about the consumption of energy for mechanical cultivation. BEPP [10] estimated that 132,553 power tillers would be required to meet the maximum daily peak demand of animal power (25,848 GJ) and 68,278 tons of diesel would be required to meet the total yearly shortage of draught energy (572,279 GJ).

Energy in rural industry

Energy is needed in rural industries in the form of high and medium temperature heat, shaft power and light. Both locally available biomass fuels and commercial fuels are used for heating purposes. Shaft power is obtained from human and animal muscle power, steam engines using biomass fuels, diesel engines and electric motors. BEPP estimated that the consumption of biomass fuels in rural industries were 04.21 million tons (92.36 PJ).

Commercial energy in rural energetics

Commercial energies (such as electricity and diesel) are directly used for irrigation to increase agricultural production and indirectly used for agricultural production through chemical fertilizer and pesticides. BEPP [10] estimated that the consumption of diesel and electricity for irrigation in 1981 were 32,000 tons (1.475 PJ) and 37,989 Mwh (0.137 PJ) respectively and 0.86 million tons (44.96 PJ) of chemical fertilizer was used in addition to 9.02 million tons of animal dung used as manure.

The Government of Bangladesh is putting emphasis on rural electrification and supply of commercial fuels [30]. Islam and Mahtab [30] reported that due to the expansion of rural electrification programme electricity is used for lighting in some area. Diesel and electricity are used in irrigation pumps and rural industries. Islam [11] pointed that energy has a crucial impact on economic development and for improving the quality of life. He mentioned that kerosene and LPG should be made available at reasonable price in order to discourage rural people from using fuelwood for domestic purposes.

According to the World Bbank, 75% of the population in Asia and Africa use traditional fuels- firewood, charcoal, agricultural residues and animal wastes- for there domestic energy requirements. The standing wood volume in Asia at 15 m^3 per person is the lowest in the world. Already vast areas of India and Bangladesh have exhausted their fuelwood supplies. A recent report by the International Fund for Agricul- tural Development (IFAD) notes that by the end of this decade Pakistan may be self-sufficient in food, but many rural people may not have firewood to cook the food with.

More efficient woodstoves have been suggested as a solution. Major programs have been initiated in countries like India, Indonesia, Sri Lanka and Napal. The stoves which worked well in laboratories have either not been accepted by rural people or did not work well under rural socioeconomic conditions. The cases where such stoves proved to be a success, as in Mali and Kenya, the development of these were based on intesive consultations with the villagers themselves. The 'top down' approach has not worked. Public involvement in such projects is not just a cliche; it is an absolute must.[31]

In 1976, concerned with the energy-environment issues of the rural poor in developing countries, the United Nations Environment Programme (UNEP) initiated the first ever pilot project on developing an integrated rural energy center in Sri Lanka. It was a demonstration project to find out if it was possible to use renewable energy sources like biogas, wind and solar energy in combination to meet the energy needs of villages that are not connected to electric grids. The success of the Sri Lanka project encouraged UNEP to initiate similar pilot projects in other countries like Philippines, Indonesia and Senegal. Other international organizations started developing rural energy centres too [31]. However, the acceptance of this integrated rural energy projects would depend on their economic viability in comparison to conventional systems. Brookhaven National Laboratory proposed a diagram for functional relation between index of physical quality of life and energy consumption percpita per year (kWhr) in developing countries [32].

2.3 Energy Modeling

In the wake of the oil crisis of late 1973, policy makers have become greatly concerned with energy issues, and have increasingly turned to analytical researches to help them grapple with these complex problems.

The most commonly used methodologies are optimization (linear programming), econometric modeling, input output analysis and system dynamics simulation. Edelman [33] gave a review of the commonly used methodologies of linear programming methods, econometric methods, input-output analysis and system dynamics simulation with frequent reference to their applications to energy policy and discussed their limitations. Deam [34] developed a linear programming (L.P) model and carried out an analysis of demand pricing and market share of global oil and gas resources. Analysis of supply, demand and pricing of Gasoline, Kerosene, distillate fuel, residual fuel and crude oil in world commodity with the help of L.P. model was carried out by Kennedy [35]. Walker [36] presented a state space method for designing and evaluating integrated energy systems as applied to agricultural production. Stout and Myers [37] designed a comprehensive manual for energy use in world-wide agriculture. The manual presents energy flow in the food production system and energy requirements for each operation of production, processing and delivery.

Pellizi [38] simulated an integrated energy system for a Kenyan village and indicated that the system can cover the villagers' energy requirements with minimum cost associated with food self-sufficiency and raised standard of living. Adame et al [39] developed an analytical model of the production and distribution of biomass liquid fuel and their economic relationship with the production of other agricultural products, by maximization of nonlinear objective functions subject to the linear restrictions, and recommended the implementation of the national alcohol plan for beneficial effects on agricultural sector.

Lewis, Slesser and Hounman [40] developed a system dynamics model for a South Indian village to demonstrate how biogas plants could develop within such a village purely under economic forces with the rate of introduction controlled by the mechanism of price. The adaptation of the system has been shown to increase food production potentiality by 200%, indigenous energy production by 85% and overall solar energy capture by over 150%, within a simulated period of 12 years.

Baughman and Hnyilicza [41] presented an over-view of modeling in the energy field and have examined the various methodological approaches available and discussed the alternative ways in which the model can be used through simulation and optimization activities. Jordanides and Meditch [42] critically reviewed the previous efforts in modeling petroleum utilization in the United states and formulated a system dynamic model for policy analysis on both short and long term utilization of petroleum.

Kennes, Parikh and Stolwijk [43] presented a detailed quantitative picture of biomass production in Bangladesh and revealed the picture of skewed energy use among nine categories of socio-economic classes.

Huq [31] proposed a quantitative model for integrated rural energy utilization of agricultural farm in Bangladesh. This model has been based on the feedback concept of control theory and can be formulated in the system dynamics form to evaluate the rural energy policies and trade offs by incorporating nonlinearity and time-lag characteristics inherent in the system. Bala and Sattar [45] also simulated a model that considers the integrated energy use for food production. The model was programmed in BASIC and was simulated in a microcomputer.

Tyers[15] studied agricultural resource allocation in Bangladesh by econometric and optimization techniques. The available data were analyzed in terms of food production model incorporating growth rate of food grain, livestocks, crop residues for cooking, and economic and technological trends. Parikh [44, 47] developed a general linear programming model to illustrate energy capture and agricultural interaction existing in the rural areas of the developing countries. The model was applied to Bangladesh. This model is linear and static. BEPP [10] developed the Rural Energy and Agriculture development Analysis [RADA] model to establish a baseline frame-work and used it to project the future supply of biomass fuels and some energy demand in agricultural sector.

But the rural energy system itself is nonlinear, dynamic and contains inherent time-lag characteristics. To overcome these limitations, this research has proposed to a system dynamics model for integrated rural energy system that contains dynamic, nonlinear and inherent time lag characteristics of this system and the potentiality of the model will be illustrated at micro as well as macro level by using the data of Bangladesh and the rural energy system will be evaluated in terms of physical quality of life. The validity of the model at macro level will also be tested.

2.3.1 System Dynamics Modeling

The methodologies applied for above modeling are applicable for steady state system analysis and exclude the transient behavior, nonlinearity, feedback phenomena, time lag characteristics, etc. of the system. However, the system dynamic simulation is a generalized approach, which includes both transient and steady state behaviour as well as other characteristics of the system. For a new combination of inputs the transient response is of prime importance, because starting from the initial stage of new input the transient state may continue for several years depending on whether the system is oscillatory, damped oscillatory, over damped or critically damped.

Wide application of system dynamics methodology in different fields is known to all. Forrester's first application [13] of his system dynamics concept was in the study of the behaviour of industrial systems. He extended the system dynamics approach to describe the growth and stagnation characteristics of an urban area [48]. Then his latest effort offers a dynamic model of world scope [49]. D.L. Medows and D.H. Medows edited research results on system dynamics in one volume [50]. Dennis L. Medows published his book on Dynamics of Commodity Production Cycles [51]. Nathan B. Forrester extends the applications of system dynamics methodology to economic development in a national level [52]. System dynamics modeling is applied for the regional development planning in Phillipines by Hsieh [53]. Similarly, a system dynamics laboratory for regional analysis in Philipines was carried out by Wadwa [54]. System dynamics is applied for rural development and income distribution policy planning for Pakistan by Syeed [55]. Bala and Satter applied system dynamics methodology for modeling and simulation of aquacultural system.[56]

Energy supply and demand analysis in USA based on system dynamics simulation was carried out by White [57]. Analysis of global energy (Coal, oil, gas, nuclear, and all other conventional sources) supply, demand, and market share based on system dynamics simulation was made by Rothkofp [58]. Market share analysis of energy (various grades of coal, oil, natural gas, and nuclear) in USA based on system dynamics simulation was carried out by Baughman [59].

As the system dynamics simulation is a generalized approach for time-domain analysis of a system, this method has been chosen in the proposed for integrated modeling of rural energy system. It is proposed to make quantitative evaluation of the system performance in terms of Physical quality of life Index (PQLI).

CHAPTER-III

MODELING APPROACH

3.1 Introduction

The selection of a methodology for any analysis depends on the nature of the problem to be studied and the purpose of the study. The methodology to be used for this research on energy utilization should be able to deal with a large number of variables with nonlinear, dynamic, and feedback characteristics. The concept and foundations of the approach to deal with these characteristics are discussed in the following sections.

3.2 Causal Loop Diagram

The energy system involves several variables which mutually affect each other. One might say that the basic structures underlying the development process are causal feedback loops. A causal feedback loop consists of two or more variables that close back on themselves. Fig. 3.1(a) and 3.1(b) show two types of causal loops, the negative and positive, respectively. If there is an odd number of negative causal relationships, the loop is a negative feedback loop; if there is an even number, the variables are connected by positive feedback loop.

3.3 Sign Diagraphs

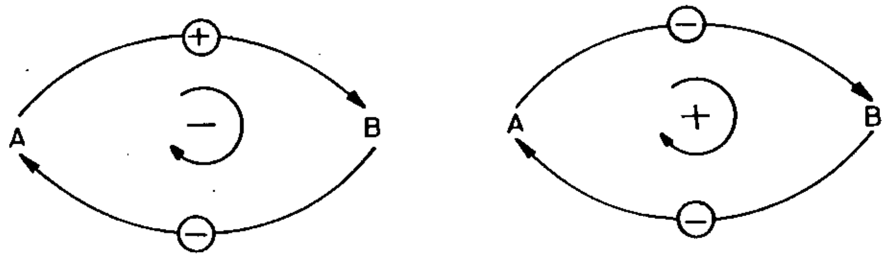
Signed diagraph is the formal way of analyzing the interactions between multiple variable. Signed Diagraphs is a branch of graph theory, that has been used by Roberts [60] to analyze causal processes. He illustrates this approach using the problem of energy demand in a given area.

The variables relevant to energy demand phenomenon are used as nodes in the digraph: energy capacity C, energy use U, energy price R, population P, number of jobs J, number of factories F, and quality of the environment Q as measured by some appropriate indicator. Basically the causal relationships between variables are as follows: (1) energy use increases with population, (2) causing an increase in energy capacity, (3) available energy increases industrialization (the number of factories), (4) which increases the number of jobs. (5) But the more energy is generated, the lower is the price and (6) the lower the price, the more energy that is used; (7) the more energy used, the lower quality of the environment. (8) Lastly, both quality of environment and the number of jobs affect population. The signed digraph for this energy example is shown in Fig. 3.2.

3.4 Identification of Methodology

3.4.1 Systems Framework

The structure of a region, because of the feedback phenomenon, must be viewed in its entirety: as a system. Analyzing the separate aspects in isolation from one another cannot even hint at the sorts of behaviour that may arise. Any system accomplishes an operational process: if input is changed the output will change. In general, the input consists of resources - and the output is in the form of goods or services.



(a) (b)

Figure 3.1 Flow Diagram of Casual Relationships.

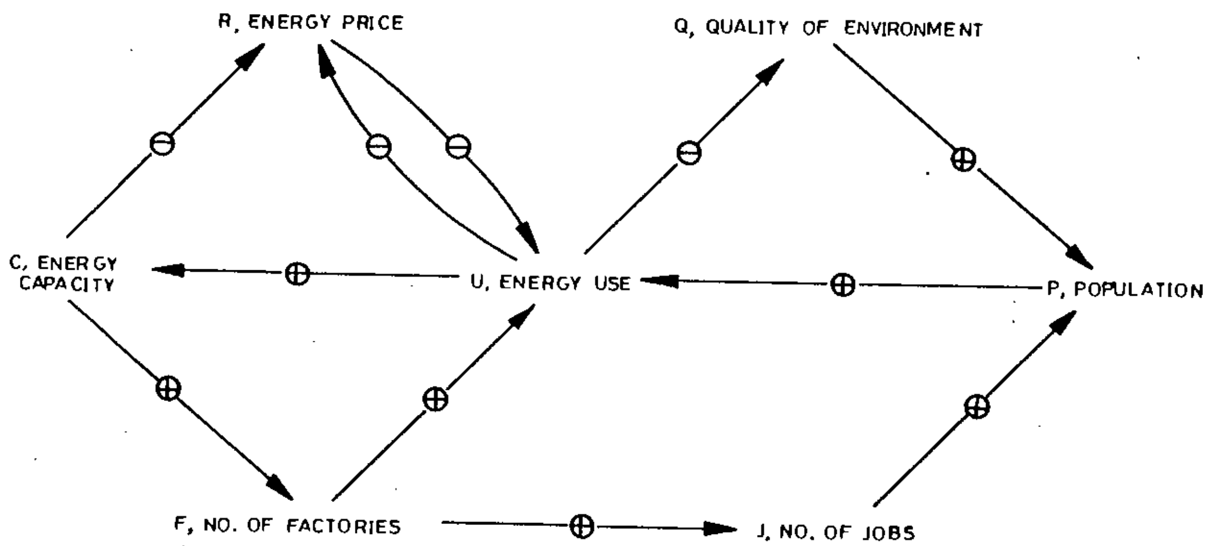


Figure 3.2 Singed Digraph for Energy Consumption Model.

In addition to the performance or intended outputs, a system almost always produces some side effects which are the results of undesirable, but concomitant, outputs interacting with the environment.

3.4.2 Modeling

The contribution of models in analyzing complex systems is well documented. When hypotheses or ideas are precisely stated and related to one another, the assembly is called a 'model'. There are many types of models but the most precise of all is a mathematical model. This is not because the mathematical model is the only logical form but because it is the most explicit and the least like to produce inconsistency. Hypotheses are not complete until the relations between the variable are specified over the entire range of all possible values, which an equation does simply and most efficiently.

The success of mathematical modeling depends on how well the procedure fits the problem. Mathematical models of complex systems, most often require simplification if they are to be solved analytically.

3.4.3 Simulation

Model Simulation offers an opportunity to solve problems without simplification or compromise. The idea behind the simulation technique is that if conditions are known at one point in time, some logic or policy expressed as equations can be used to compute the conditions at the next point in time. In this way, one can move step by step through time, producing patterns based on various technological alternatives, social changes, institutional policies or economic strategies. Conceptually, a simulation model of a socio-economic system can be viewed mathematically as follows:[54]

$$S(t+1) = f[S(t), P(t), E(t), M(t)] \quad (3.1)$$

where S(t) is the set of state variable -defining the state of the system - at time t, P(t) is the set of parameters that defines the structure of the system at time t, E(t) is the set of oxygens variables that influences system behaviour, and M(t) is the set of manipulating variables that can be used to represent policies for altering system performance. 'f' represents a function which defines the relevant relationship between the time variables, and S(t+1) is the set response of the system at (t+1).

Over the years a number of special simulation languages have been developed. One such language is DYNAMO -a computer software package closely associated with the subject of system dynamics. In this research, a dynamo compiler, professional DYNAMO plus™ for the PC family was used for the system simulation which was developed by Push-Roberts Associates, Inc; USA, 1986.

3.4.4 System Dynamics

System dynamics, a field which extends from the work began by J.W. Forrester at the M.I.T. School of Industrial Management, is a methodology for analyzing the behaviour of complex, dynamic systems - possessing technological, social, and political elements - to show how the system structure and the policies used in decision making govern the behaviour of the system. By "structure" is meant the components of the system and the communication channels by which information is made available at a decision-making point. By "policy" is meant the rationale that influences how decisions are reached such as natural-generating processes, experience, laws, rules of thumb etc. System dynamics modeling strives to express in the form of mathematical equations the structure of the system upon which policy acts. The steps are: (1) the formulation of mental model in the form of a verbal description, (2) the expression of this verbal model in the form of flow diagram, and (3) the conversion of this flow diagram to a set of simultaneous difference equations which are solved by a computer.

3.4.4.1 Flow Diagram

In converting from a verbal description of the system to be studied to a flow diagram, the structure of the system is perceived as consisting of two basic components - levels and flows. Levels represent accumulations of flows in the system, such as inventories of goods, population, amounts of different types of housing, industrial capital, arable land, etc. Rates of flow represent the activities and decision functions in the system such as the movement of goods, migration, construction and demolition of housing, generation and depreciation of capital, and the bringing of land into production through irrigation. Natural processes or decisions based on policies regulate these flows and are represented in the flow diagrams using the traditional control valve symbol. Levels are simply shown as a blocks. Information flows from which decisions are made or natural processes are controlled are represented by dashed lines; other flows such as materials, energy, men, land, and capital are represented by solid lines.

Fig. 3.3 shows a system dynamics diagram of the two fundamental loops that affect population. The loop on the left creates the birth rate (BR) which increases population and the one on the right the death rate (DR) that depletes it. These rates, BR and DR, are the total rates by which the population is changed each year and are measured in people per year. The solid lines refer to the flow of people into and out of the population. The dashed lines tell us that the number of births per year depends on the size of the population and the normal birth rate (BRN-%), while the number of deaths per year depends on population and life expectancy, LE. Clouds on each side of the figure are used in system dynamics diagrams for originating and terminating flows and so are called "source" and "sinks" respectively.

System dynamics equations are written in the DYNAMO language. In DYNAMO, the value of a level variable at time K depends only on the value of the level variable at time J (the preceding time instant) and on the rates of change over the time interval from J to K which is DT. The parameter DT is called the computing interval for the simulation. Refereeing to fig. 3.3 the level variable, population, is given by the following equation:

$$\text{L} \quad P.K = P.J + (DT)(BR.JK-DR.JK) \qquad (3.2)$$

The rate variables, birth rate, and death rate are:

$$\text{R} \quad BR.KL = (P.K)(BRN) \qquad (3.3)$$

$$\text{R} \quad DR.KL = (P.K)/(LE) \qquad (3.4)$$

In the actual application of this simple illustration, values would have to be assigned to the parameters BRN and LE and an initial value to P, population. If the formal birth rate is 3%, the life expectancy is 50 years, and the population at time zero is taken at 3.6 millions,

$$\text{C} \quad BRN = .03 \qquad (3.6)$$

$$\text{C} \quad LE = 50 \qquad (3.7)$$

$$\text{C} \quad N = 3.6 \times 10^{6} \qquad (3.8)$$

In the equations above letters L, R, C and N refer to the type of variable or parameter i.e level, rates, constant, or initial-value. A fifth type of variable is an auxiliary and it is designed by an "A" after the equation number. The symbol for an auxiliary variable - not shown in fig. 3.3 is a large circle. T will denote table. A brief explanation of system dynamics symbols and special DYNAMO functions is given in the Guideline to Appendix and also Ref.[12].

DYNAMO executes the simulation by performing a sequential solution to all equations. The sequence is as follows:

1. Computation of the values of all levels at time K based on the values given at time J and the rates over JK.
2. Computation of the new rates over KL from the values of the levels at time K.
3. Computation of output variables and placing them in the output file.
4. Shifting J, K and L ahead one DT for the next cycle of computation.

The output from DYNAMO is in the form of a time series for any desired variable. This output may be either tabular or graphical (printer-plot) form.

3.4.4.2 Parameter Estimation

System dynamics modeling offers an attractive tool for policy testing and evaluation. Policy alternatives can be

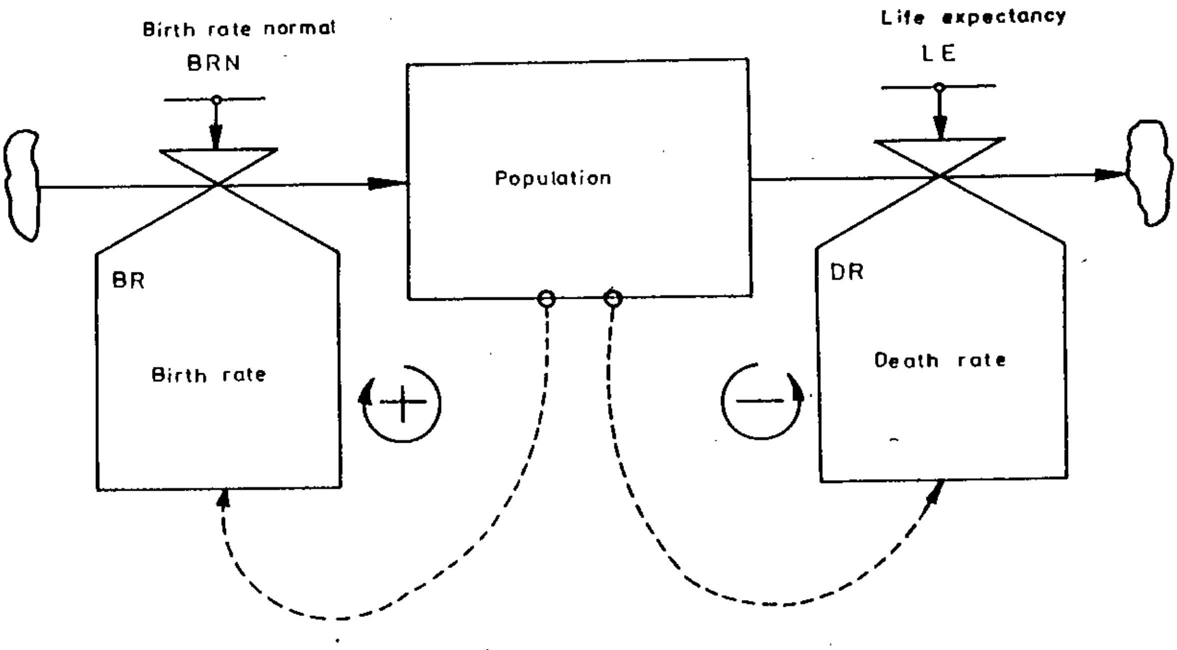


Figure 3.3 System Dynamics Diagram Showing Birth And Death Loops.

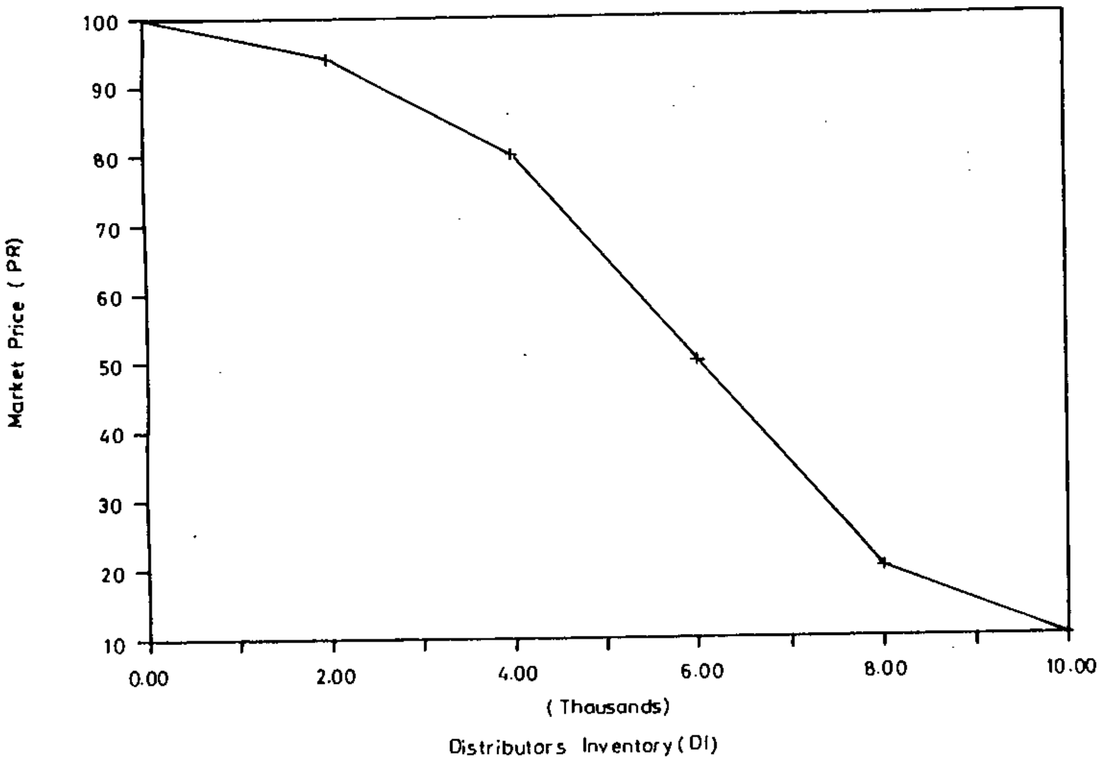


Figure 3.4 Distributor's inventory given Vs. market price.

simulated by a computer. One of the important steps in model building is the estimation of the parameters.

Parameter Estimation Techniques:

Parameter estimation techniques can be classified on the basis of assumptions and data. The data may be categorized as unaggregated data and aggregated data.

a) Estimation Using Unaggregated Data:

Many system dynamics studies including the studies of Forrester[13,48,49] use parameters determined on the basis of descriptive information obtained from the participants in the system modeling. Such information is unaggregated data.

For an example of parameters that can be estimated with unaggregated data, consider an equation representing death rate of the population model.

R DR.KL = P.K/LE (3.9)

Where, DR - Death Rate (POP/YEAR)

P - Population (POP)

LE - Average Life Time (YEARS)

The model assumes a constant average life time LE, so that every year, 1/LE of the population P are dead. LE can be estimated in many ways from unaggregated data, which are used to generate table function.

a.1 Table Functions:

This section describes a straight forward but a common technique. The table function seems to be a formidable estimation problem but it can be broken into subproblems:

i) estimation of the value and the slope of the function at one extreme, at the normal value and at the other extreme.

ii) connecting these known values and slopes with a smooth curve.

Once these subproblems are solved, the table function is known to within a narrow range of value. For example consider price versus inventory relationship of the commodity production cycles model:

A PR.K = TABLE (PT, DI, 0, 10000, 2000) (3.10)

T PT = 100/90/80/50/20/10

where,

PR - Market Price (DOLLARS/UNIT)

PT - Price Table

DI - Distributor's Inventory (UNITS)

To estimate table function for PR, the extreme condition of zero inventory is considered first. The price would be maximum. Next the normal condition is considered when there is some moderate quantity of inventory and the table function has a negative slope. At the other extreme the inventory is large and the price is very low. Now a smooth curve is drawn through the estimated points (Fig. 3.4). Thus, solving the sub-problems of extreme conditions, normal conditions, and connecting known points with smooth curves, allows the modeler to estimate a non-linear table function.[61]

b) Estimation Using Aggregated Data:

When using aggregated data to estimate parameters, the correctness of model equation(s) is (are) assumed.

b.1 Estimation Using a Model Equation:

Estimation using a model equation encompasses all single equation regression techniques.[62-65]

As an example of estimation using a model equation, consider the population model for calculating the death rate DR from the population P and average life expectancy LE. Thus, if data are available for DR and P, LE can be estimated from the model equation.

$$R\ DR.KL = P.K/LE \qquad (3.11)$$

$$LE = P/DR \qquad (3.12)$$

Estimation using a model equation is less frequent in system dynamics studies, However, two forms of model equation estimation - one involving conversion factors and the other fractional rates of flow have been useful in many studies and are discussed below:

b.1.1 Conversion factors:

Many model parameters convert quantities from one dimension to another. For example, consider the housing sector of the residential community model. Land per house (LPH) converts housing units to an equivalent number of acres as follows,

A LFO.K = (H.K * LPH)/AREA (3.13)

LFO - Land Fraction Occupied (DIMENSION LESS)

H - Housing Units (UNITS)

AREA - Area (ACRES)

LPH - Land Per House (ACRES/UNIT)

Estimating conversion factors offers a straight forward means of ensuring that the absolute magnitude of model variables are realistic.

b.1.2 Normal Fractional Rates of Flow:

Equation below defines the death rate in terms of a level (population P), a normal fractional rate of death and a dimentionless multipliers. This format is:

Rate = Level * Normal Fraction * Multipliers (3.14)

This format is widely used [66] and the multipliers can be easily estimated when it is normalized around 1.0. Under normal conditions the multipliers assume value of 1.0 so the fraction flow rate can be observed by dividing the observed rate by the observed level. Choosing a normal condition does not bias behaviour of the model. A normal condition is merely a system state about which parameters are defined.

b.2 Estimation Using Multiple Equations:

Estimation using several multiple equations consists of using several equations to compute the parameter value. For example birth rate BRN can be estimated by finding the value of BRN that causes population growth rate to fit the observed rate of growth. This estimation will use all the equations. For example of such computation, at the population growth rate be 2.5. Also from observations of the dead, assume the life expectancy LE to be 66 years - that is, 1/66 of the population are dead per year. Therefore, the BRN should be 1/66+ 0.025=.04. For more complex models multiple equation regressions are computationally efficient.[61-69]

3.4.4.3 Tests For Building Confidence In System Dynamics Models

There is no single test which serves to 'validate' a system dynamics model. Rather, confidence in a system dynamics model accumulates gradually as the model passes more tests and as new points of correspondence between the model and empirical reality are identified. The nature of the system dynamics models permits many tests of model structure and behaviour not possible with other types of models. Conversely, some widely used tests, such as standard statistical hypothesis tests are either inappropriate or, at best, supplementary for system dynamics models.

a) The Nature of Validity in System Dynamics Models:

Model testing is a part of large validation process, and this section discusses the objectives of that process for system dynamics models. It is important to realize that the word "empirical" means "derived from or guided by experience or experiment". Hence, empirical information for testing a model includes information in many forms other than numerical statistics. In system dynamics models, model structure can be compared directly to descriptive knowledge of real-system structure; and model behaviour may be compared to observation of real system behaviour. The following sections identify a few of the tests of structure and behaviour suitable for system dynamics model.[70]

b) Tests of Model Structure:

Although all tests of a system dynamics model are aimed at establishing confidence in model structure, the tests in this section asses structure and parameters directly, without examining relationships between structure and behaviour. The following are core tests of model structure:

b.1 Structure-verification test

b.2 Parameter-verification test

b.3 Extreme-conditions test

b.4 Boundary-adequacy (Structure) test

b.5 Dimensional-consistency test

Conspicuous by their absence from the preceding tests of model structure are the statistical tests usually applied to social and economic models. For example, econometric model building relies almost completely on statistical test which involve direct comparison of individual model equations to statistical data. Run on conventional statistical tests of model structure are not sufficient grounds for rejecting the causal hypotheses in a system dynamics model. Such tests may be useful for discovering possible flaws in model structures.

c) Test of Model Behaviour

Some tests of model behaviour evaluate adequacy of model structure through analysis of behaviour generated by the structure, which are as follows:

c.1 Bahaviour-reproduction tests (symptom generation, frequency generation, relative phasing, multiple mode, and behaviour characteristics.

c.2 Behaviour-prediction tests (Pattern-prediction test, Even-prediction test, and Shift-mode prediction test)

c.3 Behaviour-anamoly test

c.4 Behaviour-sensitivity test

d) Tests of policy implications

Tests can be conducted to build confidence in a model's implications for policy. Although all tests of system dynamics models aim at usefulness of a model as a policy analysis tool, tests of policy implications differ from the others in their explicit focus on comparing policy changes in a model in the corresponding reality. Such types are as follows:

d.1 System-improvement test

d.2 Changed-behaviour prediction test

d.3 Boundary-adequacy (policy) test

d.4 Policy-sensitivity test

Remarks

Almost all system dynamics models should be capable of reproducing certain "target" modes of observed behaviour and responding plausibly to a wide range of test conditions. Changed behaviour prediction and policy-sensitivity are essential tests of a model's policy implications.

CHAPTER-IV

STRUCTURAL DEVELOPMENT OF THE MODEL

4.1 Introduction

One of the major shortcomings of various national energy studies, as R.H. Socolow puts it, is that 'solar energy doesn't count'. [71] Attention is focused on fossil fuels and hydroelectricity. Solar energy is not included in the analysis. Though always regrettable, the omission is not critical for the Western industrialized nations, and for Japan. Because of their heavy dependence on oil, coal, and natural gas. for developing countries, it presents a serious error because most of the population in these countries live in rural areas. Until fairly recently this population has been either completely separated from, or marginally involved in the flow of modern commercial fuels and electricity. Bangladesh with more than 90 percent of its vast population remaining in its country-side is the foremost example of a nation where most of the people are still relying on solar energy to produce, via photosynthesis not only their food and feed for the animals - but also the necessary fuel and raw materials. For a better appreciation of Bangladesh's rural energetics, it has been attempted to develop a qualitative as well as quantitative dynamic model with all the essential sources and uses of energy in the country's rural areas.

Rural energy sources can be broadly classified into a) Animate energy sources and b) biomass or related energy sources. The sources and sinks of rural energy are so interrelated that they present a diffused picture. Bhatia [72] has proposed a net flow chart for noncommercial energy, having classified the major activities in the rural sector into a) household energy consumption, b) crop production, c) livestock maintenance, d) agro-industries and e) transport.

Using the same classification, yet utilizing the structure of solid geometry (rather than a single time flow graph) in order to emphasize the inseparability of various activities and energy form, Gupta [73] proposes an "energy cube"..

The quantitative energy flow in China was presented by Smil [74]. Another quantitative energy flow-diagram of a village in Bangladesh was reported by Brisco [17]. Huq developed a qualitative model of agricultural farm [44]. Based on Huq's model a qualitative as well as quantitative dynamic model has been developed in the present study for an integrated rural energy system (human energetics, animal energetics, cropping energetics, cooking energetics, etc.).

4.2 Integrated Rural Energy System

As mentioned already, the source and the sink (consumption) of rural energy system in developing country like Bangladesh are interrelated. Animate energy, biomass or related energy, as well as commercial energy sources are the source of energy supply. However, the net flow of energy involved in the activities of rural sector are:

1) Household
2) Crop production
3) Livestock Maintenance
4) Agro-industry
5) Trade
6) Health
7) Housing
8) Education
9) Recreation

It is evident that the physical quality of life (PQLI) of those rural people is determined by these activities. Based on this classification, a qualitative model for integrated energy flow is developed for rural energy system and is shown in Figure 4.1.

4.3 Integrated Energy Model for Rural Farming System

In Bangladesh context, the rural farming system elements are: crop, cattle, poultry-birds, fish and forest. Farming system may be considered as a set. Crops, cattle, poultry-birds, fish and forest are termed as the elements (set-variables) of the set. Therefore, farming system may be defined by the following equation:

$$\text{Farming system} = [\text{Crop}, \text{Cattle}, \text{Poultry-bird}, \text{Fish}, \text{Forest}] \quad (4.1)$$

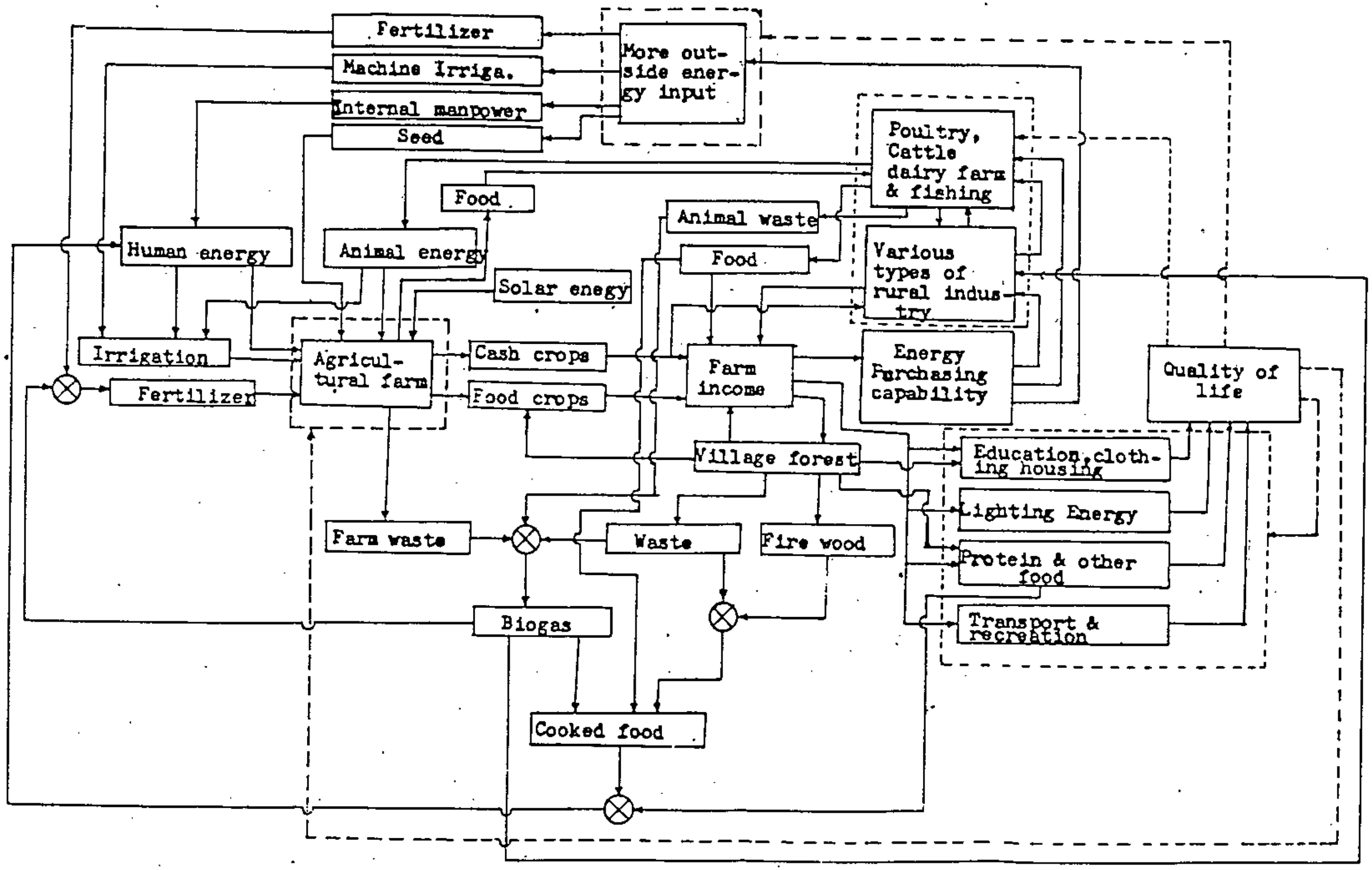


Figure 4.1 Huq s model for integrated rural energy system (Revised)

Each element may be considered as a sub-set. Then the sub-set may be defined as:

Crop = [Cash-crop,Food-crop,Vegetable] (4.2)

Cattle = [Bullock,Cow,Buffalo,Goat] (4.3)

Poultry-Bird = [Fowl,Duck,Pigeon] (4.4)

Fish = [Different species of fish] (4.5)

Forest = [Fruit and Timber,Fire-wood,Palm,Bamboo] (4.6)

All the elements of the set and the sub-set will be considered as the dynamic variables.

In 1983/84 the estimates of Bangladesh energy planning project (BEPP) show that biomass fuels (i.e. agricultural residues, wood fuel and dung) provide over 80% of total energy consumption [75]. The rural farming sector is the source of biomass fuel as well as an energy consuming sector [as inputs of different energetics] of the rural area.

A modified qualitative integrated energy model for rural farming system having above mentioned dynamic variables [Eqs. (4.1) to (4.6)] including other energy consuming variables is proposed and is shown in Figure 4.2.

It can thus be justifiably assumed that an integrated energy model for farming in the context of Bangladesh may in effect be treated as the model for integrated rural energy system.

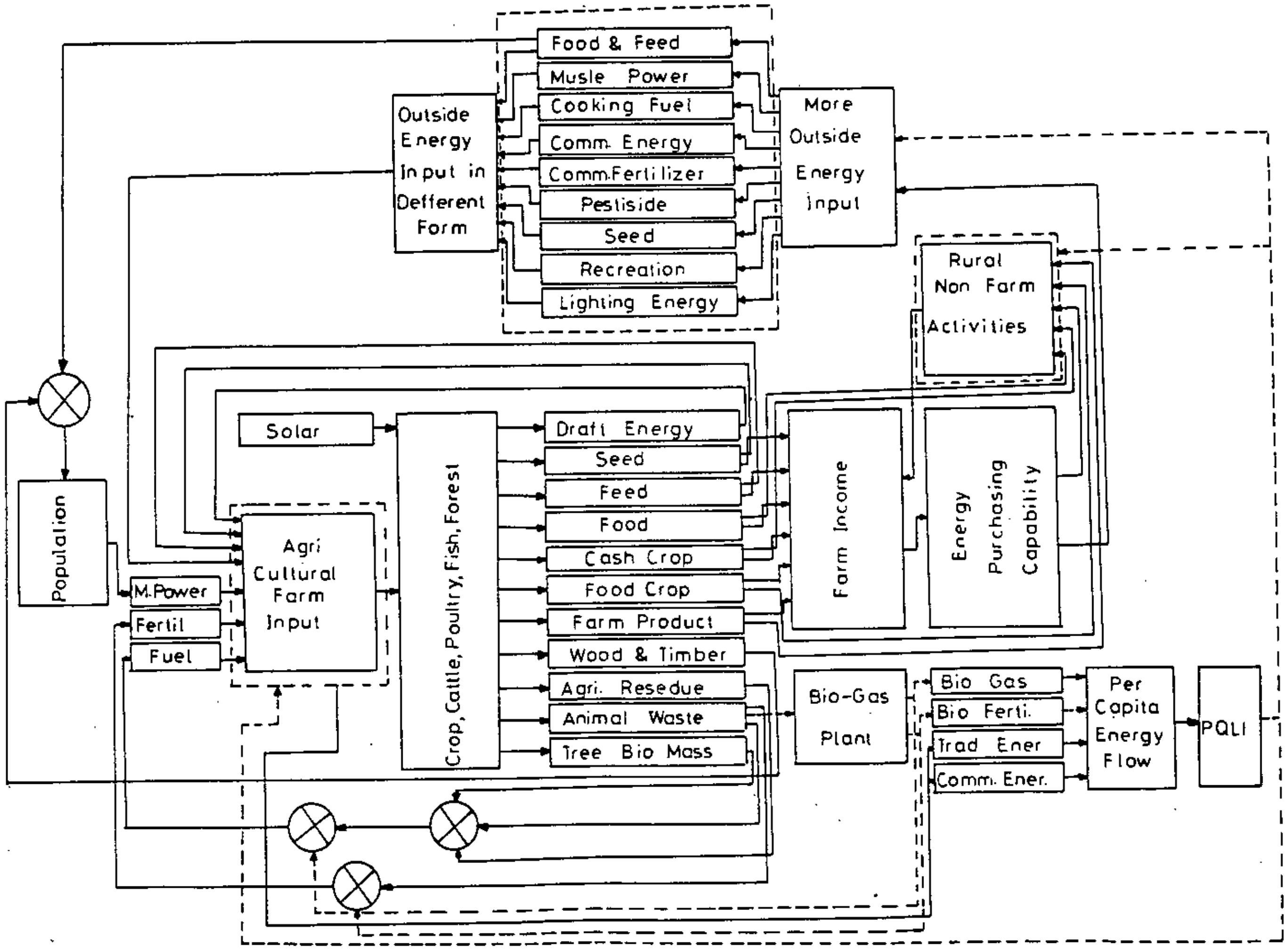


Figure 4.2 Integrated Energy Model for Rural Farming System.

4.3.1 Energy demand in farming sector

The various types of energy sources directly used for the farming are:

a) Human and animal muscle power for land preparation, planting, harvesting, transport of crop and livestock maintenance.

b) Human muscle power, diesel fuel and electricity for irrigation.

c) The indirect use of energy for facilitating agricultural production through chemical fertilizer and pesticides.

d) Crop residues, cowdung and tree-biomass, used as fuels for domestic cooking.

e) Energy in the form of heat produced by combustion of biomass fuels or other fuels, and some amount of mechanical power necessary for post harvest processing of crops. Some of these processing may take place at household level and also in rural industries.

4.3.2 Categories of energy sources in rural farm

It is possible to break up, in a general over-view of all the various activities in the farm, - (including the domestic life of the agricultural family depending for its livelihood, and other necessities, primarily on the farm), into two categories:

i) Energy that is applied for obtaining the finished products of the farm,-- namely the food crops and the cash crops.

ii) Energy that is consumed for making life possible in the farming sector.

4.3.3 Other forms of energy in the farm

It is needless to point out that in the setting up of an overall energy model for farming system, a few other types of energy directly or indirectly flowing in farming activities must also be taken into account. A preliminary list for modeling purposes may include: (i) Solar energy, (providing heat and chemical energy) (ii) Chemical energy provided by animal waste which in turn is a partial output from food provided to farm animals, (iii) Chemical energy provided by artificial fertilizers which are, in general, energy-intensive products of industry, (iv) rain water with stored potential energy deriving ultimately from Solar energy, and (v) irrigation water provided by either muscle power or by machine power (from fossil fuel or electricity) or a combination of these. The existence of energy feedback loops at various stages can also be identified in this case.

4.4 The Energy Model with Some Feedback Loops

Figure 4.1 and Figure 4.2 represent qualitative model showing the forward and backward flow of energy. An attempt has been made to make the model as complete and realistic as possible with facts known about Bangladesh. While, setting up such a model one must remember that energy, including all losses, must balance. Many facts are either not known or can not be evaluated in terms of numerical quantities. It may be stated that the aim of farming sector is to produce its edible, saleble or combustible outputs so as to secure a basic standard of living as a minimum goal. This standard of living - as is known - is commonly measured in terms of income per capita of the human beings subsisting on a particular sector. Another way of looking at the output of the sector is to determine "how much energy could have been bought (from sources outside of this sector) from the net produce of the farm after all the energy in its various forms inside the farm have been accounted for".[76] As is also known, energy consumption per capita is an index of the standard of living in a community. If, some of the energy purchasing capability of a farming sector can be reinvested in the farm - for the purposes of artificial irrigation by power pumps, or chemical fertilizers, or even better food for the animals, etc., in an ideal situation, the farm income per capita (or energy purchasing capability) should increase at a faster rate than the rate of re-investment. Saturation however, will be reached at some stage, but as pointed out earlier, the usefulness of the model would lie, on the one hand, in deciding the most suitable point of injection of energy and on the other, in raising the point (or standard) of living where saturation is reached. However, it is not difficult to realize that the quality of life is not the same as "standard of living", although the farmer to a large extent, is dependent on the later.

In order to represent the performance of the model in characterizing the dependence of the quality of life on energy consumption, an attempt will be made in the next chapter to develop a supporting mathematical model for the physical quality life as a function of energy consumption [PQLI = f(kWhr/cap)].

4.5 Energy Model: Forecasting, Policy analysis, and Optimization

The ultimate aim in analyzing the efficiency of any industrial production system -- whether with the help of model or by any other means, is to secure -- (a) optimization of the entire process, so as to achieve, in terms of energy, the maximum energy purchasing capability with the minimum application of energy and/or (b) status projection and/or (c) analysis of the alternative courses of policy oriented action [77]. The same criteria ought to be applicable to the farming sector.

CHAPTER-V

DEVELOPMENT OF THE SUPPORTING MODEL FOR PHYSICAL QUALITY OF LIFE AS A FUNCTION OF ENERGY CONSUMPTION

5.1 Introduction

Only about a quarter of the more than four billion people on this planet live in countries where the average food consumption is well above the physiological needs, where infant mortality is low (typically below 25 per 1000 live births) and life expectancy is high(around 70 years), where literacy touches on 100 per cent [78]. These are the world's most developed nations: a quarter of mankind consuming four fifths of the commercial energy and enjoying a quality of life unsurpassed in history.

For the remaining three quarters of the human population conditions are painfully different. The overwhelming majority of their people are illiterate or semi-literate poor villagers, surviving on less than adequate diets, whose infant mortality is an order of magnitude higher than in the developed world and whose life expectancy is as much as three decades shorter. The difficult present and less than promising future of this developing world, or as some prefer, the less developed, underdeveloped, or third world is, to a very large extent, the result of energy starvation: a very low consumption of commercial energy.

In developing countries, agriculture is the main source of biomass fuel as well as one of the main energy consuming sectors. The energy captured through agriculture in crops and crop residues provides food for people and fodder for draft animals. Dung and crop residues are used for cooking and heating [1,3,79]. In context of Bangladesh, Islam [11] reported that the contribution of biomass fuel is 75% of total final energy consumption in 1990. The composition of biomass fuel are 63.45% crop residues, 22.18% tree biomass, and 14.37% dung respectively In the past two decades these traditional energy sources have been supplemented by the use of coal, oil and electricity in agriculture, transport, industry and domestic sectors. The most striking feature of energy use in the third world is that the amount of useful work which the poor obtain from the energy they use is small [1]. In fact when inputs to agriculture (including directly applied energy) are increased properly the energy output per worker and per unit of land increase. Energy obtained from the consumption and sale of crops would in turn be needed to increase as an input to agriculture to raise the crop yields, extend the irrigated land, increase multicropping, mechanize construction and repairs of water projects, build modern roads and improve, in general, the quality of the life of the peasants. The question regarding how fast and with what real success the developing countries move toward the still-distant goal of rural modernization, direct and indirect energy flow into agriculture will have to take up a much larger share of the future energy consumption.

It is well known that the standard of living or in a more general and overall approach, the quality of life achieved in any community and a group of people can be measured for ordinary and practical purposes by the quantity of total energy used per capita in that community [8]. It has also been widely recognized by now that the above statement is more appropriate for societies where the production and distribution of energy is secure and widely spread.

Several studies have been reported on increasing energy requirements for economic development and enhancing the quality of life. Smil [74] reports that economic growth and energy consumptions are closely related. Smil and Knowland [81] state that energy is the primemover of economic growth and development. Revelle [80] comments that the men and women in the rural areas are tied to poverty and misery because they use too little energy and use it inefficiently. In addition, Rahman and Huq [76] claimed that there was a distinct correlation between the energy consumption in a country and its overall economic conditions. Brisco and Bari [17] pointed out that the socio-economic position of rural people would deteriorate rapidly unless increased inputs of technology and energy are made into agriculture. Friedlander [82] admitted that with a view to achieving the high standard of living, the developed countries have encouraged the consumption of energy at a very fast rate. Particularly Dalal [8] recognized that the electrical energy consumption in a country is an indicator of its economic condition. Hoque et al [7] state moreover that the total energy produced and obtained from all possible sources can be the index of physical quality of life.

Forrester [49] estimated the physical quality of life globally based on pollution, population density, food consumption and resources. Islam [83] quantized quality of life based on twenty eight variables related with the way of life in a given region. Alam et al[84] reported that the physical quality of life in developing countries depends on certain basic needs and energy consumption in various forms, and quantized it based on cooking energy (in the form of bio-gas) and population density. However, Martin [78] calculated the physical quality of life index of each country based on an average life expectancy (LE) at age one, infant mortality (IM) and literacy rates (LR).

No attempt seems to have, so far, been made to use the total energy consumption figures for quantizing meaningful levels of physical quality of life index (PQLI). With a view to quantizing the physical quality of life index of each country based on per capita energy consumption, A model showing the relation between physical quality of life and kilowatt-hour consumption per capita is presented here.

5.2. Development of the Model for Electrical energy (kWhr/cap) Consumption

Most of the literatures on physical quality of life are qualitative in nature. Planning for development requires quantitative statement rather than verbal description. As stated earlier, Martin defines physical quality of life as depended on LE, IM, and LR and estimated the physical quality of life of 147 countries. " Each countries Physical Quality Of Life Index (PQLI) is based on an average of life expectancy at age one, infant mortality, and literacy rates," which is dimentionless [78]. However, the author postulates that Martin's suggested approach of basing it on a variety of statistical social condition indices related with population under investigation leads to a set of somewhat indefinite data. Instead, it is postulated that the electricity consumption figure per capita would implicitly include and also reflect the overall physical condition of the people carrying on their various activities and passing on their lives in a certain stage of development. It may be noted that PQLI depends on total energy consumption. Due to unavailability of total energy consumption data, per capita electrical energy consumption (kWhr/cap) of 112 countries were obtained from the published literature [85] and used for subsequent analysis. Each of the variables LE, IM and LR as a function of natural logarithm of per capita electrical energy consumption [ln(kWhr/cap)], and also physical quality of life (as estimated in Ref. 78) as a function of each variable LE, IM and LR were plotted in figure 5.1 to 5.6. The scatter diagrams shown in figure 5.1 to 5.6 lead to develop the following regression models:[86-88]

In Fig 5.1, $LE = 23.52 + 5.97\ln(kwhr/cap)$ (5.1)

$$\begin{aligned} & \quad (4.74) \qquad (0.26) \\ t &= (4.96) \qquad (22.96) \\ r &= 0.91 \end{aligned}$$

In Fig 5.2, $LR = -37.58 + 16.48\ln(kwhr/cap)$ (5.2)

$$\begin{aligned} & \quad (15.15) \qquad (0.82) \\ t &= (-2.48) \qquad (20.10) \\ r &= 0.89 \end{aligned}$$

In Fig 5.3, $IM = 256.05 - 29.41\ln(kwhr/cap)$ (5.3)

$$\begin{aligned} & \quad (28.27) \qquad (1.53) \\ t &= (9.06) \qquad (-19.22) \\ r &= 0.88 \end{aligned}$$

In Fig 5.4, $PQLI = -70.74 + 2.28(LE)$ (5.4)

$$\begin{aligned} & \quad (4.48) \qquad (0.04) \\ t &= (-15.79) \qquad (57) \\ r &= 0.99 \end{aligned}$$

In Fig 5.5, $PQLI = 15.65 + 0.79(LR)$ (5.5)

$$\begin{aligned} & \quad (5.70) \qquad (0.02) \\ t &= (2.75) \qquad (39.50) \\ r &= 0.98 \end{aligned}$$

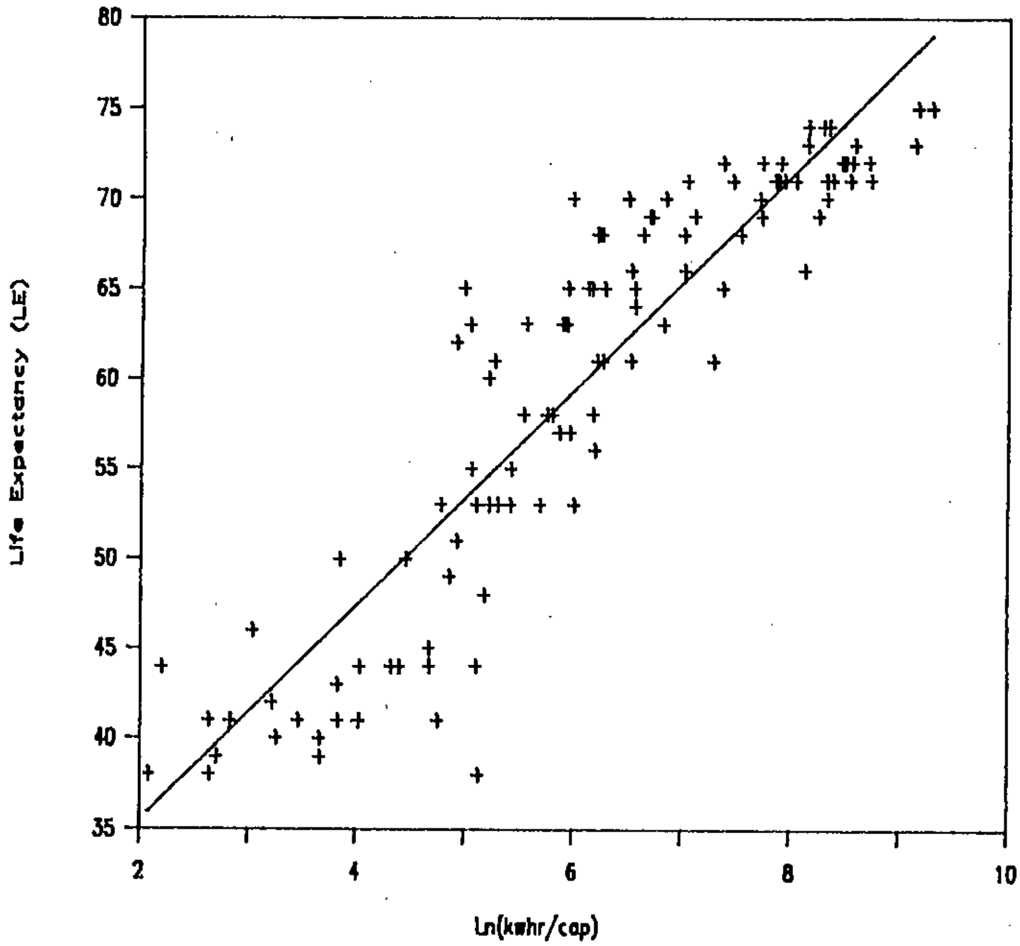


Fig. 5.1 Comparison of Reported Data (+++) and Predicted Values (——) of Life Expectancy as a Function of ln (kWhr/cap.).

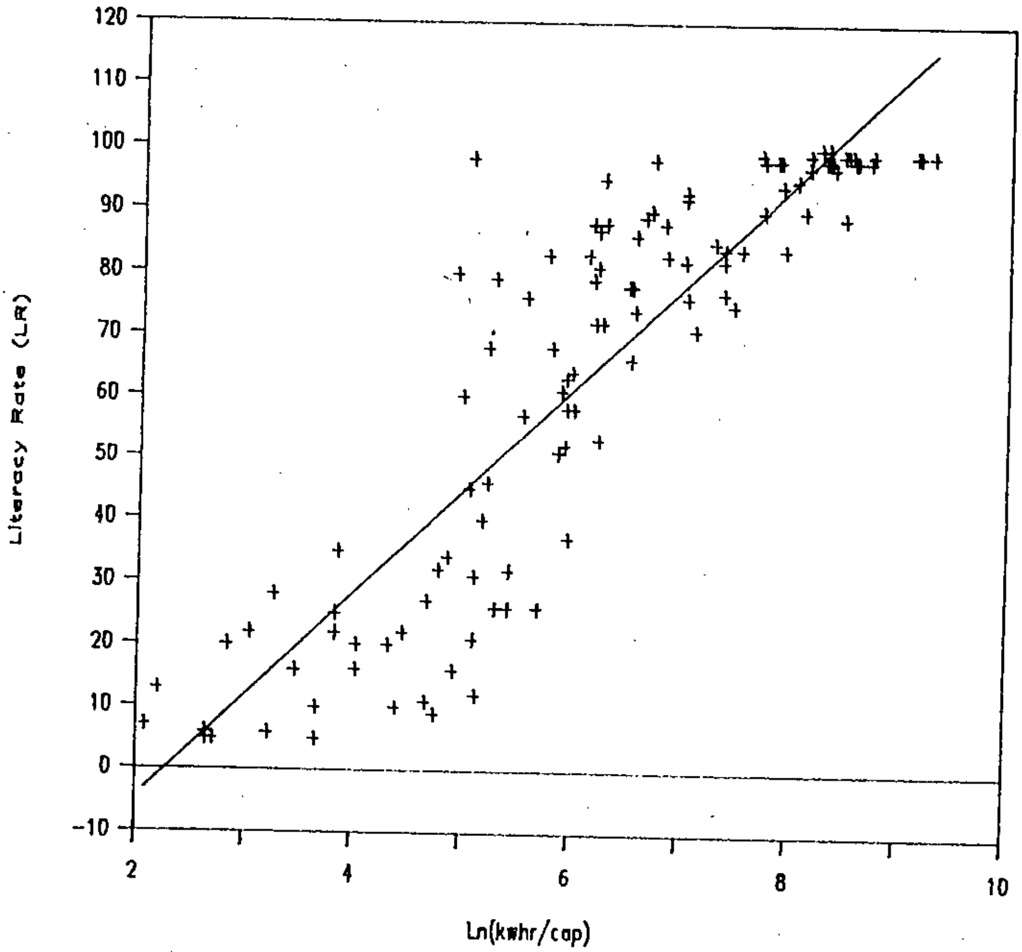


Fig. 5.2 Comparison of Reported Data (+++) and Predicted Values (——) of Literacy Rate as a Function of Ln (kWhr/cap.).

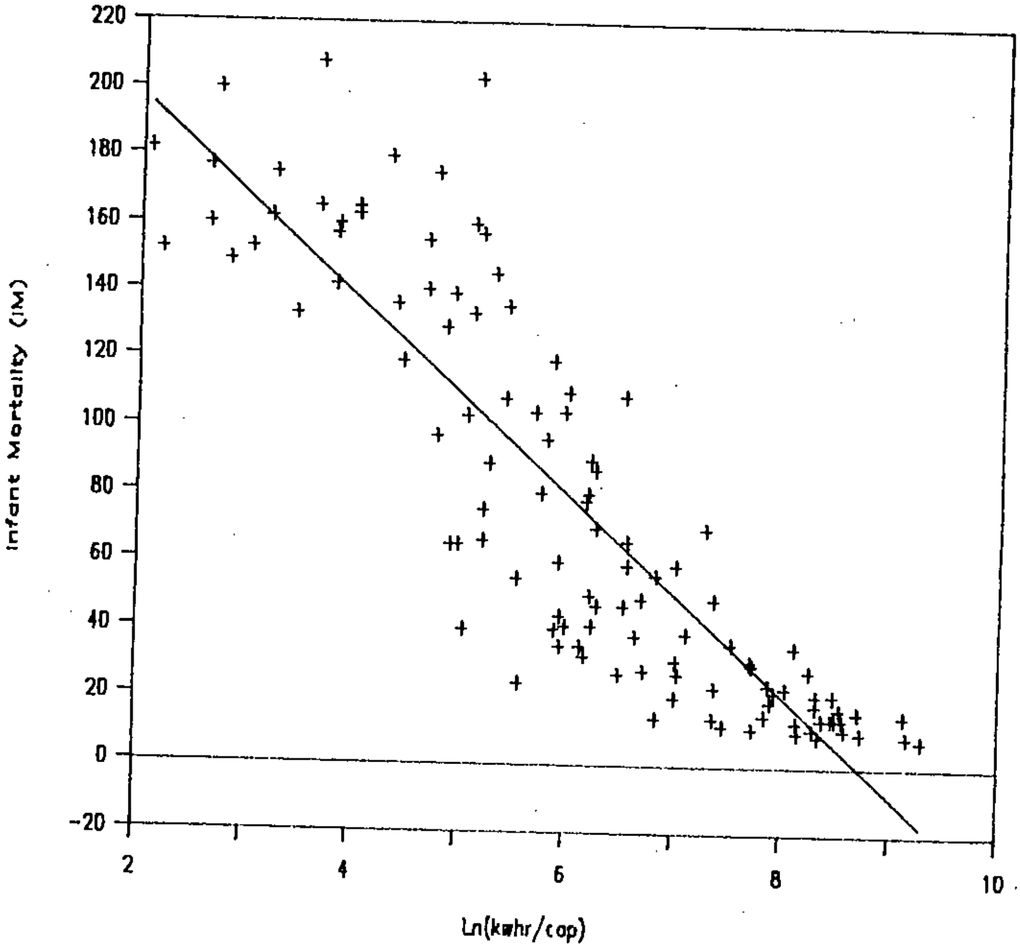


Fig. 5.3 Comparison of Reported Data (+++) and Predicted Values (——) of Infant Mortality as a Function of ln(kWhr/cap.).

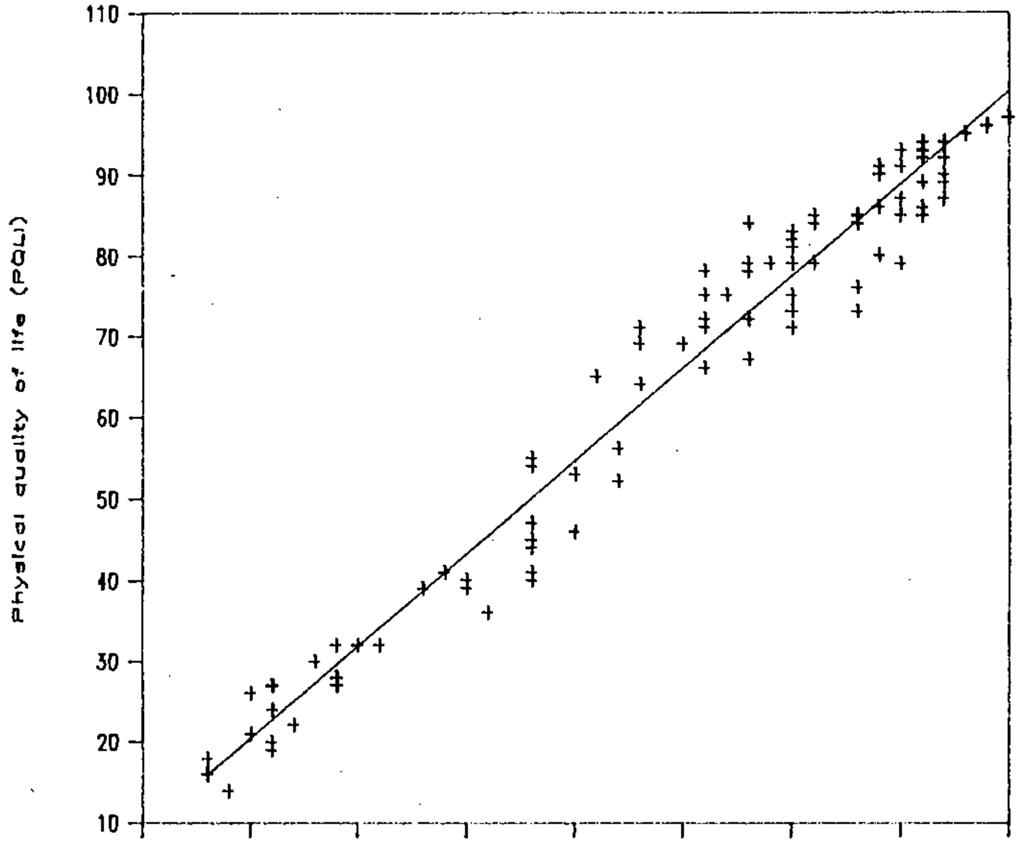


Fig. 5.4 Comparison of Reported Data (+++) and Predicted values (——) of Physical Quality of Life as a Function of Life Expectancy.

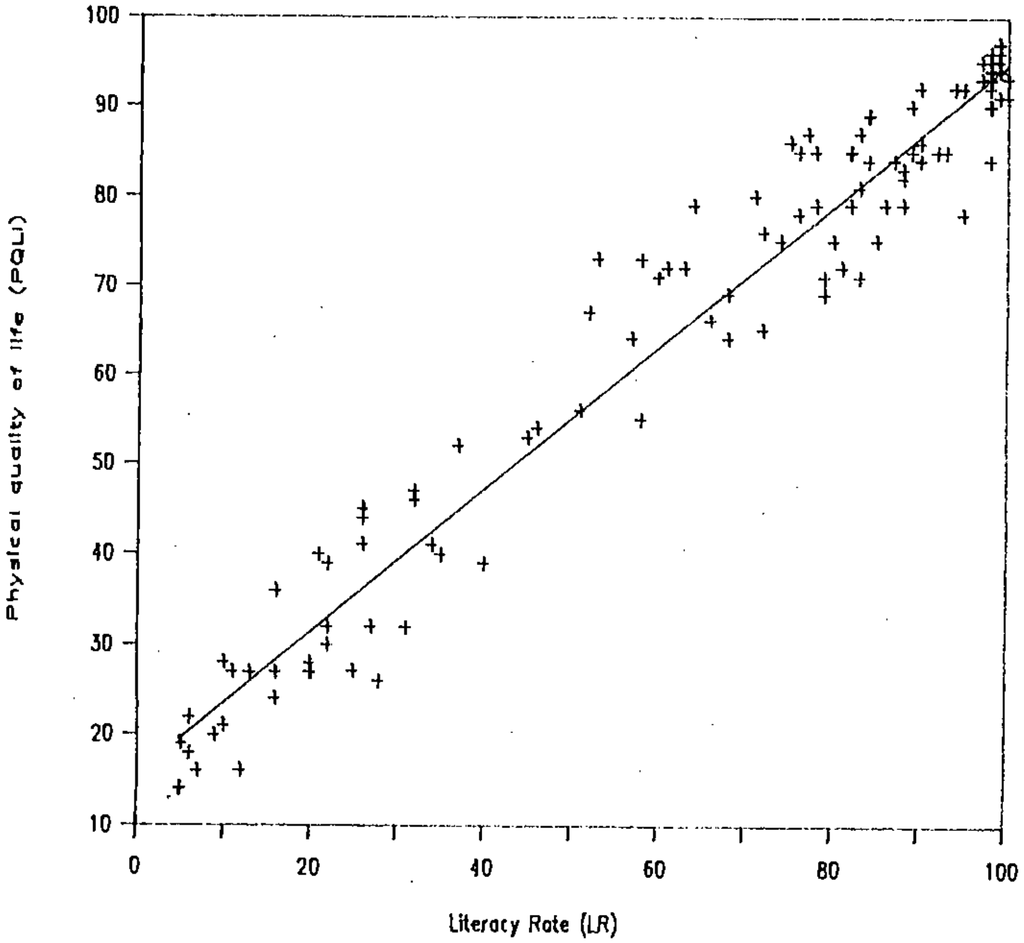


Fig. 5.5 Comparision of Reported Data (+++) and Predicted Values (——) of Physical Quality of Life as a Function of Literacy Rate.

In Fig 5.6, $PQLI = 99.32 - 0.44(IM)$ (5.6)

$$(6.06) \quad (0.01)$$

$$t = (16.39) \; (-44.00)$$

$$r = 0.97$$

Martin's estimation, and examination of the figure 5.1 to 5.6 as well as of equations (5.1) to (5.6) suggest the following functional relationship :-

$$PQLI = f_1(LE, IM, LR) \tag{5.7}$$

$$kWhr/cap = f_2(LE, IM, LR) \tag{5.8}$$

The equations (5.7) and (5.8) suggest the physical quality of life (PQLI) can be expressed as :

$$PQLI = f_3(kWhr/cap) \tag{5.9}$$

LE, LR and IM are functions of ln(kWhr/cap) (Eqns. 5.1 to 5.3) and physical quality of life is a function of LE, LR and IM (Eqns. 5.4 to 5.6). Hence we can express physical quality of life more simply as a function of ln(kWhr/cap) :

$$PQLI = A\,[\ln(kwhr/cap)] \tag{5.10}$$

where A may be taken as a technological constant. PQLI depends on kWhr/cap as well as technological constant. This technological constant depends on the form or mode of energy use and energy use efficiency. It is evident, that the technological constant

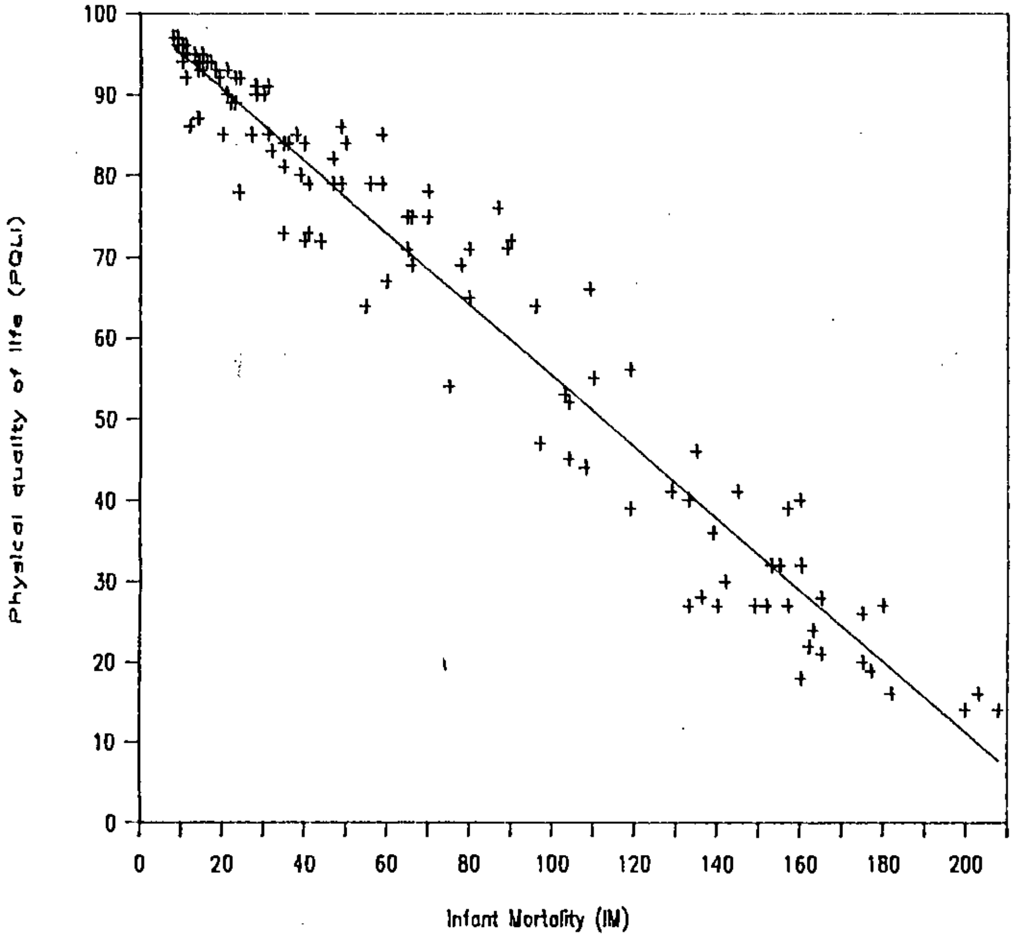


Fig. 5.6 Comparison of Reported Data (+++) and Predicted Values (——) of Physical Quality of Life as a Function of Infant Mortality.

will increase with the advancement of technology of energy utilization. "A" can be estimated by the regression analysis :

$$PQLI = 10.99\ [\ln(kwhr/cap)] \qquad (5.11)$$

$$(0.18)$$

$$t = (61.10)$$

$$r = 0.89$$

Statistical data regarding the above equations are given in Appendix D.

5.2.1 Validation of the model

The diagrams shown in figures 5.1 to 5.6 and the equations (5.1) to (5.9) show the existence of functional relationship among the variables and lead the author to develop equation (5.10). Physically this means that the effect of the variables LE, IM and LR on physical quality of life (PQLI) in Martin's [78] estimation implicitly includes the effect of per capita energy consumption (kWhr/cap). Hence it can be concluded that the physical quality of life can be more simply expressed as a function of per capita electrical energy consumption.

The utility of the proposed model in equation (5.10) can be checked [86-88]; that is, whether ln(kWhr/cap) really contributes information for the prediction of PQLI using the regression model in equation 11. From T tests, t=61.10, where the tabulated value is 1.98 at 5% level of significance [87]. This considerably large value of t leaves little doubt that PQLI and ln(kWhr/cap) are to a very large extent linearly related, with PQLI increasing as ln(kWhr/cap) increases.

Another measure of the utility of this model is the co-efficient of correlation r and rank correlation co-efficient r(rank), where r=0.89 and r(rank)=.98. The high correlations confirms the conclusion that the slope "A" differs from zero, and therefore it is evident that the PQLI and ln(kWhr/cap) are highly correlated.

Figure 5.7 also shows the difference between reported data and the predicted value of PQLI vs. kWhr/cap. The agreement appears to be quite good. Both the shape of this curve (fig 5.7) and characteristics of the equation (5.10) show that the social change (in terms of PQLI) does not linearly related with it's energy intake. Some time delay charecteristics is concerned with. Such as, when a living being is intake energy, the physiological change will not be occurred simultaneously and proportionally . This change is happened in diffusion manner and obey the time delay charecteristics. Asymptotic nature of the curve in fig. 5.7 explains the socio-economic saturation condition (PQLI) in terms of social indicators (LE, LR, IM,....), which is nearly independent of energy intake. This saturation level may be shifted due to mode of energy use as well as energy use efficiency. Figure 5.8 shows the residuals ($PQLI_i$-$PQLI_i$) vs. ln(kWhr/cap) [$PQLI_i$=computed value]. As the residuals are randomly scattered about the reference line [87], this is even more convincing evidence that the regression model used was the correct one.

From the statistical tests, correlation co-efficients, and the diagrams shown in figures 5.7 and 5.8, the regression model in equation (5.11) can be accepted as highly significant.

Therefore, this equation may be used to estimate the physical quality of life in a country, regionally or locally as an indicator of the degree of development, if it is possible to calibrate with appropriate percapita energy consumption data.

5.3 Development of the Model for developing countries

More than five-sixths of all the energy obtained from fossil fuels and hydro-electric and nuclear power is used by one billion inhabitants of the rich countries and less than one-sixth by the three billion people of the poor countries [84]. The reverse is true of the traditional sources of energy- human and animal labour, fire-wood, crop residues, and animal wastes- those were predominant through out the history.

International statistics on energy use are usually based only on consumption of "commercial" energy and hence seriously under-estimate total energy consumption in poor countries. In Bangladesh, more than eighty percent of the total energy consumption is used from the traditional sources [89]. In India for example per capita energy consumption is generally given as the UN coal equivalent of 150 to 190 kg whereas, total energy used from all sources is close to 490 kg [80]. In the rural area

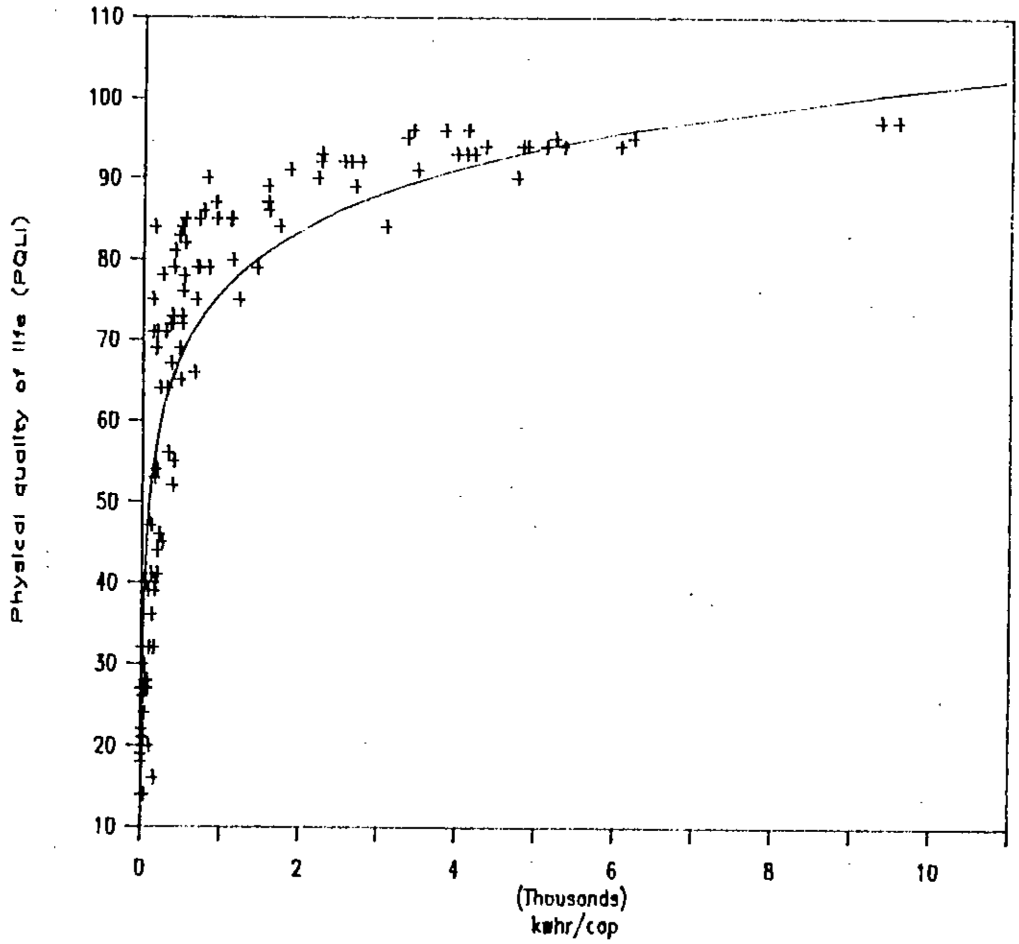


Fig. 5.7 Comparison of Reported Data (+++) and Predicted Values (——) of Physical Quality of Life as a Function of KWhr/Cap.

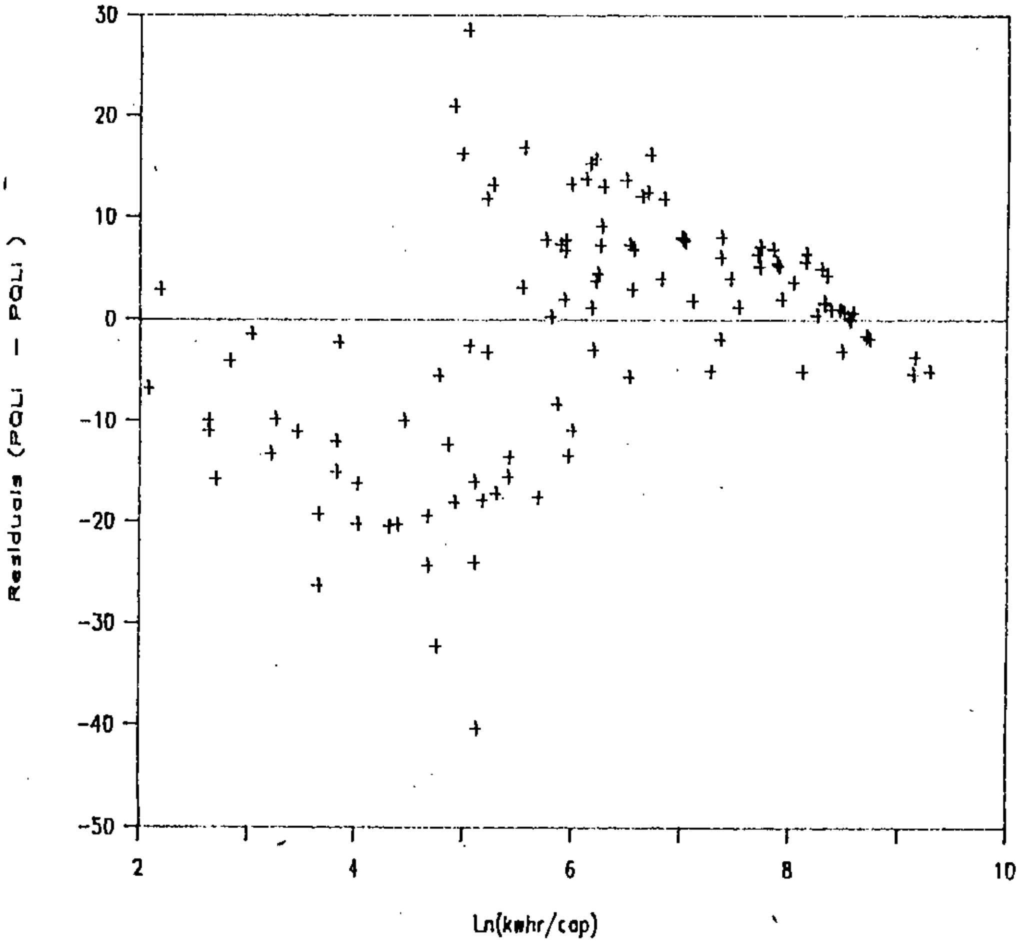


Fig. 5.8 Checking Residuals ($PQLI_i - \widehat{PQLI_i}$) from Regression (Equation 11) for Random Scatter.

of poor countries, energy provided by the people themselves is five to ten times that obtained from commercial sources [80].

5.3.1 Model for electrical energy

Dew to unavilability of sufficient data on traditional energy consumption, it (equ-5.10) has not possible to be calibrated the model with the per capita total energy consumption, specially for the traditional energy consumption figure. However, the model has been calibrated with per capita electrical energy consumption figure for some developing countries of Asian region [90]. By the use of regression analysis, the model was calibrated and was shown in Fig. 5.9 and in equation (5.12):

$$\text{In Fig. 5.9 } PQLI\ (EE) = \underset{(9.76)}{1.12} + \underset{(1.89)}{11.92} * Ln(EE/cap) \qquad (5.12)$$

$$t = (0.12) \quad (6.31)$$

$$r = 0.90$$

Where, EE/cap be percapita electrical energy consumption in kWhr.

5.3.2 Model for commercial energy

Similarly, the model was also calibrated with per capita commercial energy consumption figure for the developing countries and was shown in fig. 5.10 and in equ 5.13 :

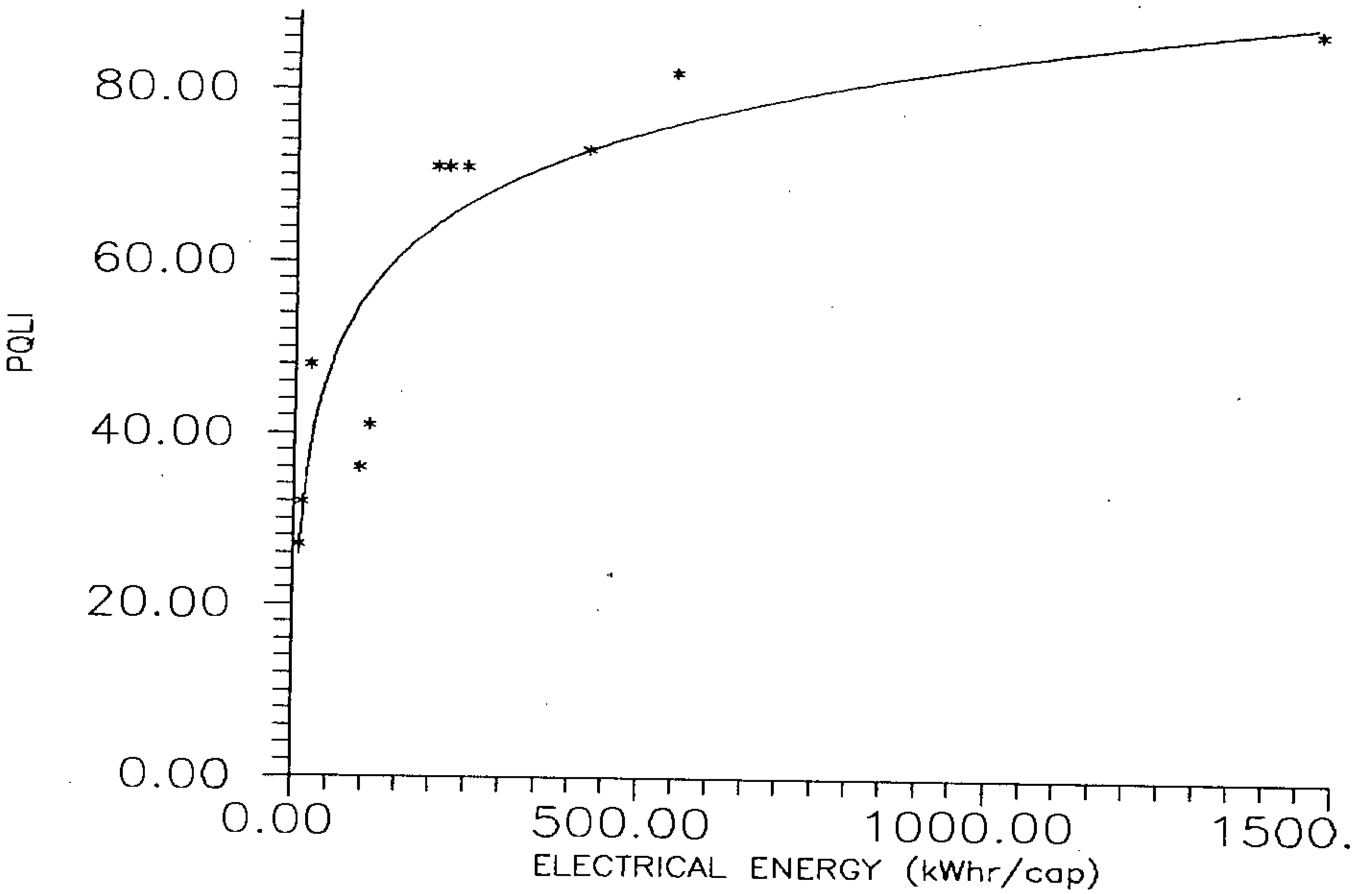


Fig. 5.9 Comparison of reported data (*) and predicted values (—) of physical quality of life as a function of electrical energy (kWhr/cap) consumption for developing countries.

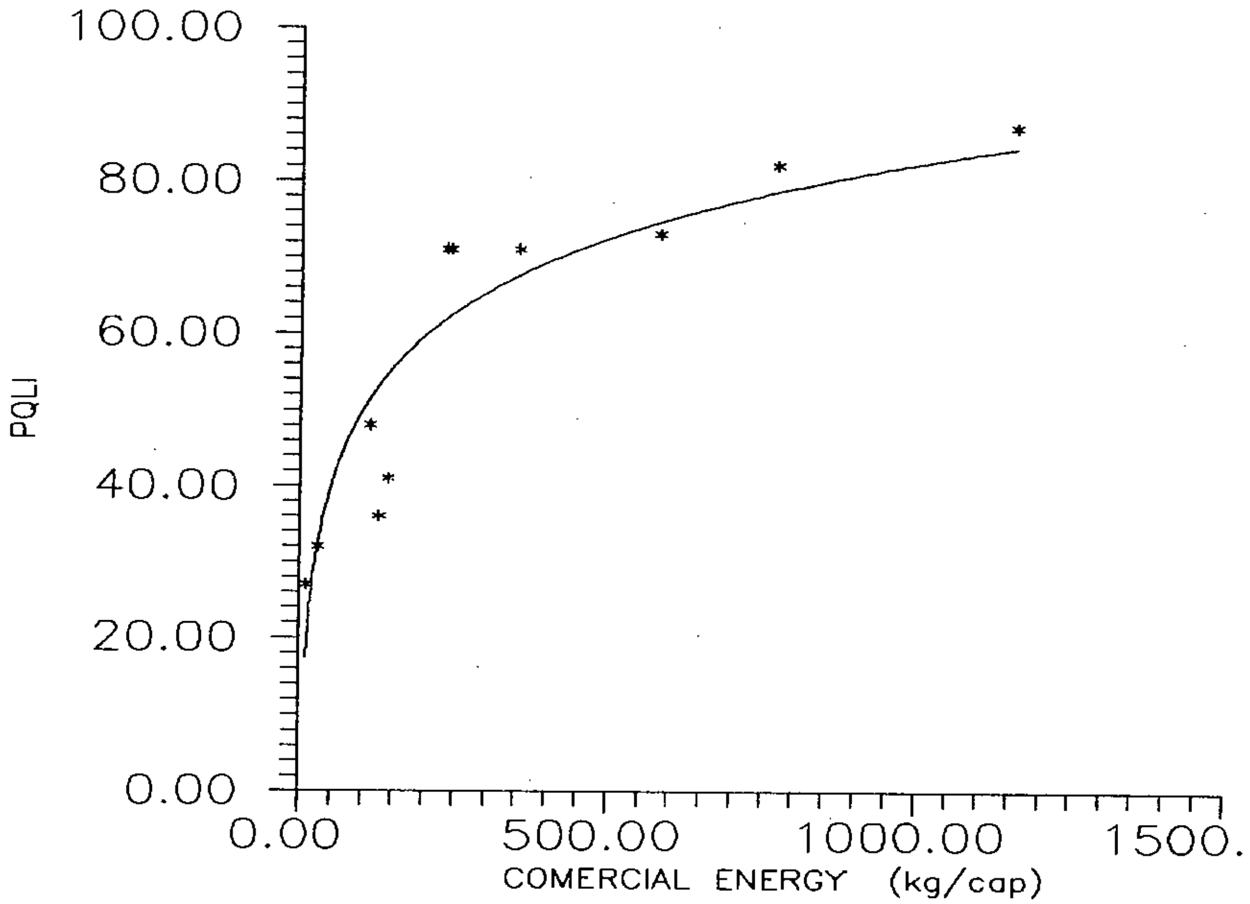


Fig. 5.10 Comparison of reported data (*) and predicted values (-) of physical quality of life as a function of commercial energy consumption for developing countries.

In Fig. 5.10 $PQLI(CE) = 15.01+14.01*Ln(CE/cap)$ (5.13)

$$(9.35) \quad (2.11)$$

$$t = (1.61) \quad (6.64)$$

$$r = 0.91$$

Where, CE/cap be percapita commercial energy consumption in kWhr.

5.3.3 Model for total energy

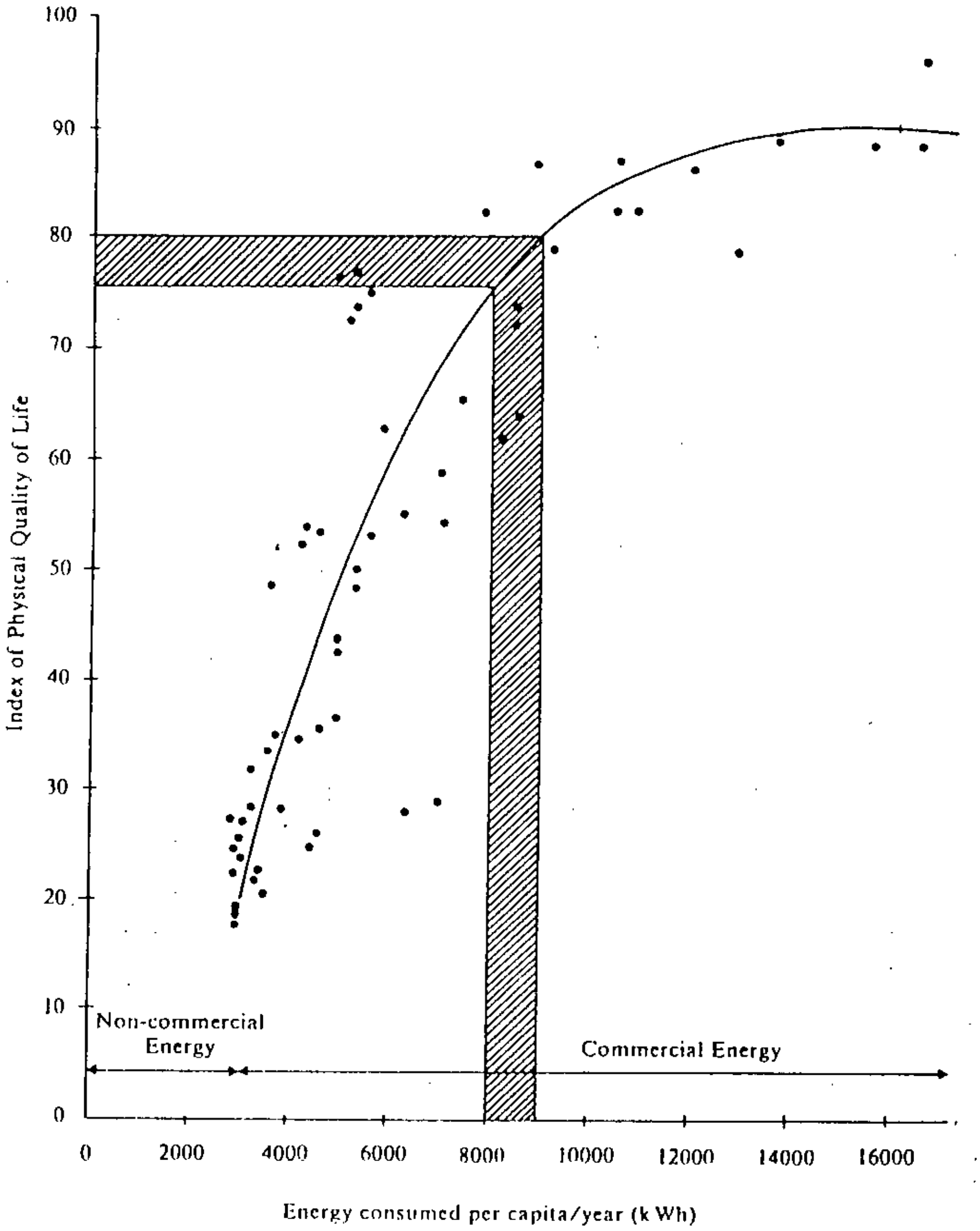
To arrive at reasonably realistic model showing the functional relationship between PQLI and total energy consumption, dependable data for various countries of the world, both for developed and developing countries, would be required. However total energy consumption data, specially regarding some of the least developed countries (LDC) are not available.

The Brookhaven National Laboratory [32] has published a curve shown in Fig. 5.11 showing the dependence of PQLI on energy consumed percapita/year (kWhr) for 80 developing countries around the world. By analysis of the curve-trend, the following mathematical model is obtained:

In Fig. 5.11 $PQLI(TE) = -310.53+42.32*Ln(TE/cap)$ (5.14)

Where, TE/cap be percapita total energy consumption in kWhr. It may be noted that the lower limit of percapita energy consumption of Brookheaven data base was 3000 kWhr/cap.

From the statistical tests (correlation coefficient and t - test) on Equ. (5.12), (5.13), and (5.14), each of the



Source: Energy Needs, Uses and Resources in Developing Countries. Brookhaven National Laboratory. Development Country Energy Programme, 1978.[32]

Fig. 5.11 Comparison of reported data (•) and predicted values (+) of physical quality of life as a function of total energy (kWhr/cap) consumption for developing countries.

equation can be accepted as highly significant at 5% level of significance.

Therefore, the equation (5.14) may be used to estimate the physical quality of life for different developing countries like Bangladesh as a guide line for local, regional, and national development policy planning provided the percapita energy consumption data are within the range (3000 - 16000 kWhr/cap/yr) of brookheaven data. The relevant statistical information is shown in Table 5.1.

Table 5.1

Per Capita Energy Consumption and Physical Quality of Life of Different Developing Countries.

Country	Percapita Electricity consumption kwhr	Percapita Comercial Energy kg/oil equivalent	Physical Quality of Life PQLI	Estimated PQLI (EE)	Estimat-ed PQLI (CE)
Bangladesh	12	30	32	34.557	34.557
Nepal	08	10	27	16.557	16.557
Pakistan	95	128	36	52.744	52.744
Indonesia	22	113	48	45.235	45.235
Malaysia	421	584	73	73.912	73.912
India	108	143	41	58.567	58.567
Korea,Rep. Of	547	774	82	76.663	76.663
Thailand	203	236	71	63.328	63.328
China	246	355	71	67.352	67.352
Philippin-es	220	243	71	70.838	70.838
Taipei, china	1473	1160	87	79.151	79.151

Source : ADB (Asian Development Bank), 1989. [90]

CHAPTER - VI

ANALYSIS OF RURAL ENERGY SYSTEM IN BANGLADESH

6.1 Introduction

Traditional fuels (Biomass) in rural areas in Bangladesh such as fire wood, crop residues and animal dung, have always been available to whoever takes the effort to collect and gather them. Draft animals and human labour through muscle power still provide most of the motive power and transportation. The serious difficulty of traditional fuel utilization is a very poor conversion efficiency (10%). Muscle power is often inefficiently harnessed or weakened due to poor nutrition.

The traditional energies will continue to play a major role in most developing countries for decades to come. Traditional fuels presently account for about one third of China's primary energy use, half of all the energy consumed in India, three quarters of the energy consumption of Bangladesh and 90% or more in several African countries [91]. On the other hand world bank estimates that only 4% of African rural population have access to electrical power. The situation is some what better in the Asian and Latin American countryside, but at present rate of rural electrification only a quarter of the developing world's villagers is likely to use electricity by the end of this century [92]. The need is to produce fuels and electricity in rural areas for farming, households and manufacturing with simple and inexpensive technology. This would allow for large scale labour participation, reliance on local resources for manufacturing of components and would reduce dependence on costly imports of advanced machinery and materials.

The people of third world would fulfill their energy needs to the extent that they can primarily and in many cases almost entirely by the use of solar energy. This use of solar energy is dominated by photo-synthetic conversion. The energy captured through agriculture in crops and crop residues provide food for people and fodder for draft animals. In some areas dung and crop residues are used for cooking and heating.

For developing countries, self-sufficiency in food production is prime important aspect. Self-sufficiency in food production must be achieved through prudent use of the available energy sources. Knowledge of availability of energy and energy-use patterns is essential for policy planning in rural energy management and conservation. Rural electrification programmes have been launched with the prime objective of improving the standard of living through judicious and efficient management of energy.

Several studies have been conducted to determine energy-use patterns at the national and for rice and wheat at the farm level in Bangladesh [93-98]. Kennes et al.[99] reported rural biomass-use patterns for nine socio-economic classes in

Bangladesh. Rural energy flow network in quantitative form of China's energetics was presented by V. Smill [74].

A comparison of energy use patterns and the nature of energy flow for rural energy system at three typical villages in Bangladesh is made in this chapter. The energy use patterns for these villages (Ulipur [16], Sakoa [19], Langulia [84]) are presented to derive quantative energy flow network for the rural energy system of each village.

Comparative analysis of energy flow pattern in three villages (Ulipur, Sakoa, and Langulia) of Bangladesh are based on the study of Brisco [16] in 1979, Quader and Omar [19] in 1982, and Alam et al [84] in 1990 respectively.

6.2 Rural Energetics

The different energy coefficient of different elements of the rural energetics are taken for this research work, are shown in table 6.1.

Agricultural crops serve a variety of food and energy need. The rice husks are used for cooking fuel or animal feed. The leaves from the paddy are used primarily as fodder, and occasionally as fuel. The upper tender straw of the paddy plant is primarily a fodder source, and occasionally fills in as a fuel or even as compost. The coarse lower straw is used as fuel, compost, and frequently as fodder and construction material.

6.3 Micro level Rural Energy System

All system variables are changing due to population growth, new agricultural technology and penetration of the market economy into rural areas. The traditional energy sources in these areas are not completely relied upon where there has been widespread adoption of high-yielding crop varieties and mechanization of agriculture. In this connection, with a view to assessment of the role of energy-use in micro level rural energy system, it has been found necessary to take into account the household energy consumption, energy input and output of cropping system, animal energetics, as well as solar conversion efficiency in cropping system, and the utilization of draft power and labour force. Percapita major energy flow in the modified integrated rural energy model for farming for village Ulipur, Sakoa, and for electrified village Langulia, has been constructed.

6.3.1 Ulipur

Ulipur is a settlement of 96 families located in flood plain of Dhanu river in the Comilla district of eastern Bangladesh. The densely populated (888/sq.km) region contains numerous small villages or baris that sit atop artificial earthen mounds and become tiny islands during the summer monsoon season. Rich peasants own 80% of the fuel wood and fruit trees but they take only 10.8% of their fuel supply from this source. Poor, on the other hand, depend on wood for 31.1% of their fuel.

Table 6.1

Energy co-efficients of the elements of rural energy sources.

Description		Co-efficient
1. Human muscle power/capita	[100]	628×10^{-6} GJ/hr
2. Draft animal power/animal	[101]	1674×10^{-6} GJ/hr
3. Nitrogen in dung	[101]	0.5%
4. Phosphorus in dung	[101]	0.2%
5. Potasium in dung	[101]	0.47%
6. Energy required for Irrigation equipment	[102]	86.7×10^{-6} GJ/kg
7. Energy for pesticide	[103]	101.3×10^{-3} GJ/kg
8. Energy in seed	[104]	15.49×10^{-3} GJ/kg
9. Energy in cowdung	[45]	13.46×10^{-3} GJ/kg
10. Energy in comercial fertilizer, Nitrogen	[45]	77.4×10^{-3} GJ/kg
11. Energy in comercial fertilizer, Phosphorus	[45]	13.8×10^{-3} GJ/kg
12. Energy in comercial fertilizer, Potassium	[45]	09.6×10^{-3} GJ/kg
13. Enegy in tree Biomass	[104]	15.16×10^{-3} GJ/Kg
14. Energy in Kerosene	[10]	46.05×10^{-3} GJ/kg
15. Energy in Rice	[105]	14.53×10^{-3} GJ/kg
16. Energy in Rice husk	[45]	15.57×10^{-3} GJ/kg
17. Energy in Rice straw	[45]	15.17×10^{-3} GJ/kg
18. Power tiller output power	[10]	9.8 kW/unit
19. Average solar energy incident	[15]	65.15×10^{3} GJ/ha

During the rainy months of May to December, when no other fuel resources are available to them, the poorest villagers must either somehow manage to collect their cooking fuel or purchase it with money that would otherwise be used for food.

In Ulipur, the impact of high-yielding varieties has been small. The main crop, broadcast among paddy is grown using local seeds and traditional technology. During the winter season unirrigated crops predominate, with boro rice being grown in some low-lying areas. Only 14.83 kg of chemical fertilizer are used per hectare cropped area, and pesticides are infrequently used.

6.3.1.1 Household fuel consumption (Ulipur):

Fuel for cooking is major use of energy. In Ulipur the fuel used by 330 people is estimated to be 2281.37 GJ, whereas produced 2218.58 GJ are produced per year.

Fuel energy of 1348.23 GJ/yr were obtained from of crop residues. Fuel energy amounting to 63.45 GJ/yr were obtained from fire-wood. 330.15 GJ/yr were obtained from fire-wood produced at the home-stead and village forest, and 117.42 GJ/yr from fire-wood source were purchased from local market. Only a small amount of energy was collected from fuel from uncommon resources, such as bamboo, water hyacinth etc. The above data are presented in Table 6.2.

Table 6.2

Annual Fuel Consumption in Ulipur

Fuel Type	Quantity of Fuel GJ/Yr	Percentage %
a) Cooking & Parboiling:		
i) Agri. Residues	1348.23	72
ii) Cow-dung	63.54	3
iii) Tree-biomass	447.57	25
SUBTOTAL	1859.34	100
b) Other Fuels (Bamboo, Water-hyacinth etc.)	421.32	---
TOTAL	2280.66	---

Source: Brisco & Bari [16]

6.3.1.2 Energetics of cropping system (Ulipur)

The energetic efficiency of cropping system is defined as the ratio of total energy output (food, fodder and fuel) from crop production system to the total energy input (muscle power, fertilizer, pesticide, irrigation and seed) to cropping system. This definition does not include the solar energy absorbed to the plants. The solar energy efficiency is defined as the ratio of the total energy output in terms of food, fodder, and fuel to incident solar energy, and the food surplus index is the ratio of food produced to food consumed.

In Ulipur 17.4 hectares are cultivable land. Thus the incident solar energy is 6.52×10^4 GJ/ha/yr, the total solar energy input is 113.52×10^4 GJ/yr. The annual energy inputs for the crop production as human muscle power, 21.35 GJ; animal power, 13.76 GJ; organic fertilizer, 194.68 GJ; seed, 46.1 GJ; chemical fertilizer, 20.1 GJ and the annual energy output from the crop production system in term of food, fodder and fuel is 1650.87 GJ. In Table 6.3 the useful output and the input energy of the crop production system are presented.

6.3.1.3 Animal Energetics (Ulipur)

The useful output from cattle - dung, milk, meat and work are available only because of the food provided for the entire cattle population. The average gross energy intake for the 10 bullocks, 20 cows and 18 immature cattle is 779.05 GJ/yr. On the table 6.4 the input-output of the cattle energetic are presented.

Table 6.3

Input-Output Energy Of Cropping Energetics (Ulipur)

Source	Input (GJ/Yr)	Output (GJ/Yr)
1. Human Power	21.35	
2. Organic Ferti. (Dung)	194.65	
3. Animal Power	13.76	
4. Seed	46.10	
5. Chemical Ferti.	21.10	
6. Crop Residue (Fuel & Fodder)		1599.78
7. Food Grains		346.66
TOTAL	296.96	1946.44

Source: Brisco & Bari [16]

Table 6.4

Input-output Energy of Animal Energetics (Ulipur)

Source	Input (GJ/Yr)	Output (GJ/Yr)
1. Energy Intake:		
Kher	373.25	
Water Hyacinth	248.00	
Paddy Weeds	137.00	
Paddy Leaves	17.50	
2. Animal Care by Human	3.30	
3. Useful Work Output		13.76
4. Milk		3.85
5. Beef		1.69
6. Dung:		
Fuel		63.54
Fertilizer		194.65
Construction Material		10.00
Waste		6.70
TOTAL	779.05	294.19

Source: Brisco & Bari [16]

6.3.1.4 Human Energetics (Ulipur)

The annual food intake of the 330 people of Ulipur : total food grain, 750.66 GJ of which 404.00 kg/yr are obtained from import; meat, 2.93 GJ; milk, 3.87 GJ; fish, 20 GJ. Useful work done by these people as output of the human system is 77 GJ/yr. The utilization of labour in farming are 0.23 GJ/cap and 4.42 GJ/ha (1.79 GJ/acre.) On table 6.5 the input-output of human energetic system has been shown.

6.3.1.5 Overall Flow of Energy in Ulipur

Village, Ulipur represents the micro level rural energetics and in traditional form. House-hold energy consumption, energetics of crop production, human energetics and cattle energetic systems are the components of the energetics of Ulipur. On Fig 6.1 the annual per capita energy flow in this village are presented.

6.3.2 Sakoa

The area is in the northern-most part of Bangladesh at latitude 26^{o} north and longitude 93^{o} east. The village Sakoa is under the union council of Kulaghat under the police station of Lalmonirhat in the district of Rangpur. The area has no electricity supply and there is no major industry in the region. Here the total population is 1407 and the population density is 713 people/sq.km.

Cattle is used as the only source of draft power. 4.88% of total cropped area is under mechanized irrigation and 1.77%

Table 6.5

Input-output Energy of Human Energetics (Ulipur)

Source	Input (GJ/Yr)	Output (GJ/Yr)
1. Food Grains (Produced)	346.66	
2. Food Grains (Imported)	404.00	
3. Meat	2.93	
4. Milk	3.87	
5. Fish	20.00	
6. Cooking Fuel	2280.00	
7. Useful Work Output (Animal Care, Agri., Domes.)		77.00
TOTAL	3057.46	77.00

Source: Brisco & Bari [16]

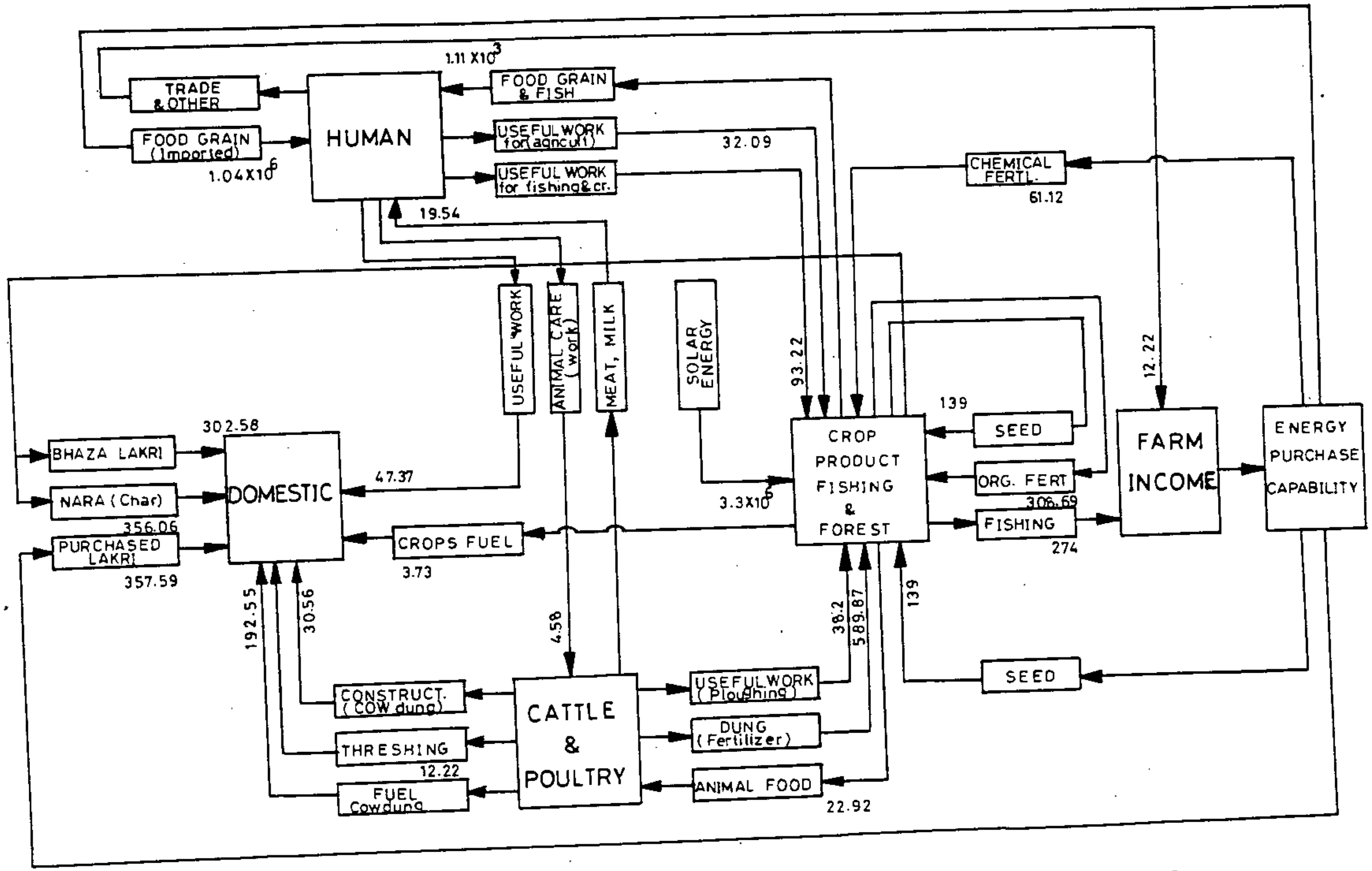


Figure 61 Yearly Per Capita Energy Flow in Village Ulipur (in KJL X 10^3)

of total cropped area is irrigated by power pumps. The primary source of irrigation is from the rains. 2275.57 GJ/ha of commercial fertilizer, and of 5.36 GJ/ha of pesticide are used. Therefore uses of agriculture inputs such as machine irrigation, fertilizer, pesticide etc., although to a significant extent, are small.

6.3.2.1 Household fuel consumption (Sakoa)

The house-hold energy consumption for cooking and lighting is a major use of energy in rural energy system and the index of quality of life. 7.8 GJ/capita energy is consumed for cooking and parboiling. The main fuel used for cooking and parboiling comes from tree biomass (fire-wood, leaves and twigs and tree branches). On heating value basis these contribute to about 63% of the total fuel consumed for cooking and parboiling (57.6% by weight). Of these total amount of fuel used for cooking the share of cattle dung is only 3% and the share of agricultural residues is 34%. Kerosene is used lighting and per capita consumption of lighting energy is 0.29 GJ/yr. The annual fuel consumption in house-hold affairs are presented in Table 6.6.

6.3.2.2 Energetic of cropping system (Sakoa)

Draft animal are the only source of power for ploughing, mowing, harrowing, transportation and thrashing. For cultivating the available land, that is for ploughing and mowing, the total animal power required is 25,218 kWhr and the total man-days

Table 6.6

Annual Fuel Consumption in Sakoa

Fuel Type	Quantity Of Fuel x10E3 GJ/Yr	Percentage %
a) Cooking & Parboiling:		
i) Agri. Residues	3.78	34
ii) Tree-biomass	6.94	63
iii) Cattle Dung	0.28	3
TOTAL	11.00	100
b) Gur Making:		
i) Bagsse	0.69	---
c) Illumination:		
i) Kerosene	0.41	---

Source: Quader & Omar [19]

required starting from preparation of land, to storing the products in the farmer's house for paddy, jute, wheat and sugarcane is 40,500 for cropped area of 170.15 hectare.

The application of chemical fertilizer and insecticide per unit of land is small. Compost cattle dung is extensively used and the area covered is 41% of the total cropped area, compared to 21% covered by chemical fertilizer. 0.05 kg of insecticide is used per hectare of cropped area per year. .03244 GJ/ha is used for irrigation. The available output of the cropping energetic system in terms of food, fodder and fuel are 36.32 GJ/ha, 20.0 GJ/ha, and 26.27 kJ/ha respectively. The solar conversion efficiency is 0.13%, and the food surplus index is 1.56. On Table 6.7 the inputs and outputs of the cropping energetics are presented.

6.3.2.3 Animal energetics (Sakoa)

Cattle is the only draft power source of the animal energetics of this energy system. 396 number of cattle population is available in this energetics. Fodder and some human energy are used as inputs to the animal energetics and output is obtained as draft power and cow-dung. The draft power output of the cattle energetics is 0.89 GJ/ha and the efficiency of the cattle energetics is 42.6%. On the table 6.8 the input-output of the animal energetics are presented.

Table 6.7

Input-output Energy of Cropping Energetics (Sakoa)

Source	Input (GJ/Yr)	Output (GJ/Yr)
1. Human Power	377.94	
2. Organic Ferti. (Dung)	730.00	
3. Animal Power	150.00	
4. Seed	167.51	
5. Chemical Ferti.	387.20	
6. Irrigation	5.50	
7. Pesticide	0.91	
8. Food Grains		6180
9. Crop Residue:		
a) Straw		3800
b) Fuel		4470
	1819.06	14450

Source: Quader & Omar [19]

Table 6.8

Input-output Energy of Animal Energetics (Sakoa)

Source	Input (GJ/Yr)	Output (GJ/Yr)
1. Energy Intake	5620.00	
2. Animal Care By Human	55.73	
3. Useful Work Output		150.00
4. Cattle Dung		2268.91
TOTAL	5675.73	2418.91

Source: Quader & Omar [19]

6.3.2.4 Human Energetics (Sakoa)

The total population of this village is 1407. The population supplies the human energy to the rural energetics. Food and fuel are used as input to the human energetics for farm production and maintenance,and human muscle power is obtained as an output. The per capita energy input to human energetics is 11.74 GJ/cap and output is 0.31 GJ/cap. The factor for labour force utilization in farming can therefore be expressed as 0.31 GJ/cap or 2.55 GJ/ha (1.03 GJ/acre). On table 6.9 the inputs and outputs of the human energetics are presented.

6.3.2.5 Overall flow of energy in Sakoa

Village Sakoa represents the micro level rural energetics in transitional form. House-hold energy consumption, energetics of crop production, human energetics, cattle energetics system are the components of the energetics of Sakoa. On Fig 6.2 the annual per capita energy in this village are presented.

6.3.3 Electrified village, Langulia

An electrified village named Langulia in the Muktagacha Upazilla of Mymensingh district has been selected. Its population is 1121. The total cultivated land is 103 hectare (254 acres) and the main cultivated crop is rice which is cultivated twice per year.

Table 6.9

Input-output Energy of Human Energetics (Sakoa)

Source	Input (GJ/Yr)	Output (GJ/Yr)
1. Food Grains	3960	
2. Cooking Fuel:		
a) Crop Residue	3760	
b) Cow-dung	1490	
c) Tree-biomass	6900	
3. Illumination:		
a) Kerosene	412	
4. Useful Work Output (Agri., Domestic etc.)		433.67
TOTAL	16522	433.67

Source: Quader & Omar [19]

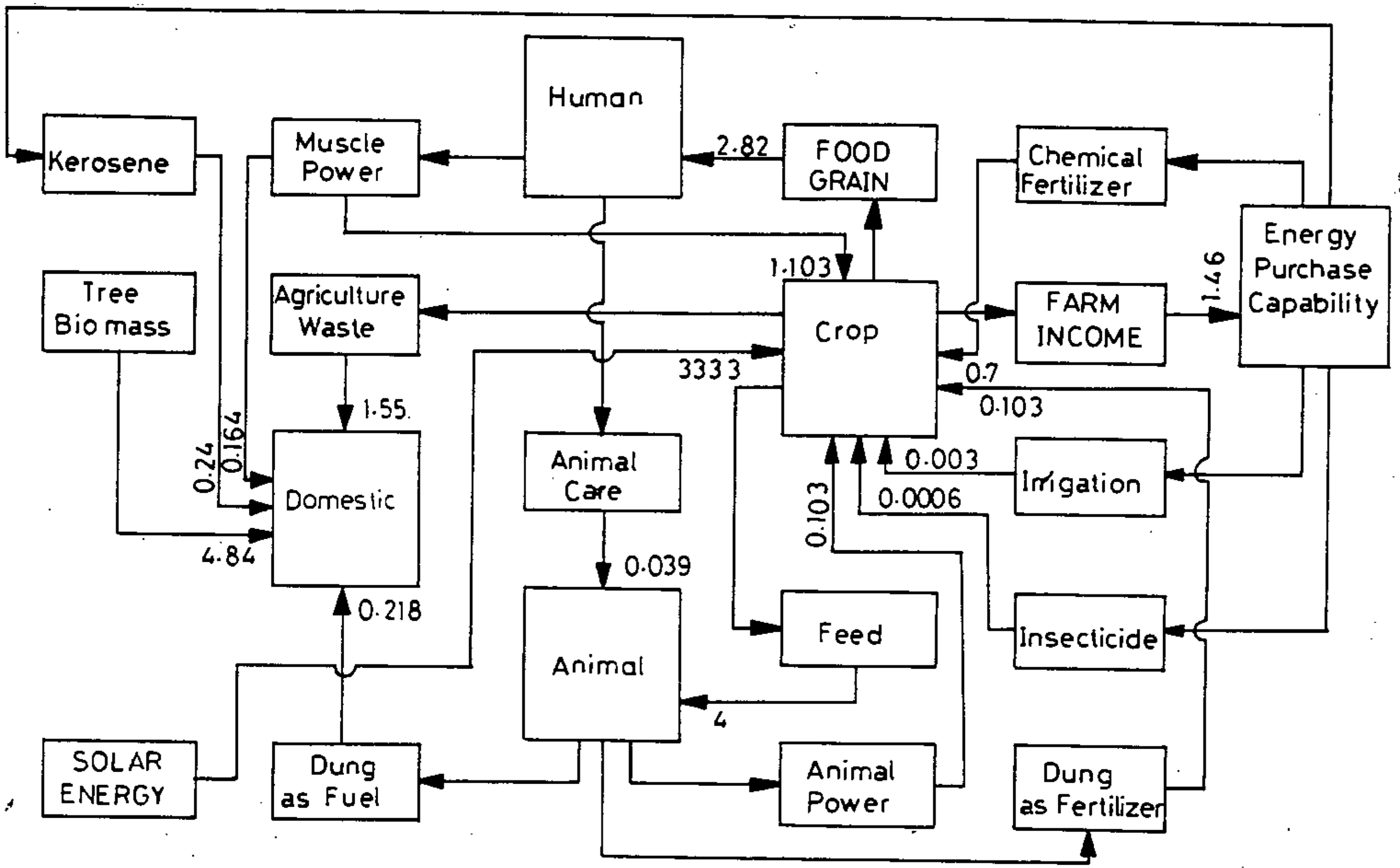


Figure 6.2 Yearly Per Capita Energy Flow in Village Sakoa (in KJL X10^{6})

6.3.3.1 Household fuel consumption (Langulia)

Cooking and lighting are the main energy consuming sections. Fire-wood, twigs and leaves and agricultural residues are the source of cooking fuel; kerosene and electricity are the source of lighting energy. 3.15 GJ from fire wood, 1.11 GJ from twigs and leaves and 1.05 GJ from farm waste are used percapita as cooking fuel. The fire-wood comes from Madhupur reserved forest. The village is electrified. However, the house-hold of landless and small farmers have not yet been provided with electrical connections. Kerosene is mainly used as fuel for illumination. The electrical energy requirement was on an average 70.44 kWhr per capita per year which is 58% of the total illumination energy. The amount of kerosene was about 3.96 kg/capita/yr. The annual fuel consumption in house-hold affairs are presented in table 6.10.

6.3.3.2 Energetics of cropping system (Langulia)

For land preparation, the farmer uses a plough drawn by a pair of bullock. 103 hectares of land was under crop production. The whole cultivated land was irrigated by deep tube-wells driven by electric motor. The total number of cattle is 328 and almost all cow dung is used as fertilizer. An average of 763.74 kg commercial fertilizer is used per hectare per year. The average amount of pesticide used is 4.75 kg/ha. Transplanting, weeding and harvesting are performed manually in this village

Table 6.10

Annual Fuel Consumption in Langulia

Fuel Type	Quantity Of Fuel X 10E3 GJ/Yr	Percentage %
a) Cooking & Parboiling:		
i) Agri. Residues	1.18	20
ii) Tree-biomass	4.71	80
TOTAL	5.89	100
b) Illumination:		
i) Kerosene	0.20	42
ii) Electricity	0.28	58

Source: Alam at el. [84]

Table 6.11

Input-output Energy of Cropping Energetics (Langulia)

Source	Input X 10E3(GJ/Yr)	Output X 10E3(GJ/Yr)
1. Human Power	0.18	
2. Organic Ferti. (Dung)	3.22	
3. Animal Power	0.07	
4. Seed	0.13	
5. Chemical Ferti.	1.87	
6. Irrigation	0.13	
8. Food Grains		6.7
9. Crop Residue		15.0
TOTAL	5.60	21.7

Source: Alam at el. [84]

and are energy intensive i,e, $0.18x10^3$ GJ. On Table 6.11 input-output energetics of the cropping system is shown.

6.3.3.3 Animal Energetics (Langulia)

The animal system consists mainly of cattle and is the only source of draft power for crop production in Langulia. The inputs and outputs of the animal energetics are shown in Table 6.12. Energy inputs in the form of draft power used for crop production were .727 GJ per hectare; thus the available draft power per hectare were 0.53 kW.

6.3.3.4 Human Energetics (Langulia)

The population of this village is 1121. Entire human energy supplied for the operation of tillage- sowing, weeding, crop production, irrigation and fertilizer management, harvesting and thrashing is 1.72 GJ/ha. Percapita energy input and output are 8.36 GJ and .16365 GJ respectively. The factor for labour force utilization in farming is 0.164 GJ/cap or 1.78 GJ/ha (0.72 GJ/acre) The input-output of human energetics are shown in Table 6.13.

6.3.3.5 Overall Major Energy Flow in Langulia

An electrified village Langulia represents the micro level rural energetics for an area with improved technology. Traditional as well as commercial energy are used for the operation of different systems in this type of village. On the Figure 6.3, the over all percapita energy flow in this village is presented.

Table 6.12

Input-output Energy of Animal Energetics (Langulia)

Source	Input X 10E3(GJ/Yr)	Output X 10E3(GJ/Yr)
1. Energy Intake	13.9	
2. Useful Work Output		0.08
3. Cattle Dung		5.15
TOTAL	13.90	5.23

Source: Alam at el. [84]

Table 6.13

Input-output Energy of Human Energetics (Langulia)

Source	Input (GJ/Yr)	Output (GJ/Yr)
1. Food Grains	3000	
2. Cooking Fuel:		
a) Crop Residue	1180	
b) Tree-biomass	4710	
3. Illumination:		
a) Kerosene	200	
b) Electricity	280	
4. Useful Work Output(Agri., Domestic etc.)		183.45
TOTAL	9370	183.45

Source: Alam at el. [84]

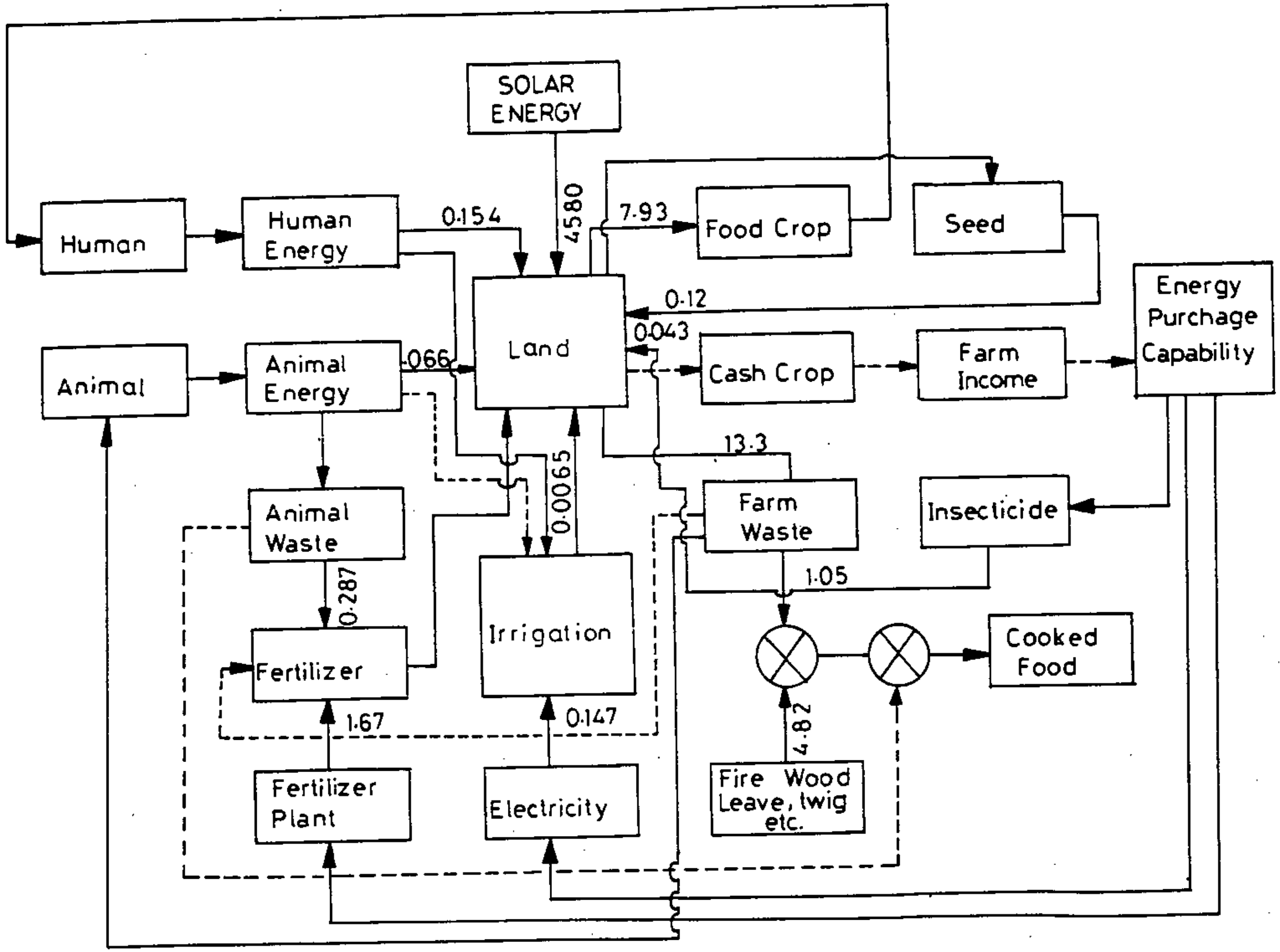


Figure 6.3. Yearly Per Capita Energy Flow in Electrified Village Langulia (in KJL X 10^6)

6.4 Rural Energy System Evaluating Indicators:

Socio-economic status of a social system may be evaluated in terms of it's different indicators (either separately or combinationaly), such as literacy rate, infant mortality, life expectancy, birth rate, GNP, per capita export earning, per capita education expenditure etc. In this research work, an attempt has been taken to evaluate a rural energy system in terms of energy dependent indicators in similar way. These evaluating indicators are per capita cooking energy, per capita lighting energy, labour force participation in production, food surplus index, fuel-fodder and food ratio, efficiency of animal energetics, input energy in cropping energetics, and per capita energy consumption in rural energetics. The rural energy system evaluating indicators of three typical villages are shown in Table 6.14.

To adequately feed the expanding population & draft animal and meet social & economic goal i.e. achieving the desirable quality of life, the amount of useful energy used per hectare in agricultural production, processing and distribution will have to be increased from present level to supplement man's meagre work capacity as much as possible , and for efficient photosynthetic conversion of solar energy with a view to increasing the output.

Table 6.14

The rural energy system evaluating indicators of three typical villages.

System Indicators		Ulipur	Sakoa	Langul.
1. Percapita cooking energy	(GJ/yr)	6.90	7.80	5.25
2. Percapita lighting energy	(GJ/yr)	-	0.29	0.42
3. Labour force participation in production	(GJ/cap)	0.23	0.31	0.16
	(GJ/ha)	4.42	1.03	1.78
4. Food surplus index		0.46	1.56	2.33
5. Fuel-Fodder to Food ratio		4.60	1.4	2.30
6. Efficiency of Animal Energetics	(%)	37.76	42.6	37.63
7. Input energy in croping energetics	(GJ/ha)	2.80	1.74	9.00
8. Percapita energy consumption in rural energetics	(GJ/yr)	7.90	9.26	11.10

6.5 Discussion

The people of the third world countries like Bangladesh fulfill a major part of energy needs by the use of solar energy. This use of solar energy is dominated by photosynthetic conversion. The energy captured through agriculture in crops and crop residues provide food for people and fodder for draft animal, and dung and crop residues are used for cooking and heating. In fact, when inputs to agriculture i.e. energy, are increased properly, the energy output per unit of land increases thereby. That is plants capture solar energy more efficiently. This means, "The subsistence agriculture that barely supplies enough food, fuel and fodders for the poor can be transformed into one that provides surplus energy (in the form of excess grains and crop residues) to the other part of the economy even while it provides enough food and fodder for the villagers and their draft animals respectively" [15]. Therefore, modernization i.e. mechanization of agricultural system is essential for more efficient solar energy conversion. If everyone has equal access to the new technology, modern agriculture offers the possibility of improving the overall physical quality of life.

The traditional energy system disappearing more rapidly in areas where there has been wide spread adoption of high yielding crop varieties and modernization of agriculture, and a higher solar conversion efficiency is being achieved, which fact secures a positive improvement in the physical quality of life of a country.

The role of energy of rural energy system i.e. agricultural system of Bangladesh has been studied here in the quantitative basis based on some formulation of energy dependent indicators.

In Ulipur the impact of high yielding varieties has been very small. The main crop, broadcast among paddy is grown using local seed and the level of technology is traditional in nature. In Sakoa, use of machine irrigation (4.88% of cropped area), pest controlling (6% of cropped area), chemical fertilizer (12% cropped area) are planned to be introduced as inputs of farming sector as an initial step of agricultural modernization. The electrified village Langulia is in the highest position of modernization of farming technology in the context of Bangladesh's rural energy system characteristics. The whole cropped area is irrigated by power pump, 58% lighting energy is derived from electricity, and chemical fertilizer, pesticide etc. are frequently used. A general qualitative as well as quantitative information for the sake of comparison between the different energy system elements of three typical villages.

6.5.1 Per-capita domestic energy consumption

The percapita cooking energy consumption of Ulipur is 6.9 GJ whereas 5.25 GJ for electrified village Langulia which is shown in Fig. 6.4. So far as lighting energy is concerned,

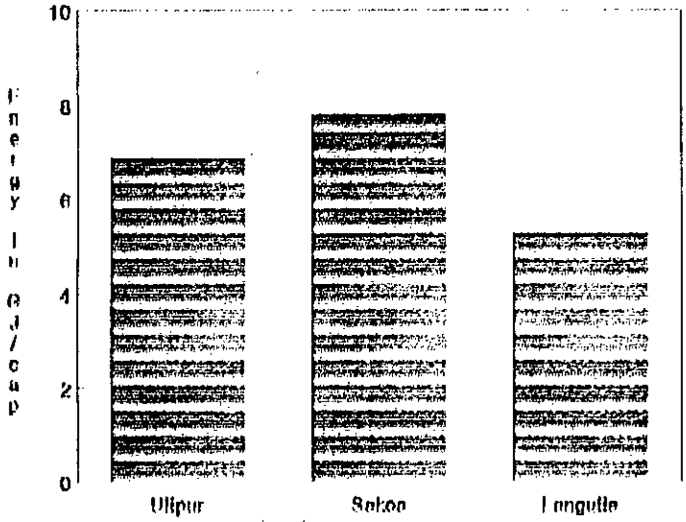


Fig. 6.4 Per Capita Fuel Consumption
of Cooking and Parboiling

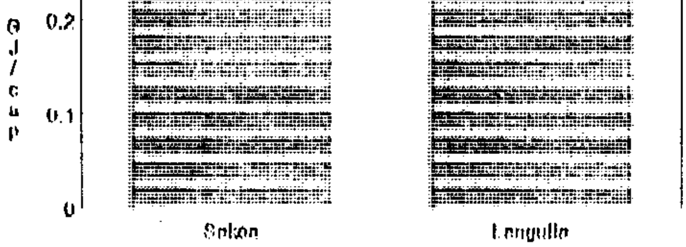


Fig. 6.5 Per Capita Energy Consumption
For Lighting

Fig. 6.5 shows that it has increased from 0.29 GJ/cap/yr for Sakoa to 0.43 GJ/cap/yr in electrified village.

6.5.2 Percentage of fuel type composition

The tree biomass is gradually taking the larger share of cooking fuel whereas the crop residue is gradually reducing in nature. Cowdung plays a significant role (30% contribution at national level) in fuel. 72% crop residue and 25% tree biomass takes share of cooking fuel for Ulipur but 20% crop residues and 80% tree biomass take share of cooking fuel for electrified village. The types of fuel compositions are shown in Fig. 6.6.

6.5.3 Food production

The rate of increase per capita and per acre food production in Ulipur as compared to an electrified village are 35% and 78% respectively, which is shown in Fig. 6.7.

The solar energy conversion efficiency for Ulipur is 0.17%, and for electrified village is 0.32%, and is shown in Fig. 6.8 which has significantly increased. Fuel-fodder to food ratio is declining in nature (4.6 for Ulipur and 2.3 for electrified village). The Food surplus indicators are found 0.46, 1.56, and 2.23 for Ulipur, Sakoa and Langulia.

6.5.4 Inputs of cropping energetics

The effect of increasing energy which is converted to useful forms such as irrigation, fertilizer, pesticide and draft power (as input energy per hectare) is the higher efficiency of capture of solar energy. 17.00 GJ/ha for Ulipur and 10.6 GJ/ha

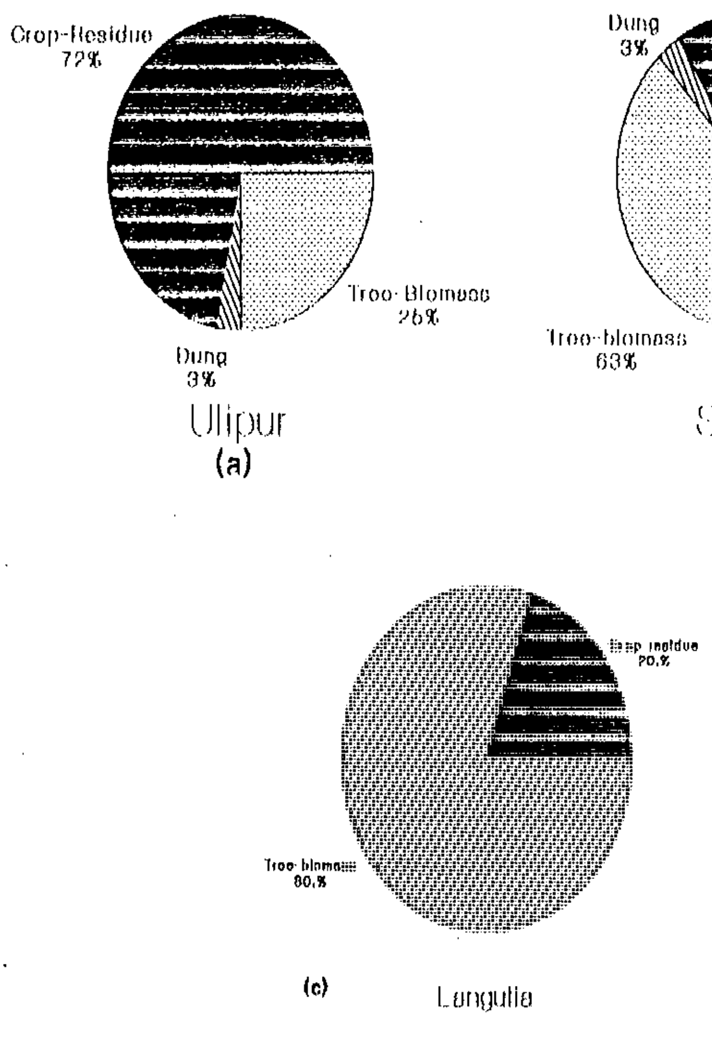


Fig. 6.6 Percentage of Fuel Composition for Cooking and Parboiling a) Ulipur b)Sakoa c) Langulia

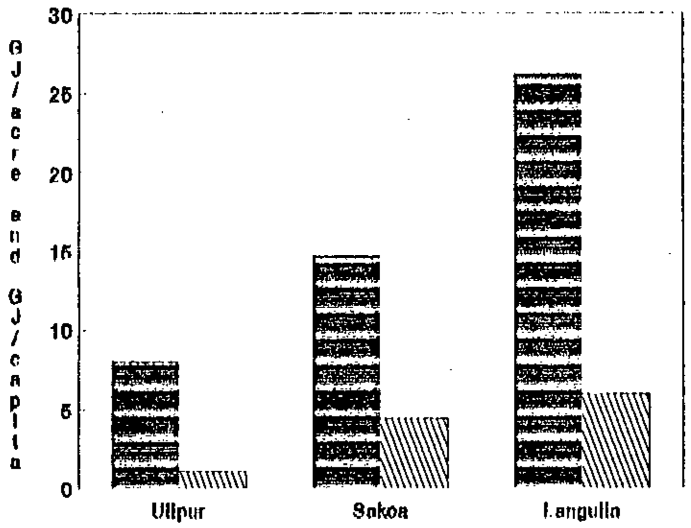


Fig. 6.7 Food Production
per Acre and per Capita

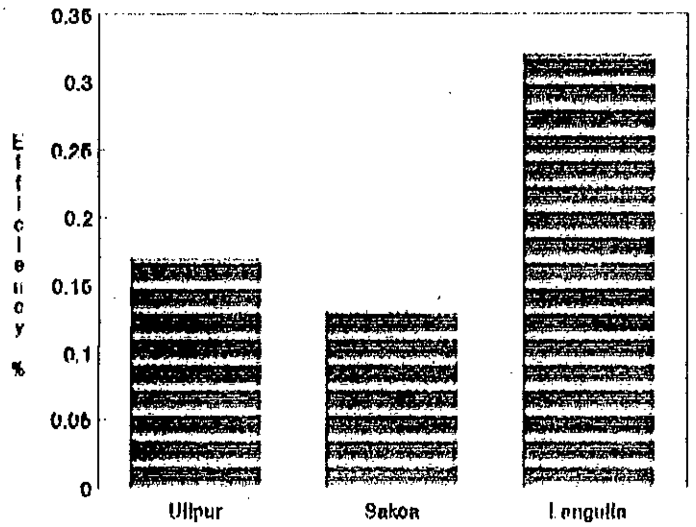


Fig. 6.8 Conversion Efficiency of
Solar Energy

for Sakoa, and 4.36 GJ/ha for electrified village langulia, are the input energies of the cropping energetics. The trend of commercial energy contribution (as inputs- Fig 10) to the rural energetics is gradually increasing. Commercial energy contributes 6.8%, 21.63%, and 36.55% of the energetics of Ulipur, Sakoa and electrified village, Langulia (Fig 9) as an impact of technology diffusion in developed. For this reason, the labour force participation in farming sector is declining in nature (Fig 11).

6.5.5 Energy system

The trend of per capita energy use in rural energetic is gradually increasing (Fig 12). The rate of change of per capita energy use from Ulipur to Sakoa and Sakoa to electrified village are 20% and 14% respectively. In energy terms, since human nutritional requirements are met principally from grains, and since grains are not directly edible but require treatment using energy intensive processes such as parboiling and cooking prior to their consumption, the question of ecosystem productivity should be considered more broadly, and include the fuels needed for food processing and preparation. It is evident that major portion of the biomass fuel used for food processing and preparation are drawn from household woodlots, forests, farm products, crop residues, and livestock dung. Thus, the rural population in Bangladesh is predominantly dependent on its agriculture both for food and fuels at the present time, and the

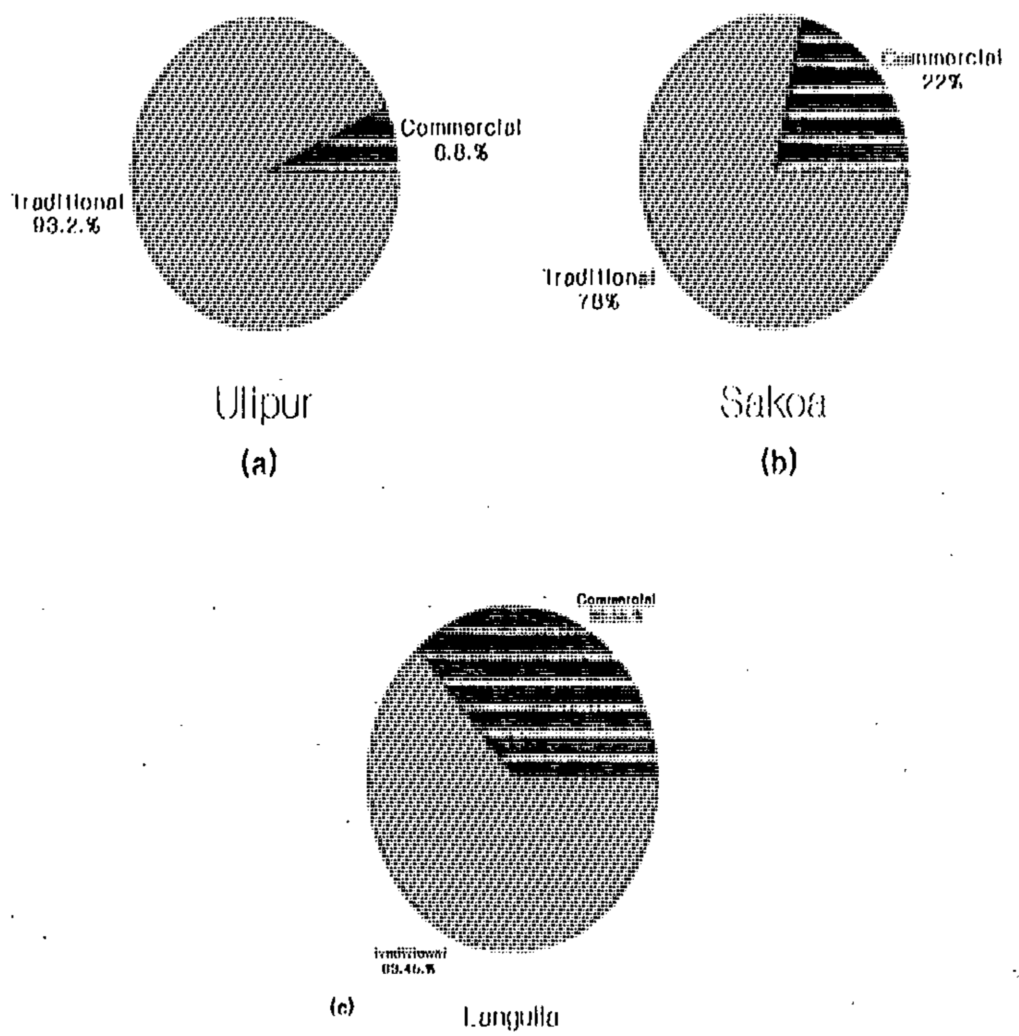


Fig. 6.8 Percentage Composition of Trad. & Comm. Energy a) Ulipur b) Sakoa c) Langulia

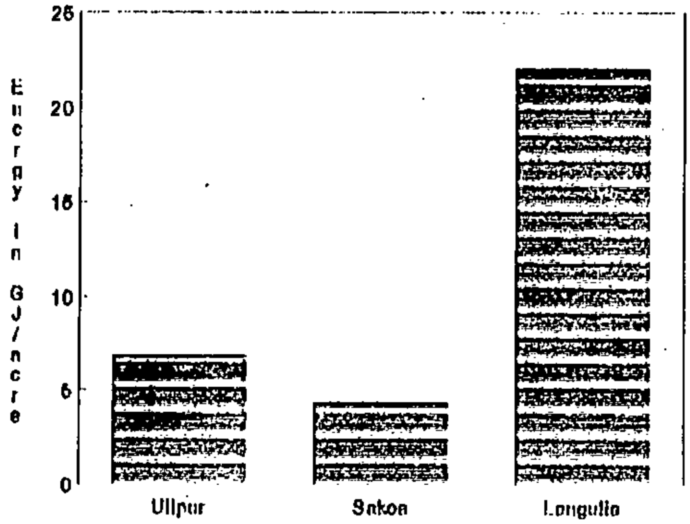
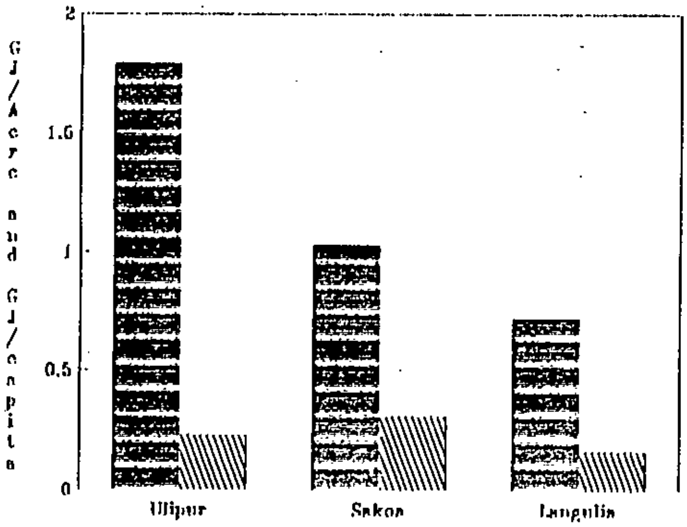


Fig. 6.10 Input Energy Per Acre of Cropping Energetics



6.11 Labour Force Participation GJ/Acre & GJ/Capita

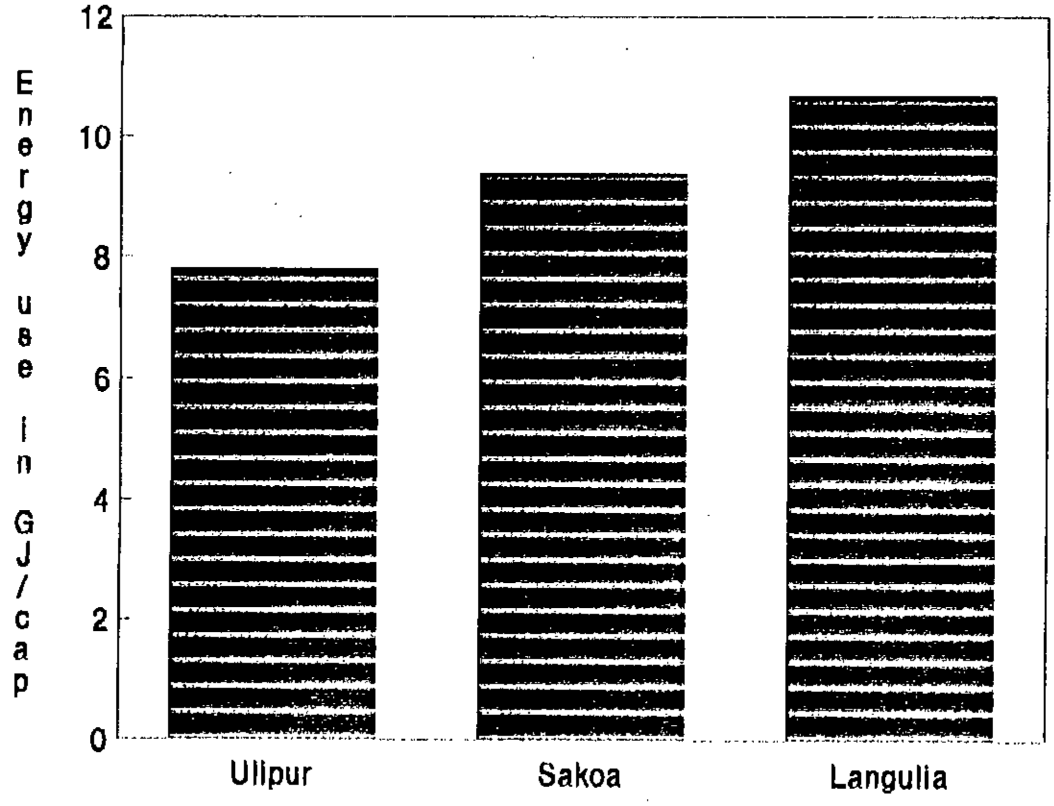


Fig. 6.12 Per Capita Energy Used
GJ.

capacity of the overall ecosystem to continue to provide these in sufficient quantities is dependent on continued improvements in agricultural productivity with respect to these commodities.

The previous discussions indicate that, via the opening of the ecosystem somewhat through the injection of energy in the form of artificial fertilizers, pesticides, and commercial fuels for mechanized irrigation, productivity of the entire agricultural system with respect to food-grains can be expected to maintain adequate levels of growth. However, there are a number of reasons to believe that the output of the traditional fuels will not keep pace with that of food grains obtained from HYV dependent on mechanized agriculture, and to fear that the availability of fuels from the agricultural sector may fall in relation to the needs of the rural population.

Thus, a significant improvement in the energy productivity of rural sector in Bangladesh will be possible in the next decades, only when a considerable amount of energy is increased as inputs to the farming sector, ensuring more efficient conversion of solar energy into usable form.

6.5.6 Energy and quality of life

Percapita fuel consumption in Ulipur, Sakoa, and Langulia estimated in the previous section are respectively as follows: 1648 kWhr /cap /yr (6.90 GJ /cap /yr), 1933 kWhr /cap /yr (8.09 GJ/cap/yr), and 1355 kWhr/cap/yr (5.67 GJ/cap/yr).

On the basis of the equation (5.14), PQLI values for Ulipur, Sakoa, and Langulia are estimated respectively as follows: 3, 9, and -5. Due to the absence of primary data [e.g. literacy rate (LR), life expectancy (LE), and infant mortality (IM)], it has not been possible to calculate the actual value of PQLI of the said villages. In this context, the calculated value of PQLI= 32 for Bangladesh may be considered as the proxy-value for all the three villages. It may be observed that PQLI values of three villages estimated by the equation (5.14) are far less than the actual PQLI value of Bangladesh. This is probably due to the fact that the percapita energy consumption of the three village (1648 kWhr/cap/yr,1933 kWhr/cap/yr and 1355 kWhr/cap/yr) are less than the lower limit (3000 kWhr/cap/yr) for which the equation (5.14) was valid. It means that the equation (5.14) is not applicable to co-relate physical quality of life and percapita energy consumption for value less than 3000 kWhr/cap/yr. It may be necessary to develop a separate model for Physical Quality of Life as a function of percapita energy for the lower range of energy consumption than 3000 kWhr/cap/yr.

In this context, it become necessary to consider a separate model interrelating quality of life as a function of percapita energy consumption for the low energy consuming countries/ regions.

It has been discussed earlier that Forrester [49] used a different concept to represent quality of than Martin's concept of physical quality of life index. In Forrester's concept quality of life has been represented by the following variables: pollution, population density, food consumption and resources. In rural areas of Bangladesh, pollution and resources factors are not so important. In the next chapter, a Modified Quality of Life Indicator (MQLI) consisting of population density and food consumption has been used for maintaining the co-relation with per capita energy consumption data.

CHAPTER - VII

SIMULATION OF RURAL ENERGY SYSTEM MODEL IN BANGLADESH

7.1 Introduction

The analysis in the previous chapters have presented static quantitative picture model of the energy situation of three typical villages in Bangladesh. This model for integrated rural energy system form the basis for the development of a computer model using system dynamics methodology of Forrester for policy planning. A dynamics model of integrated rural energy system is presented here according to revised Huq's model [84]. The model considers the integrated energy use in the form of i) draft power from cattle, ii) organic manure and biogas from cow dung, and iii) food production and consumption. The physical quality of life has also been discussed.

The model effectively takes into account the existing feedback loops, non-linearity, and time-lag characteristics inherent in the real world system. The model has been simulated for integrated energy use for an electrified village (micro level) as well as for entire rural Bangladesh (macro level) for assessment of quality of life in the country. The simulated results for policy changes and potential implications of the model are also evaluated.

7.2 Rural Energy System Model

Successful integration of rural energy system requires detailed information on the dynamic behaviour of the system components. By substituting the models for the real systems the designers of integrated energy system can perform tests to find the alternative courses of action and trade-offs, provided the models are accurate representation of the real systems. But human mind unaided by computer is not adequate for constructing and interpreting dynamic models like rural energy systems.

In a broad sense models can be classified according to purpose into two groups: (1) Predictive models and (2) Prescriptive models. Simulation modeling is a powerful predictive tool for policy planning whereas an optimizing model is a prescriptive model.

As pointed out earlier, among the various techniques of analysis, the system dynamics methodology appears to be the most appropriate technique to handle such complex systems. The steps in system dynamics approach are : (1) the formulation of a mental model in the form of verbal descriptions, and (2) conversion of this verbal model to flow diagrams, and formulation of equivalent mathematical equations.

Descriptive statements are conveniently translated into feedback loop structures in system dynamics studies. Feedback loops are either positive or negative. Positive feedback loops cause growth wherein action builds a result that generates still greater action. Negative feedback loops are goal seeking. The cause and effect relationship around this type of loop is such that the loops respond to a disturbance not by explosive growth but by equilibrium restoring motion towards a finite value or goal.

7.2.1 Micro level rural energy system model

The system dynamic model has been constructed considering the integrated energy in the form of draft power from cattle, organic manure and biomass from cow-dung and food production and consumption, and has been based on the model of integrated rural energy system (Fig. 4.1). The aim is to improve the physical quality of life as determined by edible, saleble and combustible outputs. The simulated results for some policy changes have been examined.

7.2.1.1 Basis of the model

Modeling of integrated rural energy system in Bangladesh was initiated by Huq [44]. Bala and Sattar [45] developed a dynamic model for integrated energy systems for food production, based on Huq's model. Here, an integrated rural energy model for food and energy production is presented to illustrate the potential implications of the model using data from a village.

7.2.1.2 The model for an electrified Village

The rural energy system consists of several closed loops. Feedback for these loops simulates the dynamic behaviour of a highly complex system. The model for integrated energy in rural farming sector based on dynamics methodology of Forrester for the village Langulia is shown in Fig. 7.1. The legend list (Fig 7.1) appears in Appendix-E. The system components are the following :

The crop production system is mainly concerned with the production of food grain and straw. The straw is primarily used for cattle feed. The major inputs for crop production are draft power, irrigation, fertilizer and human energy. Crop production can be increased either by increasing the cropped area or the yield. Since land is limited, crop production must be increased by using high-yielding varieties in conjunction with irrigation and fertilizers. The yield is influenced by draft power from animal system. The animal system, in turn, is influenced by crop production. Thus, crop production forms loop with animal production. The cattle-production system provides cowdung, which is supplied to the biogas system. The biogas system is essentially a biogas digester for the production of biogas and treated slurry by anaerobic digestion. The treated slurry replaces the use of inorganic fertilizer in crop production. The straw from crop production is used as a cattle feed. Thus, crop, animal and biogas production form a closed loop. The proposed biogas production system supplies biogas as a fuel for cooking and therefore reduces the pressure on rural forest and also diminishes pollution. This process in turn reduces ecological imbalance. The domestic cooking fuel is supplied

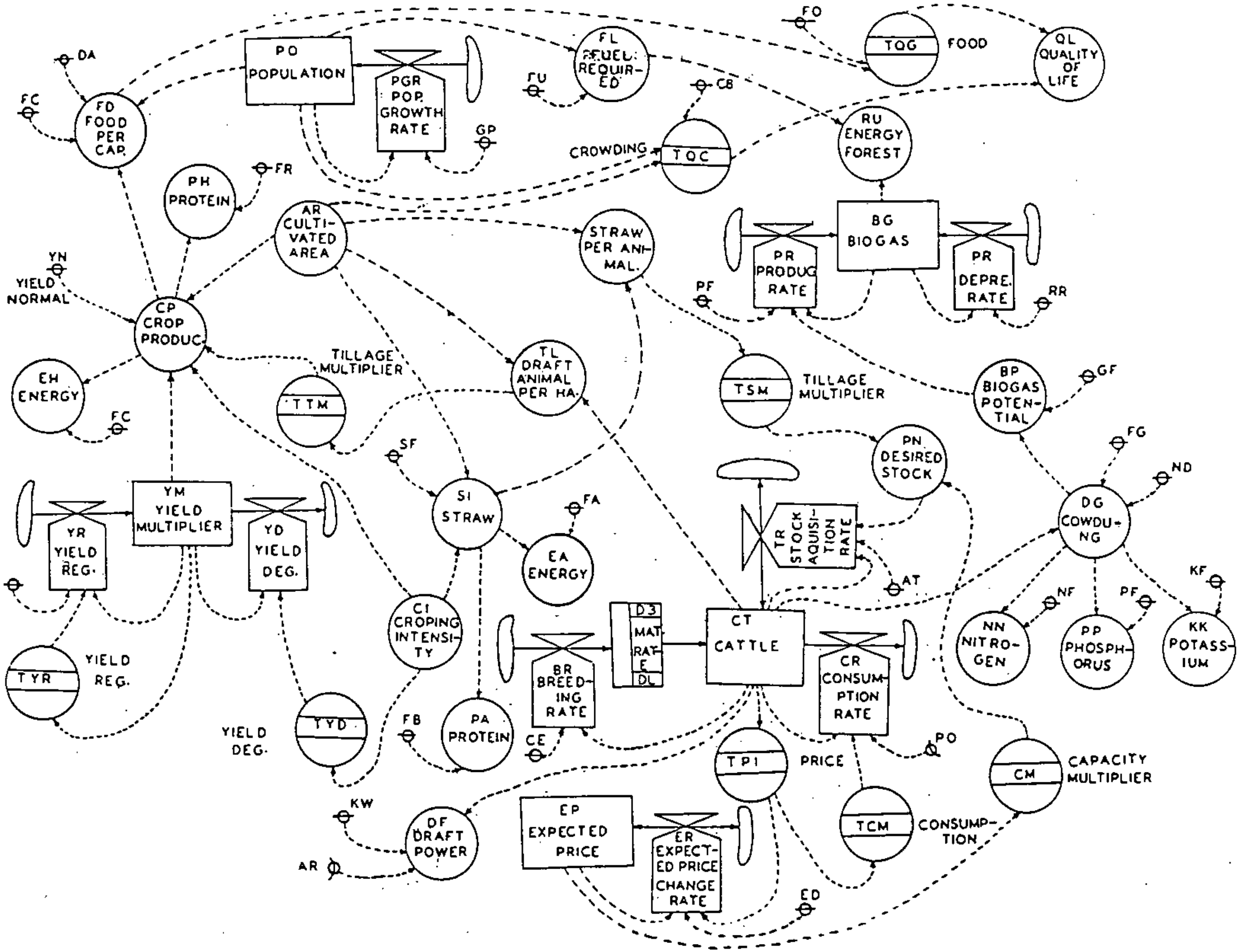


FIG 7.1 Integrated energy model for rural systems based on the system dynamics methodology of forrester.

particularly for this village from agriculture residues, and tree biomass collected from reserve forest at Madhupur.

Physical quality of life is used here as a measure of performance of the integrated rural energy system. It is computed as a quality of life standard multiplied by multipliers [M (t)] derived from food, and crowding:-

$$PQLI(t)=F[M_1(t) \times M_2(t)] \quad (7.1)$$

where,

$$M_1(t)=f_1[Food(t)/Food(Base\ yr.)] \quad (7.2)$$

$$M_2(t)=f_2[Population(t)/ Population(Base\ yr.)] \quad (7.3)$$

The multipliers are assumed to be 1 in 1990 level.

The mechanics of formulation are based on Forrester's system dynamics approach and the model takes into account- (i) the inherent nonlinear, (ii) dynamic, (iii) feedback, and (iv) timelag characteristics of the system. The model has been programmed in BASIC. The model definitions, equations and parameters are given in Appendix C.

7.2.1.3 Description of the village, Langulia

Its population is 1121. The total cultivated land is 103 ha and the main cultivated crop is rice which is grown twice a year. The number of cattle is 328. Per capita energy consumption for cooking in this village is 4.21 GJ [84]. This energy mainly comprises of firewood, leaves and twigs. Cooking fuel in this village is predominantly firewood and it is about

80% of the energy consumption for cooking. This firewood comes from nearly Modhupur reserve forest.

7.2.1.4 Results and discussion

Rice is the main food grain in Bangladesh and it is the only food grain cultivated in the village Langulia. Major energy inputs are in the form of fertilizer (both organic and inorganic), irrigation, interculture operations and land preparation. The annual output of edible energy per hectare from food grain (rice) is 65.0 GJ. The biological efficiency of rice for food utilization in the human system is 68% [107]. Hence, the net availability of energy from 1 ha of land under rice become 44.2 GJ/yr. The annual energy per ha from rice straw is 73.08 GJ. The rice straw is used as a source of nutrient to feed the cattle in the village. In the animal system, the efficiency of energy utilization of rice straw in the animal system is 40% to 60%. [108, 109]

The animal system consists mainly of cattle. The energy inputs in the form of draft power used for crop production in 1988 were .727 GJ/ha; thus, the available draft power per hectare was 0.53 kW. The availability of the draft power is more than the minimum requirement of 0.373 kW/ha [45]. The inputs to the animal-production system are in the form of rice straw, green fodder and concentrates. The animal system supplies energy and protein through meat and milk to the human system.

The proposed biogas production system accepts cowdung as input and provides treated slurry and biogas. The biogas system has a potential of 875.7 GJ of energy per year as cooking fuel, which is equivalent to 57.92 tons of firewood. However some energy may be recovered without loss of nutrient to the residual organic fertilizers if the facilities of anaerobic digestion is available. The digested slurry has the potentials of 3591.6 kg. of N, 2394.4 kg of P_2O_5 and 1197.2 kg of K_2O. (Section-6.2)

The traditional Earthen stoves are mainly used for cooking and its efficiency is less than 10%. Fuel research institute has developed an improved earthen stoves for cooking and its efficiency is claimed to be double of the traditional one and this is yet to be introduced [110]

Eusuf [111] developed an equation involving benefit-cost ratio (BCR) for the economic evaluation of family-size biogas digesters and showed that if the substituted fuels are firewood of price Taka 0.5/kg (1 US Dollar = Taka 30.00), the BCR value is 2.25 at 15% interest rate. This shows that biogas in Bangladesh is an economic proposition. Furthermore, the adverse effects of the depletion of forest and pollution of environment are now being realized in Bangladesh. Again, Bala and Satter [112] reported that the production of biogas from anarobic digestion of cattle slurry for cooking is not economic in terms of return when compared with the cost of fuel-wood. However, assigning values to the treated slurry as fertilizer and pollution hazards, and the consideration of the threats to the ecological balance justify the installation of biogas digesters.

To illustrate the use of the model as a tool for policy planning, the model was simulated at both basic mode and policy planning mode. The basic mode corresponds to the existing conditions and the policy planning mode corresponds to the conditions of policy options being tested. The simulated results of the model for both basic mode and policy mode is presented in Fig. 7.2 to Fig. 7.6. The policy mode in this study was the birth control measures (2.55 down to 2.0% during 1988 to 2000) and the improvement of cropping intensity (200% to 300% during the period 1988 to 2000). The solid lines in the figures indicate the results of basic modes and the dotted lines indicate the results of the policy mode. Figure 7.2 shows population, food energy and food per capita in both basic mode and policy mode. The population of the village in basic mode increases from 1121 to 1511 in the period 1988 to 2000, whereas, in the policy mode the population slowly increases from 1121 to 1456 by 2000. The energy availability from rice in the basic mode is almost constant at a level 13432 GJ during the period 1988 to 2000, whereas, in policy mode the food energy supply increases as a result of the increase in the cropping intensity. The improvement is quite significant. As a result the food per capita increases from an almost constant value of 0.034 GJ per day to a peak value of 0.04 GJ per day in 1994 and then

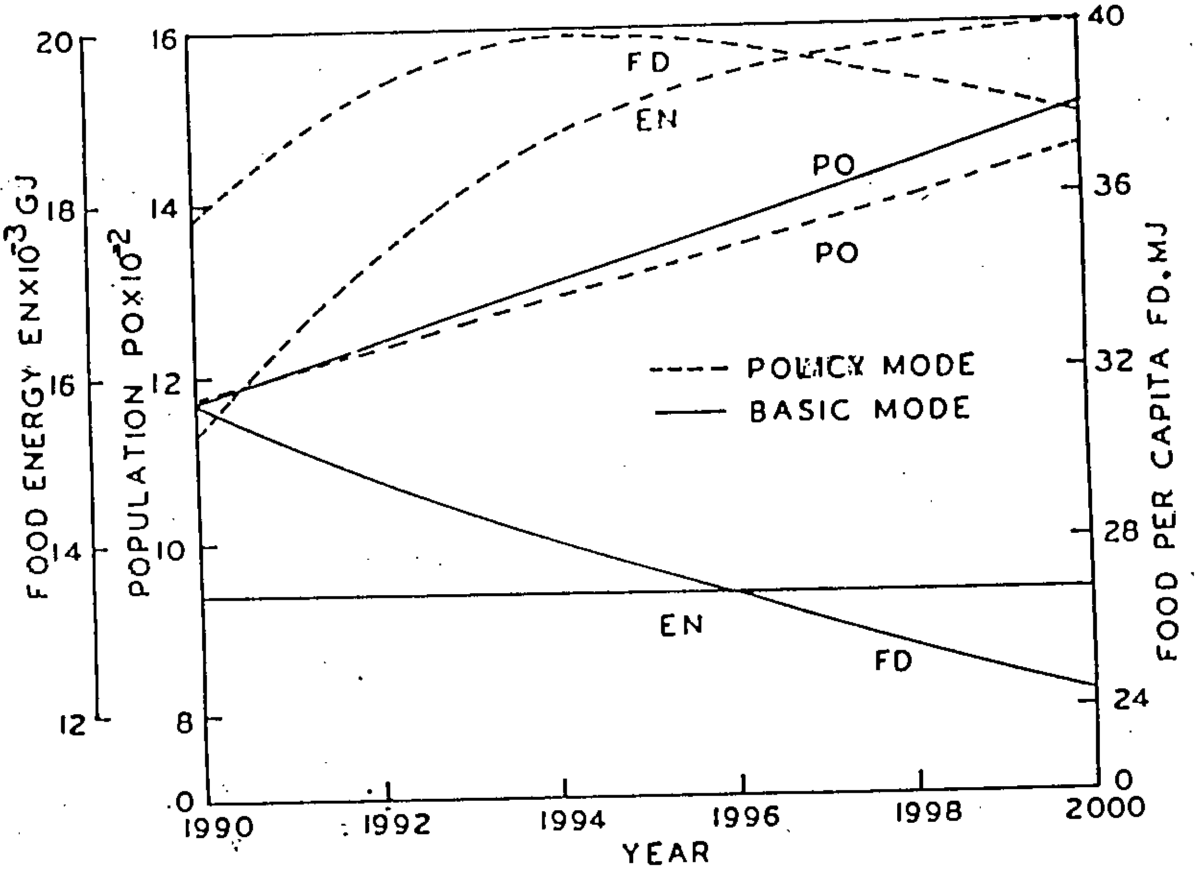


Fig. 7.2 Population Food Energy Food Per Capita During the Period 1990-2000.(—— Basic Mode and --- Policy Mode)

decreases to 0.038 GJ per day in the year 2000. The gap between the two levels of food per capita is quite large.

Figure 7.3 shows the cattle population and draft power/ha in both basic mode and policy mode and Figure 7.4 shows available amounts of N_2, P_2O_5 and K_2O in both basic mode and policy mode. The cattle population is almost at a constant level of 324 during the period of 1988 to 2000. As a result, draft power per hectare, and N_2, P_2O_5, K_2O, and biogas potentials are almost constant. In policy mode cattle population slightly increases from 328 in 1988 to 387 in 2000. As a result draft power per hectare, N_2, P_2O_5, K_2O, and biogas potentials are improved. The adoption of the policy for installation of biogas digesters at a rate of 30% of the difference between the biogas potentials and the actual level of the biogas production for both basic mode and policy mode is illustrated in Fig. 7.5. The situation is improved in the policy mode.

The quality of life is taken to be a product function of food and crowding [49]. In the basic mode the quality of life is reduced to 0.6341 in 2000 from 1 in 1988. In the policy mode the quality of life is improved and is always greater than 1 (Figure 7.6). This implies that the adoption of the policy would provide better condition in terms of food energy and crowding with respect to 1988.

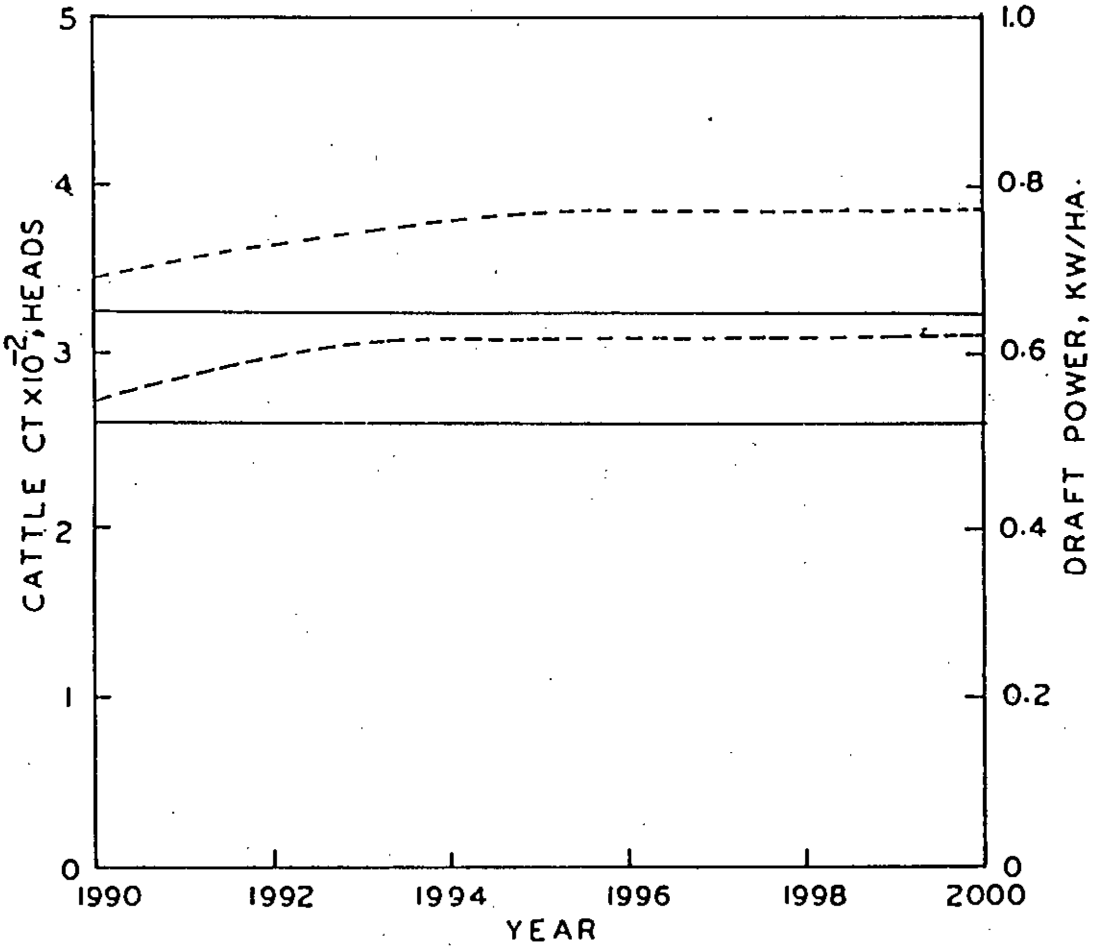


Fig. 7.3 Cattle and Draft Power During the Period 1990-2000.
(—— Basic Mode and --- Policy Mode).

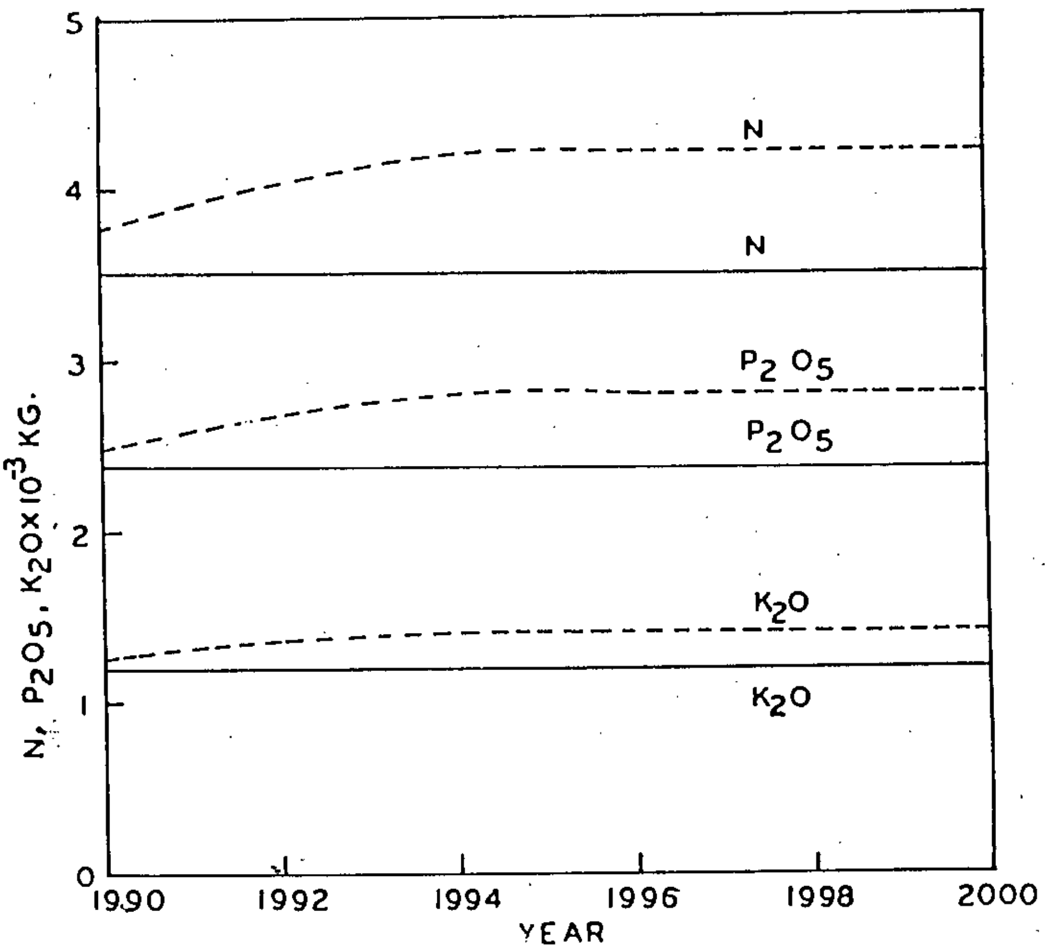


Fig. 7.4 N_2, P_2O_5,K_2O During the Period 1990-2000.
(—— Basic Mode and --- Policy Mode).

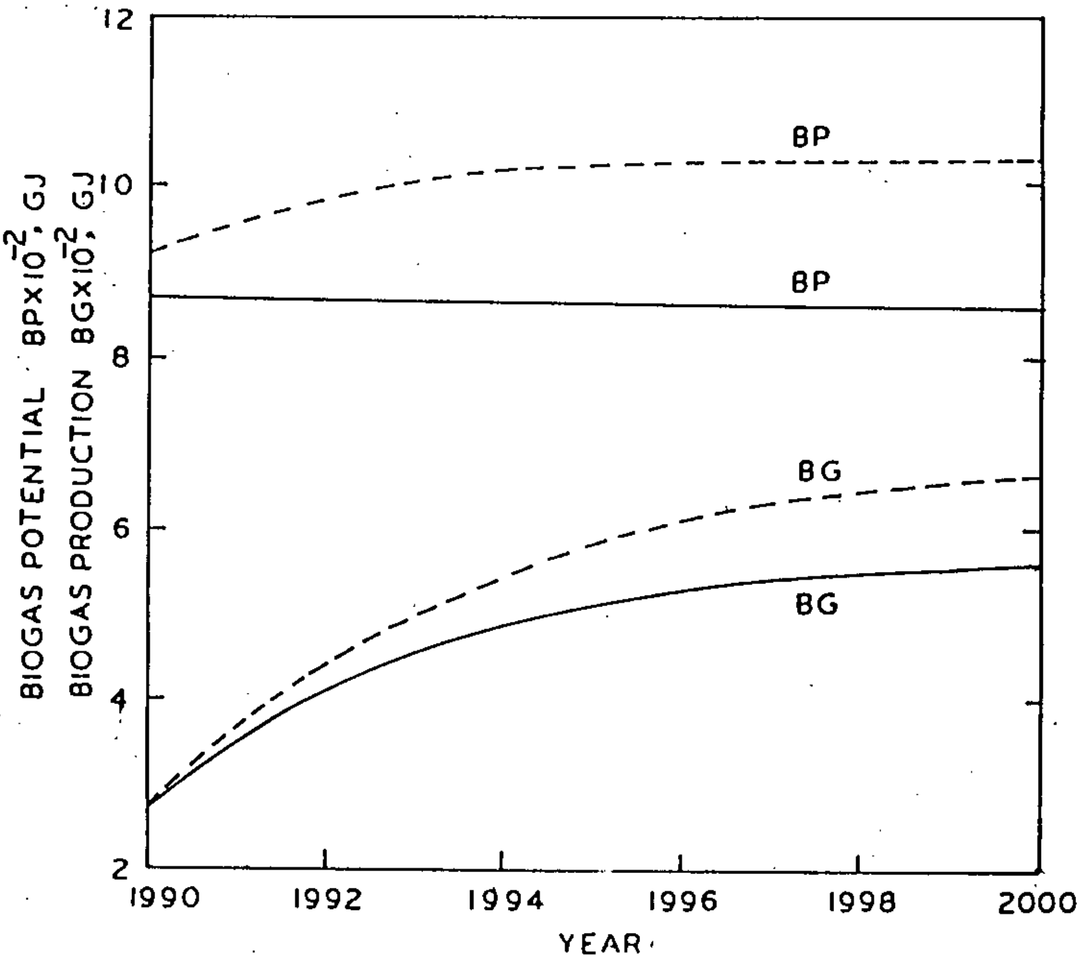


Fig. 7.5 Bio-Gas Potential and Bio-Gas Production During the Period 1990-2000. (--- Basic Mode and ----Policy Mode).

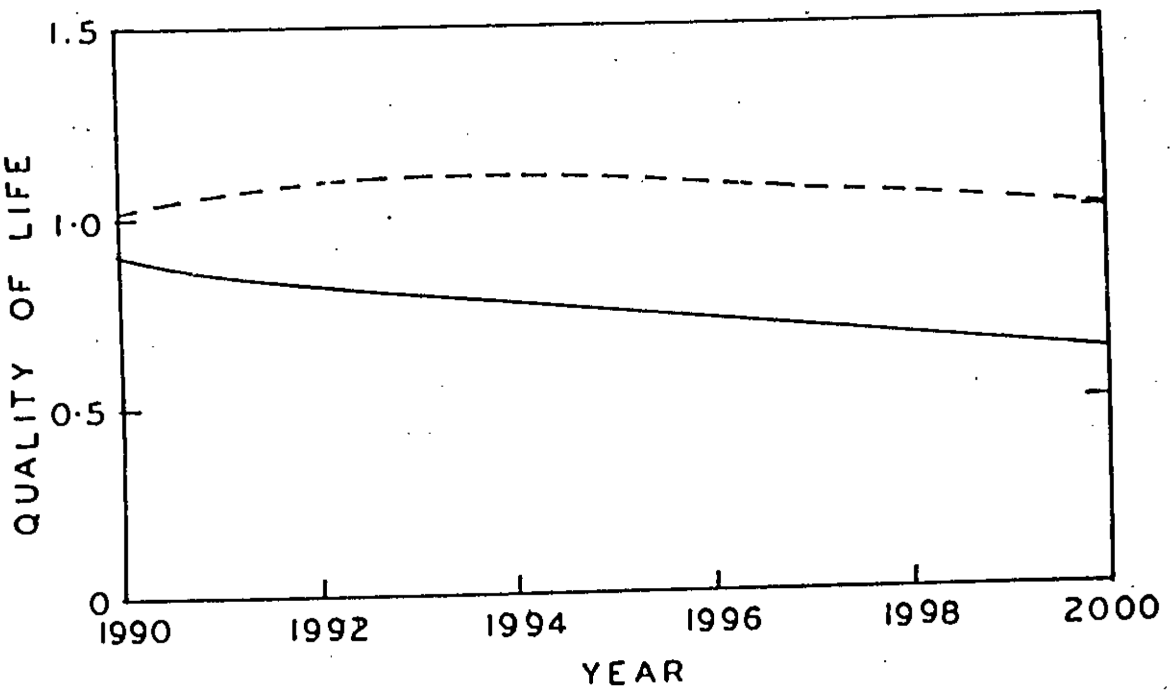


Fig. 7.6 Physical Quality of Life During the Period 1990-2000. (--- Basic Mode and --- Policy Mode).

For implementation of the model a continuing survey of parameters, constants, initial values and table functions are needed. Sensitivity of the parameters are also required to be analyzed for identifying the priorities on data collection and for determining policy entry points. The model should be continuously calibrated for the purpose of keeping it up to date.

Although Huq's revised model is in qualitative form it provides greater insight into rural energy problems and also provides the guidelines for optimization and policy planning for integrated rural energy system. Revised Huq's model based on system dynamics methodology for rural energy systems has been utilized and the model has been used as a computer laboratory for policy planning for rural energy systems.

7.2.2 Macro Level rural energy system model for Bangladesh

System dynamics model of rural dynamic energy system has been developed based on the model for integrated rural energy system (Fig 4.2). This model forms the basis for the development of a computer model. The model considers the integrated energy use in the form of draft power from cattle, organic manure and biogas from cow-dung, and food production and consumption. The model has been simulated for integrated energies for food production and assessment of quality of life in entire rural Bangladesh. The simulated results for policy changes and potential implications of this model have been evaluated.

7.2.2.1 Basis of the macro model

Bangladesh has one of the highest population densities in the world, with 618 persons/km^2, i.e. 89 million over 144,000 km^2 (1981). Ninety percent of the population lives in rural areas, where 93% of the household energy consumption is provided by biomass fuels, such as cowdung, straw, jute sticks, twigs, wood, etc. The challenging problem is how rural population of 73 million obtains food, fuels, building materials (dung, straw, sticks, mud, etc.) and sustain livestock from scarce land it has [47]. The present situation of Bangladesh may be of interest to other developing countries whose population growth is high and who may have similar population densities in the next three decades.

Self reliant development of Bangladesh should not only consider population control measures and increased production policies but also need to take into account the planned and integrated use of energy for improving quality of life and self sufficiency in energy. A rational approach striving for self reliance in food and energy should consider an integrated approach i.e. systems approach to the food production through sagacious use of available energy. This is the background for energy planners where the computer models have great potentiality to help understand for better decision making processes. But the rural energy system itself is nonlinear, dynamic and contains inherent time-lag characteristics. To overcome these limitations, Alam et. al.[88] developed a system dynamics model for integrated rural energy system that contains dynamic, nonlinear and inherent time lag characteristics of this system and the potentiality of the model was illustrated in the micro-level by using the data of a village of Bangladesh. In the following section, the author presents the system dynamics model for integrated rural energy system for macro-level policy analysis.

7.2.2.2 The model for rural Bangladesh

The rural energy system consists of several closed loops. Feedback for these loops simulates the dynamic behaviour of a highly complex system. The system dynamics flow diagram of the integrated rural energy system is shown in figures 7.7 to 7.12.

(a) Population sub-model

Fig. 7.7 shows the human population sub-model. The population supplies the human energy to the rural energy system. The population is determined by birth, death rates and growth rates of each sex and age groups of this population system. Quality of life, food per capita and population density link the population nonlinearly. These factors act as the mechanism of population control.

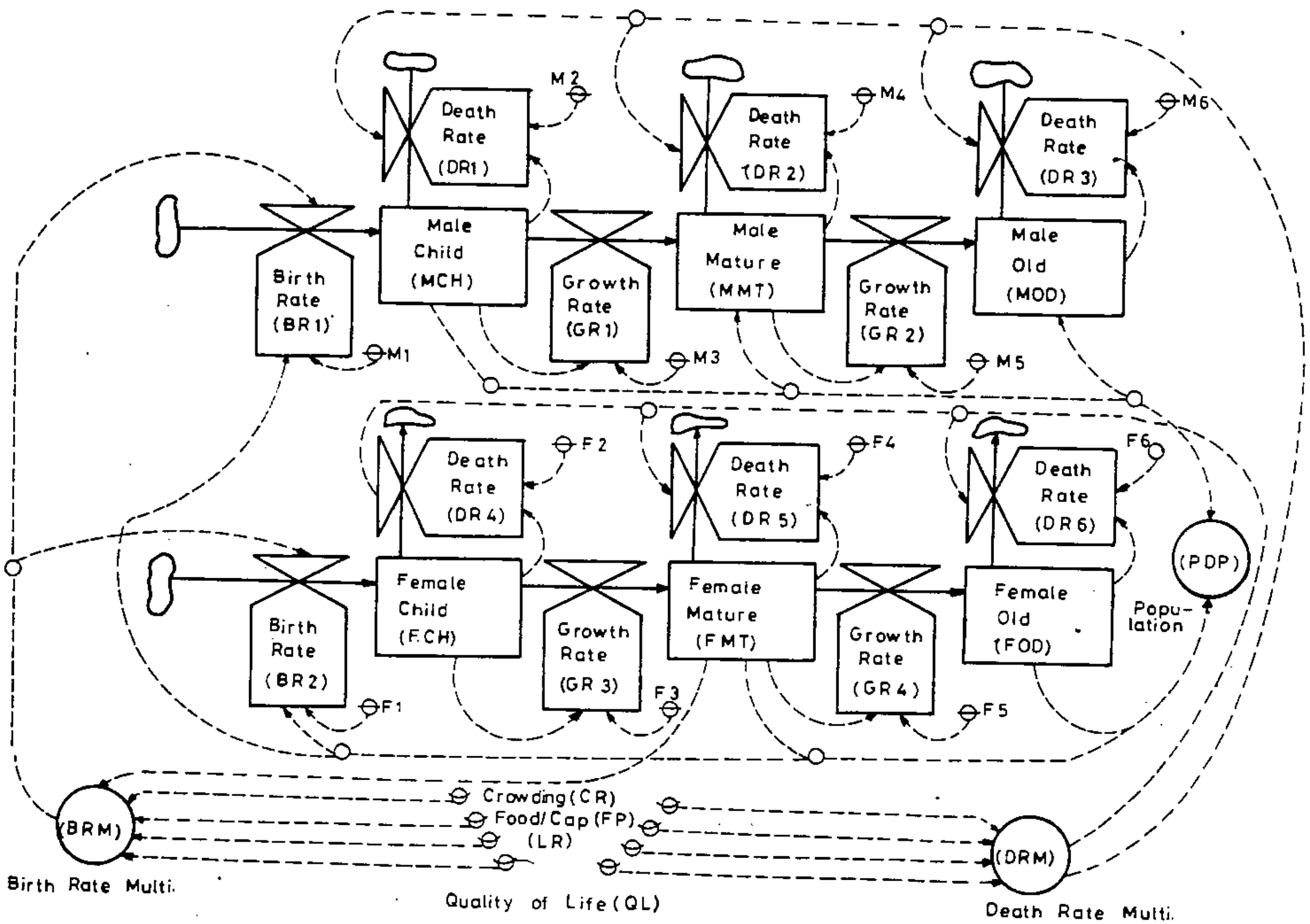


Fig. 7·7 System Dynamics Block Diagram of Population Sub-Model.

(b) Cattle sub-model

Cattle sub-model is shown in Fig. 7.8 The cattle supplies almost the entire draft energy for land preparation in Bangladesh. The cattle population is determined by birth rates, importation rates and consumption rates. Price links cattle population nonlinearly through deficit in draft power, production and consumption. Cattle raisers adjust their current expected price from prices received in the past, and accordingly their plans to raise cattle are being continuously adjusted by the mechanism of price. The cattle production rate is either increased or decreased continuously to adjust the gap between actual and ownership capacity over a period of 2.25 years [45]. The cattle production rate is also highly influenced by straw availability which is the principal source of staple food supply for Bangladesh cattle.

The agricultural system consists of an integrated crop and animal production system. Drought power shortage may be compensated by partial mechanization of agricultural production system. With a view to mechanization, the projected quantity of power tiller is to proportional to the difference of optimum draft power required for tillage operation, and draft power available from cattle population. The proportionality constant is output power rating of a power tiller.

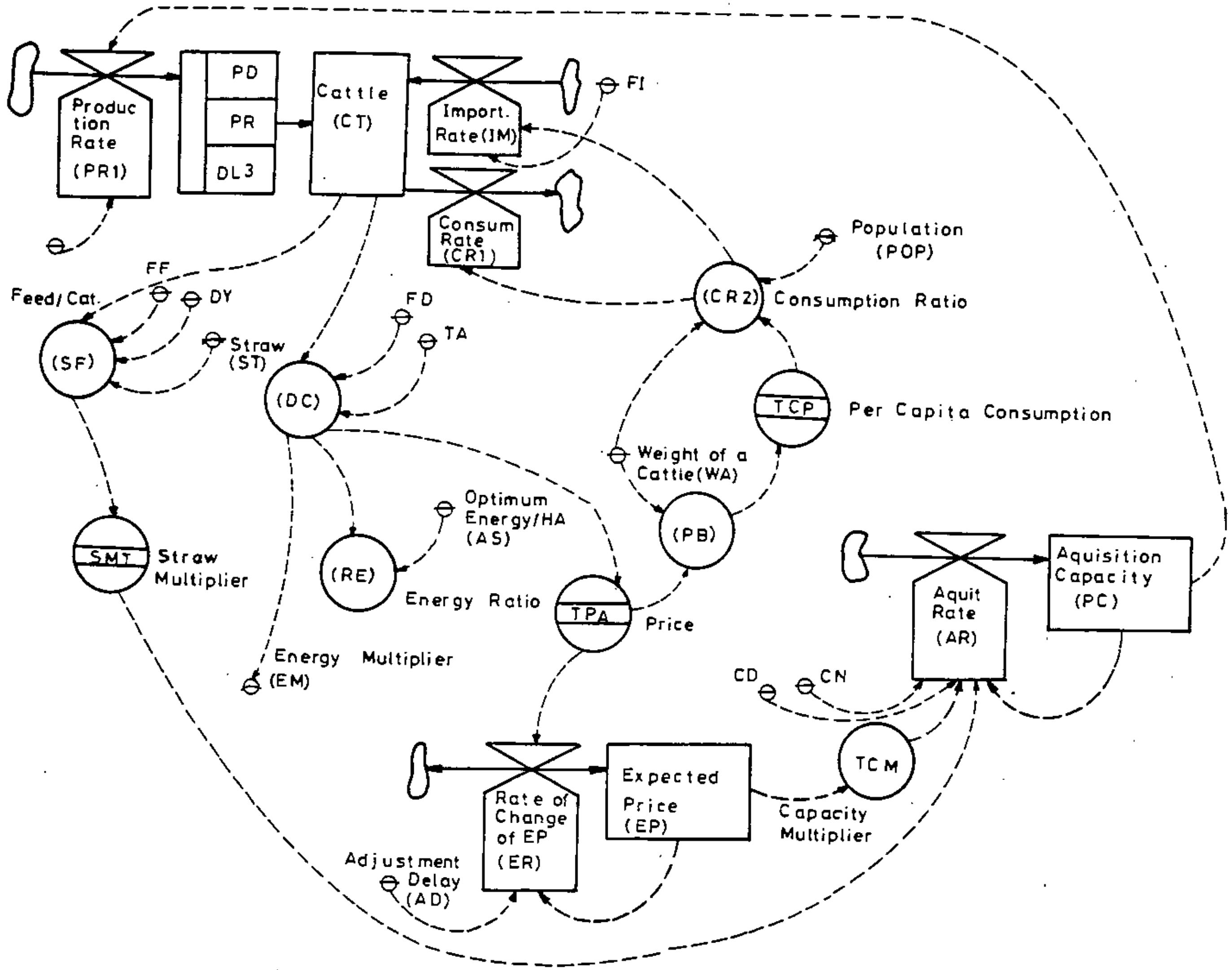


Fig. 7.8 System Dynamics Block Diagram of Cattle Population Sub-Model.

(c) Crop production sub-model

Fig. 7.9 shows the crop production sub-model. The crop production system is mainly determined by the production of food grain and straw. The straw is primarily used for the cattle feed. The major inputs for the crop production are draft power, irrigation, fertilizer, and human energy. Crop production can be increased either by increasing the cropped area or the yield. Since land is limited, crop production must be increased by using high-yielding varieties in conjunction with irrigation and fertilizers. The yield is influenced by draft power from the animal system. The animal system, in turn, is influenced by crop production. Thus, crop production forms a closed loop with animal production.

(d) Bio-gas production sub-model

The cattle production system provides cowdung, which is supplied to the biogas system. The biogas production system is shown in Fig. 7.10. The biogas system is essentially a biogas digester for the production of biogas and treated slurry by anaerobic digestion. The treated slurry replaces the use of inorganic fertilizer in crop production. Thus, crop, animal and biogas production form a closed loop. The proposed biogas system supplies biogas as a fuel for cooking and therefore reduces the pressure on rural forest and also diminishes pollution. The treated slurry replaces the use of commercial fertilizer in crop

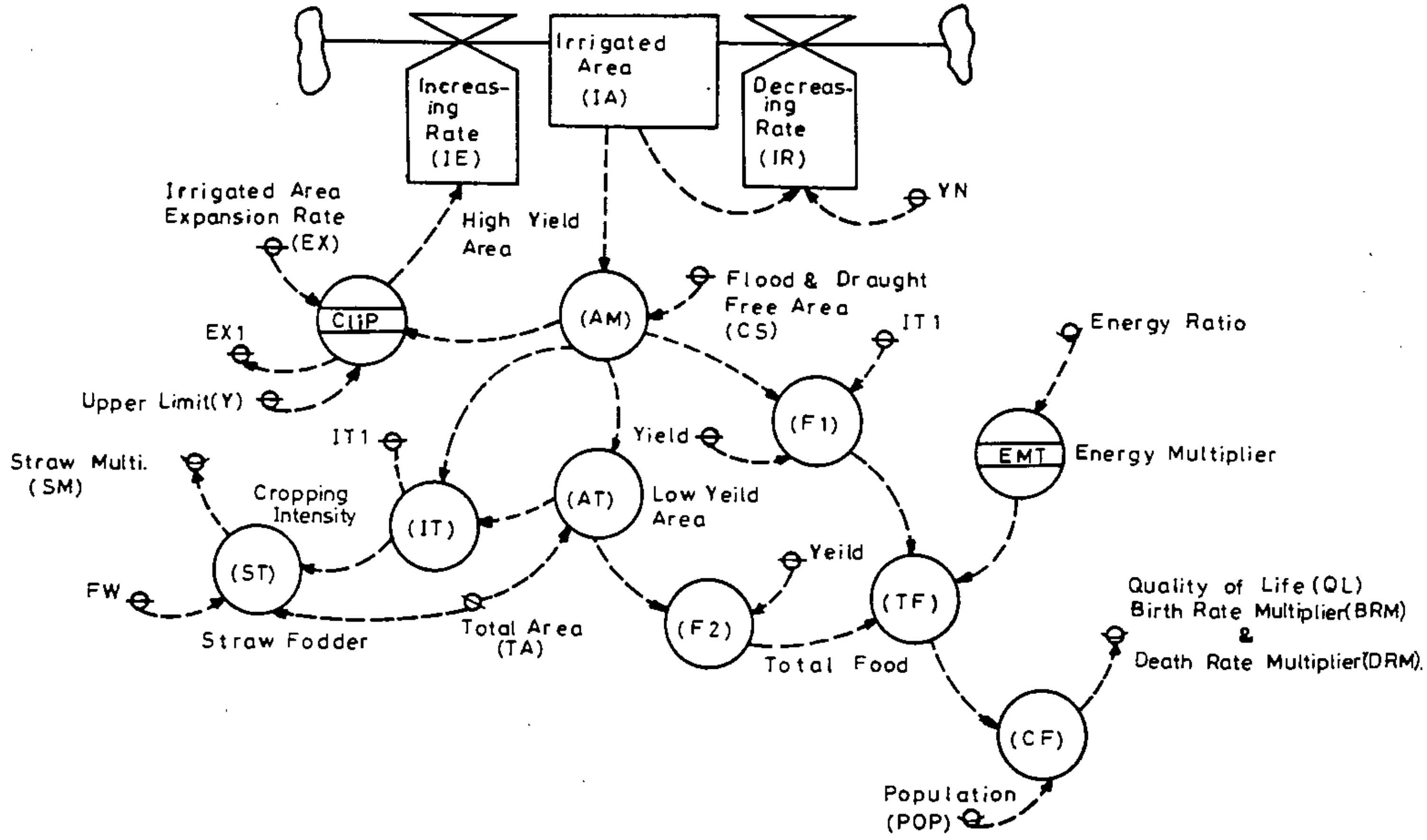


Fig. 7.9 System Dynamics Block Diagram of Food Production Sub-Model.

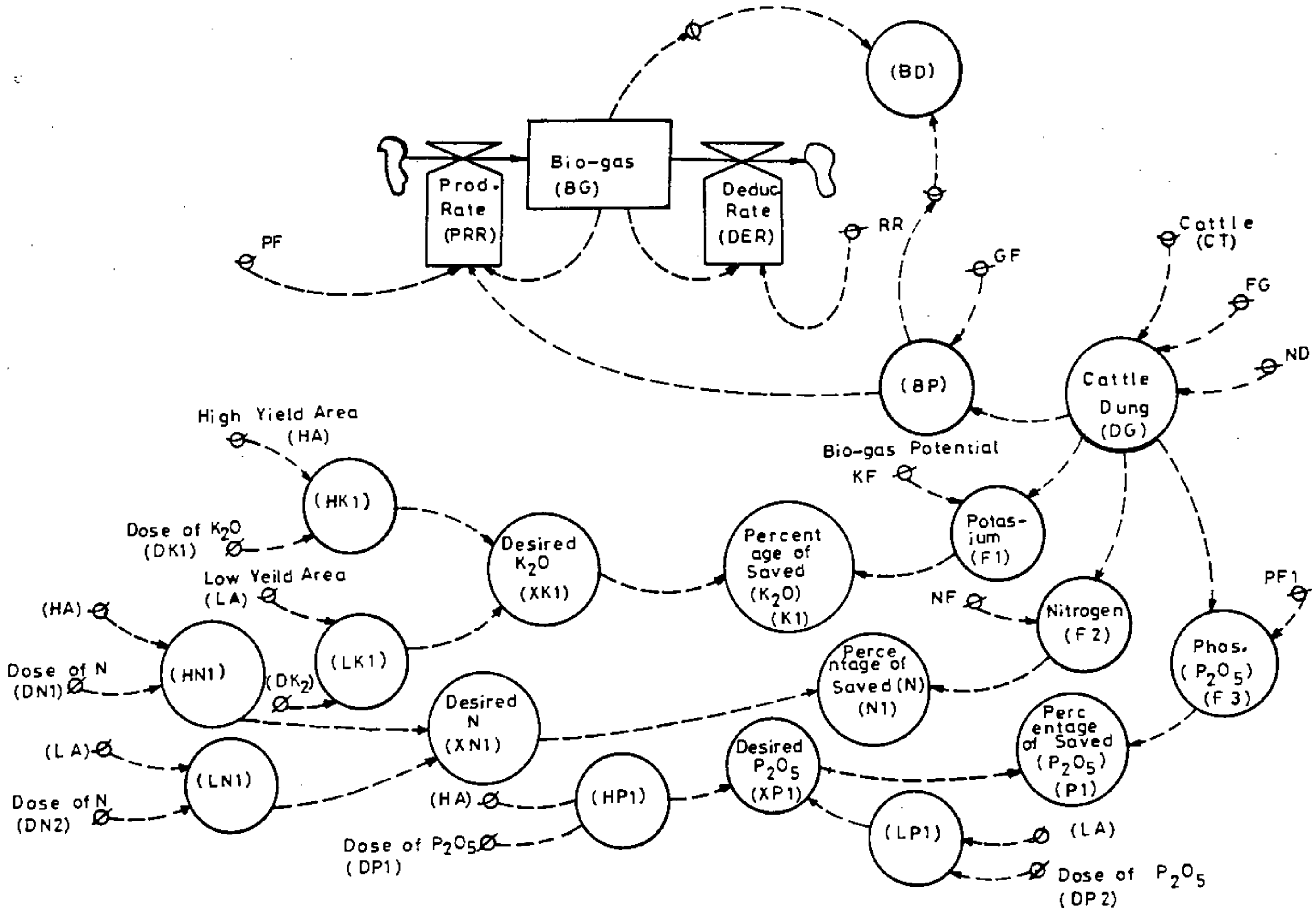


Fig. 7.10 System Dynamics Block Diagram of Bio-Gas Production Sub Model.

production. This process, in turn, reduces the ecological imbalance.

(e) Rural cooking fuel sub-model

Biomass is still the only source of cooking fuel in rural Bangladesh and is available from three sources:

i) field crops

ii) trees

iii) livestock

Depending upon their characteristics and quality, biomass resources are used as food, fodder, building materials, industrial raw materials, fuel and manure. The rural cooking fuel sub-model is shown in Fig. 7.11.

Biomass available from field crops may be classified as crop and crop residues. The availability of biomass depends on the species and genetic variety such as local and high yielding variety (HYV). Different components of residues are used for specific purposes and in some cases the same residue component has several end uses which are integral part of the crop production sub-model. However paddy is the major source of agriculture residues. After allowances have been made for fodder requirements, crop residues are used for building materials, fuel, industrial raw materials, burning in site or waste. Biomass is also produced by livestock in the form dropping from cattle, buffalo, goat and sheep dung, and poultry droppings. However, mainly cattle dung is used for fuel which is the

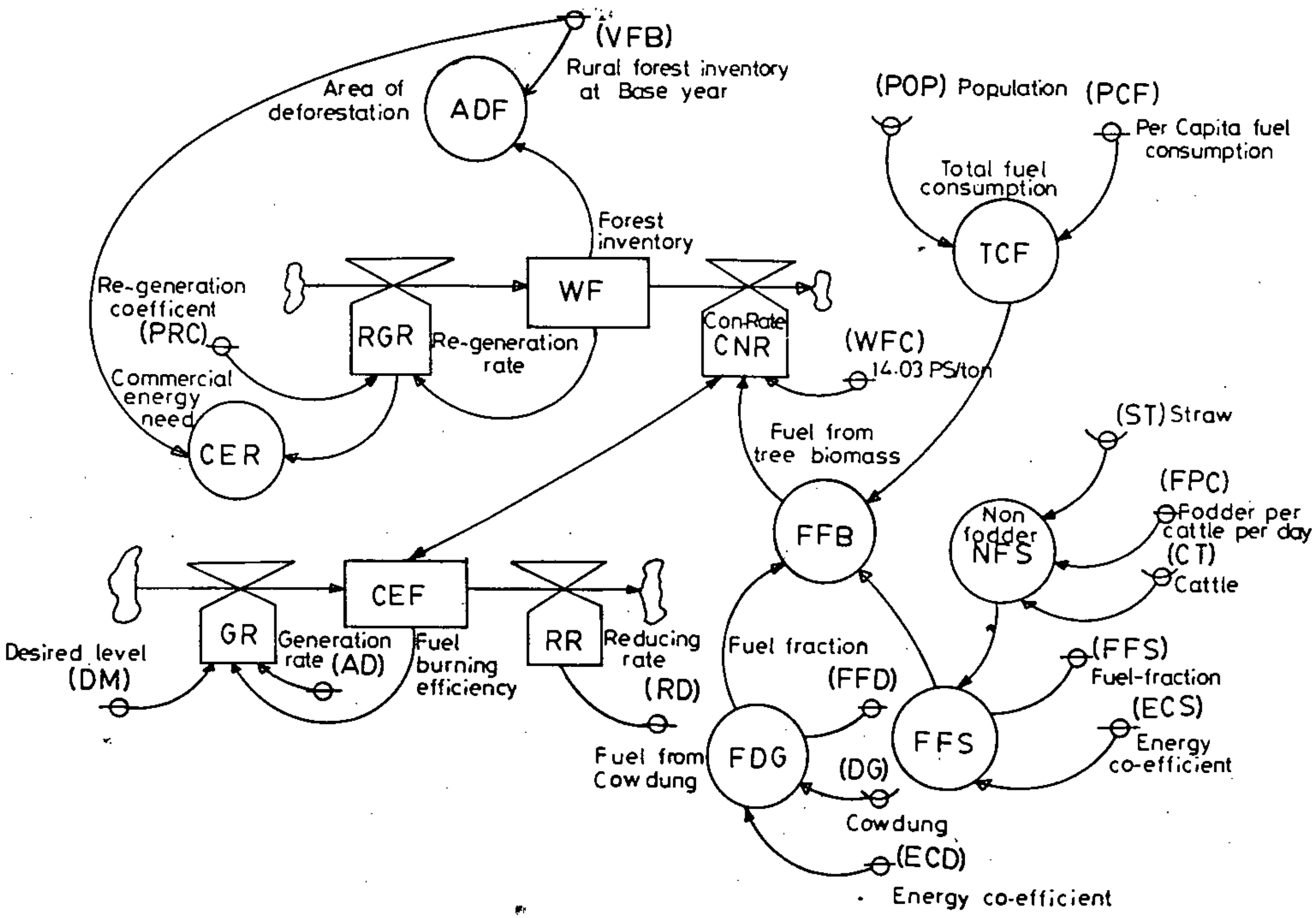


Fig. 7.11 System Dynamics block diagram of household fuel consumption sub-model in rural Bangladesh

integral part of the cattle population sub-model as well as biogas sub-model. In addition to fuel, dung is used as manure and as a building material with the remainder going to waste. Based on these facts, the end use coefficients are to be estimated.

Generally fuelwood is defined as the wood fuel obtained from the stem portion of felled trees. In the BEPP [22] analysis, fuel wood includes one or more of the following types of biomass: splits, trunks, roots, branches of large trees (felled), trunks of small trees and shrubs, roots, lopped branches of standing trees and sawn log waste. Tree biomass fuel includes fuelwood and naturally fallen twigs and leaves from tree resources. The supply of tree biomass fuel is obtained from two sources: village forests and reserve forests. The village forest mainly contributes tree biomass fuel to the rural areas.

The demand of cooking fuel which is proportional to the population level, is supplied from crop residues as well as cattle dung, with the remainder going to be met by tree biomass from village forest. In line with prevailing practice it is assumed that kerosene is not used as cooking fuel.

(f) Quality of life sub-model

The quality of life is used here as a measure of performance for integrated rural energy systems. Quality of life sub-model is shown in Fig. 7.12. It is computed by taking the product of multipliers derived from food, crowding and biogas as

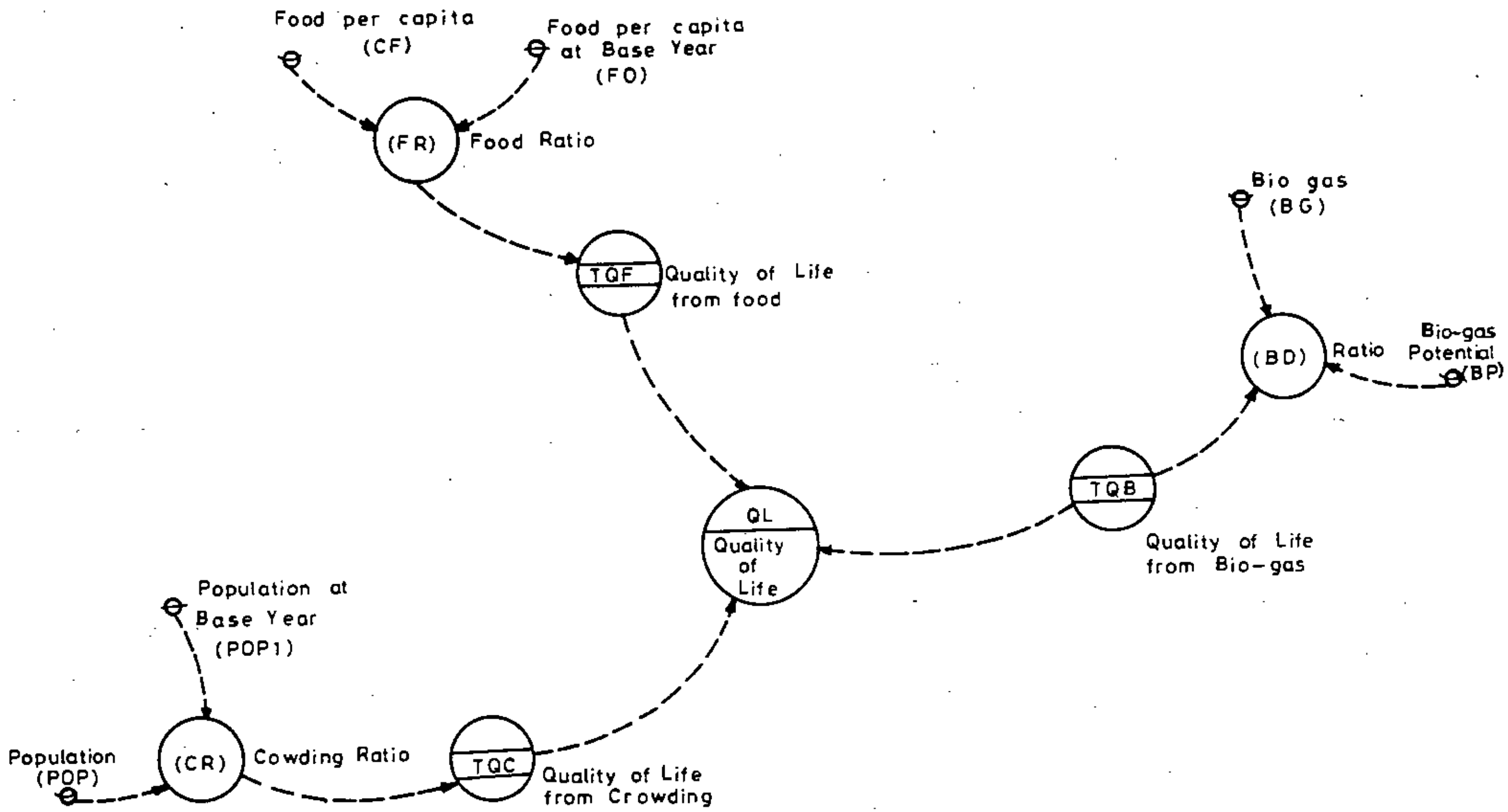


Fig. 7·12 System Dynamics Block Diagram of Physical Quality of Life.

cooking fuel. The multipliers are chosen to be 1 for 198 [49, 84] The model was programmed in DYNAMO and simulated in a microcomputer. The computer listing of the equations are shown in Appendix B.

7.2.2.3 Simulated results

To illustrate the use of the model as a tool for policy planning, the model was simulated for both the basic mode and the policy planning mode during the period 1980 to 2010. The basic mode corresponds to increase in irrigated area at the rate of 8.5% [114] and the other existing conditions; and the policy planning mode corresponds to the condition for policy option being tested. The simulation results of the model for both the basic mode and policy mode are shown in figures 7.13 to 7.28. The policy mode in this study involves biogas production at the rate of 15% of the difference between biogas potential and actual level of biogas production, draft power constraint remaining constant throughout the simulation period, and 5% increment of importation rate of the cattle as ramp input of the cattle production system. The policy mode in this study also involves fuel burning efficiency at 155%, 160%, and 165% when the efficiency is to be considered 1 at base year 1981. The solid lines in the figures indicate results for the basic mode while the other lines indicate the results of the policy mode.

The irrigated area is increased from 1.22×10^6 to 4.224×10^6 hectares by the year of 2010 (Fig. 7.13). Total food production

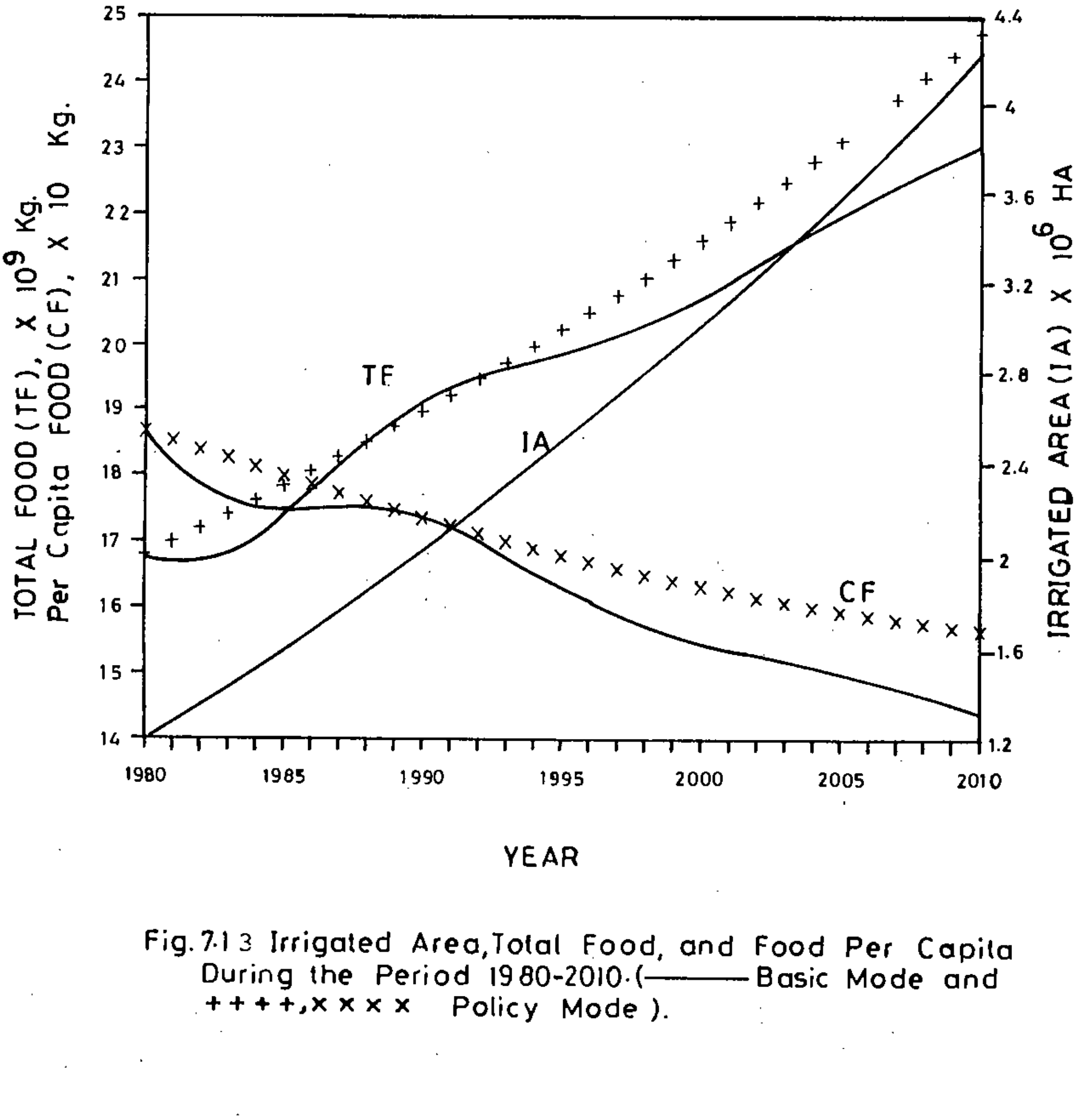


Fig. 7.13 Irrigated Area, Total Food, and Food Per Capita During the Period 1980-2010 (——— Basic Mode and ++++, x x x x Policy Mode).

in basic mode is shown to rise from $16.76X10^9$ kg to $23.04X10^9$ kg in the years 1980 to 2010 whereas in policy mode total food production rises to $24.76x10^9$ kg by the year of 2010 (Fig. 7.13). But the per capita food available is found to vary from 186 kg to 144 kg in basic mode and 186 kg to 157 kg in policy mode. (Fig. 7.13)

Cattle population and draft power level are shown to change with time and is oscillating in nature (Fig. 7.14). The amplitude range in basic mode is from $22.18X10^6$ to $19.23X10^6$ for cattle population, and is 0.242 kW/hectare to 0.210 kW/hectare for draft power. Where the draft power/cattle 0.1521 kW. [45] But in policy mode, the amplitude range is $22.51X10^6$ to $20.00X10^6$ heads for cattle population and 0.245 to 0.220 kW/hectare for draft power whereas the optimum requirement of draft power/hectare is 0.373 kW. [45]

The level of the draft power shortage, and the power tillers required to compensate the draft power shortage also show to change with time and is oscillating in nature [Fig. 7.15]. The amplitude range is $972.8x10^3$ kW to $1109x10^3$ kW for draft power shortage and $107x10^3$ to $122x10^3$ power tillers requirement. The draft power output rating of a power tiller is 9.8 kW [10].

Percentage of commercial fertilizer (N, P_2O_5 and K_2O) which is saved, the biogas potential and actual level of biogas production are illustrated in Fig. 7.16 with the adoption of the

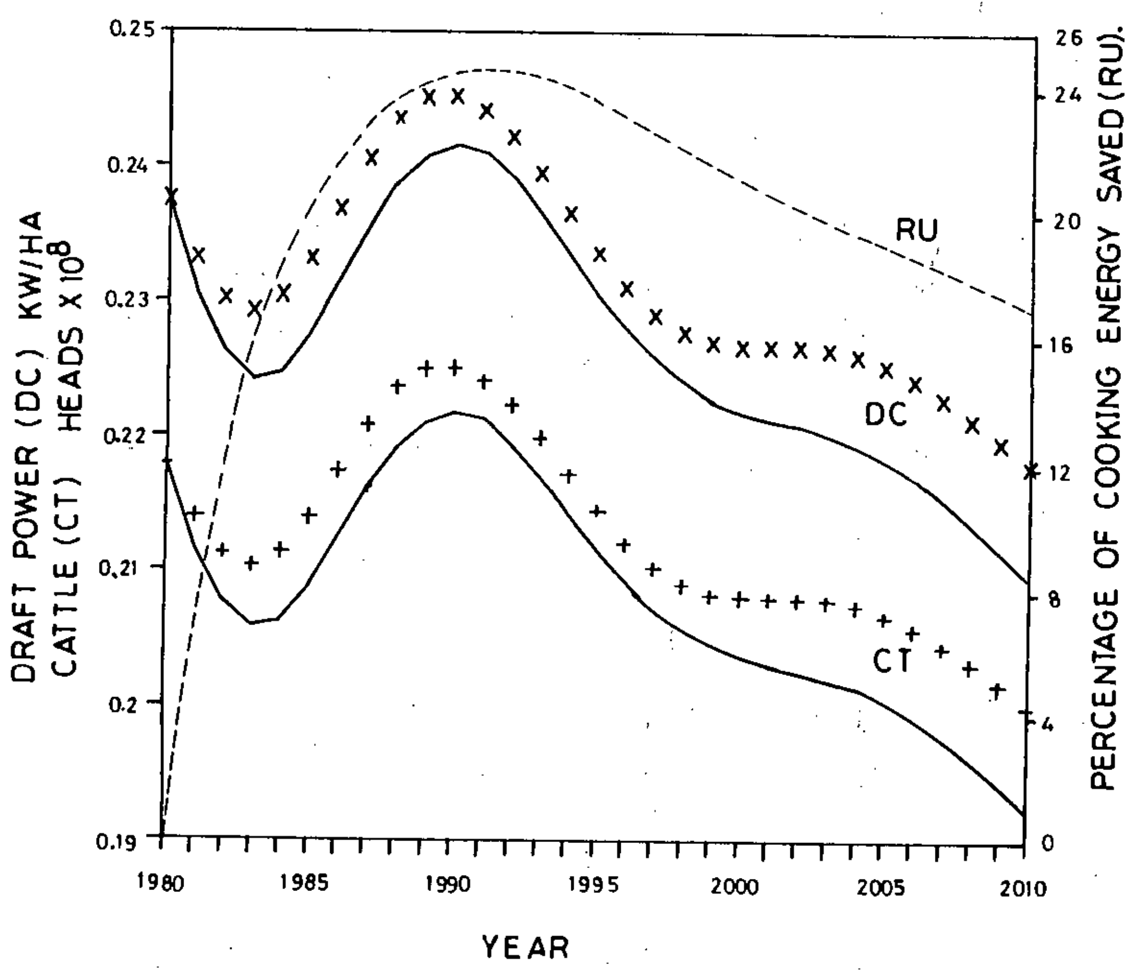


Fig. 7.14 Cattle, Draft Power per hectare and percentage of cooking Energy Saved During the period 1980-2010. (——— Basic Mode and ++++, xxxx, ---- Policy Mode)

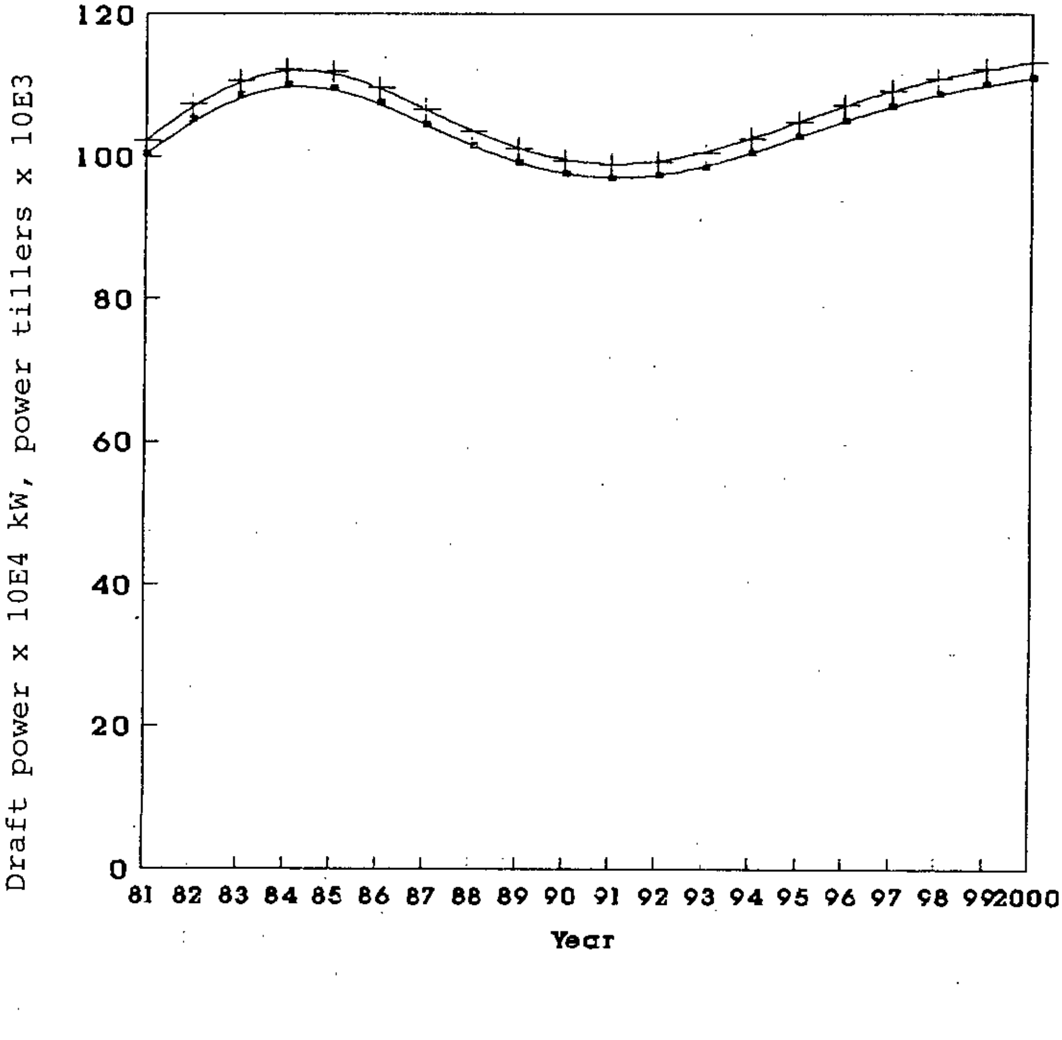


Fig 7.15 Simulating results of draft power shortage (+) and power tillers requirement (•) during the year of 1981-2000.

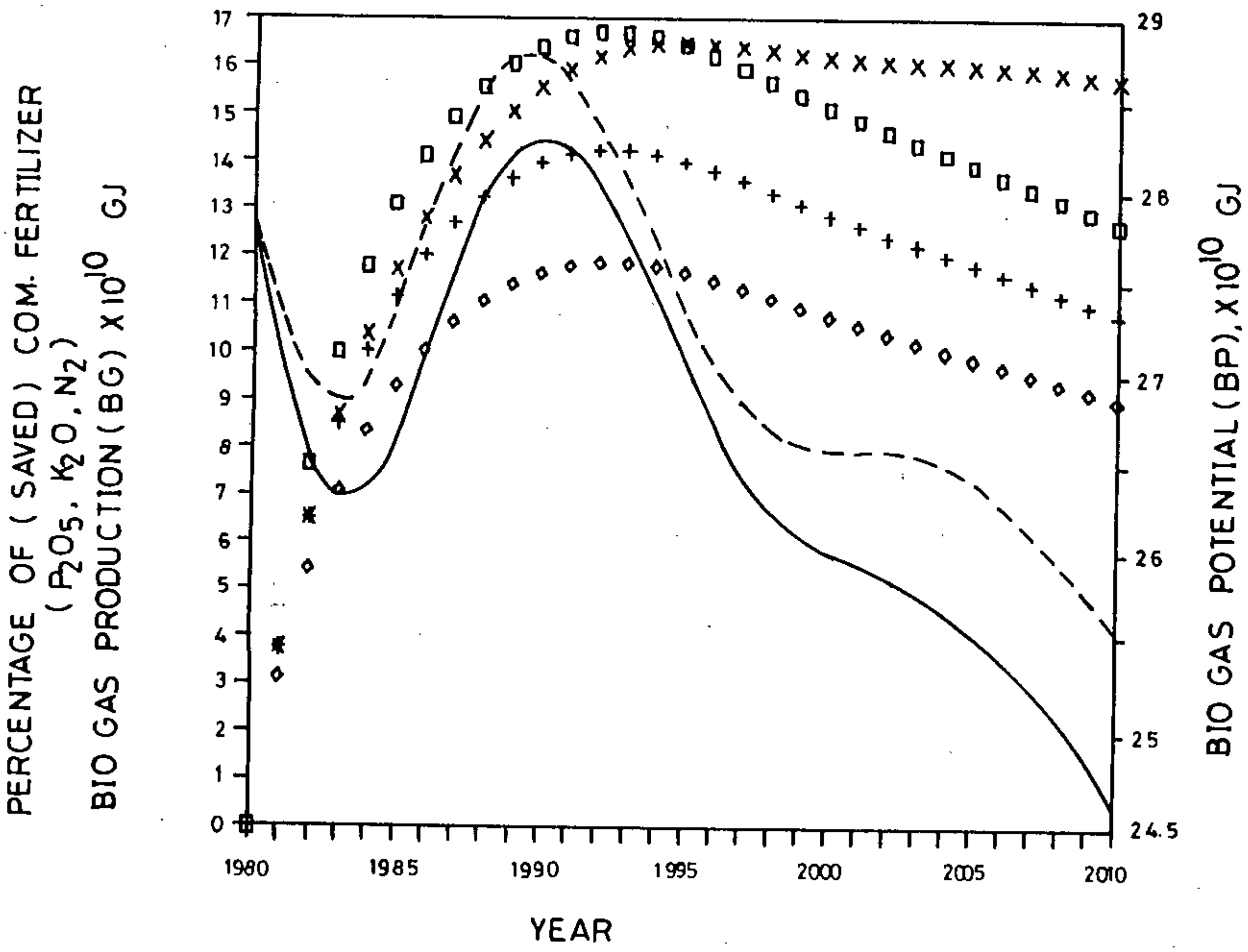


Fig. 7.16 Percentage of commercial Fertilizer N_2, P_2O_5 and K_2O saved, Biogas potential and Biogas production During the period 1980—2010. (——— Basic Mode and ◇◇◇, □□□, +++, - - -, ××× Policy Mode.)

policy for installation of biogas digesters, the produced biogas can save 24.79% of the cooking energy (Fig. 7.14). Fig. 7.17 projects organic manure availability from slurry used as a fertilizer to substitute the N, P_2O_5 and K_2O requirements.

Fig. 7.18 - 7.20 and Fig. 7.24 & Fig. 7.25 show that the simulated results of total biomass fuel consumption, fuel consumption from tree biomass, fuel consumption from cattle dung, fuel consumption from crop residues, the fuel input required from outside to the rural energetics for sustaining the base year rural forest profile, percentage of area deforestation (base year as reference), and overcutting of rural forest during the simulated period (1981-2000) are shown in Table 7.1.

Fig. 7.19 to 7.27 show the impact of increasing fuel burning efficiency over the simulated period where the incremental change of burning efficiency is 3.33%.

At the end of the simulated period (2000), fig. 7.19 - 7.24 show the reducing rates of percentage of deforestation are 19.60%, 23.22%, and 28.90%; reducing rates of percentage of overcutting of village forest are 35%, 36.8%, and 39%; the total energy consumption reducing rates are 3.05%, 2.96%, and 2.87%; village forest inventory improving rates are 66.93%, 38.15%, and 26.32%; fuel consumption reducing rates from tree biomass are 11.78%, 12.57%, and 13.55%; and reducing rates of external fuel input requirement to the rural energetics for maintaining the

Table 7.1

Simulated results of rural cooking fuel sub-model

Simulated variables	Range
Total biomass fuel consumption	345.0 - 490.5 (PJ)
Fuel consumption from tree biomass	41.8 - 126.9 (PJ)
Fuel consumption from cattle dung	112.4 - 105.7 (PJ)
Fuel consumption from crop residues	185.2 - 257.9 (PJ)
External fuel input required for sustaining base year rural forest	4.5 - 116.0 (PJ)
Equivalent kerosene as an external fuel input	68.2 - 904.0 (10^6kg)
Percentage of area deforestation from base year	0.0 - 77.3%
Percentage of over-cutting of rural forest	20.0 - 340.0%

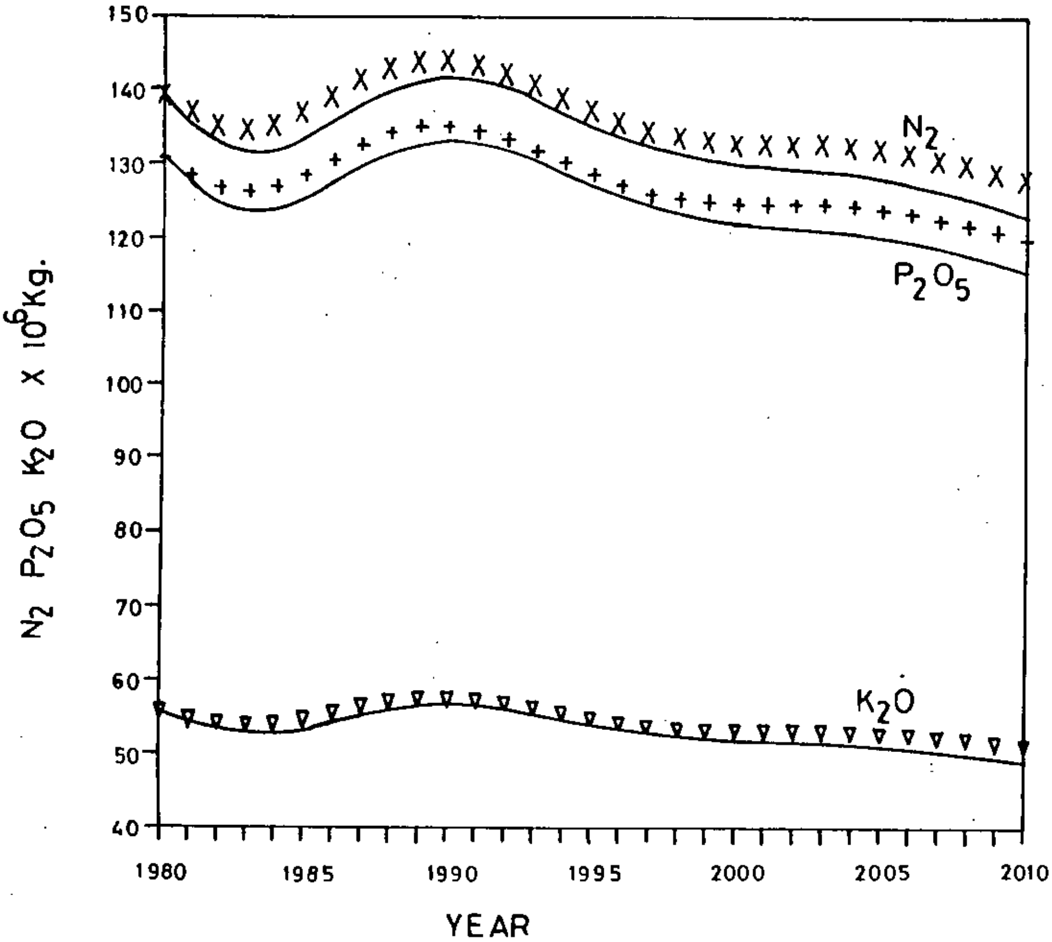


Fig. 7.17 N_2, P_2O_5, K_2O During the period 1980–2010.
(——— Basic Mode and × × ×, + + +, ∇ ∇ ∇ Policy Mode).

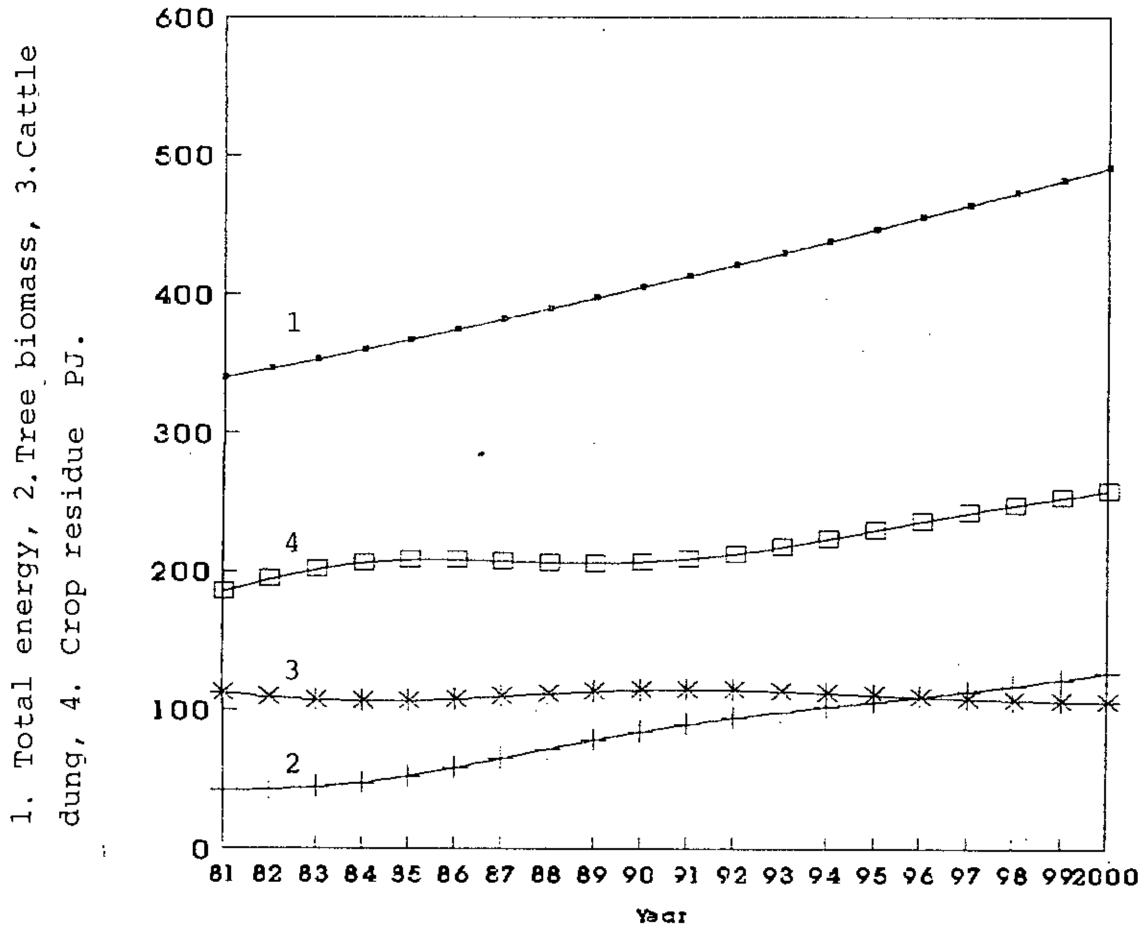


Fig 7.18 Simulating results of composition of fuel consumption during the year of 1981-2000; 1. Total energy (TEC) 2. Tree-biomass 3. Cattle dung 4. Crop residue (FFS).

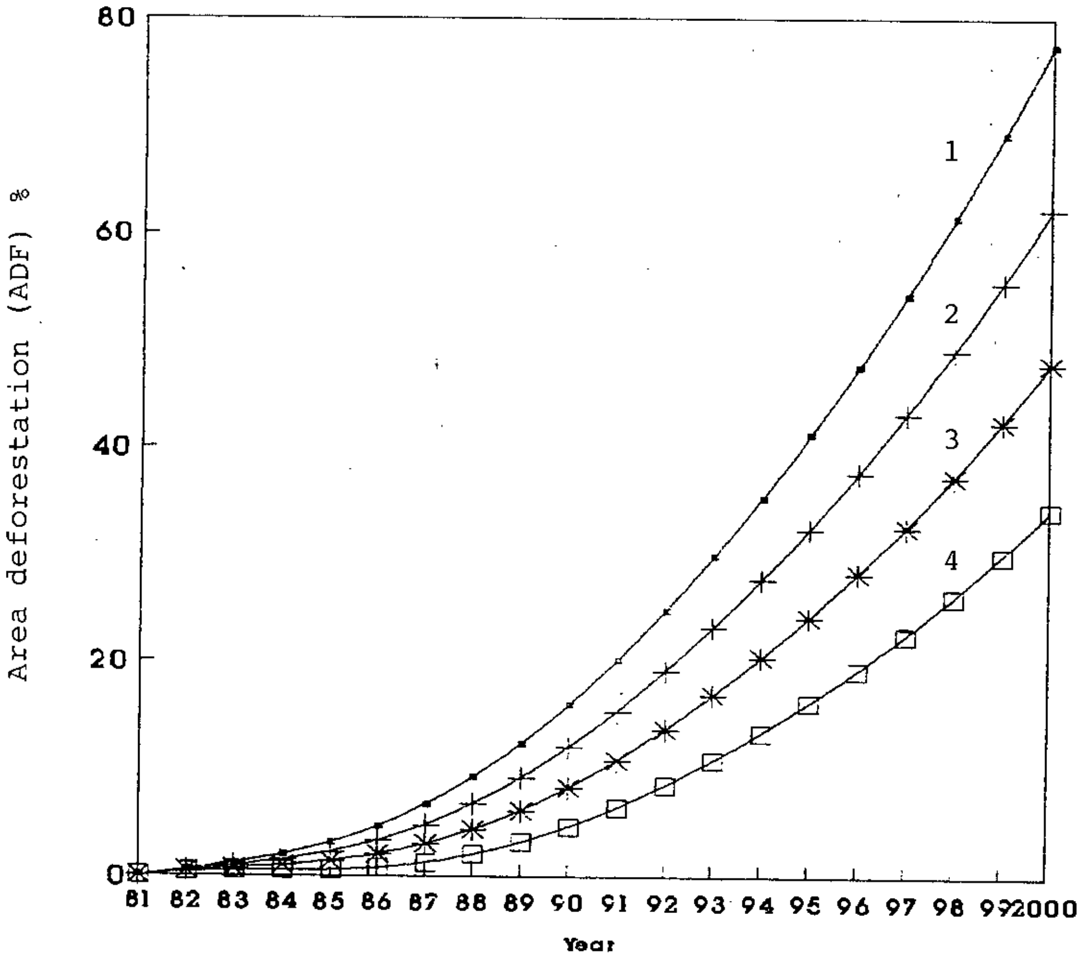


Fig. 7.19 Simulating results of percentage of area deforestation (ADF) during the year of 1981-2000. (in basic mode 1 and in policy mode 2,3,4)

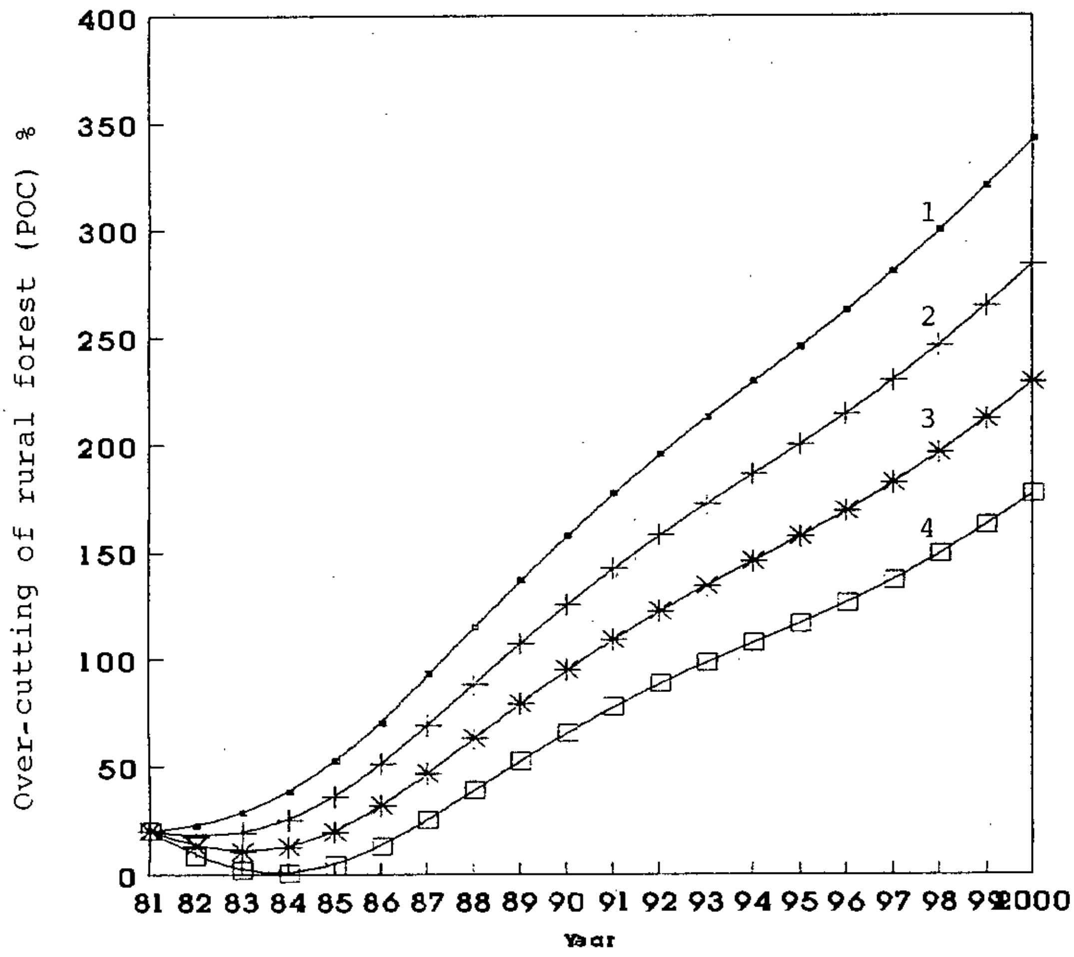


Fig. 7.20 Simulating results of percentage of over-cutting (POC) during the year of 1981-2000. (in basic mode 1 and in policy mode 2,3,4)

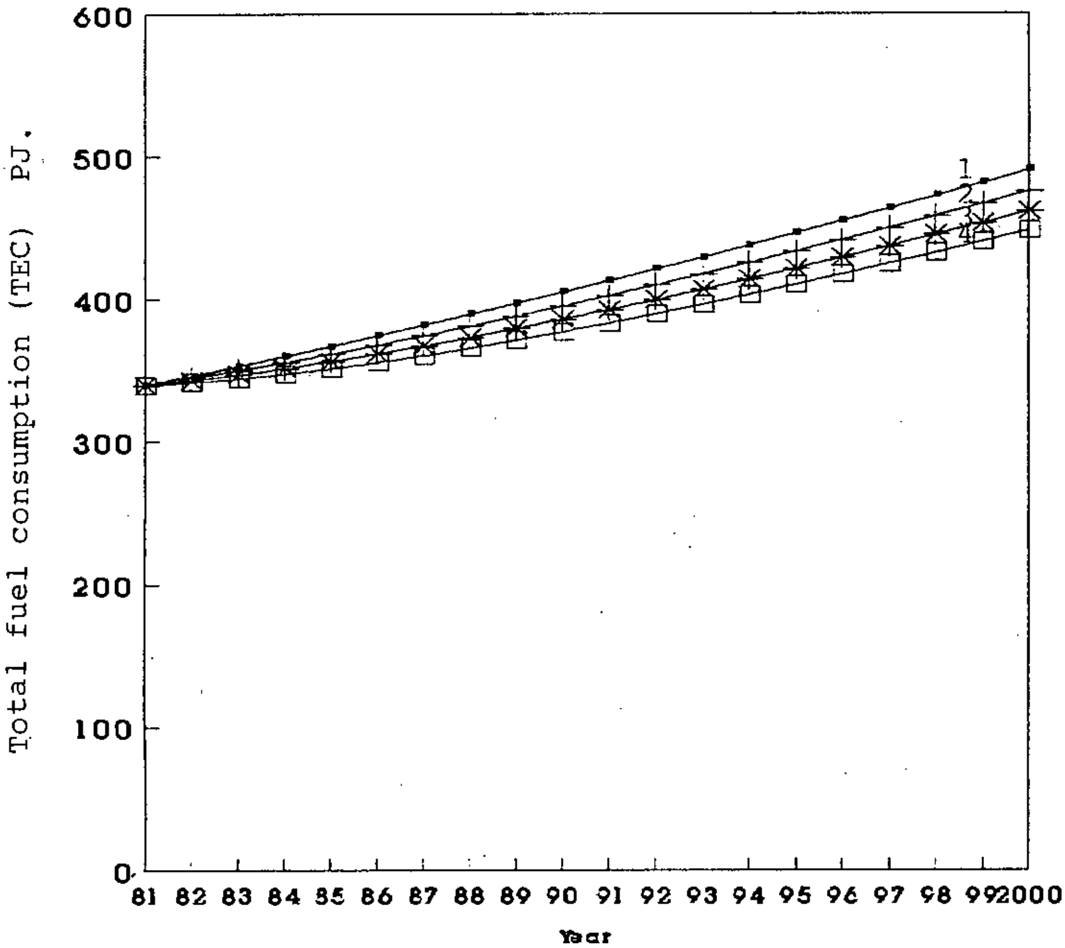


Fig. 7.21 Simulating results of total fuel consumption (TEC) during the year of 1981-2000 (in basic mode 1 and in policy mode 2,3,4)

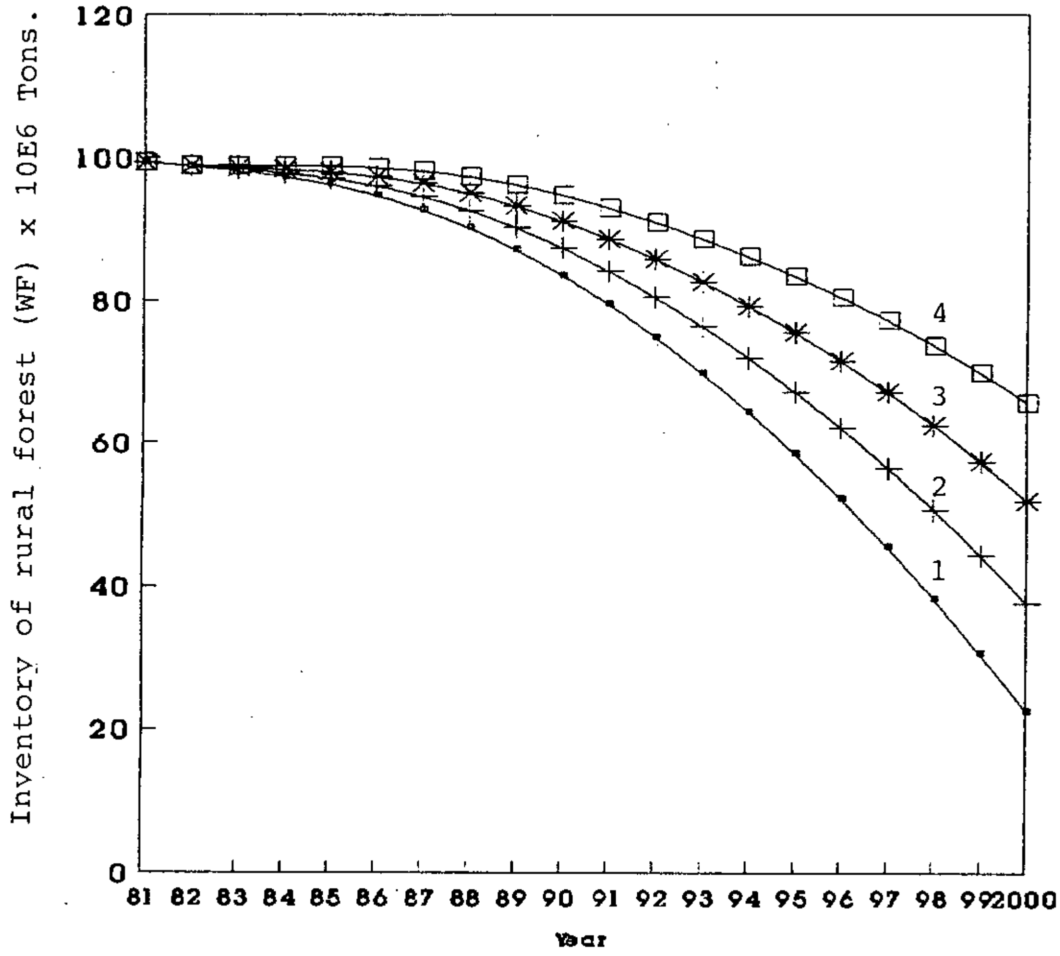


Fig. 7.22 Simulating results of inventory of rural forest (WF) during the year of 1981-2000. (in basic mode 1 and in policy mode 2,3,4)

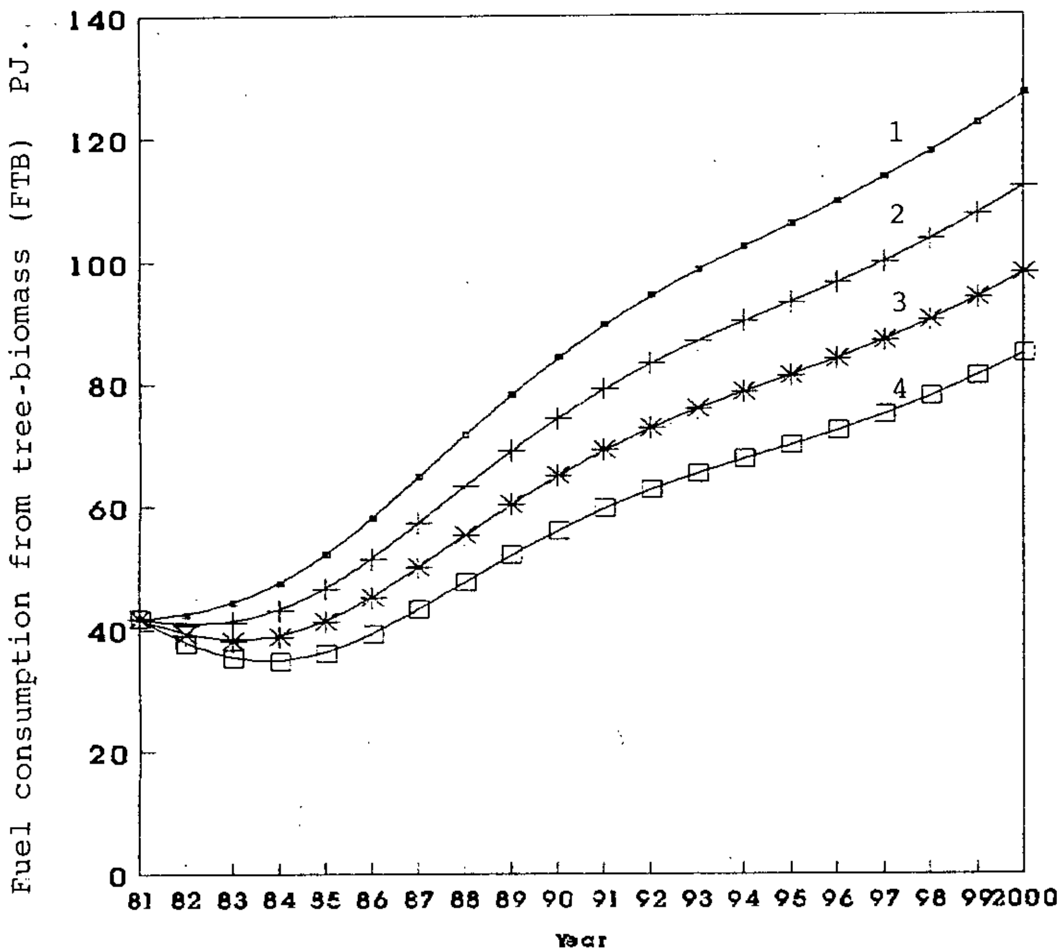


Fig. 7.23 Simulating results of fuel consumption from tree-biomass (FTB) during the year of 1981-2000. (in basic mode 1 and in policy mode 2,3,4)

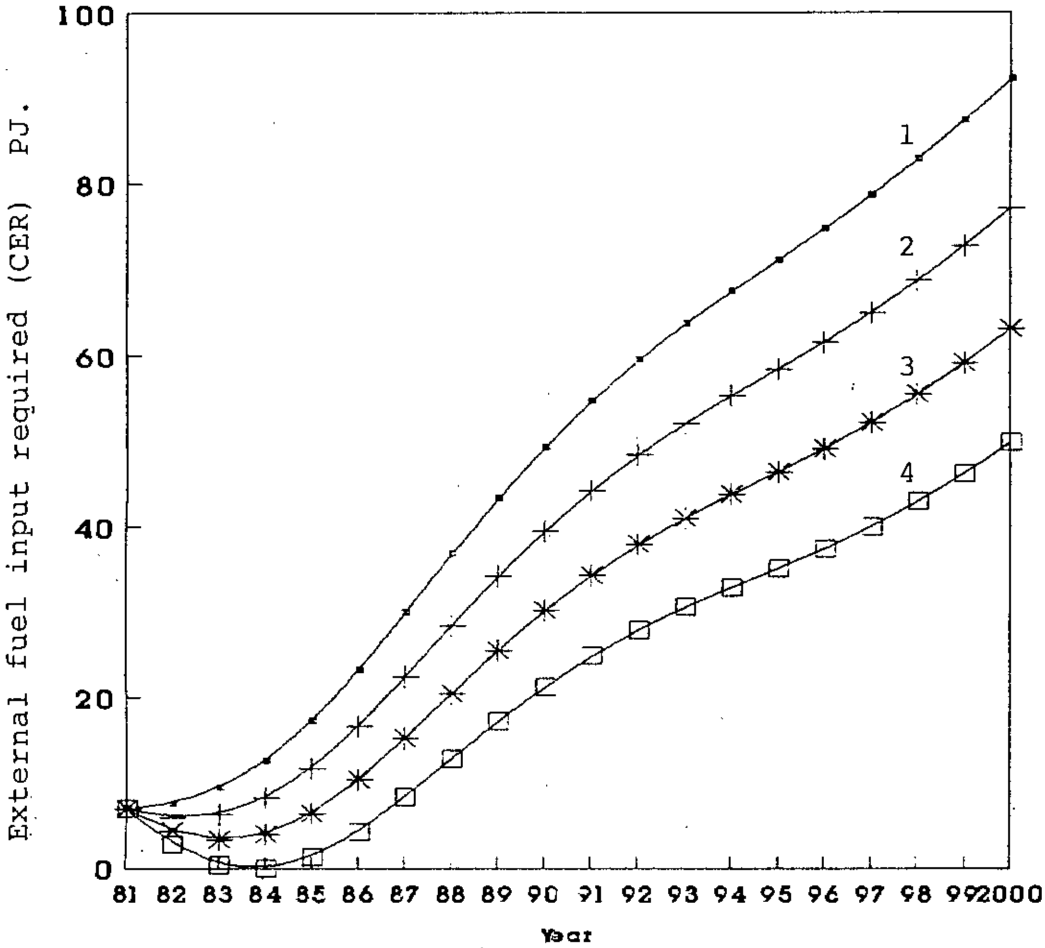


Fig 7.24 Simulating results of external fuel input required for sustaining the base year rural forest profile (CER) during the year of 1981-2000. (in basic mode 1 and in policy mode 2,3,4)

base year rural forest profile (or equivalent kerosene oil in Fig 7.25) are 22.21%, 27.39%, and 36.22% respectively.

Per capita cooking fuel input to the rural energetics from outside during the simulated period (1981-2000) for sustaining the base year village forest profile is 0.077 GJ/YR - 0.708 GJ/yr shown in fig. 7.26 (in case of kerosene, 0.90 kg/yr - 8.22 kg/yr in fig. 7.27).

Population increases from $89.93X10^6$ to $159.80X10^6$ in basic mode and $89.93X10^6$ to $159.00X10^6$ in policy mode by the year 2010 (Fig. 7.28). The quality of life is assumed to be a product function derived from food, crowding, and biogas as cooking and lighting energy. In basic mode the quality of life is reduced to 0.77 in 2010 from 1 in 1980 and is always greater than 0.97 in policy mode with a peak of 1.2 in 1984. (Fig. 7.28)

7.2.2.2 Discussion and conclusions

Validation of a model is a process of establishing confidence in the soundness and usefulness of the model [113]. Figs 7.29 - 7.33 and Table 7.2 shows the comparison of results as predicted by the developed model in this research work with data obtained by other investigators and survey teams. on certain major indicators (human and cattle population, irrigated area, and food production) for energy system in farming sector. The predicted behaviour of the model agrees with the observed behaviour [114-116].

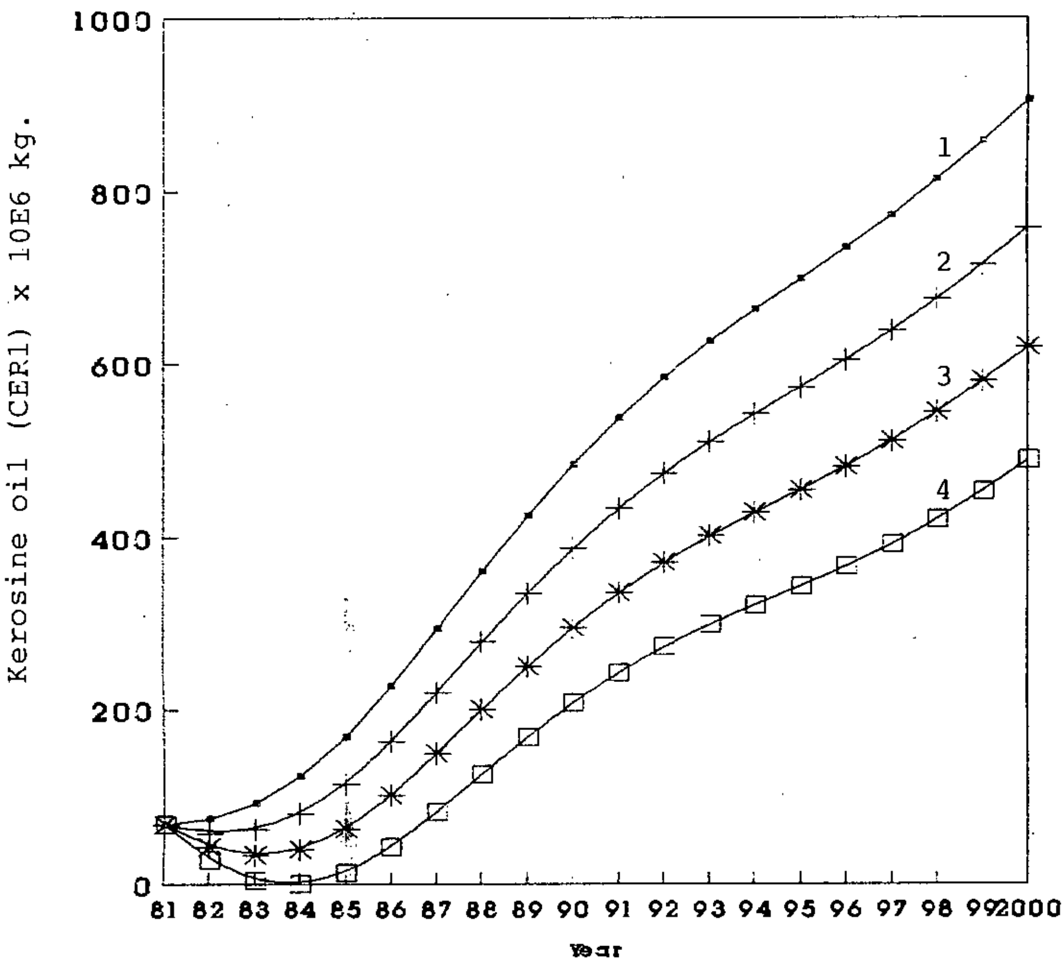


Fig. 7.25 Simulating results of kerosine required as an external fuel input (CER1) during the year of 1981–2000. (in basic mode 1 and in policy mode 2,3,4)

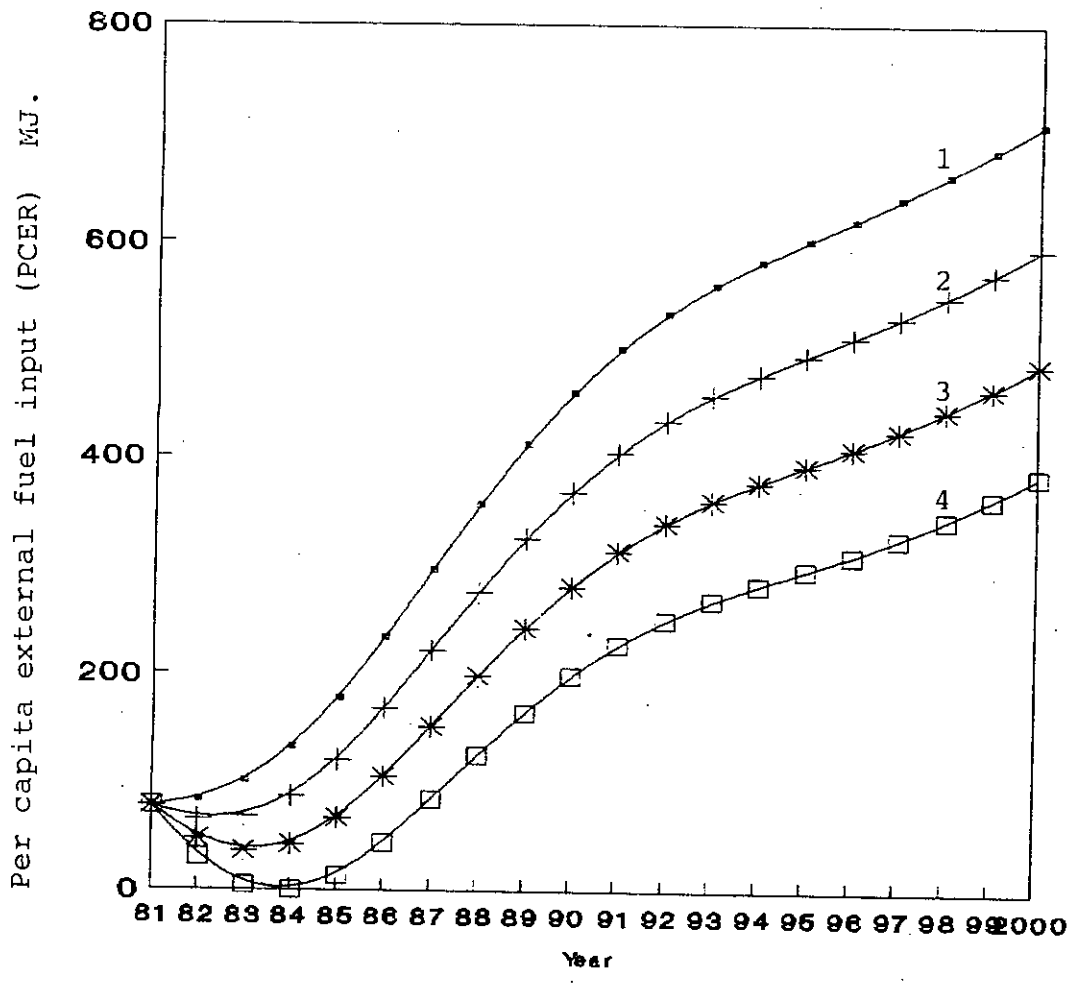


Fig. 7.26 Simulating results of per capita external fuel input required (PCER) during the year of 1981-2000. (in basic mode 1 and in policy mode 2,3,4)

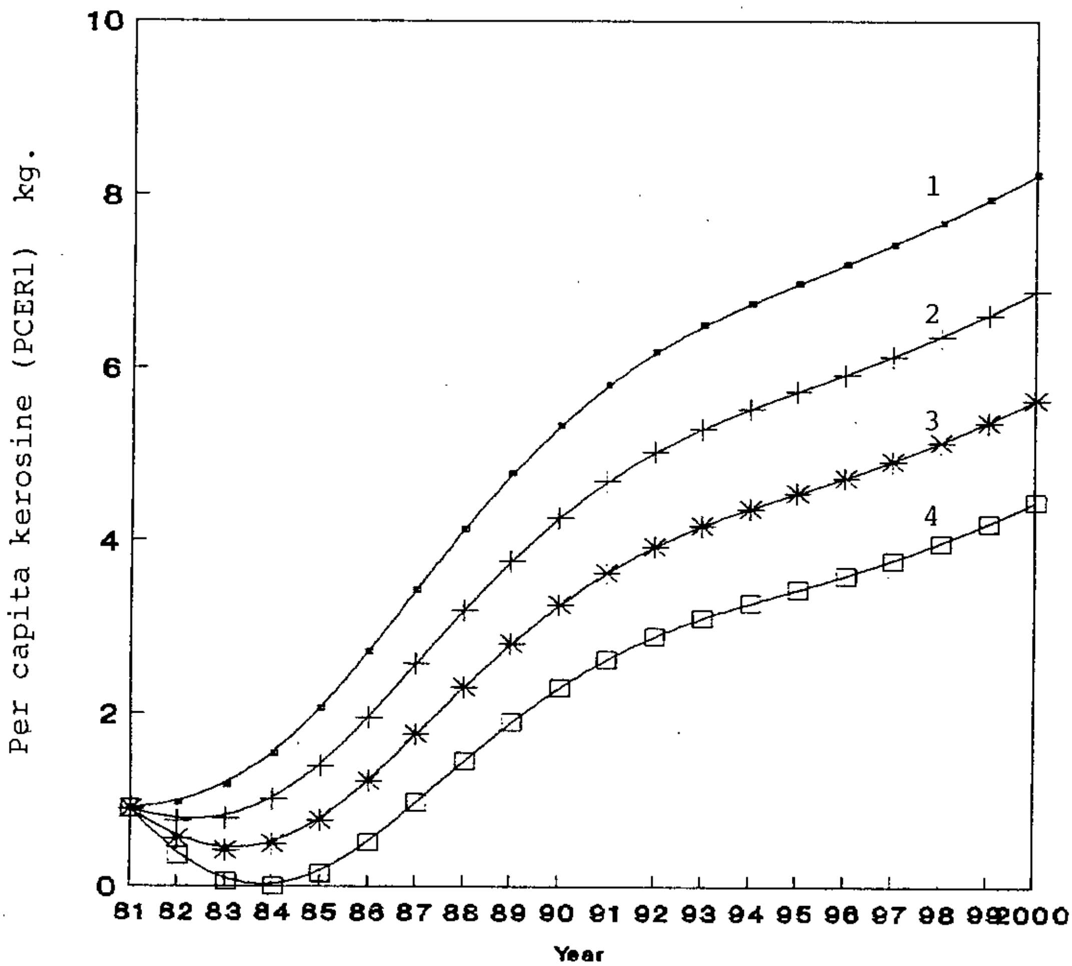


Fig. 7.27 Simulating results of per capita kerosine required as an external fuel input (PCER1) during the year of 1981-2000. (in basic mode 1 and in policy mode 2,3,4)

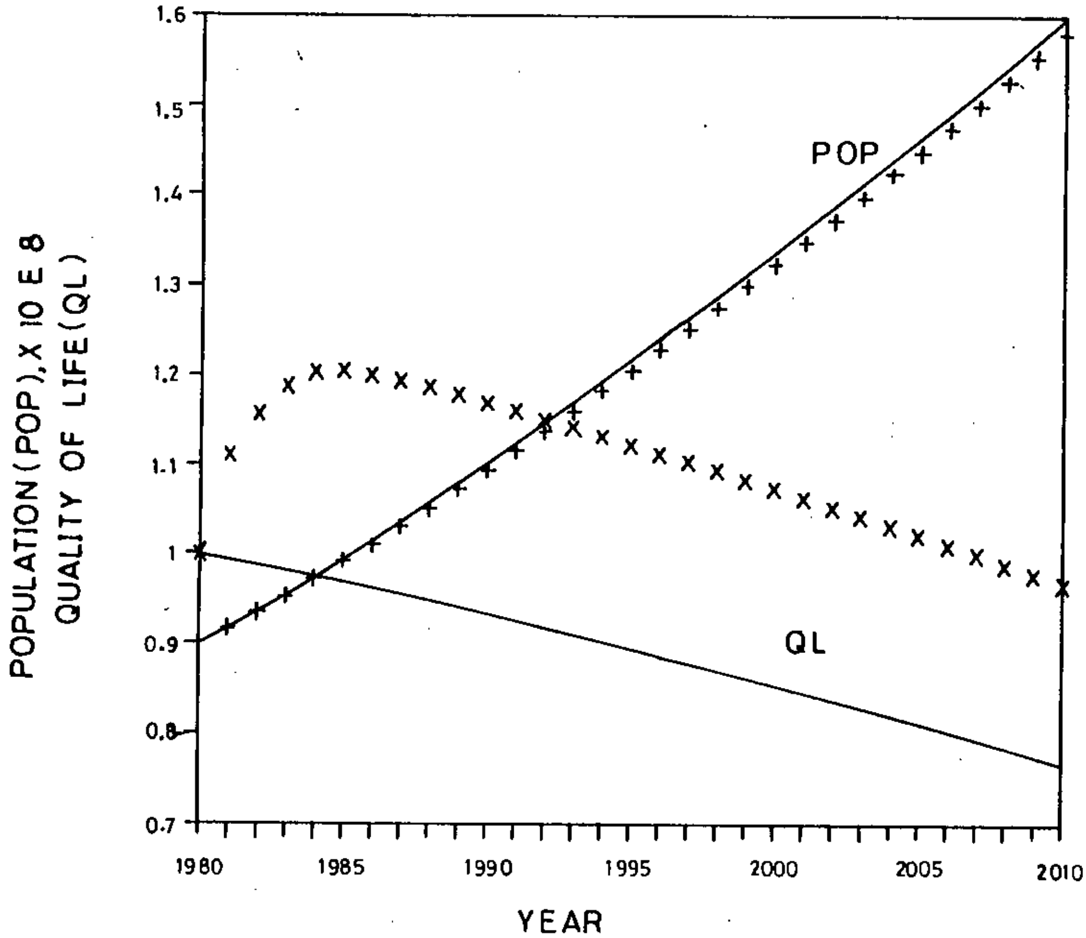


fig. 7.28 Population and Quality of Life During the period of 1980 2010.(——— Basic Mode and + + + +, x x x x Policy Mode).

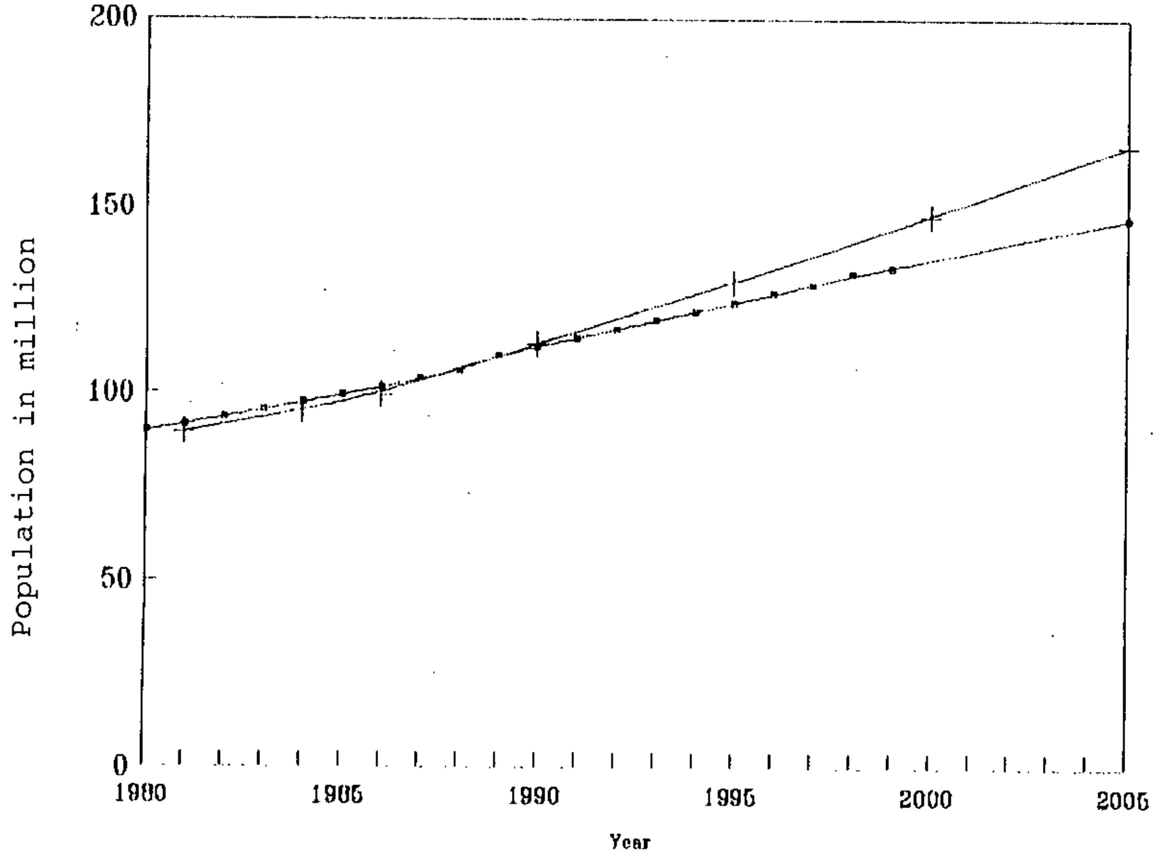


Fig. 7.29 Comparison of human population during the year 1980-2005.

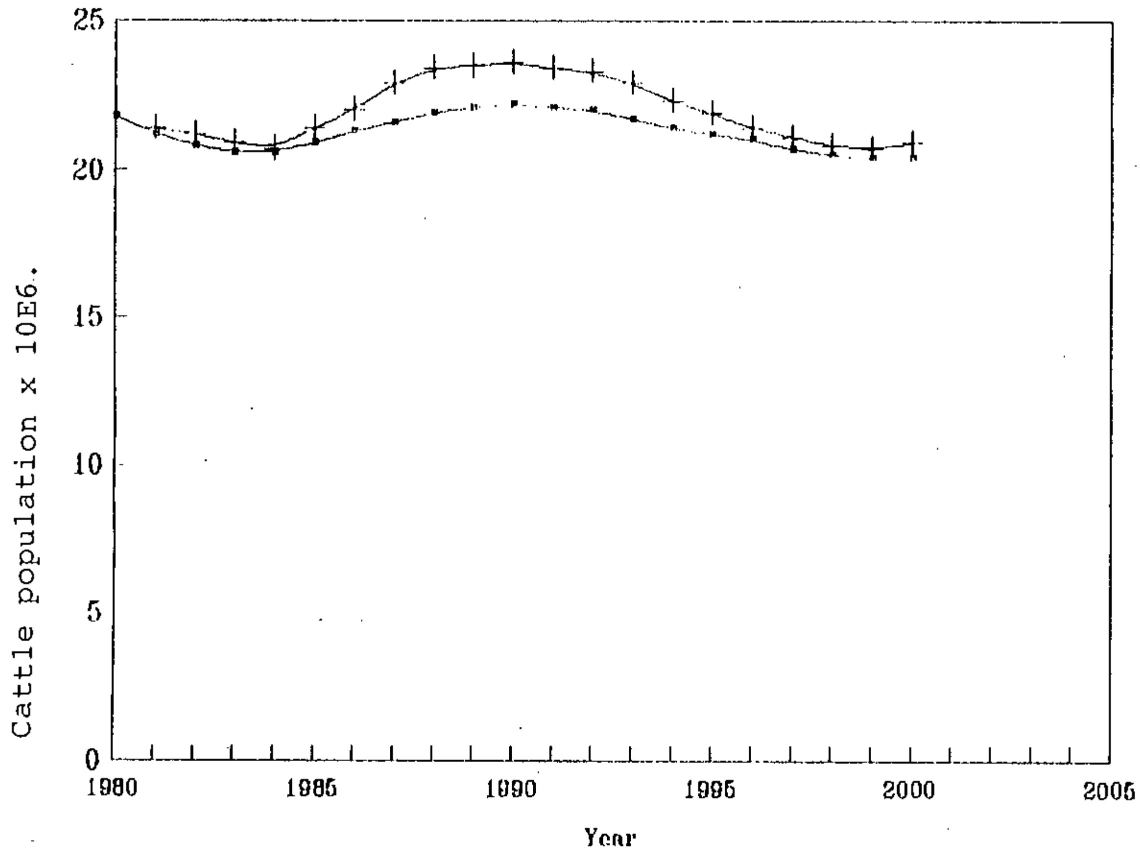


Fig. 7.30 Comparison of cattle population during the year 1980-2005.

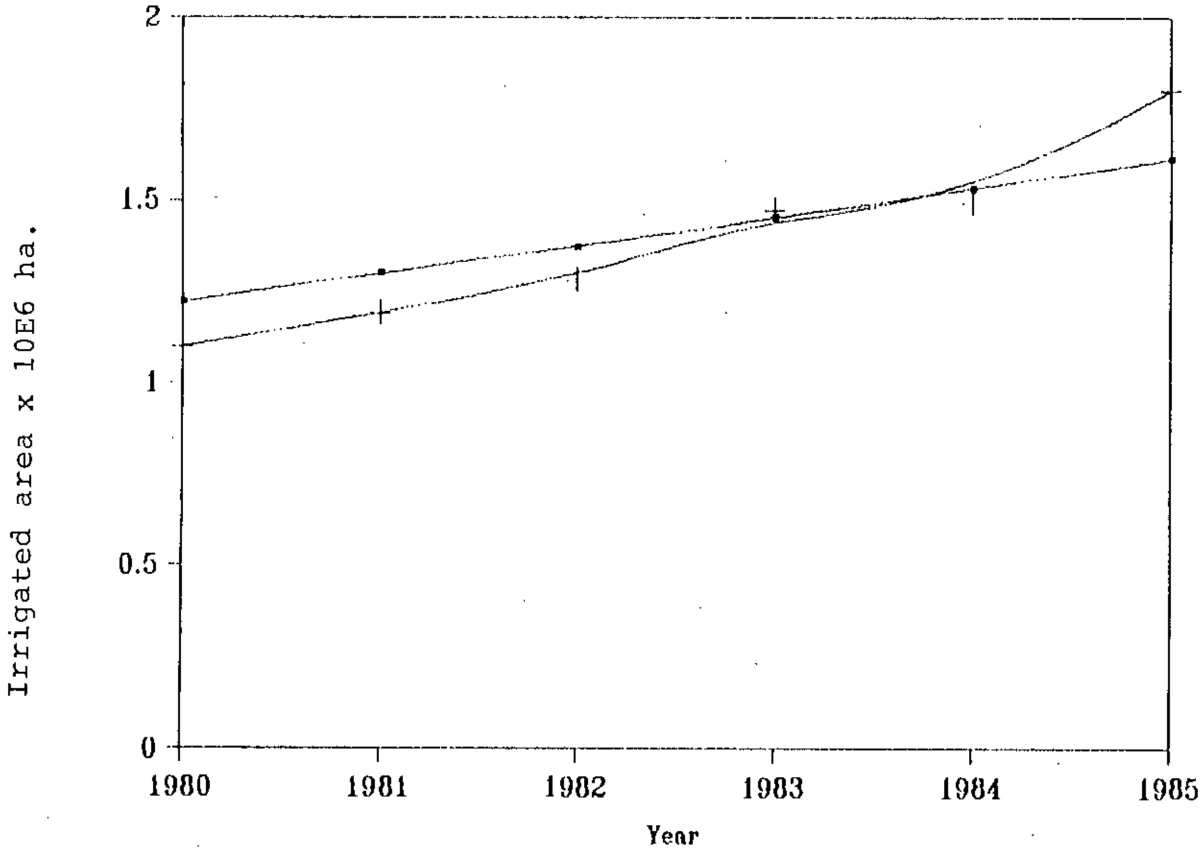


Fig. 7.31 Comparison of irrigated area during the year 1980-2005.

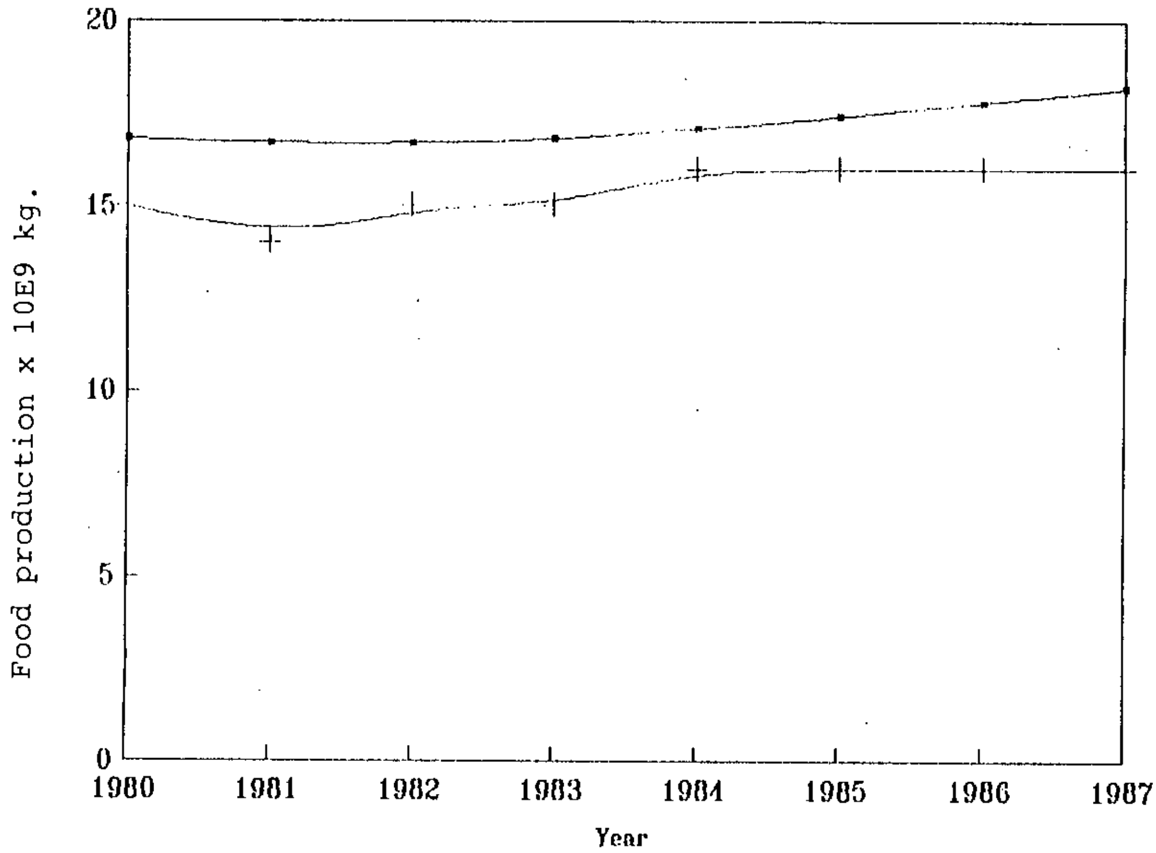


Fig. 7.32 Comparison of food production during the year 1980-1987

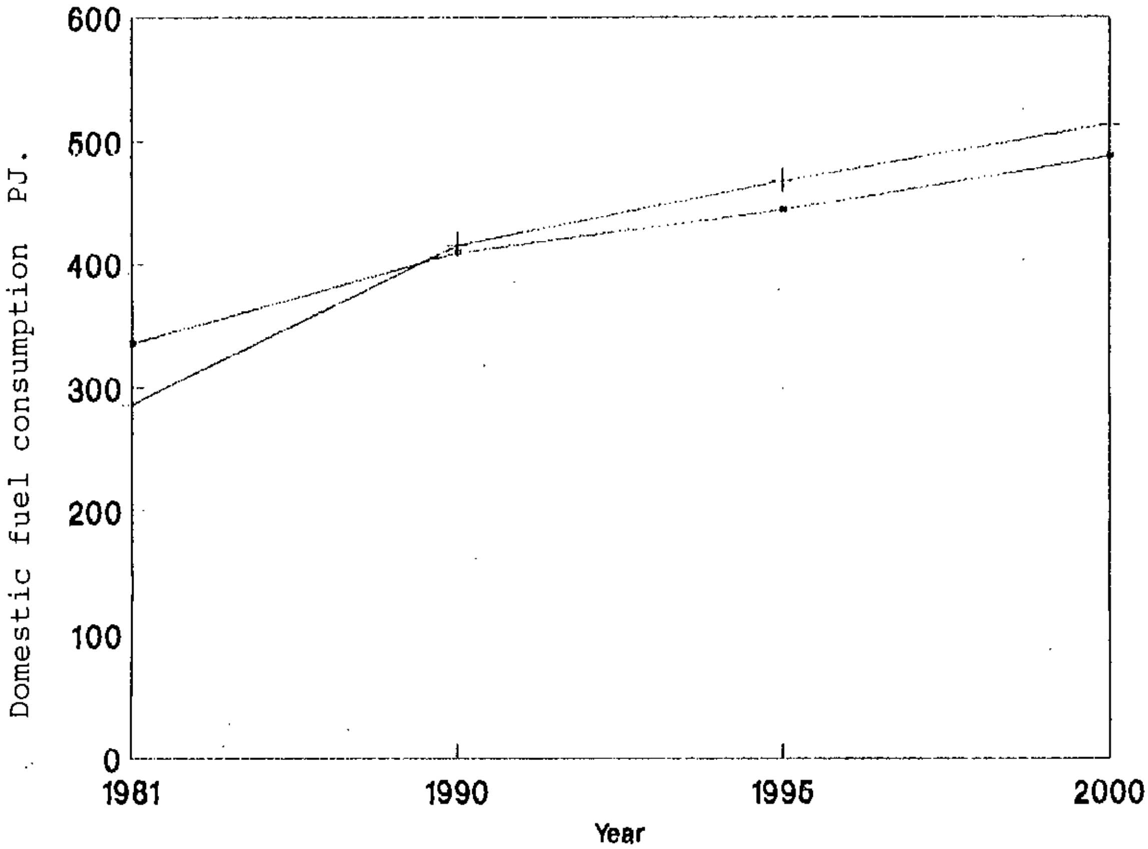


Fig. 7.33 Comparison of rural domestic fuel consumption during the year 1981 - 2000.

Table 7.2

Year-wise System Indicators (Population, Cattle, Irrigated Area, Food Production and Bio-fuel Consumption)

	Pop. x 10^6			Catt. x 10^6		Irri. Area x10^6ha			Food x 10^9 kg.			Biofuel PJ.	
Year	A	B	C	A	B	A	B	D	A	B	E	A	F
1980	89.9	-		21.8	-	1.22		1.10	16.8	-	15.0	-	
1981	91.7	87.4	89.7	21.2	21.4	1.30	1.25	1.19	16.7	14.6	14.6	334	337
1982	93.5	89.2	-	20.8	21.2	1.37	1.29	1.28	16.7	14.5	15.3	-	-
1983	95.5	91.1	95.2	20.6	20.9	1.45	1.32	1.47	16.8	14.4	15.7	-	-
1984	97.5	93.0	-	20.6	20.7	1.53	1.34	1.49	16.1	14.4	16.1	-	
1985	99.5	95.0	99.6	20.9	21.4	1.61	1.37	1.80	17.4	14.4	16.1	-	-
1986	101.3	97.0		21.3	22.0	1.70	1.39	-	17.8	14.7	16.2	-	-
1987	103.7	99.0		21.6	22.9	1.77	1.42	-	18.2	14.9	16.4	-	-
1988	105.8	101.1		21.9	23.4	1.87	1.44	-	18.5	15.3	-	-	-
1989	108.0	103.2		22.1	23.5	1.96	1.46		18.9	15.5		-	-
1990	110.2	105.1	113.0	22.2	23.6	2.05	1.47		19.1	15.6	-	408	487
1991	112.4	108.0		22.2	23.4	2.14	1.49	-	19.4	15.6	-	-	-
1992	114.7	109.9	-	22.0	23.[illegible]	2.24	1.51	-	19.5	15.6	-	-	-
1993	117.0	112.2	-	21.8	22.9	2.33	1.52	-	19.6	15.6	-	-	-
1994	119.4	114.6		21.4	22.5	2.43	1.54		19.8	15.5	-	-	-
1995	121.7	116.9	129.4	21.2	21.9	2.53	1.55	-	19.9	15.3	-	443	550
1996	124.1	119.4	-	21.0	21.4	2.63	1.56	-	20.0	15.1	-	-	-
1997	126.5	121.9		20.7	21.1	2.73	1.57	-	20.1	14.9	-	-	-
1998	128.9	124.4	-	20.5	20.8	2.83	1.58	-	20.3	14.9	-	-	-
1999	131.9	127.1		20.4	20.7	2.94	1.59		20.5	14.8		-	-
2000	133.4	129.7	147.3	20.4	20.9	3.05	1.60		20.7	14.8	-	487	604
2005	146.6		166.2										-

Source: A Present Study, B Bala [108], C- Mustaq [128], D- Statistical Year Book [129], E UNDP [130], & F- BEPP [10] (Approximately 85% of which may be assumed as rural domestic consumption)

The model predicts the generally observed phenomenon of increased food production with increased irrigated area coverage by exogenous policy input of irrigation. The pulsating behaviour of the simulated food production has been contributed by the possible limit cycle oscillation of the cattle production system which is mainly due to the inherent nonlinearity of the system. As the cattle population supplies the draft power for the tillage operation, this phenomenon is obvious as long as there is any deficit of draft power in any form. Again the cattle population is influenced by the availability of food in the form of straw and fodder which in turn supplies draft power and dung as fertilizer. Thus food production is closely related to animal production in Bangladesh and the pulsating behaviour of the quantum of food production can be ironed out possibly by the removal of the deficit in draft power. The simulated cattle population is not very different from the prediction of Dickey and Hoque [117], but shows limit cycle oscillation as explained above and has been subjected to ramp input of cattle importation.

The simulated results show that the total yearly average shortage draft power is 1.047×10^6 kW (0.1415 kW/ha). If the power tillers are used only to meet the estimated shortage of draft power, average 1,15,055 power tillers will be required. Where BEPP estimated 1,32,553 power tillers to meet the shortage of draft power.

Animal draft power and cowdung are an integral part of food production in Bangladesh which therefore should be utilized with considerable judgment [118,119]. Thus integrated energy system for food production should not only consider the animal draft power but also the full potentiality of animal dung and biogas production for the purpose of evaluating the whole system.

Crop residues, cattle dung, and tree biomass are the components of the rural cooking fuel. From the simulated projecting results, it is observed that per capita fuel supply from crop residues as well as cow dung are gradually reducing in nature due to the impact of the HYV, population growth, and reduction of cattle population. Village forest is the only source of tree biomass fuel. 2.1% of the total land area of Bangladesh is under village forest. Tree resources in village forest are managed by individual owners and have reached almost saturation point, which means that there is limited room for new plantations. For the short term policy planning, aforestation is not effective for biomass fuel contribution.

In 1981 tree biomass contribution is made 12.31% (41.78 PJ) to total rural cooking fuel consumption. At the end of the simulated period 2000, the contribution is 26% (490.5 PJ, Which is 10.74 times higher than 41.78 PJ), which ultimately makes deforestation gradually at higher rate. In order to maintain the profile of existing tree resources there is a need to supply additional energy input to the rural energetics from outside.

Fuel burning efficiency is highly sensitive to tree biomass consumption as well as deforestation.

Rural domestic energy production and consumption from tree plantation and biogas is also an important integral part of food production system and abundant supply in food and energy is essential to raise the quality of life. This implies that adoption of the proposed policy would provide better condition in terms of food, crowding and biogas existing in 1980.

For implementation of the model a continuing survey of parameters, constants, initial values and table functions are needed. The model should be continuously calibrated for the purpose of keeping it up to date. Finally it is concluded that this model would provide better understanding and greater insight into the system and the model in its present form can be used as a tool of policy analysis.

CHAPTER-VIII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The results of each of the sections have been discussed in detail in the relevant sections. The essential features of each of the main sections are now drawn together and their general implications are discussed. Finally, suggestions are put forward so as to provide possible directions of future research.

8.1 Summary

The purpose of this research is constructing an operational dynamic and interactive digital computer model that can simulate the process of rural energy system with respect to the interfaces of the components of the rural energy sector. This is done with a view to assess the Physical Quality of Life (PQLI) as a degree of development. The Rural area of Bangladesh at micro as well as macro level serve as the test case for the model.

The system dynamics methodology, which is a continuous form of simulation to deal with the micro as well as macro structure of higher-order, multiple-loop, non-linear complex socio-economic-technological systems was used for building the simulation model. The work has been carried out in the following stages:

(1) Structure of the model framework

As the foundation of rural energy system, infrastructure has been given special emphasis in this research. This research work developed the structure of rural energy system integrating crop production, bio-gas production, rural forest and agro-based industries with the aim of optimizing edible, salable and inflammable outputs to improve the quality of life. The model is capable of forming the basis for the development of a computer model by using system dynamics methodology and/or optimization technique. (chapter-IV)

(2) Mathematical model for PQLI

With a view to quantize the Physical Quality of Life (PQLI) as a function of per capita electrical as well as commercial energy consumption, this research work presented a set of mathematical models. (chapter-V)

(3) Quantitative analysis of micro-level rural energy systems

All of the outputs of the rural energy system are changing due to population growth, new agricultural technology and penetration of the market economy into rural areas. The traditional energy sources are not completely relied upon in areas where there has been widespread adoption of high yielding crop varieties and mechanization of agriculture. In this connection, with a view to assess the role of energy-use in micro level rural energy system has been investigated. This has been followed by an evaluation of household energy consumption, energy input and output of cropping system, animal energetics, solar conversion efficiency in cropping system, utilization of draft power and labour force, and, the resulting Physical Quality of Life.

Per capita major energy flow in the integrated rural energy model for the three typical villages of which two non-electrified (Ulipur, Sakoa), and one electrified village (Langulia) have been separately studied to investigate the energy flow situation of the micro level rural energetics. (chapter-VI)

(4) Formulation

A dynamic simulation approach with special flow charting technique and using special purpose programming language DYNAMO was identified for model formulation to be particularly suitable for this research. Its usefulness in studying different energetics which are characterized by large number of variables, non-linearities, feedback, delays, and data deficiency has been established by J. W. Forrester, Meadows, Hamilton, N. B. Forrester, and others as stated earlier. The insights into the rural energy system for refinement of the mental model were obtained through available information and discussion with the people familiar with the system. Finally, the mental models were converted to mathematical equations. The conversion

a. provides greater precision in description and identification of assumptions made in the study,

b. facilitates communication of the model to others, and

c. permits effective manipulation of the model.

Appendix A and B embody the model formulation for micro as well as macro level.

In this research, the rural energy system for farming has been formulated as a model in micro level, and five sub-models in macro level have also been formulated for different components in the farming sector. The output from this model supports the population, and generates the Modified Quality of Life (MQLI) as an indicator for the degree of development.(chap-VII)

(5) Simulating the rural energy system

The primary objective of this research is to simulate the rural energy system in micro as well as macro level in Bangladesh. The parameters, constants, and initial values used in the model are chosen to represent the present conditions of Bangladesh. The performances of the system has been evaluated by incorporating the alternative policies, and the model has been simulated to project the status of the system over an extended period of time. Several types of output variables are selected with a view to assess the system response as well as the impact of the policies. Some of the types of output are: total food, food per capita, irrigated area, draft power per hectare, draft power shortage, cooking fuel from rural forest, crop rasidue, cowdung, percentage of area deforestation, percentage of over cutting, energy need for preventing over cutting, percentage of cooking energy saved, percentage of commercial fertilizer saved, available amounts of organic fertilizer, biogas potential, biogas production, cattle population, power tiller requirement for pertial mechanization, human population and quality of life etc. These indicators are quity useful for performing the local or national rural energy system analysis in a system framework. Assessment of local or regional or national development may be made by assessing the quality of life which reflects the economic, social, technological, and institutional development.

The results of simulating the rural energy system for electrified rural energy system show that in micro level the total food production is nearly constant, the population increases almost 36%, and so the Modified Quality of Life Index (MQLI) reduces by about 27% over a period of 12 years (1990-2000). In macro level the total food production increases almost 38%, whereas the population increases about 78%, and the Modified Quality of Life Index (MQLI) reduces almost by 23% over a period of 30 years 1980-2010). (chapter VII)

<u>(6) A laboratory for rural energy system analysis</u>

The most important objective of this research was to demonstrate that a system dynamics model of rural energy system for farming can serve as a powerful planning laboratory where the probable impacts of various alternative policies can be simulated by performing controlled experiments using the model.

This has been accomplished by a set of tests to evaluate the policies. These policies are only a few of the wide range of policies that can be tested using the model. It will be appreciated that conducting experiments on the model, in many cases, does not require any more than changing the values of a few parameters, and running the model on the computer, which is quick and inexpensive.

The model, thus, serves as a laboratory where local or regional or national rural energy system analysis can be performed and the effects of alternative options based on social, technological, economic, or institutional considerations can be examined. The evaluation is based on the trends of the important indicator MQLI, which has already been discussed earlier. The adoption of any policy would exhibit its effects through changes in the values of some or all of the dynamic variables. These results are valuable guidelines for formulating policies and making rational choices amongst available alternatives while the options are still open.

8.2 Conclusions

From the previous discussions, the following conclusions can be drawn on the basis of the work done in this thesis:

1. Rural energy system may be evaluated in terms of energy dependent indicators: per capita cooking energy, per capita lighting energy, labour force participation in production,

food surplus index, fuel-fodder to food ratio, efficiency of animal energetics, input energy in croping energetics, solar conversion efficiency, and per capita energy consumption in rural energetics.

2. The results of simulating (in the basic mode) the rural energy system in Bangladesh at micro as well as macro level show that the population growth rate is higher than that of growth rate of food production, and the Physical Quality of Life declines in nature over the period. In macro level, the pulsating behaviour of the simulated food production has been contributed by the limit cycle oscillation of the cattle production.

3. Average draft power shortage has been estimated 1.047×10^6 kW (0.1415 kW/ha). The requirement of tillers for partial mechanization of agricultural system to meet the shortage of draft power has been estimated as 1,15,055 units.

4. Tree biomass is taking gradually larger share of total biomass fuel consumption which contributes in increasing the rate of deforestation.

5. Fuel burning efficiency is highly sensitive particularly to tree biomass consumption as well as deforestation.

6. However, in the policy mode the Physical Quality of Life in micro as well as macro level is found to improve significantly.

Therefore, a method of mathematical model for evaluating the rural energy system was obtained ultimately.

8.3 Recommendations

The present research work has established a systematic framwork for estimating various parameters related to rural energy system. There is a scope for further refinement and updating the findings of the study. Suggestions for updating model implementation and recommendations for future research are proposed as follows:

(a) Modification and extension of formulation of the model may be undertaken to include additional energy flow loops.

(b) Sensitivity analyses are needed, not only for identifying the priorities for data collection, but also for determining policy entry points for decision-makers.

(c) Continuing survey of specific rural areas of Bangladesh are needed to estimate the relevant parameters, constants, initial values, and table values.

(d) Continuous model calibration is needed for the purpose of keeping the model up-to-date and to cope with changes in development policies and environmental conditions.

e) Dynamic nature of the technological constant of Eq. (5.10) [PQLI=A LN (kWhr/cap)] may be investigated over a time period. The dynamic nature of the technological constant can be evaluated as a function of time [A=f(t)] which will incorporate the effect of energy use efficiency and mode of energy use in various forms.

f) For the most desirable system model, which would include the optimum combination of input policies, these system models should be optimized by presently available methods, such as linear programming, optimal control theory for obtaining the maximum possible Physical Quality of Life in the rural sector.

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A GUIDE TO THE APPENDICES

The technical aspects of the model developed in this thesis are given in the following four Appendices. Appendix A and B describe the logic of the model equations. Appendix C and D give a complete model listing in the computer code: DYNAMO, and Appendix E and F give a list of the variables, their definitions and the equations in which they are used. The four appendices provide sufficient technical detail for performing the appropriate experiments of this thesis.

The details of the computer code DYNAMO used in the model can be found in Professional DYNAMO-Plus User's Manual written by Alexander L. Pugh III and published by MIT press. Salient features of the code are described below.

1. Equation Form

A DYNAMO equation is written in the following form:

TYPE VARIABLE = EXPRESSION

TYPE is a single letter designating the type of variable being defined. Each equation is specified in the model by its TYPE. The following letters are used to designate TYPE.

- L for "level" equations representing accumulations
- R for "rate" equations representing rates of change of accumulations.
- A for "auxiliary" equations representing algebraic computations forming parts of rate equations.
- N for initial values of variables.
- T for "table functions" representing non-linear relationships between pairs of variable.
- C for constant parameters.
- S for "supplementary" equations used for computing variables for studying the output.

In addition, model simulation parameters such as solution interval, length of simulation, printing and plotting intervals for output, are specified by an equation TYPE designated as SPEC. Specifications can also be individually stated as C equations.

VARIABLE name is the specified abbreviation for the variable being defined by the equation. The name is followed by an appropriate timescript, depending on the TYPE of variable Levels, and auxiliaries have the timescript .K, rates have the timescript .KL. Levels are represented as difference equations, by adding the rate of change over the solution interval(DT) to the level at the past instant. The quantities at the past instant have transcripts .J (for levels) and .JK (for rates).

EXPRESSION is any algebraic expression. It may range from a simple number or single variable to a complicated combination of factors and terms involving functions, variables and numerical values. Each co-efficents, each prameters, and each initial values is constant, and each multipliers is variable.

2. Special Functions:

Several special functions have been built into DYNAMO in the form of MACROs. The special functions frequently used in the model are described below:

- SMOOTH — computes an exponential average of the variable or expression being operated upon by SMOOTH over a specified time interval.
- STEP — allows a step change in a quantity at a specified time and can be used in switching configurations for experimenting with the model.
- PULSE — introduces a momentary change in a quantity at a designated time, and is used in switching configurations similar to STEP.
- FIFGE — changes the value of a variable depending on the relative magnitudes of two designated variables, and can be used to change policy related variables at any desired instant, while performing policy tests with the model.

3. Flow Diagrams:

A FLOW DIAGRAM illustrates the postulated relationships between the elements in a model system. Main components of FLOW DIAGRAMS are shown in Tab. A-1

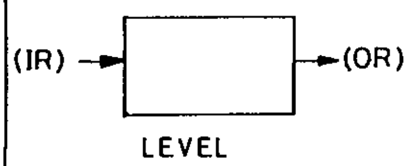
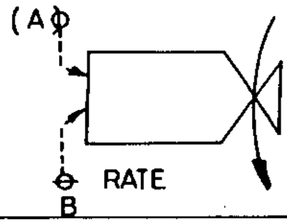
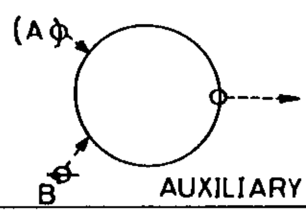
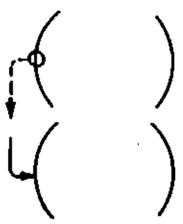
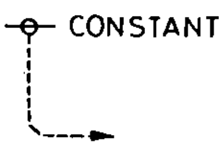
4. Technical Description of the Model

A detailed description of rural farming system energy model (micro-level as well as macro-level similar to Bangladesh) has been presented. As a result the user can satisfy himself about the assumptions from which follow the consequences of alternative strategies, policies and the programs for promoting energy utilization, economic and social development, and therefore the quality of life of the rural areas.

The description of the model is presented in the form of mathematical equation. The equations are written in DYNAMO programming language which is designed specially for system dynamics model.

In effect the model is a system of these mathematical

TABLE A-1 SYSTEM DYNAMICS SYMBOLS

SYMBOL	EXPLANATION
	A LEVEL is represented by a rectangular with the rates entering and/or leaving the level.
	A RATE is identified by a valve symbol with information inputs and physical flow.
	AN AUXILIARY is represented by a circle. It is a part of the rate equation.
	Variables from/to other diagrams are indicated with the origin or destination written within paranthesis.
	A CONSTANT or a PARAMETER is repres- -ented by an overline and its symbol.

(Source: Principles of systems by J.W. Forrester, Wright Allen Press, Cambridge, Mass, 1968) equations described in the perceived relationships between rural energy system variables. The point is that although it is believed that the equations do represent the central framework of the integrated energy system of farming activities of a village (Langulia) i.e. Micro-level and of rural Bangladesh i.e. Macro-level, the purpose, in general is to describe a method of Micro-level as well as Macro-level rural energy system analysis of rural farming activities.

APPENDIX - A

DESCRIPTION OF MODEL EQUATION OF AN ENERGY SYSTEM OF A VILLAGE IN BANGLADESH

a) Population Section

The population of the village Langulia is presented by a level of integrated equations which is the source of entire human muscle power for the farming:-

```
L   PO.K =  PO.J + DT*PGR.JK
N     PO = IPO
C    IPO = 1121
```

```
where      PO = POPULATION                  (PERSONS)
          PGR = GROWTH RATE OF POPULATION(PERSONS/YEAR)
          IPO = INITIAL POPULATION          (PERSONS)
```

PO is the level variable. It is being added by growth rate. The population growth rate is determined by manipulation of population (level) and the percentage of population growth due to birth and death:-

```
R  PGR.KL = PO.K*GP
C      GP = 2.5
```

```
where     PGR = POPULATION GROWTH RATE    (PERSONS/YEAR)
           PO = POPULATION                (PERSONS)
           GP = PERCENTAGE OF PO. GROWTH (DIMENSIONLESS)
```

b) Crop Production Section

The crop production system is mainly concerned with the production of food grain and straw. The straw is primarily used as cattle feed. The major inputs of crop production are draft power, irrigation, fertilizer, and human energy. Crop production can be increased either by increasing the crop area or the yield. Since the land is limited, crop production must be increased by using high-yield varieties in conjunction with irrigation and use of fertilizers. The yield is influenced by draft power from animal system. The animal system, in turn, is influenced by crop production. Thus, crop production system forms a closed loop with animal production system.

The crop production(CP) is calculated by the multiplication of cultivated land (AR), yield normal (YN), productivity multiplying factors i.e. yield multiplier (YM) and tillage multiplier (TM), (as described in Sec. c later):-

```
A     CP.K = AR*YN*YM.K*TM.K
C       AR = 103
C       YN = 4474
```

where		
	CP = TOTAL CROP PRODUCTION	(KG/YEAR)
	AR = CULTIVATED AREA	(HA)
	YN = YIELD/UNIT OF LAND	(KG/HA)
	TM = TILLAGE MULTIPLIER	(DIMENSIONLESS)
	YM = YIELD MULTIPLIER	(DIMENSIONLESS)

Food energy (EH) is obtained from crop by the multiplication of total crop (CP) and energy co-efficient (FC):-

```
A     EH.K = CP.K*FC
C       FC = 527E-3
```

where		
	EH = FOOD ENERGY	(GJ/YEAR)
	CP = TOTAL CROP PRODUCTION	(KG/YEAR)
	FC = ENERGY CONTENT/KG	(GJ/KG)

Food energy per capita is determined by the devision of food energy (EH) by population (PO) and number of days of a year:-

```
A     FD.K = EH.K/(POP.K*DA)
C       DA = 365
```

where		
	FD = FOOD PER CAPITA	(GJ/DAY)
	EH = FOOD ENERGY	(GJ/YEAR)
	PO = POPULATION	(HEADS)
	DA = DAYS OF A YEAR	(DAY)

Straw (ST) from crop production can be calculated by the multiplications of croping intensity (CI), cultivated area (AR) and straw co-efficient (SF):-

```
A     ST.K = CI.K*AR*SF
C       AR = 103
C       SF = 1950
```

where		
	ST = STRAW	(KG/YEAR)
	CI = CROPING INTENSITY	(DIMENSIONLESS)
	AR = CULTIVATED AREA	(HA)
	SF = STRAW/UNIT OF LAND	(KG/HA)

Energy from straw (EA) can be calculated by the multiplication of straw (ST) and energy co-efficient of straw (FA):-

```
A     EA.K = ST.K*FA
C       FA = 18.738E-3
```

where		
	EA = FEED ENERGY	(GJ/YEAR)
	ST = STRAW	(KG/YEAR)
	FA = ENERGY/KG OF STRAW	(GJ/KG)

c) Yield Multiplier Factor

Yield Multiplier Factor (YM) is presented by a level or integral equation. It is added by the difference of yield regeneration rate (YR) and yield degeneration rate (YD):-

```
L     YM.K = YM.J+DT*(YR.JK-YD.JK)
N       YM = IYM
C      IYM = 1
```

where		
	YM = YIELD MULTIPLIER	(DIMENSIONLESS)
	IYM = INITIAL YIELD MULTIPLIER	(DIMENSIONLESS)
	YR = YIELD REGENERATION RATE	(DIMENSIONLESS)
	YD = YIELD DEGENERATION RATE	(DIMENSIONLESS)

The yield multiplier factor (YM) has been introduced in this model to consider the long term affect of cultivation. When the pressure for food increases, the demand for more food necessisates more areas under cultivation. But when there is no choice of expanding area, only alternative remains to increase cultivation intensively which increases the cropping intensity. Every land degenerates its capability at certain rate with cultivation, and every land has a certain natural regeneration capacity. In this model YM has been assumed consistent with present cultivation practices and fertilizer levels. Yield will be changed over time according to YM :-

Yield Rergeneration

```
R   YR.KL = (1-YM.K)/YT.K
A    YT.K = TABHL(YTT,YM.K,0,1,.2)
T     YTT = 120/80/45/20/8/1
```

where		
	YR = YIELD REGENERATION RATE	(DIMENSIONLESS)
	YT = YIELD REGENERATION TIME	(YEARS)
	YTT = YIELD REGENERATION TIME TABLE	(FIG. A-1)

In this model yield regeneration rate has been assumed as a function of yield multiplier factor itself. As the land has

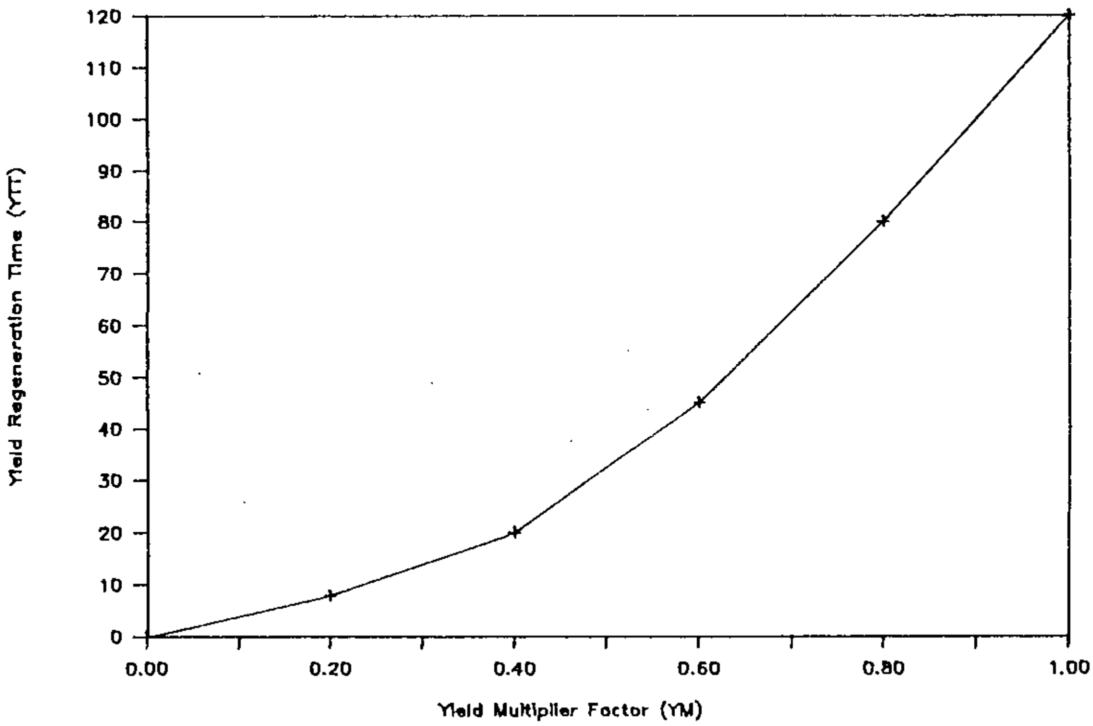


Fig. A-1 Yield Multiplier Factor vs.Yield Regeneration Time.

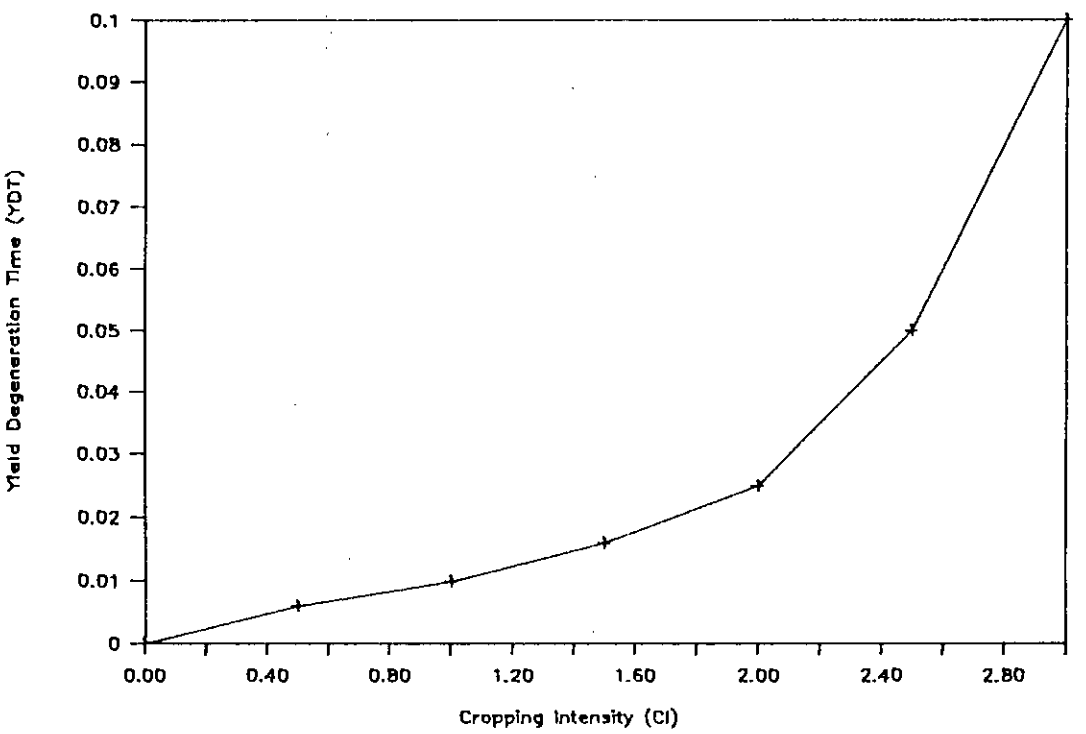


Fig. A-2 Cropping Intensity vs. Yield Degeneration Time.

more and more potential productivity it will take less and less time to recover the loss. But as the potential productivity decreases yield regeneration time increases. The yield multiplier factor has the value of unity when there is no loss in productivity.

Yield Degeneration

```
R    YD.KL = TABHL(YDT, CI.K, 0, 300, 50)
T      YDT = 0.0/.006/.01/.016/.025/.05/.1
```

where YD	= YIELD DEGENERATION RATE	(DIMENSIONLESS)
YDT	= YIELD DEGENERATION RATE TABLE	(FIG. A-2)
CI	= CROPPING INTENSITY	(DIMENSIONLESS)

Yield degeneration has been assumed as a function of cropping intensity. When there is no cultivation, there is no loss in potential productivity. As the cultivation becomes intensive, the productive capacity loss increases steeply. The absolute values as shown in the table are the fractional potential productivity loss at that particular cropping intensity. The inverse of these values will give the years needed to render the land unproductive, if under continuous cultivation at that cropping intensity. The cropping intensity/yr is obtained from the following equation :-

```
A    CI.K = TABHL(CIT, YRT.K, 0, 12, 2)
T     CIT = 2/2.3/2.6/2.8/2.9/3.0/3.0
```

where CI	= CROPPING INTENSITY	(DIMENSIONLESS)
CIT	= CROPPING INTENSITY TABLE	(FIG. A-3)
YRT	= TIME	(YEAR)

Increasing additional agricultural product necessity increasing cropping intensity upto 300% over a period of 12 years. The time period (YRT) is a level variable and is presented by an integral equation :-

```
L   YRT.K = YRT.J+DT*1
N     YRT = IYRT
C    IYRT = 1988
```

where YRT	= TIME	(YEAR)
IYRT	= INITIAL TIME	(YEAR)

d) Animal-production System

The animal-production system provides cow-dung, which is supplied to the biogas system, also provides draft power. Cattle

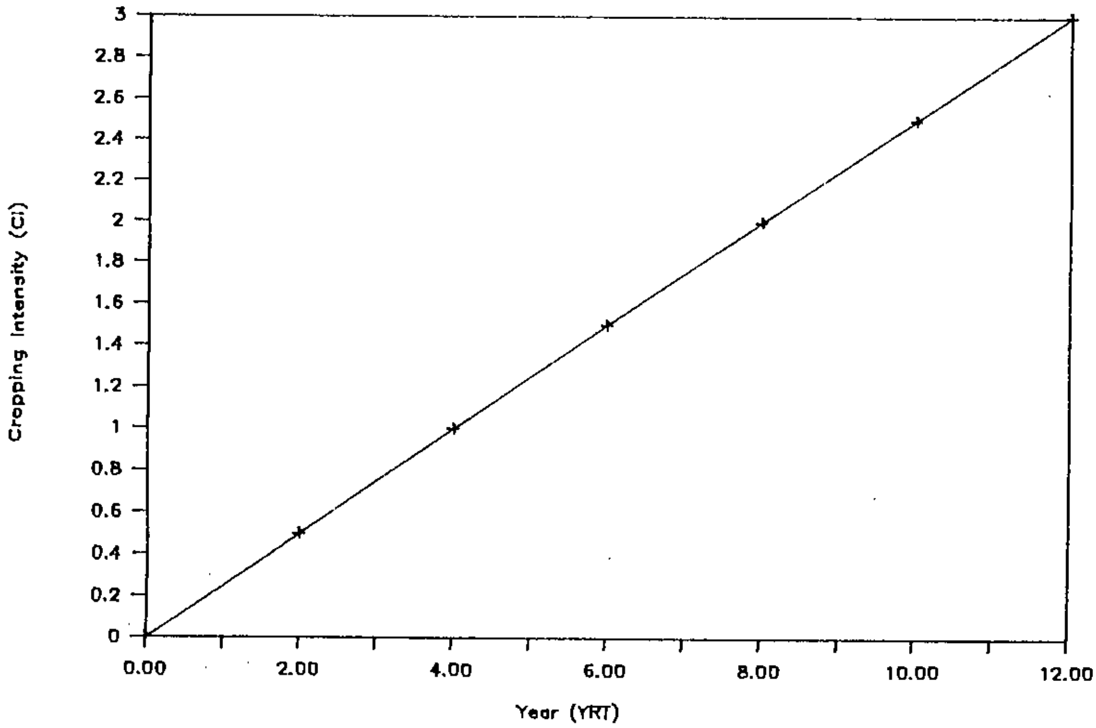


Fig. A-3 Time vs. Cropping Intensity.

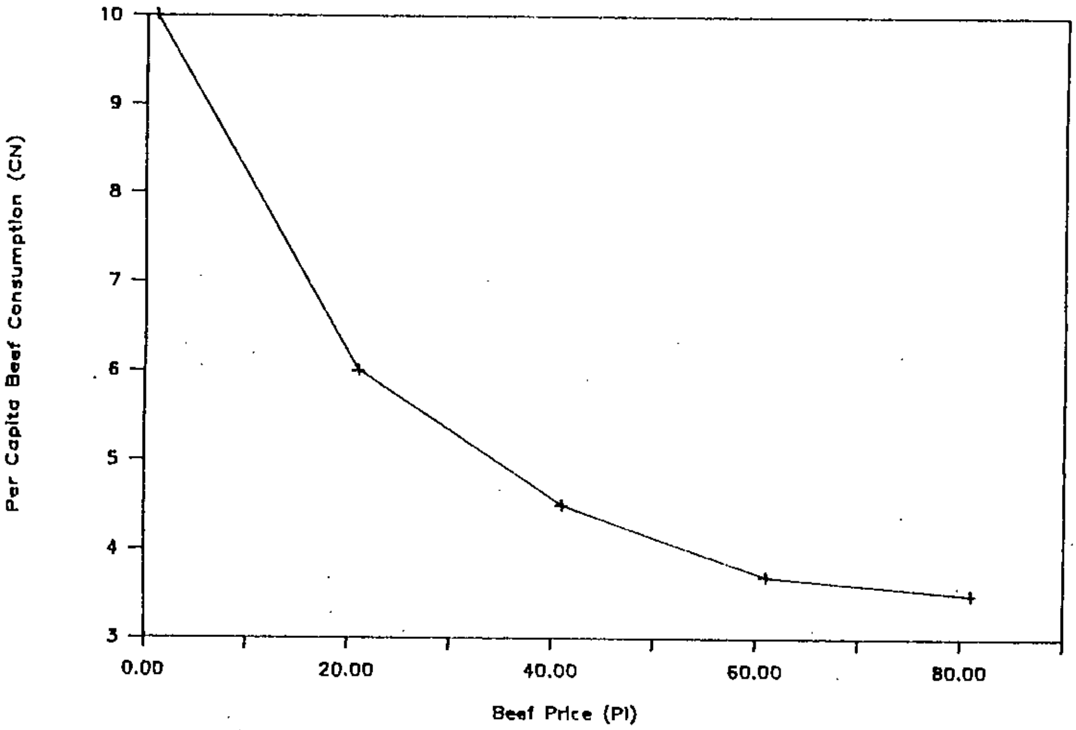


Fig. A-4 Beef Price vs. Per-Capita Beef Consumption.

production, consumption and aquisition determine the level or inventory of the cattle which is presented by the integral equation :-

```
L     CT.K = CT.J+DT*(DBR.J+TR.JK-CR.JK)
N       CT = ICT
C      ICT = 328
```

where	CT =	INVENTORY OF THE CATTLE	(HEADS)
	ICT =	INITIAL VALUE OF CATTLE INVENTORY	(HEADS)
	DBR =	PRODUCTION RATE AFTER DELAY	(HEADS/YR)
	TR =	AQUISITION RATE	(HEADS/YR)
	CR =	CONSUMPTION RATE	(HEADS/YR)

Third order delay is assumed in cattle production system. The maturity time for a cattle is assumed to be 2.5 years. The production rate is determined by the multiplication of the inventory of the cattle and breeding co-efficient (CE):-

```
A     DBR.J = DELAY3(CT.K*CE,DL3)
C        CE = 17.5
C       DL3 = 2.5
```

where	DBR =	PRODUCTION RATE AFTER DELAY	(HEADS/YR)
	CT =	INVENTORY OF CATTLE	(HEADS)
	CE =	PERCENTAGE OF PRODUCTION	(DIMENSIONLESS)
	DL3 =	MATURATION DELAY PERIOD	(YEAR)

The consumption rate (CR) is given by the per capita consumption times the total population :-

```
R     CR.KL = (CN.K*PO.K)/WB
C        WB = 120
```

where	CR =	CONSUMPTION RATE	(HEADS/YR)
	CN =	PER CAPITA CONSUMPTION	(KG/YR)
	PO =	POPULATION	(HEADS)
	WB =	WEIGHT PER CATTLE	(KG)

The annual per capita consumption (CN) is assumed to be the function of price (PI). The assumed relationship is shown in figure A-4 :-

```
A     CN.K = TABHL(CNT, PI.K, 1, 81, 20)
T      CNT = 10/6/4.5/3.7/3.5
```

```
where       CN = PER CAPITA CONSUMPTION              (KG/YR)
           CNT = PER CAPITA CONSUMPTION TABLE        (FIG. A-4)
            PI = CURRENT PRICE                       (TAKA)
```

The functional relationship assumed between inventory of cattle and its price is shown in Figure A-5 :-

```
A    PI.K = TABHL(PIT, CT.K, 0, 600, 100)
T     PIT = 11250/6750/4500/4050/2250/1125
```

```
where       PI = CURRENT PRICE                       (TAKA)
            CT = INVENTORY OF THE CATTLE             (HEAD)
           PIT = PRICE TABLE                         (FIG. A-5)
```

The current rate of change in the expected price C as proposed by Narlove [56,57] is proportional to the difference between recent expected value and recent actual price. There is a time lag for a producer to adjust his expectations to a change in the actual value. In this model farmers' expected-price adjustment delay has been assumed to be equal to 0.5 years :-

```
A    ER.KL = (PI.K-EP.K)/ED
C       ED = 0.5
```

```
where       ER = RATE OF CHANGE OF EXPECTED          (TAKA/YR)
                 PRICE
            PI = CURRENT PRICE                       (TAKA)
            EP = EXPECTED PRICE                      (TAKA)
            ED = ADJUSTMENT DELAY                    (YEAR)
```

Expected price (EP) is the level variable which is presented by an integral equation :-

```
L    EP.K = EP.J+DT*ER.JK
N      EP = IEP
C     IEP = 4500
```

```
where       EP = EXPECTED PRICE                      (TAKA)
           IEP = INITIAL EXPECTED PRICE              (TAKA)
            ER = RATE OF CHANGE OF EXPECTED          (TAKA/YR)
                 PRICE
```

Desired stock is an equilibrium concept.[57] It specifies the amount of stock which would be maintained in the long run, if the price were to remain at its currently expected level. However, there are constraints on fodder availability. The desired stock (PN) is calculated by the multiplication of

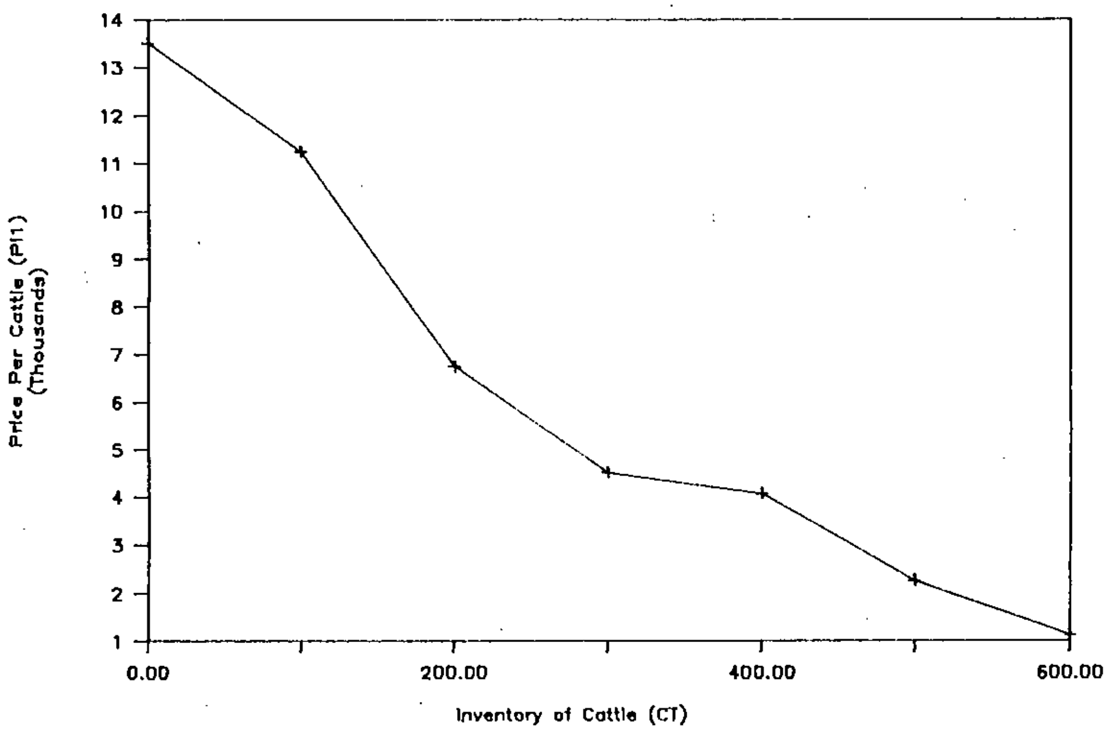


Fig. A-5 Inventory of Cattle vs. Beef Price.

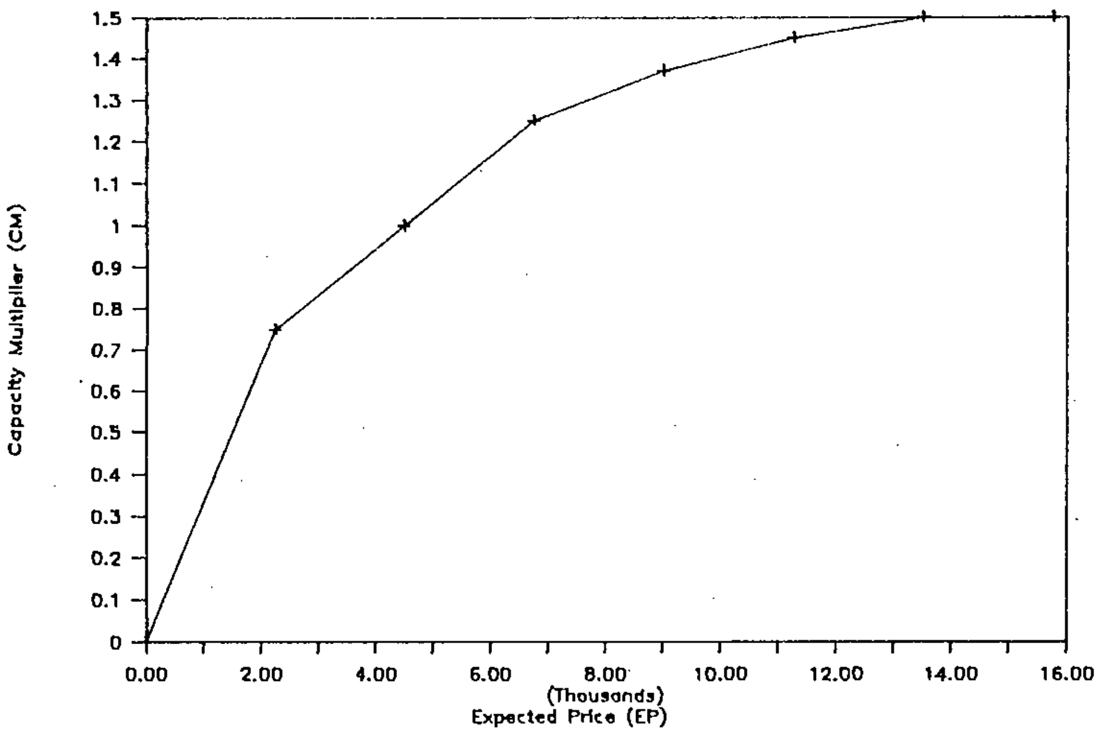


Fig. A-6 Expected Price vs. Capacity Multiplier.

current stock (PD), straw multiplier (SM) and capacity multiplier (CM):-

```
A     PN.K = PD*CM.K*SM.K
C       PD = 328

where      PN = DESIRED STOCK                      (HEADS)
           PD = INITIAL STOCK                      (HEADS)
           CM = CAPACITY MULTIPLIER                (DIMENSIONLESS)
           SM = STRAW MULTIPLIER                   (DIMENSIONLESS)
```

The rate of change of stock aquisition rate (TR) is proportional to the difference between the desired stock and the current stock. There is a time lag for aquisition to adjust the desire:-

```
R     TR.K = (PN.K-CT.K)/AT
C       AT = 0.5

where      TR = AQUISITION RATE                    (HEADS/YR)
           PN = DESIRED STOCK                      (HEADS)
           CT = INVENTORY OF THE CATTLE            (HEADS)
           AT = TIME DELAY                         (YEAR)
```

In this model the capacity multiplier (CM) has been assumed as a function of expected price (EP). This functional relationship is shown in Figure A-6 :-

```
A     CM.K = TABHL(CMT, EP.K, 0, 15750, 2250)
T      CMT = 0/0.75/1.25/1.37/1.45/1.50/1.50

where      CM = CAPACITY MULTIPLIER                (DIMENSIONLESS)
          CMT = CAPACITY MULTIPLIER TABLE          (FIG. A-6)
           EP = EXPECTED PRICE                     (TAKA)
```

Straw per cattle (SI) which is determined by dividing the straw (ST) by the inventory of cattle (CT) and by averaging over a period of one year (three sixty days):-

```
A     SI.K = ST.K/(CT.K*365)

where      ST = STRAW                              (KG/YEAR)
           SI = STRAW PER CATTLE PER DAY           (KG/HEAD/DAY)
           CT = INVENTORY OF CATTLE                (HEADS)
```

Draft animal per hactare (TL) is obtained by dividing inventory of cattle (CT) by cultivated area (AR):-

```
A     TL.K = CT.K/AR
C       AR = 103
```

where	TL = DRAFT ANIMAL PER HECTARE	(HEAD)
	CT = INVENTORY OF THE CATTLE	(HEAD)
	AR = CULTIVATED AREA	(HA)

The straw multiplier (SM) is a function of straw per cattle (SI). This functional relationship is shown in Figure A-7 :-

```
A     SM.K = TABHL(SMT, SI.K, 0, 9, 1)
T      SMT = 0.5/0.75/0.9/1/1.2/1.27/1.31/1.35/1.4/1.4
```

where	SM = STRAW MULTIPLIER	(DIMENSIONLESS)
	SMT = STRAW MULTIPLIER TABLE	(FIG. A-7)
	SI = STRAW PER CATTLE PER DAY	(KG/HEAD/DAY)

Tillage multiplier (TM) is related to the draft animal per hectare (TL) in the manner shown in Figure A-8 :-

```
A     TM.K = TABHL(TMT, TL.K, 0, 5, 0.5)
T      TMT = 0.25/0.52/0.75/0.95/1/1/1/1/1/1/1
```

where	TM = TILLAGE MULTIPLIER	(DIMENSIONLESS)
	TMT = TILLAGE MULTIPLIER TABLE	(FIG. A-8)
	TL = DRAFT POWER PER HACTARE	(HEAD)

e) Fuel Section

The proposed biogas production system supplies biogas as a fuel for cooking and therefore reduces the pressure on rural forest and also diminishes pollution. This process, in turn, reduces ecological imbalance. Fuel requirement(FR) is given by per capita fuel consumption (FU) multiplied by the total population (PO) :-

```
A     FR.K = PO.K*FU
C       FU = 4.2
```

where	FR = FUEL REQUIREMENT	(GJ)
	PO = POPULATION	(HEAD)
	FU = PER CAPITA FUEL CONSUMPTION	(GJ)

Biogas (BG) production is determined by the biogas production (PR) and depreciation rate (RR). This is assumed level variable and is represented by an integral equation :-

```
L     BG.K = BG.J+DT*(PR.JK-RR.JK)
N       BG = IBG
I      IBG = 1
```

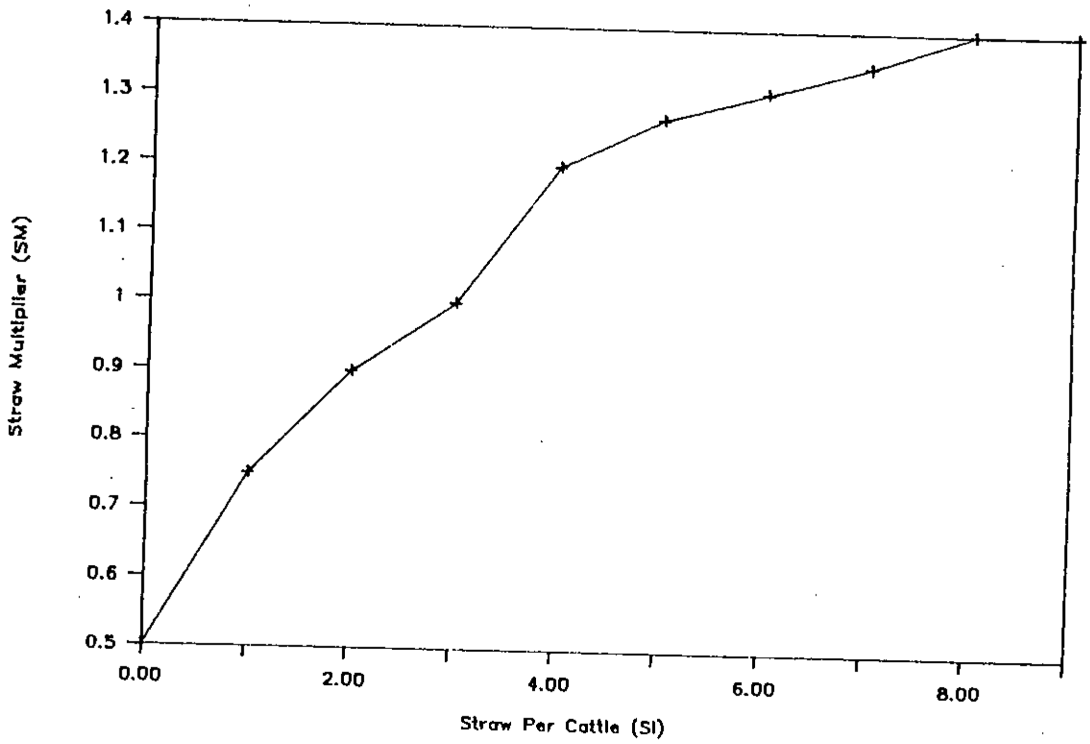


Fig. A-7 Straw Per Cattle vs. Straw Multiplier.

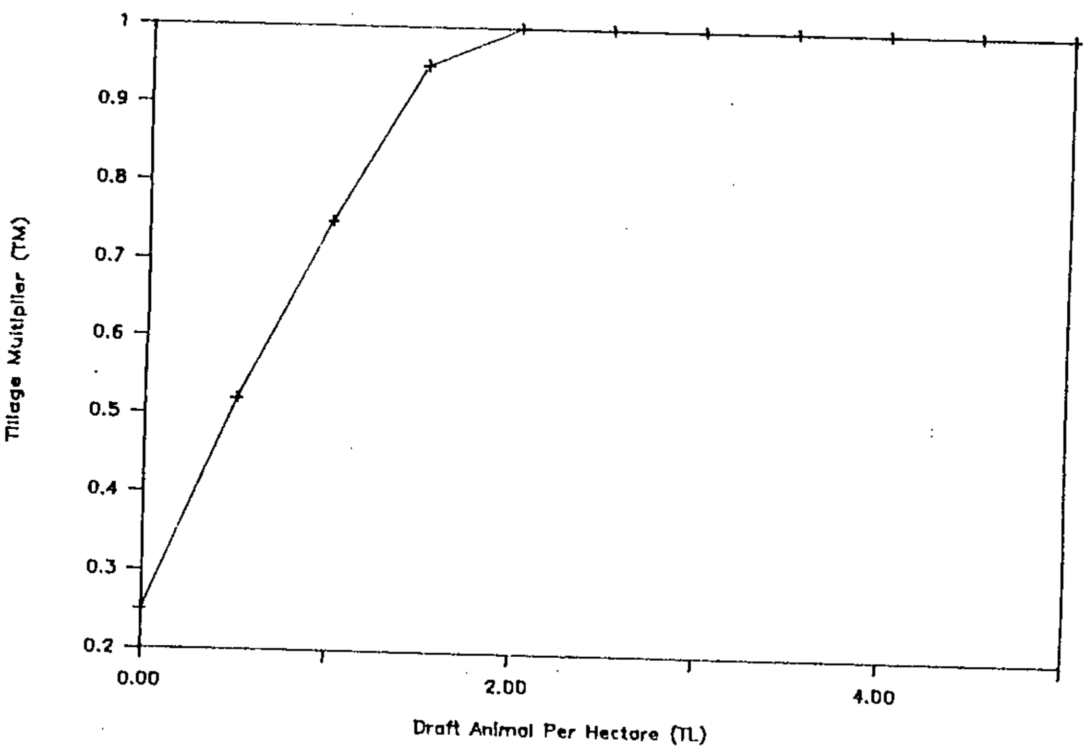


Fig. A-8 Draft Animal Per Hectare vs. Tillage Multiplier.

```
where      BG = ASSUMED INVENTORY OF BIOGAS    (GJ)
          IBG = INITIAL LEVEL OF BIOGAS        (GJ)
           PR = BIOGAS PRODUCTION RATE         (GJ/YR)
           RR = BIOGAS DEPRECIATION RATE       (GJ/YR)
```

The biogas production rate (PR) is proportional to the difference between the biogas potential (BP) and the inventory of biogas and the proportionality of constant is a fraction which is arbitrarily assumed :-

```
R     PR.KL = (BP.K-BG.K)*PF
C        PF = 0.30

where      PR = BIOGAS PRODUCTION RATE          (GJ/YR)
           BP = BIOGAS POTENTIAL                (GJ)
           BG = ASSUMED INVENTORY OF BIOGAS     (GJ)
           PF = FRACTION                        (DIMENSIONLESS)
```

The biogas depreciation rate depends upon the inventory of biogas production and the life-time of biogas digester :-

```
R     DR.KL = BG.K*PR
C        RR = 0.10

where      DR = DEPRECIATION RATE               (GJ/YR)
           BG = CURRENT INVENTORY OF BIOGAS     (GJ)
           RR = LIFE-TIME OF BIOGAS DIGESTER    (YEAR^-1)
```

The estimated energy from forest (RU) is the difference between the total fuel requirement (FR) and the current level of biogas (BG) production :-

```
A     RU.K = FL.K-BG.K
where      RU = ENERGY FROM FOREST              (GJ)
           FL = FUEL REQUIREMENT                (GJ)
           BG = CURRENT INVENTORY OF BIOGAS     (GJ)
```

Biogas potential is calculated by multiplying cattle dung (DG) with the energy co-efficient (GF) :-

```
A     BP.K = DG.K*GF
C       GF = 0.73E-3

where      BP = BIOGAS POTENTIAL                (GJ)
           DG = CATTLE DUNG                     (KG)
           GF = ENERGY CONTENT/KG DUNG          (GJ/KG)
```

The cattle dung (DG) is estimated by multiplying inventory of cattle (CT) with the dung co-efficient (GF) over a period of one year (ND) :-

```
A     DG.K = CT.K*FG*ND
C       FG = 3.5
C       ND = 365
```

where		
	DG = CATTLE DUNG	(KG/YR)
	FG = DUNG/ CATTLE	(KG/CATTLE)
	ND = TIME PERIOD	(DAYS)

The organic fertilizer i.e. Nitrogen (NN), Phosphorus (PP) and Potassium (KK) is calculated by multiplying the cattle dung (DG) with their respective co-efficients (NF1, PF1 and KF1) :-

```
A     NN.K = DG.K*NF1
A     PP.K = DG.K*PF1
A     KK.K = DG.K*KF1
C      NF1 = 0.1
C      PF1 = 0.3
C      KF1 = 0.2
```

where		
	NN = NITROGEN	(KG/YR)
	PP = PHOSPHORUS	(KG/YR)
	KK = POTTASIUM	(KG/YR)
	DG = CATTLE DUNG	(KG/YR)
	NF1 = CO-EFFICIENT OF NITROGEN	(PERCENTAGE)
	PF1 = CO-EFFICIENT OF PHOSPHORUS	(PERCENTAGE)
	KF1 = CO-EFFICIENT OF POTASSIUM	(PERCENTAGE)

f) Quality of Life Section

Quality of life is used here as a measure of performance of the integrated rural energy systems for farming. It is computed as a function of biogas as fuel, food/cap, and crowding. Here, for an electrified village quality of life is considered to be a product function of food, and crowding. Each of the multipliers in the product fuction assumed to be 1 at 1990 :-

```
A     QL.K = QF.K*QC.K
```

where		
	QL = QUALITY OF LIFE	(DIMENSIONLESS)
	QF = QUALITY OF LIFE MULTIPLIER FROM FOOD	(DIMENSIONLESS)
	QC = QUALITY OF LIFE MULTIPLIER FROM CROWDING	(DIMENSIONLESS)

The quality of life multiplier (QF) from food is presented as nonlinear function of the food-ratio (FX) as illustrated in Figure A-9 :-

```
A    QF.K = TABHL(QFT, FX.K, 0, 5, 1)
T     QFT = 0/1/2/2.4/2.7/2.9
```

where			
	QF =	QUALITY OF LIFE MULTIPLIER FROM FOOD	(DIMENSIONLESS)
	QFT =	TABLE FOR QUALITY OF LIFE MULTIPLIER FROM FOOD	(FIG. A-9)
	FX =	FOOD RATIO	(DIMENSIONLESS)

Food ratio is the food per year (FD) divided by the food per year (FO) for the base year :-

```
A    FX.K = FD.K/FO
C      FO = 3432379
```

where			
	FX =	FOOD RATIO	(DIMENSIONLESS)
	FD =	FOOD ENERGY	(GJ/YR)
	FO =	FOOD FOR BASE YEAR	(GJ/YR)

The quality of life multiplier from crowding (QC) is presented as a nonlinear function of crowding ratio (CR) as illustrated in Figure A-10 :-

```
A    QC.K = TABHL(QCT, CW.K, 0, 5, 1)
T     QCT = 2/1/0.7/0.5/0.3/0.2
```

where			
	QC =	QUALITY OF LIFE MULTIPLIER FROM CROWDING	(DIMENSIONLESS)
	QCT =	TABLE FOR QUALITY OF LIFE MULTIPLIER FROM CROWDING	(FIG. A-10)
	CW =	CROWDING RATIO	(DIMENSIONLESS)

The crowding ratio is determined by dividing population per hactare by population per hactare for base year :-

```
A    CW.K = (PO.K/AR)/CC
C      CC = 822
```

where			
	CW =	CROWDING RATIO	(DIMENSIONLESS)
	PO =	POPULATION	(HEAD)
	AR =	CULTIVATED AREA	(HECTARE)
	CC =	POPULATION PER HACTARE AT BASE YEAR	(HEAD)

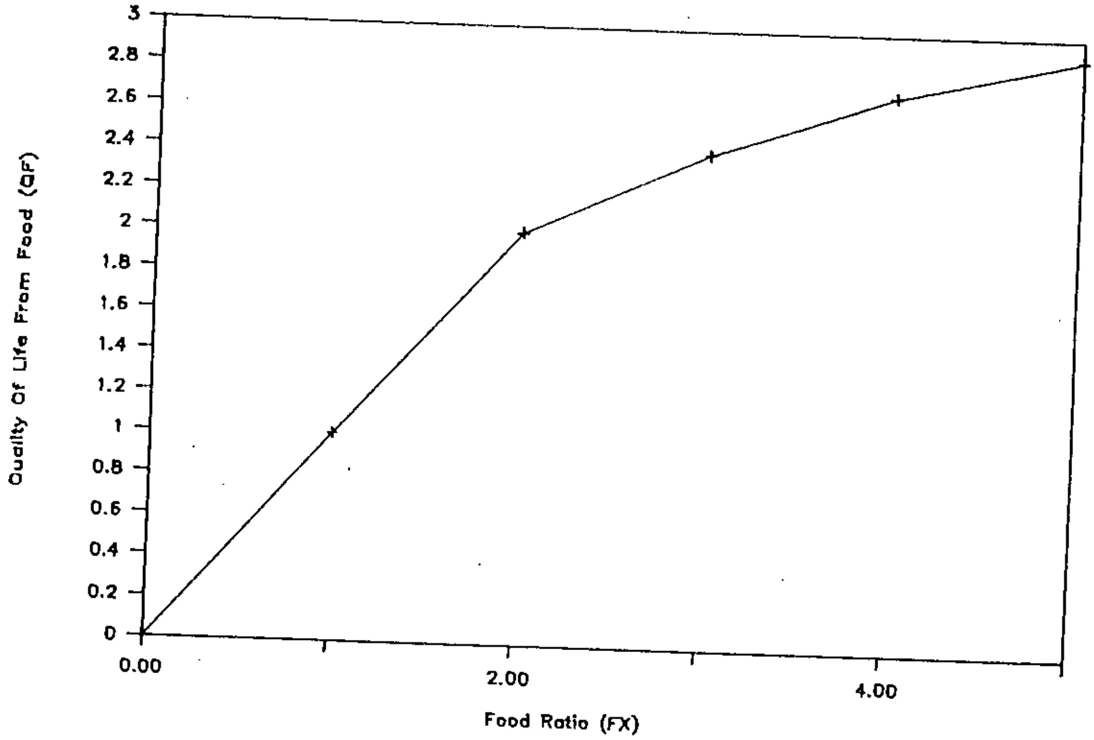


Fig. A-9 Food Ratio vs. Quality of Life From Food.

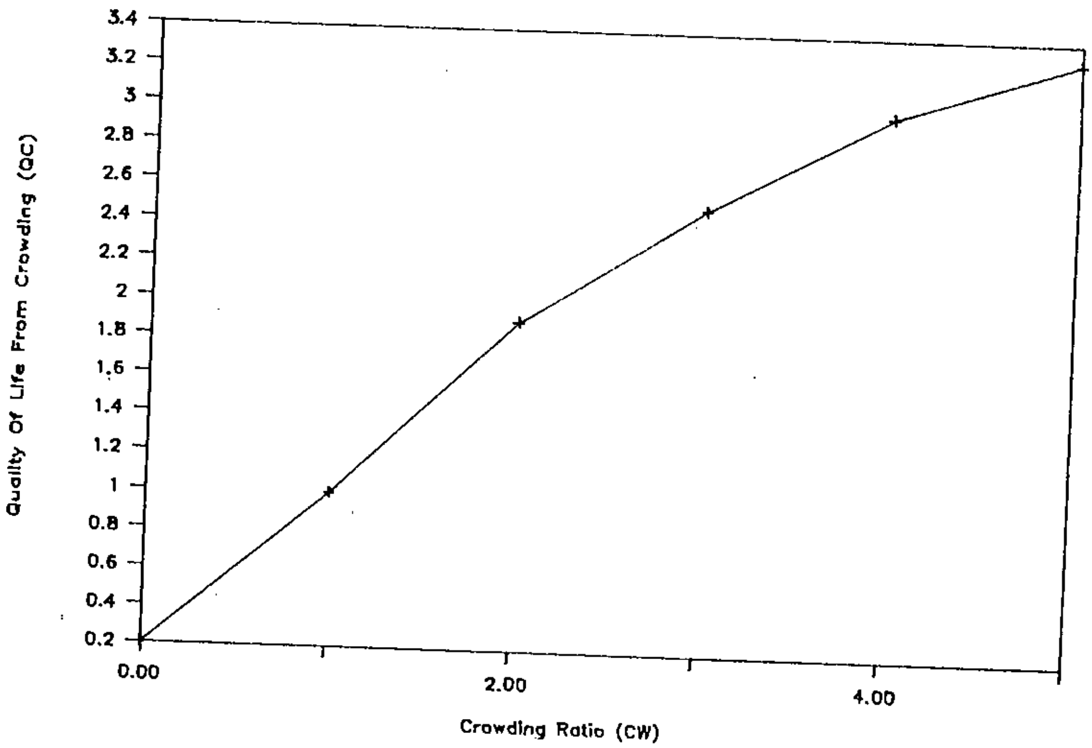


Fig. A-10 Crowding Ratio vs. Quality of Life from Crowding.

CONTROL STATEMENT

```
NOTE CONTROL STATEMENT
SAVE PO, EH, PH, FD, CT, EA, PA, DF, BP, BG, FL, RU, NN, PP,^
    KK, QL
SPEC DT =.01/LENGTH=12/SAVPER=1
```

NOTE: The mathematical formulation of the model based on system dynamics has been translated into BASIC which is in Appendix G.

N.B. 1) Source of co-efficients, parameters, and initial values: Alam et al. [88], Bala & Satter [109], and Statistical Year Book [129].

2) Source of Multipliers : Forrester [52], Hsieh [56], Wadhwa [60], Alam et al.[87], and Bala & Satter [108].

APPENDIX - B

DESCRIPTION OF MODEL EQUATION OF AN ENERGY SYSTEM OF RURAL BANGLADESH

Rural energy resources in Bangladesh as in many other developing countries, are mainly comprised of biomass, animal and human energy and, to a lesser extent, of natural gas and fossil fuels and hydro electricity. Energy is used to grow and prepare food, provide shelter and protect health, and there by improve the quality of life.

B.1. POPULATION SUB-MODEL

Two determinants of population change - births and deaths are considered in modeling of the population sector of this model. The population is divided into sex, each sex is divided into three age groups; children (0-14), adults (15-55) and old (over 55); to account for the varying effects on births, deaths and labour force participation. The system dynamics diagram for this sector is presented in Figure 7.2.

Population Level:

The number of people in each age group are presented by levels or integral equations which are affected by relevant rates of births, growths and deaths.

Male Children:

```
L    MCH.K = MCH.J+DT*(BR1.JK-GR2.JK-DR2.JK)
N      MCH = IMCH
I     IMCH = 21523000
```

where	MCH =	MALE CHILDREN	(HEAD)
	BR1 =	BIRTH OF MALE CHILDREN	(HEAD/YEAR)
	GR2 =	GROWING FROM MALE CHILD TO MALE ADULT	(HEAD/YEAR)
	DR2 =	DEATH OF MALE CHILD	(HEAD/YEAR)

Male Adult:

```
L     MMT.K = MMT.J+DT*(GR2.JK-GR4.JK-DR4.JK)
N       MMT = IMMT
I      IMMT = 21030000
```

where	MMT =	MALE ADULT	(HEAD)
	GR2 =	GROWING FROM MALE CHILD TO MALE ADULT	(HEAD/YEAR)

```
        GR4 = GROWING FROM MALE ADULT TO    (HEAD/YEAR)
              MALE OLD
        DR4 = DEATH OF MALE ADULT           (HEAD/YEAR)
```

Male Olds:

```
L     MOD.K = MOD.J +DT*(GR4.JK-DR6.JK)
N       MOD = IMOD
I      IMOD = 3762000

where   MOD = MALE OLD                      (HEAD)
        GR4 = GROWING FROM MALE ADULT TO    (HEAD/YEAR)
              MALE OLD
        DR6 = DEATH OF MALE OLD             (HEAD/YEAR)
```

Female Children:

```
L    FCH.K = FCH.J+DT*(BR2.JK-GR3.JK-DR3.JK)
N      FCH = IFCH
I     IFCH = 20391000

where   FCH = FEMALE CHILDREN               (HEAD)
        BR2 = BIRTH OF FEMALE CHILDREN      (HEAD/YEAR)
        GR3 = GROWING FROM FEMALE CHILD     (HEAD/YEAR)
              TO FEMALE ADULT
        DR3 = DEATH OF FEMALE CHILD         (HEAD/YEAR)
```

Female Adult:

```
L     FMT.K = FMT.J+DT*(GR3.JK-GR5.JK-DR5.JK)
N       FMT = IFMT
I      IFMT = 18882000

where   FMT = FEMALE ADULT                  (HEAD)
        GR3 = GROWING FROM FEMALE CHILD     (HEAD/YEAR)
              TO FEMALE ADULT
        GR5 = GROWING FROM FEMALE ADULT TO  (HEAD/YEAR)
              FEMALE OLD
        DR5 = DEATH OF FEMALE ADULT         (HEAD/YEAR)
```

Female Olds:

```
L     FOD.K = FOD.J +DT*(GR5.JK-DR7.JK)
N       FOD = IFOD
I      IFOD = 4344000
```

where		
	FOD = FEMALE OLD	(HEAD)
	GR5 = GROWING FROM FEMALE ADULT TO FEMALE OLD	(HEAD/YEAR)
	DR7 = DEATH OF FEMALE OLD	(HEAD/YEAR)

<u>Birth Rate:</u>

Basic birth rate depends on adult female and the co-efficient of birth rate normal. Birth rate normal states the birth-rate per year as a fraction of the adult female. It is the rate at which children are being added to the levels of male children and female children. The basic birth rate depends on and altered by so many real world situations. Hence in this model three multiplier effects have been considered. Birth rate multiplier from crowding (BMC), birth rate multiplier from food (BMF) and birth rate multiplier from quality of life (BMQ) will determine the actual birth rate.

<u>Birth rate for male children (BR1):</u>

```
R     BR1.KL = FMT.K*M1*BRM.K
C         M1 = 0.117
```

where		
	FMT = FEMALE ADULT	(HEAD)
	BR1 = BIRTH RATE OF MALE CHILD	(HEAD/YEAR)
	M1 = BIRTH RATE NORMAL FOR MALE CHILD	(PER-HEAD/YEAR)
	BRM = BIRTH RATE MULTIPLIER	(DIMENSIONLESS)

<u>Birth rate for female children (BR2):</u>

```
R     BR2.KL = FMT.K*F1*BRM.K
C         F1 = 0.096
```

where		
	FMT = FEMALE ADULT	(HEAD)
	BR2 = BIRTH RATE OF FEMALE CHILD	(HEAD/YEAR)
	F1 = BIRTH RATE NORMAL FOR FEMALE CHILD	(PER-HEAD/YEAR)
	BRM = BIRTH RATE MULTIPLIER	(DIMENSIONLESS)

<u>Death Rate:</u>

Like birth rate, basic death rate depends on respective group of population and the respective co-efficient (death-rate normal). It is the rate at which people are being depleted for the respective population levels. The basic death rate has been assumed to be affected by food, crowding and quality of life. The death rate multipliers are death rate multiplier from crowding (DMC), death rate multiplier from food (DMF) and death rate multiplier from quality of life (DMQ). The death rate multiplier (DRM) is calculated by the multiplication of DMC, DMF and DMQ.

Death Rate for Male Children (DR2):

```
R     DR2.KL = MCH.K*M2*DRM.K
C         M2 = 0.0166
```

where			
	DR2	= DEATH RATE FOR MALE CHILD	(HEAD/YEAR)
	MCH	= MALE CHILD	(HEAD)
	M2	= DEATH RATE CO-EFFICIENT FOR MALE CHILD	(PER-HEAD/YEAR)
	DRM	= DEATH RATE MULTIPLIER FOR MALE CHILD	(DIMENSIONLESS)

Death Rate for Male Adults (DR4):

```
R     DR4.KL = MMT.K*M4*DRM.K
C         M4 = 0.026
```

where			
	DR4	= DEATH RATE FOR MALE ADULT	(HEAD/YEAR)
	MMT	= MALE ADULT	(HEAD)
	M4	= DEATH RATE CO-EFFICIENT FOR MALE ADULT	(PER-HEAD/YEAR)
	DRM	= DEATH RATE MULTIPLIER FOR MALE ADULT	(DIMENSIONLESS)

Death Rate for Male Olds (DR6):

```
R     DR6.KL = MOD.K*M6*DRM.K
C         M6 = 0.070
```

where			
	DR6	= DEATH RATE FOR MALE OLD	(HEAD/YEAR)
	MOD	= MALE OLD	(HEAD)
	M6	= DEATH RATE CO-EFFICIENT FOR MALE OLD	(PER-HEAD/YEAR)
	DRM	= DEATH RATE MULTIPLIER FOR MALE OLD	(DIMENSIONLESS)

Death Rate for Female Children (DR3):

```
R     DR3.KL = FCH.K*F2*DRM.K
C         F2 = 0.016
```

where	DR3 =	DEATH RATE FOR FEMALE CHILD	(HEAD/YEAR)
	MCH =	FEMALE CHILD	(HEAD)
	F2 =	DEATH RATE CO-EFFICIENT FOR FEMALE CHILD	(PER-HEAD/YEAR)
	DRM =	DEATH RATE MULTIPLIER FOR FEMALE CHILD	(DIMENSIONLESS)

Death Rate for Female Adults (DR5):

```
R     DR5.KL = FMT.K*F4*DRM.K
C         F4 = 0.025
```

where	DR5 =	DEATH RATE FOR FEMALE ADULT	(HEAD/YEAR)
	MMT =	FEMALE ADULT	(HEAD)
	F4 =	DEATH RATE CO-EFFICIENT FOR FEMALE ADULT	(PER-HEAD/YEAR)
	DRM =	DEATH RATE MULTIPLIER FOR FEMALE ADULT	(DIMENSIONLESS)

Death Rate for Female Olds (DR7):

```
R     DR7.KL = FOD.K*F6*DRM.K
C         F6 = 0.068
```

where	DR7 =	DEATH RATE FOR FEMALE OLD	(HEAD/YEAR)
	MOD =	FEMALE OLD	(HEAD)
	F6 =	DEATH RATE CO-EFFICIENT FOR FEMALE OLD	(PER-HEAD/YEAR)
	DRM =	DEATH RATE MULTIPLIER FOR FEMALE OLD	(DIMENSIONLESS)

Growing Rate:

Growing rate depends on respective population level and co-efficients. It is the rate at which the respective population migrate out from one level and migrate in to another.

Growing Rate for Male Children (GR2):

```
R     GR2.KL = MCH.K*M3
C         M3 = 0.072
```

where	GR2 =	GROWING RATE FOR MALE CHILD	(HEAD/YEAR)
	MCH =	MALE CHILD	(HEAD)
	M3 =	GROWING RATE CO-EFFICIENT FOR MALE CHILD	(PER-HEAD/YEAR)

Growing Rate for Male Adults (GR4):

```
R     GR4.KL = MMT.K*M5
C         M5 = 0.0185
```

where			
	GR4 =	GROWING RATE FOR MALE ADULT	(HEAD/YEAR)
	MMT =	MALE ADULT	(HEAD)
	M5 =	GROWING RATE CO-EFFICIENT FOR MALE ADULT	(PER-HEAD/YEAR)

Growing Rate for Female Children (GR3):

```
R     GR3.KL = FCH.K*F3
C         F3 = 0.072
```

where			
	GR3 =	GROWING RATE FOR FEMALE CHILD	(HEAD/YEAR)
	FCH =	FEMALE CHILD	(HEAD)
	F3 =	GROWING RATE CO-EFFICIENT FOR FEMALE CHILD	(PER-HEAD/YEAR)

Growing Rate for Female Adults (GR5):

```
R     GR5.KL = FMT.K*F5
C         F5 = 0.02
```

where			
	GR5 =	GROWING RATE FOR FEMALE ADULT	(HEAD/YEAR)
	FMT =	FEMALE ADULT	(HEAD)
	F5 =	GROWING RATE CO-EFFICIENT FOR FEMALE ADULT	(PER-HEAD/YEAR)

Birth Rate Multipliers:

In this model, three multipliers effects have been considered. Birth rate multiplier from crowding (BMC), birth rate multiplier from food (BMF), and birth rate multiplier from quality of life (BMQ) will determine the actual birth rate.

```
A     BRM.K = BMF.K*BMC.K*BMQ.K
```

where			
	BRM =	BIRTH RATE MULTIPLIER	(DIMENSIONLESS)
	BMF =	BIRTH RATE MULTIPLIER FROM FOOD	(DIMENSIONLESS)
	BMC =	BIRTH RATE MULTIPLIER FROM CROWDING	(DIMENSIONLESS)
	BMQ =	BIRTH RATE MULTIPLIER FROM QUALITY OF LIFE	(DIMENSIONLESS)

Birth Rate Multiplier from Crowding (BMC):

As the crowding ratio remains below the normal, there is a little effect on birth rate. But when it goes up birth rate starts declining due to the psychological pressures, social stress and conflict :-

```
A     BMC.K = TABHL(BMCT, CR1.K, 1, 5, 1)
T      BMCT = 1/0.95/0.88/0.8/0.7

where BMC = BIRTH RATE MULTIPLIER FROM        (DIMENSIONLESS)
            CROWDING
      CR1 = CROWDING RATIO                    (DIMENSIONLESS)
     BMCT = BIRTH RATE MULTIPLIER FROM        (FIG. B-1)
            CROWDING TABLE
```

Birth Rate Multiplier from Food (BMF):

The availability of food has its pronounced effect on birth rate. The food availability alone can regulate both birth and death rates in such a manner that population becomes stationary depending on the availability of food. At zero food, life becomes impossible and zero birth rate is indicated. At the other extreme an abundance of food is assumed to raise the birth rate :-

```
A     BMF.K = TABHL(BMFT, FP.K, 1, 5, 1)
T      BMFT = 1/1.05/1.12/1.2/1.3

where      BMF = BIRTH RATE MULTIPLIER FROM    (DIMENSIONLESS)
                 FOOD
            FP = FOOD PER CAPITA RATIO         (DIMENSIONLESS)
          BMFT = BIRTH RATE MULTIPLIER FROM    (FIG. B-2)
                 FOOD TABLE
```

Birth Rate Multiplier From Quality of Life (BMQ)

Birth rate is inversely proportional to the quality of life ratio. The effect of quality of life on birth rate is to control the population growth through birth control:-

```
A     BMQ.K = TABHL(BMQT, QL.K, 1, 5, 1)
T      BMQT = 1/0.85/0.72/0.6/0.5

where      BMQ = BIRTH RATE MULTIPLIER FROM    (DIMENSIONLESS)
                 QUALITY OF LIFE
            QL = QUALITY OF LIFE               (DIMENSIONLESS)
          BMQT = BIRTH RATE MULTIPLIER FROM    (FIG. B-3)
                 QULAITY OF LIFE TABLE
```

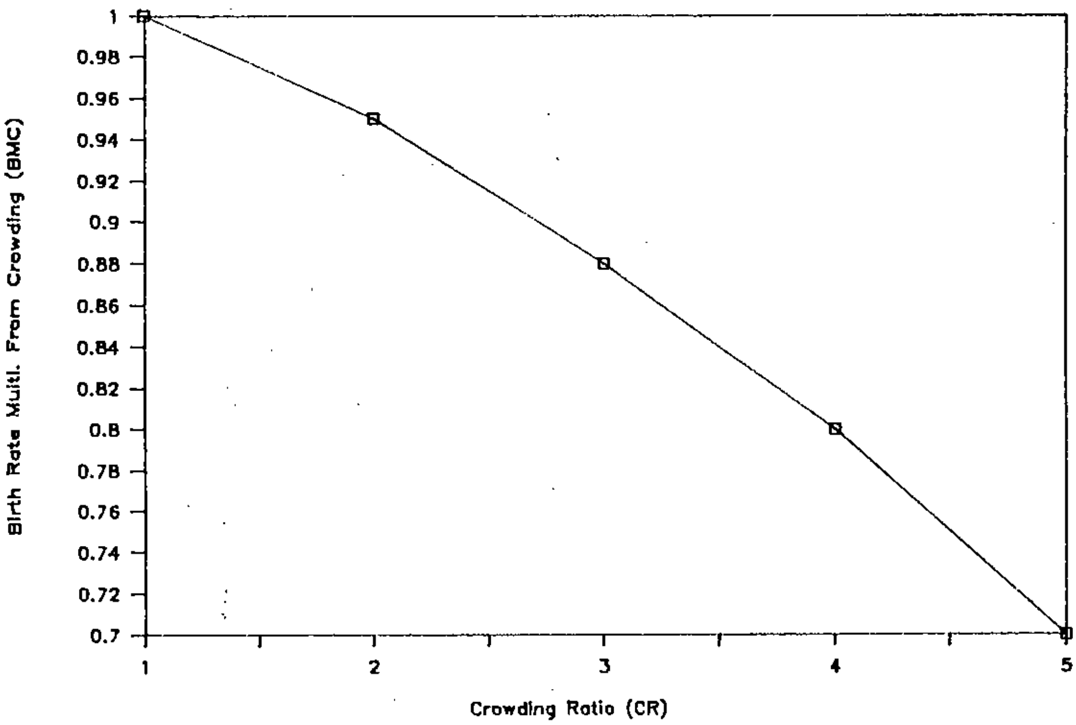


Fig. B-1 Crowding Ratio vs. Birth Rate Multiplier from Crowding.

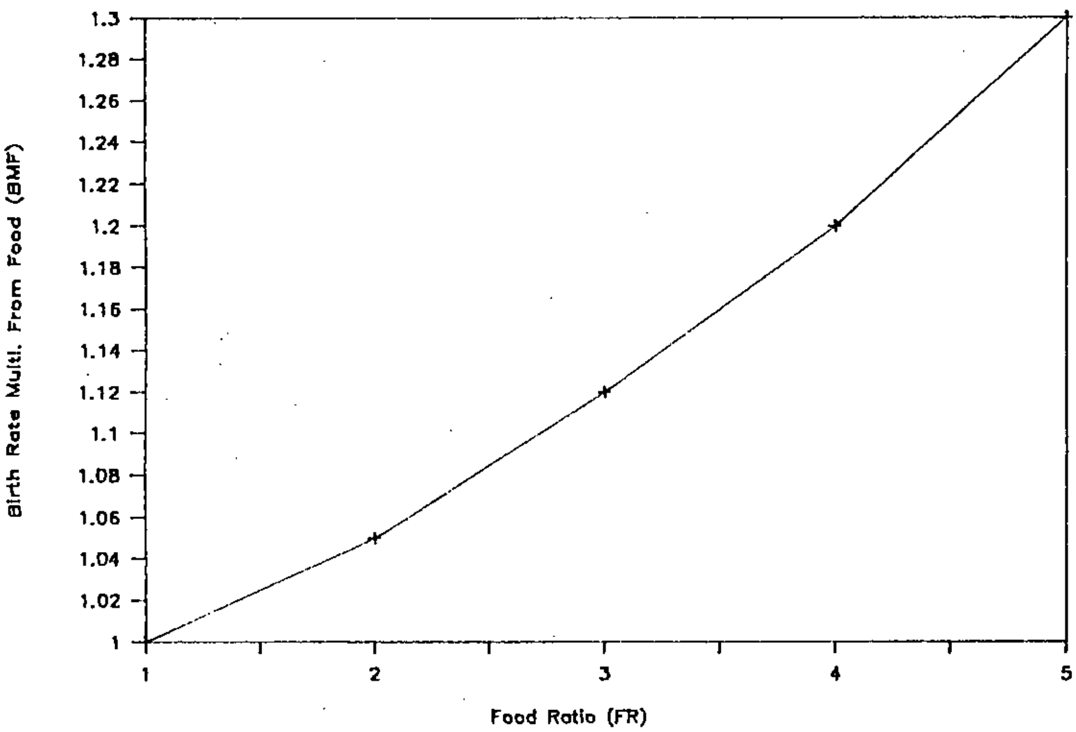


Fig. B-2 Food Ratio vs. Birth Rate Multiplier from Food.

Death Rate Multipliers:

The basic death rate has been assumed to be affected by food, crowding and quality of life. The death rate multipliers are death rate multiplier from food (DMF), death rate multiplier from crowding (DMC) and death rate multiplier from quality of life (DMQ):-

```
A    DRM.K = DMF.K*DMC.K*DMQ.K

where    DRM = DEATH RATE MULTIPLIER           (DIMENSIONLESS)
         DMF = DEATH RATE MULTIPLIER           (DIMENSIONLESS)
               FROM FOOD
         DMC = DEATH RATE MULTIPLIER           (DIMENSIONLESS)
               FROM CROWDING
         DMQ = DEATH RATE MULTIPLIER           (DIMENSIONLESS)
               FROM QUALITY OF LIFE
```

Death Rate Multiplier From Food (DMF)

Food essentially is the most powerful regulator of population. As the food availability approaches zero, death rate approaches to infinity. With increasing food availability death rate still will not be reduced to the desirable extent, because of the effect of pressure level of education, health and living condition :-

```
A    DMF.K = TABHL(DMFT, FR.K, 1, 5, 1)
T     DMFT = 1/0.95/0.89/0.86/0.84

where    DMF = FOOD MULTIPLIER FOR DEATH       (DIMENSIONLESS)
        DMFT = FOOD MULTIPLIER FOR DEATH       (FIG. B-4)
               TABLE
          FR = FOOD RATIO                      (DIMENSIONLESS)
```

Death Rate Multiplier From Crowding (DMC)

If no other influences were to intervene, excessive crowding would eventually limit population. As Forrester suggests crowding can give rise to pressures which include psychological effects, social stress that causes crime and conflict:-

```
A    DMC.K = TABHL(DMCT, CR.K, 1, 5, 1)
T     DMCT = 1/1.1/1.15/1.22/1.3
```

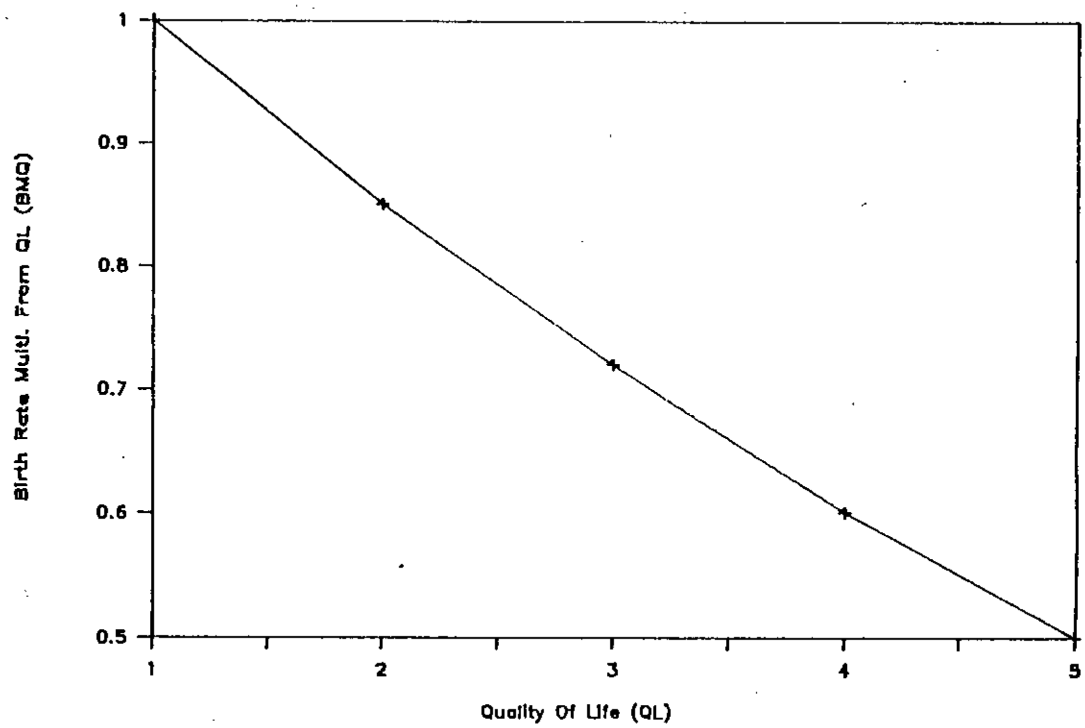


Fig. B-3 Quality of Life vs. Birth Rate Multiplier from Quality of Life.

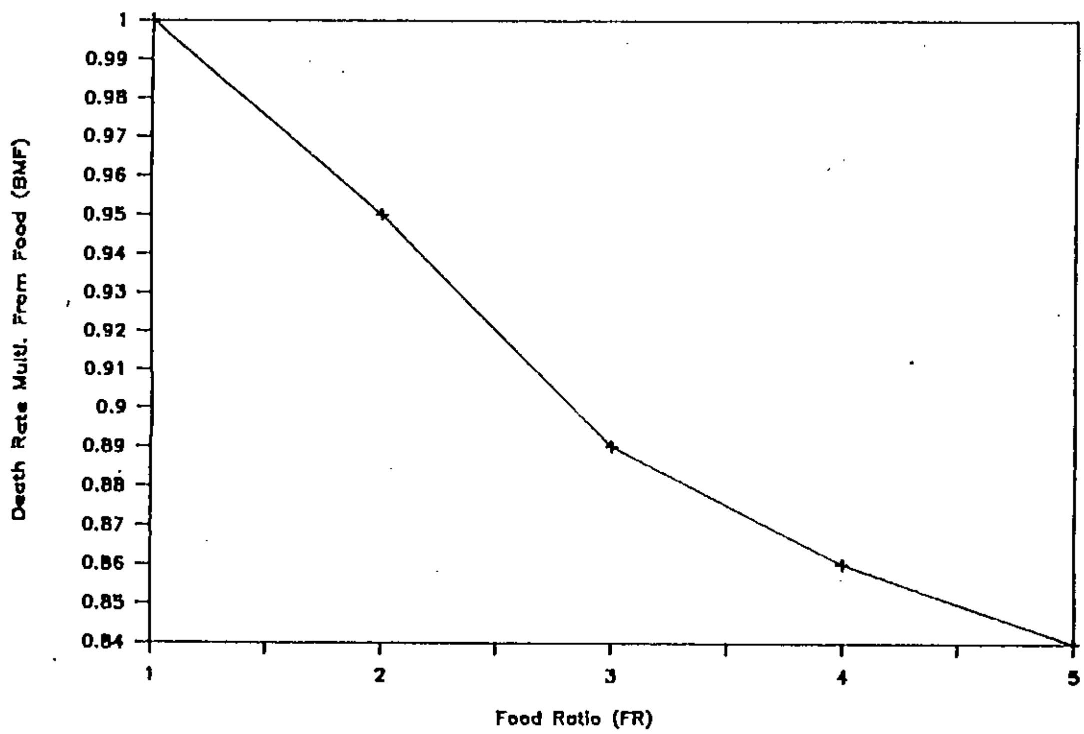


Fig. B-4 Food Ratio vs. Death Rate Multiplier from Food.

where DMC = FOOD MULTIPLIER FOR DEATH (DIMENSIONLESS)
DMCT = FOOD MULTIPLIER FOR DEATH TABLE (FIG. B-5)
CR = CROWDING RATIO (DIMENSIONLESS)

Death Rate Multiplier From Quality of LIfe (DMQ):

As the crowding multiplier of death, quality of life multiplier regulates the death rate effectively:-

A DMQ.K = TABHL(DMQT, QL.K, 1, 5, 1)
T DMQT = 1.0/.92/0.86/0.81/0.77

where DMQ = QULAITY OF LIFE MULTIPLIER FOR DEATH (DIMENSIONLESS)
DMQT = QUALITY OF LIFE MULTIPLIER FOR DEATH TABLE (FIG. B-6)
QL = QUALITY OF LIFE RATIO (DIMENSIONLESS)

Remarks:

Muscle power provided by population constitutes one of the inputs of the rural farming system. Population growth is major for increasing energy demand in each componenet of the farming sectors.

B.2. CATTLE POPULATION SUB-MODEL

The essentials of the cattle system are three coupled elements with feedback loops -- consumption, production and importation. Each is acting to adjust inventory converging to the desired level.

When stock are lower than desired, there are price increases. These increases effect changes in consumption, production and importation which act to restore inventory to its desired level. The price increases lower the per-capita consumption. With less consumption drain, inventories will tend to rise. Production relationships act with the same effect. The increase in current price raises producers' price forcasts and thus the capacity they wish to utilize. After production and importation delays, additions to capacity result in increased production and higher inventory.

When inventory rises beyond desired level, the resulting price decreases would again be propagated around both the production, importation and the consumption loops to yield counteracting forces, decreased production, acquisition and increased consumption. Importation is also affected by the feed per cattle. Crop production is influenced by the inventory of draft animal per hactare.

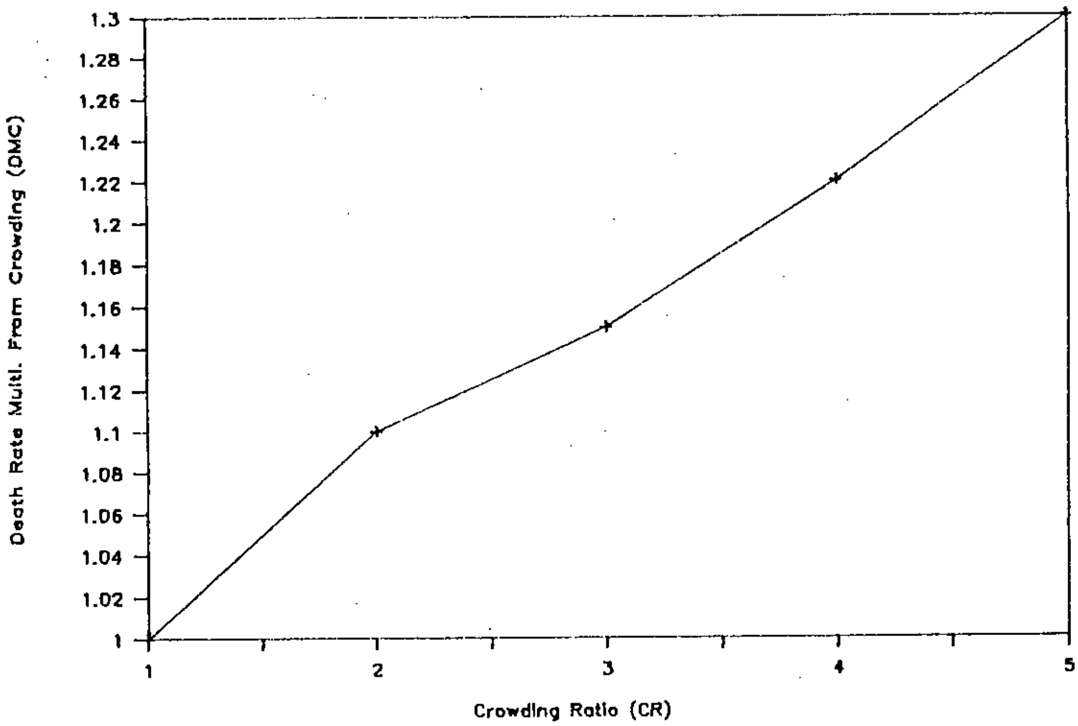


Fig. B-5 Crowding Ratio vs. Death Rate Multiplier from Crowding.

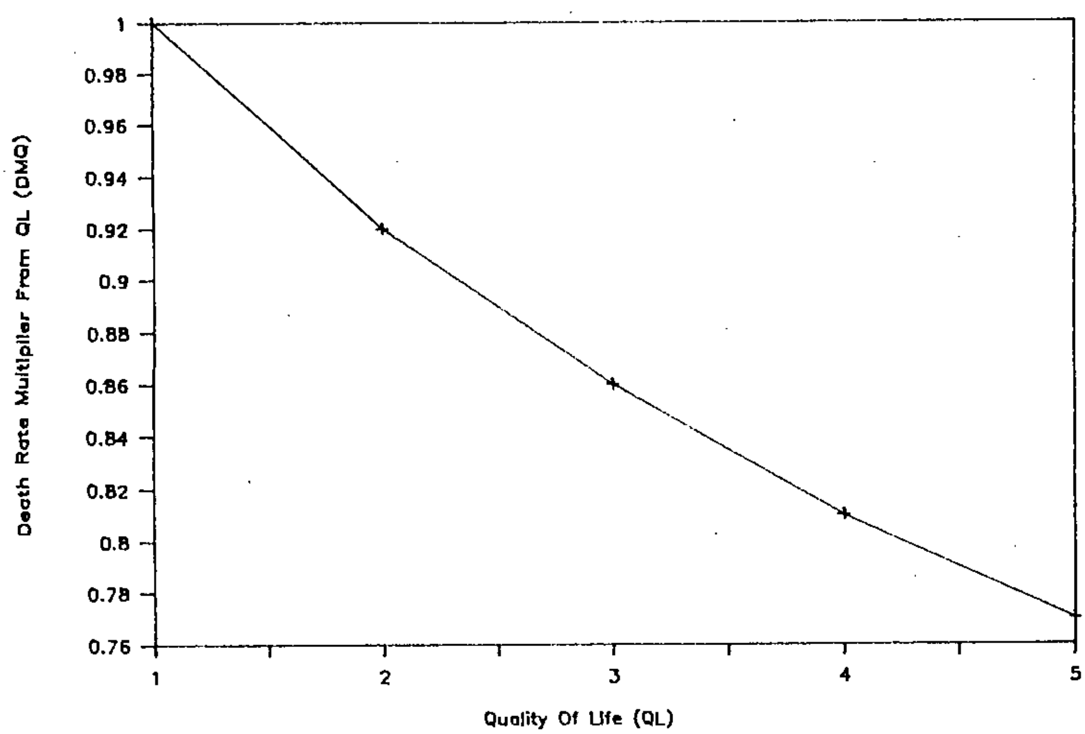


Fig. B-6 Quality of Life vs. Death Rate Multiplier from Quality of Life.

Production, importation and consumption determine the combined level or inventory and is presented by an integral equation:-

```
L     CT.K = CT.J+DT*(DIR.JK+IM.JK-CR.JK)
N       CT = ICT
I      ICT = 21.8E6
```

where			
	CT	= INVENTORY OF CATTLE	(HEAD)
	ICT	= INITIAL INVENTORY OF CATTLE	(HEAD)
	DIR	= PRODUCTION RATE AFTER DELAY	(HEAD/YEAR)
	IM	= IMPORTATION RATE	(HEAD/YEAR)
	CR	= CONSUMPTION RATE	(HEAD/YEAR)

<u>Production Rate (PR1):</u>

There is a delay between production and initiation -- taking decision to increase or decrease production -- and the realization of production of cattle. The cattle production rate (DIR) is obtained using the third order delay function :-

```
A     DIR.K = DELAY3(PR1.KL, 2.25)
```

where			
	DIR	= PRODUCTION RATE AFTER DELAY	(HEAD/YEAR)
	PR1	= PRODUCTION RATE	(HEAD/YEAR)

The production rate (PR1) is assumed to be equal to the aquisition capacity (PC):-

```
R     PR1.KL = PC.K
```

where			
	PR1	= PRODUCTION RATE	(HEAD/YEAR)
	PC	= ACQUISITION CAPACITY	(HEAD/YEAR)

<u>Consumption Rate (CR):</u>

The consumption rate is calculated by the per capita consumption (CR) times the total population (POP) and dividing by the weight of a cattle (WA):-

```
R     CR.KL = (POP.K*CP.K)/WA
C        WA = 120
```

where			
	CR	= CONSUMPTION RATE	(HEAD/YEAR)
	POP	= POPULATION	(HEAD)
	CP	= PERCAPITA CONSUMPTION	(KG/YEAR)
	WA	= WEIGHT PER CATTLE	(KG)

Importation Rate (IM):

Cattle is supplied from outside Bangladesh i.e. importation rate is assumed to be twenty-five percent of the total consumption [131]:-

```
R     IM.KL = CR1.KL*IM1
C       IM1 = 0.25

where    IM = IMPORTATION RATE                (HEAD/YEAR)
        IM1 = IMPORTATION CO-EFFICIENT        (PER-HEAD/YEAR)
```

Acquisition Capacity:

Acquisition capacity (PC)is level variable. It is represented by an integral equation in addition with acquisition rate (AR):-

```
L     PC.K = PC.J+DT*AR.KL
N       PC = IPC
I      IPC = 3.31E6
where     PC = ACQUISITION CAPACITY             (HEAD/YEAR)
         IPC = INITIAL ACQUISITION CAPACITY     (HEAD/YEAR)
          AR = ACQUISITION RATE                 (HEAD/YEAR)
```

Acquisition Rate (AR):

Acquisition rate is proportional to the difference of capacity normal (CN) and current acquisition capacity (PC) and is adjusted over a period (CD). The capacity normal (CN) is affected by the capacity multiplier (CM), and acquisition rate (AR) is affected by straw multiplier (SM):-

```
R     AR.KL = ((CM.K*CN-PC.K)/CD)*SM.K
C        CN = 4.14E6
C        CD = 2

where    AR = ACQUISITION RATE                (HEAD/YEAR)
         CM = CAPACITY MULTIPLIER             (DIMENSIONLESS)
         CN = CAPACITY NORMAL                 (HEAD)
         PC = ACQUISITION CAPACITY            (HEAD/YEAR)
         CD = ADJUSTMENT PERIOD               (YEAR)
         SM = STRAW MULTIPLIER                (DIMENSIONLESS)
```

Expected Price (EP):

Expected price (EP) is the level variable which is represented by an integral equation and is obtained by averaging the difference of the current market price (PA) and the previous expected price (EP) over a period (AD) of two years. This is done because, with wide fluctuations in the current price(PA) the expectation of the producers do not fluctuate widely :-

```
L     EP.K = EP.J+DT*(PA.K-EP.K)/AD
N       EP = IEP
I      IEP = 1900
C       AD = 2
```

where			
	EP	= EXPECTED PRICE	(TAKA)
	IEP	= INITIAL EXPECTED PRICE	(TAKA)
	PA	= CURRENT PRICE	(TAKA/HEAD)
	AD	= ADJUSTMENT PERIOD	(YEAR)

Straw Multiplier (SM):

Straw multiplier depends on feed per cattle (SF). The functional relationship is shown in Figure B-7:-

```
A     SM.K = TABHL(SMT, SF.K, 0, 9, 1)
T      SMT = 0.35/0.5/0.75/0.9/1.07/1.27/1.31/1.35/1.4/1.4
```

where			
	SM	= STRAW MULTIPLIER	(DIMENSIONLESS)
	SF	= FEED PER CATTLE	(KG/YEAR)
	SMT	= STRAW MULTIPLIER TABLE	(FIG. B-7)

Feed Per Cattle (SF):

Feed per cattle is obtained from the multiplication of available straw (ST) and by feed co-efficient (FF) averaging over a period (DY) of one year :-

```
A     SF.K = (ST.K*FF)/(CT.K*DY)
C       FF = 0.8
C       DY = 365
```

where			
	SF	= FEED PER CATTLE	KG/DAY
	ST	= AVAILABLE STRAW	KG/YEAR
	FF	= FRACTION OF STRAW	(DIMENSIONLESS)

Capacity Multiplier (CM):

Capacity is the function of expected price. The functional relationship between capacity multiplier (CM) and the expected price (EP) is shown in Figure B-8 :-

```
A     CM.K = TABHL(CMT, EP.K, 0, 7000, 1000)
T      CMT = 0/0.75/1.0/1.25/1.365/1.45/1.5/1.5
```

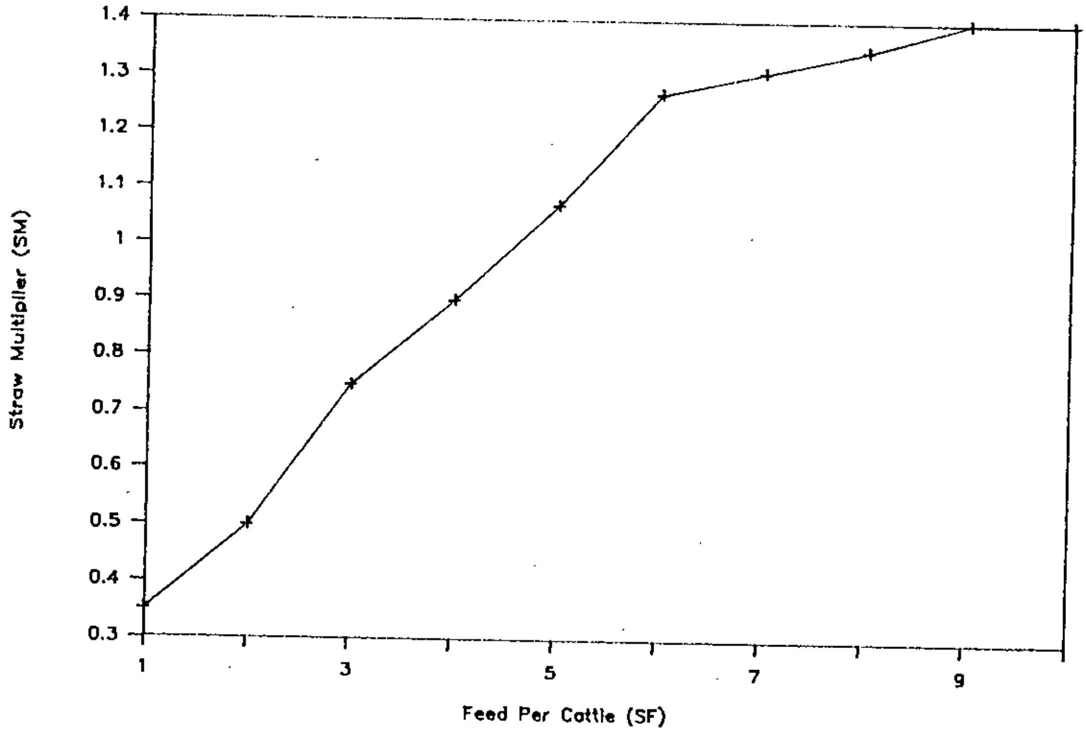


Fig. B-7 Feed Per Cattle vs. Straw Multiplier.

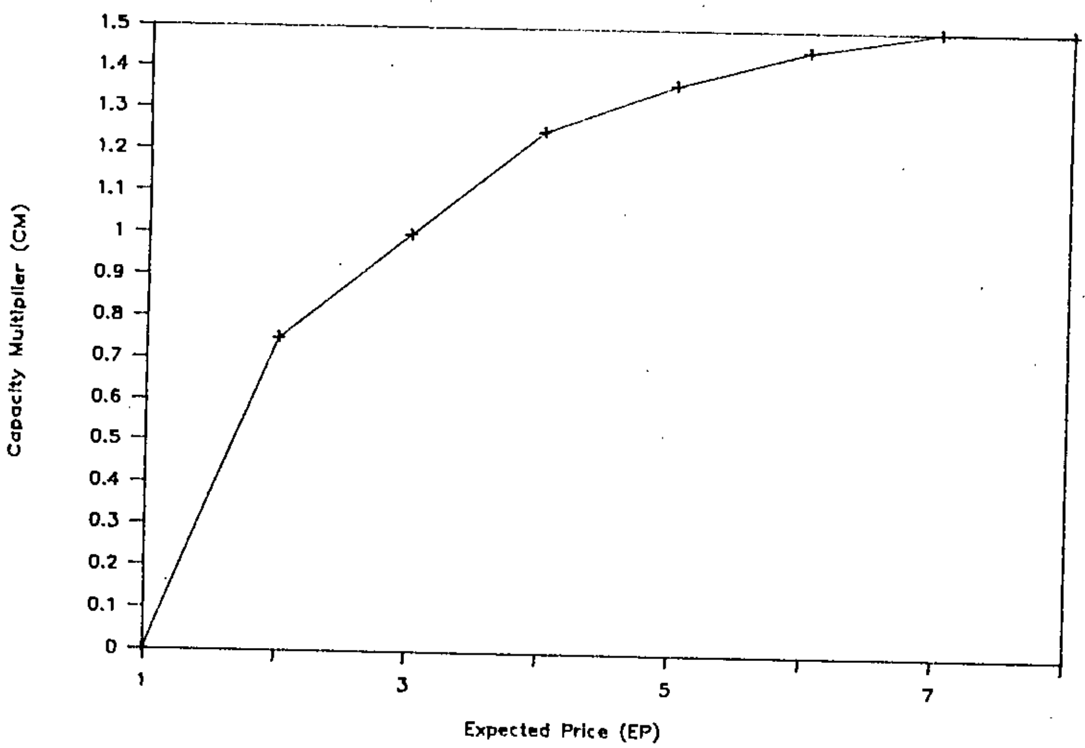


Fig. B-8 Expected Price vs. Capacity Multiplier.

where	CM =	CAPACITY MULTIPLIER	(DIMENSIONLESS)
	EP =	EXPECTED PRICE	(TAKA)
	CMT =	CAPACITY MULTIPLIER TABLE	(FIG. B-8)

Draft Power Available (DC):

The calculation of available draft power per hectare depends on the percentage of effective cattle utilizing muscle power and the draft power co-efficient (FD):-

```
A    DC.K = DC1*(CT.K*FD)/TA
C     DC1 =0.53
C      FD = 0.1521
C      TA = 7.4E6
```

where	DC =	AVAILABLE DRAFT POWER PER HECTARE	(WATT/HA)
	CT =	CATTLE	(HEAD)
	DC1 =	FRACTION OF CATTLE FOR DRAFT POWER	(DIMENSIONLESS)
	FD =	DRAFT POWER PER CATTLE	(KW)
	TA =	TOTAL CULTIVATED AREA	(HECTARE)

Price (PA):

Cattle price is determined by the draft power already available per hectare. The functional relationship is shown in Figure B-9 :-

```
A    PA.K = TABHL(PAT, DC.K, 0.17, 0.34, 0.1)
T     PAT = 5000/4800/4525/4350/4100/3700/3100/2500/2000/
            1600/1300/1150/1000/900/850/800/750/725
```

where	PA =	CURRENT PRICE	(TAKA/HEAD)
	PAT =	CURRENT PRICE TABLE	(FIG. B-9)
	DC =	AVAILABLE DRAFT POWER	(KW/HA)

Price of Beef (PB):

Price of beef (PB) is calculated from the cattle price (PA) divided by estimated weight of cattle (WA) :-

```
A    PB.K = PA.K/WA
C      WA = 120
```

where	PB =	BEEF-PRICE	(TAKA/KG)
	PA =	PRICE OF A CATTLE	(TAKA/HEAD)
	WA =	WEIGHT OF A CATTLE	(KG)

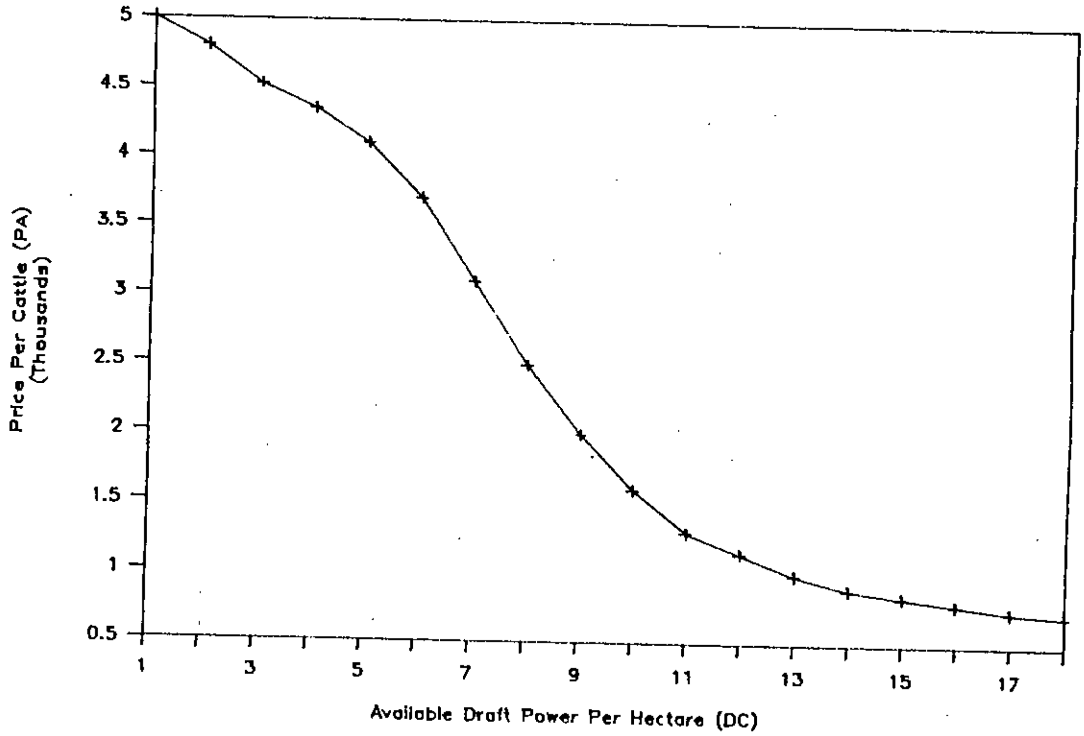


Fig. B-9 Available Draft Power Per Hectare vs. Price Per Cattle.

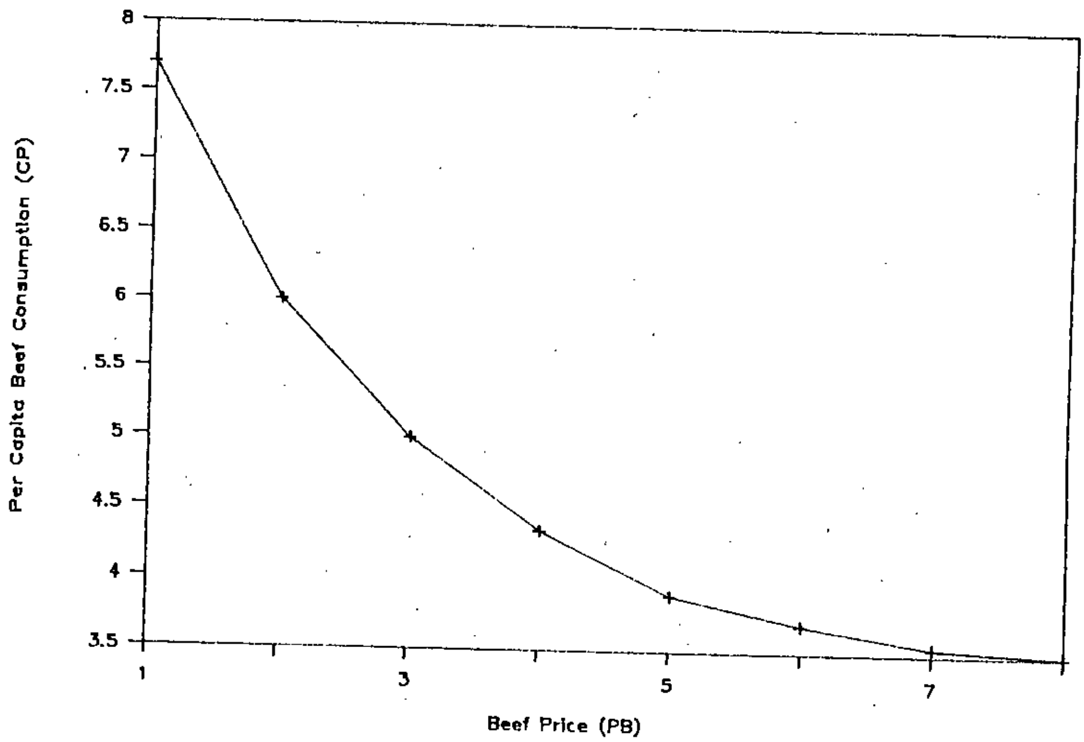


Fig. B-10 Beef Price vs. Per Capita Beef Consumption.

Per Capita Consumption (CP):

Per capita consumption (CP) of beef is related with the beef price (PB) nonlinearly. Thies relationship is shown in Figure B-10 :-

```
A     CP.K = TABHL(CPT, PB.K, 10, 80, 10)
T     CPT  = 7.7/6/5/4.35/3.9/3.7/3.55/3.5
```

where	CP =	PER CAPITA CONSUMPTION	(KG/YEAR)
	CPT =	PER CAPITA CONSUMPTION TABLE	(FIG. B-10)
	PB =	BEEF PRICE	(TAKA)

Energy Ratio (RE):

Energy ratio (RE) is determined from the draft power available per hactare (DC) divided by the optimum draft power per hectare (AS):-

```
A     RE.K = DC.K/AS
C     AS   = 0.373
```

where	RE =	ENERGY RATIO	(DIMENSIONLESS)
	DC =	DRAFT POWER AVAILABLE PER HECTARE	(KW/HA)
	AS =	DRAFT POWER PER HECTARE	(KW/HA)

Energy Multiplier (EM):

The energy multiplier (EM) depends on energy ratio (RE). The functional relationship is shown in Figure B-11 :-

```
A     EM.K = TABHL(EMT, RE.K, 0, 1.5,0.25)
T     EMT  = 0.5/0.7/0.875/1.1/1.2/1.25/1.3
```

where	EM =	ENERGY MULTIPLIER	(DIMENSIONLESS)
	EMT =	ENERGY MULTIPLIER TABLE	(FIG. B-11)
	RE =	ENERGY RATIO	(DIMENSIONLESS)

B.3. CROP PRODUCTION SUB-MODEL

Irrigated Area (IA):

The irrigated area is a level variable and is represented by integral equation :-

```
L     IA.K = IA.J+DT*(IE.JK-IR.JK)
N     IA   = IIA
I     IIA  = 1.22E6
```

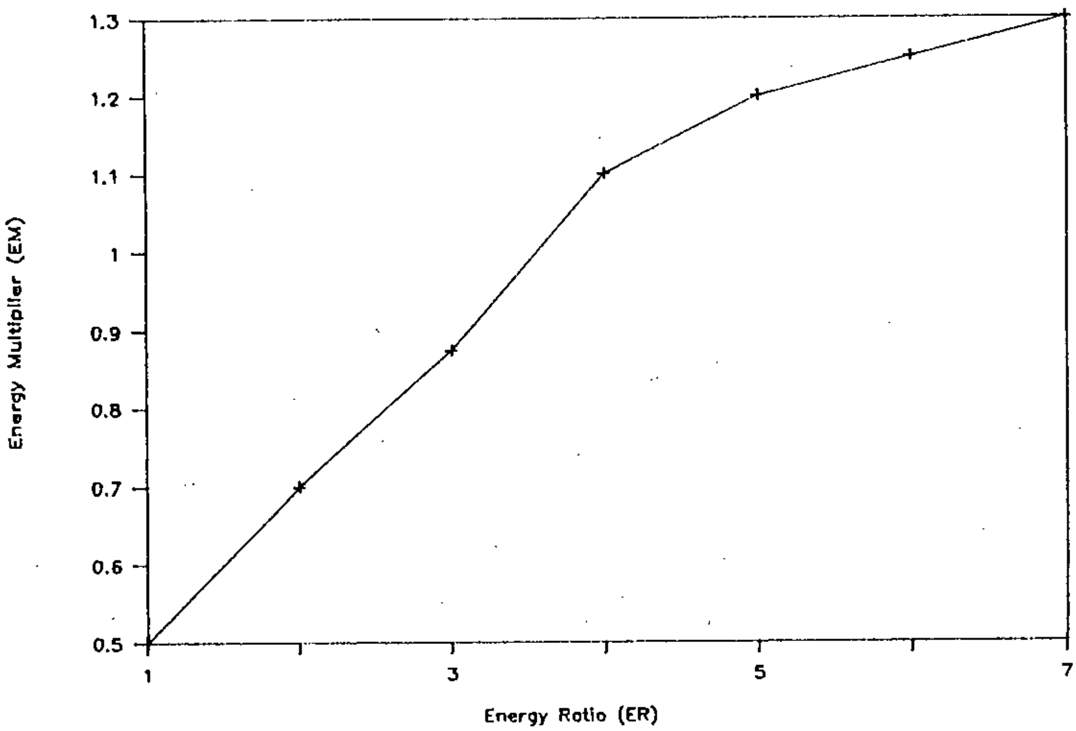


Fig. B-11 Energy Ratio vs. Energy Multiplier.

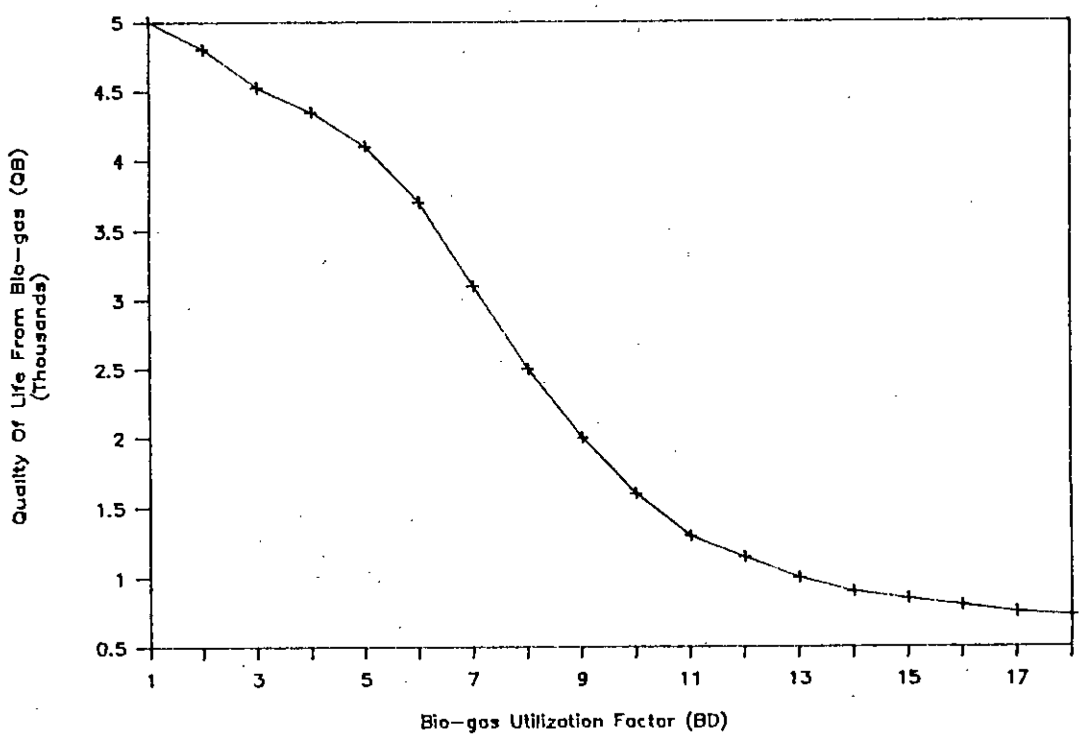


Fig. B-12 Bio-Gas Utilization Factor vs. Quality of Life from Bio-Gas.

where			
	IA =	IRRIGATED AREA	(HECTARE)
	IIA =	INITIAL IRRIGATED AREA	(HECTARE)
	IE =	INCREASING RATE OF IRRIGATED AREA	(HECTARE/YR)
	IR =	DECREASING RATE OF IRRIGATED AREA	(HECTARE/YR)

Increasing Rate (IE):

Increasing rate (IE) is a logic function CLIP which is a built in function in DYNAMO. If the high yield area (AM) is less than upper limit (Y) then the increasing rate of the irrigated area will be equal to irrigated area expansion rate which is calculated by the multiplication of irrigated area by its expansion co-efficient (IN). When AM is greater than or equal to the upper limit (Y) then IE will be equal to zero :-

```
R     IE.K = CLIP(EX1, EX.K, AM.K, Y)
C     EX1  = 0
C     Y    = 7.4E6
```

where			
	IE =	INCREASING RATE OF IRRIGATED AREA	(HECTARE/YR)
	EX =	EXPANSION RATE OF IRRIGATED AREA	(HECTARE/YR)
	EX1 =	EXPANSION RATE OF IRRIGATED AREA	(HECTARE/YR)
	AM =	HIGH YIELD AREA	(HECTARE)
	Y =	UPPER LIMIT OF IRRIGATED AREA	(HECTARE)

Decreasing Rate of Irrigated Area (IR):

Decreasing rate of irrigated area (IR) is calculated by dividing irrigated area (IA) by its co-efficient (YN):-

```
R     IR.KL = (IA.K-IA1)/YN
C     IA1   = 0.8E6
C     YN    = 15
```

where			
	IR =	DECREASING RATE OF IRRIGATED AREA	(HECTARE/YR)
	IA =	IRRIGATED AREA	(HECTARE)
	IA1 =	NATURAL IRRIGATED AREA	(HECTARE)
	YN =	AVERAGE LIFE-TIME OF IRRIGATION DEVICE.	(YEAR)

Expansion Rate (EX):

Expansion rate (EX) of irrigated area is estimated by the multiplication of irrigated area (IA) by its expansion co-efficient (IN):-

```
A     EX.K = IA.K*IN
C     IN    = 8.5
```

where			
	EX1	= EXPANSION RATE OF IRRIGATED AREA	(HECTARE/YR)
	IA	= IRRIGATED AREA	(HECTARE)
	IN	= PERCENTAGE OF EXPANSION	(DIMENSIONLESS)

High Yield Area (AM):

High yield area (AM) is obtained by summation of irrigated area, and flood and draught-free area (CS):-

```
A     AM.K = IA.K+CS
C     CS    = 2.83E6
```

where			
	AM	= HIGH YIELD AREA	(HECTARE)
	IA	= IRRIGATED AREA	(HECTARE)
	CS	= FLOOD AND DRAUGHT FREE AREA	(HECTARE)

Low Yield Area (AT):

The difference between high yield area (AM) and total cultivated area (TA) is denoted as non-irrigated area (AT):-

```
A     AT.K = TA-AM.K
C     TA    = 7.4E6
```

where			
	AT	= NON-IRRIGATED AREA	(HECTARE)
	AM	= HIGH YIELD AREA	(HECTARE)
	TA	= TOTAL AREA	(HECTARE)

Cropping Intensity (IT):

Cropping intensity (IT) is calculated by the summation of the product of high yield area (AM) and the frequency of cropping (IT1), and low yield area (AT), and then averaging by the total area (TA):-

```
A     IT.K = (AM.K*IT1+AT.K)/TA
C     IT1   = 2
```

where			
	IT = CROPPING INTENSITY		(DIMENSIONLESS)
	IT1 = FREQUENCY OF CROPPING		(DIMENSIONLESS)
	AM = HIGH YIELD AREA		(HECTARE)
	AT = LOW YIELD AREA		(HECTARE)
	TA = TOTAL AREA		(HECTARE)

Fodder (ST):

The fodder (ST) is directly proportional to the cropping intensity and the cropped area. The proportionality constant is the fodder co-efficient (FW):-

```
A     ST.K = FW*TA*IT.K
C     FW   = 3200
C     TA   = 7.4E6
```

where		
	ST = FODDER	(KG)
	IA = IRRIGATED AREA	(HECTARE)
	IT = CROPPING INTENSITY	(DIMENSIONLESS)
	FW = FODDER PRODUCED/HECTARE	(KG)

Total Food (TF):

Estimated total food production (TF) depends on high yield cropped area (AM) and low yield cropped area (AT), their respective yields (HD, LD) and draft power multiplier (EM):-

```
A     TF.K = (AM.K*IT1*HD+AT.K*LD)*EM.K
C     IT1  = 2
C     HD   = 2800
C     LD   = 1300
```

where		
	TF = TOTAL FOOD	(KG/YEAR)
	AM = HIGH YIELD CROPPED AREA	(HECTARE)
	AT = LOW YIELD CROPPED AREA	(HECTARE)
	HD = YIELD FOR HIGH YIELD CROPPED AREA	(KG/HECTARE)
	LD = YIELD FOR LOW YIELD CROPPED AREA	(KG/HECTARE)
	IT1 = FREQUENCY OF CROPPING	(DIMENSIONLESS)
	EM = DRAFT POWER MULTIPLIER	(DIMENSIONLESS)

Food Per Capita (CF):

Food per capita (CF) is obtained by dividing the total food (TF) by population (POP):-

```
A     CF.K = TF.K/POP.K
```

where	CF = FOOD PER CAPITA	(KG/HEAD/YEAR)
	TF = TOTAL FOOD	(KG/YEAR)
	POP = POPULATION	(HEAD)

B.4. BIO GAS PRODUCTION SUB-MODEL

Biogas Production (BG):

Biogas production (BG) is a level variable and is presented by an integral equation:-

```
L    BG.K = BG.J+DT*(PRR.JK-DER.JK)
N    BG   = IBG
I    IBG  = 0
```

where	BG = BIOGAS	(GJ)
	IBG = INITIAL PRODUCED BIOGAS	(GJ)
	PRR = BIOGAS PRODUCTION RATE	(GJ/YEAR)
	DER = REDUCING RATE OF BIOGAS	(GJ/YEAR)

Biogas Production Rate (PRR):

Biogas production rate (PRR) is proportional to the difference of biogas potential (BP) and produced biogas (BG). Proportionality constant is PF:-

```
R    PRR.KL = (BP.K-BG.K)*PF
C    PF     = 0.15
```

where	PRR = BIOGAS PRODUCTION RATE	(GJ/YEAR)
	BP = BIOGAS POTENTIAL	(GJ)
	BG = BIOGAS PRODUCTION	(GJ)
	PF = BIOGAS PRODUCTION RATE/PER YEAR	(DIMENSIONLESS)

Biogas Reduction Rate (DER):

Biogas reducing rate (DER) is estimated by dividing the produced biogas (BG) by the life period (RR) of the digester:-

```
R    DER.KL = BG.K/RR
C    RR     = 10
```

where	DER = REDUCING RATE OF BIOGAS	(GJ/YEAR)
	BG = BIOGAS PRODUCTION	(GJ)
	RR = LIFE PERIOD OF A BIOGAS DIGESTER	(YEAR)

<u>Biogas Potential (BP):</u>

Biogas potential (BP) is estimated through-out the year from the cowdung :-

```
A     BP.K = CT.K*FG*ND*GF
C     FG   = 3.5
C     ND   = 365
C     GF   = 0.73E-3
```

```
where     BP = BIO-GAS POTENTIAL                 (GJ/YEAR)
          CT = INVENTORY OF CATTLE               (HEADS)
          FG = DUNG CO-EFFICIENT                 (KG/CATTLE/DAY)
          ND = TIME PERIOD                       (DAY)
          GF = CO-EFFICIENT OF BIOGAS FOR        (GJ/KG)
               COW DUNG
```

<u>Cooking Energy Saving (RU):</u>

Percentage of cooking energy saveing (RU) for rural area is obtained from the difference of minimum cooking energy requirement and energy produced biogas (BG):-

```
A     RU.K = (1-(POP.K*PEC-BG.K)/POP.K*PEC)*100
C     PEC  = 4.2
```

```
where     RU = PERCENTAGE OF COOKING ENERGY      (DIMENSIONLESS)
               SAVING
          BG = ENERGY PRODUCED FROM BIOGAS       (GJ)
         POP = POPULATION                        (HEAD)
         PEC = OPTIMUM COOKING ENERGY            (GJ/HEAD)
               REQUIRED
```

<u>Bio-Fertilizer (K11,N11,P11):</u>

Bio-fertilizer i.e. potassium (K11), nitrogen (N11) and phosphorus (P11) obtained from cow dung (DG) is estimated by the multiplication of cow dung (DG) by the respective co-efficient:-

```
A     K11.K = DG.K*KF1
A     N11.K = DG.K*NF1
A     P11.K = DG.K*PF1
C     KF1   = 0.002
C     NF1   = 0.005
C     PF1   = 0.0047
```

```
where       K11 = POTASSIUM                          (KG)
            N11 = NITROGEN                           (KG)
            P11 = PHOSPHORUS                         (KG)
            DG  = COW DUNG                           (KG)
            KF1 = FRACTION OF POTASSIUM              (DIMENSIONLESS)
            NF1 = FRACTION OF NITROGEN               (DIMENSIONLESS)
            PF1 = FROCTION OF PHOSPHORUS             (DIMENSIONLESS)
```

Commercial Fertilizer Saving (K1,N1,P1):

Due to biogas policy implementation, the percentage of commercial fertilizer i.e. potassium (K1), nitrogen (N1) and phosphorus (P1) is calculated from the difference of fertilizer requirement for high yield and low yield cropped area and organic fertilizer obtained from the bio-gas production process:-

```
A     K1.K = 100-(((AM.K*IT1*DK1+AT.K*DK2)-(BG.K/GF)*KF1)/ ^
             (AM.K*IT1*DK1+AT.K*DK2))*100
A     N1.K = 100-(((AM.K*IT1*DN1+AT.K*DN2)-(BG.K/GF)*NF1)/ ^
             (AM.K*IT1*DN1+AT.K*DN2))*100
A     P1.K = 100-(((AM.K*IT1*DP1+AT.K*DP2)-(BG.K/GF)*PF1)/ ^
             (AM.K*IT1*DP1+AT.K*DP2))*100
C     IT1  = 2
C     DK1  = 20
C     DK2  = 10
C     KF1  = 0.002
C     DN1  = 60
C     DN2  = 30
C     NF1  = 0.005
C     DP1  = 40
C     DP2  = 20
C     PF1  = 0.0047
C     GF   = 0.73E-3
```

```
where   K1 = PERCENTAGE OF POTASSIUM SAVING   (DIMENSIONLESS)
        N1 = PERCENTAGE OF NITROGEN SAVING    (DIMENSIONLESS)
        P1 = PERCENTAGE OF PHOSPHORUS SAVING  (DIMENSIONLESS)
        AM = HIGH YIELD AREA                  (HECTARE)
        AT = LOW YIELD AREA                   (HECTARE)
       IT1 = FREQUENCY OF CROPPING            (DIMENSIONLESS)
       DK1 = DOSE OF POTASSIUM FOR HIGH       (KG/HECTARE)
             YIELD AREA
       DK2 = DOSE OF POTASSIUM FOR LOW        (KG/HECTARE)
             YIELD AREA
       DN1 = DOSE OF NITROGEN FOR HIGH        (KG/HECTARE)
             YIELD AREA
       DN2 = DOSE OF NITROGEN FOR LOW         (KG/HECTARE)
             YIELD AREA
```

DP1	=	DOSE OF PHOSPHORUS FOR HIGH YIELD AREA	(KG/HECTARE)
DP2	=	DOSE OF PHOSPHORUS FOR LOW YIELD AREA	(KG/HECTARE)
KF1	=	CO-EFFICIENT FOR POTASSIUM	(DIMENSIONLESS)
NF1	=	CO-EFFICIENT FOR NITROGEN	(DIMENSIONLESS)
PF1	=	CO-EFFICIENT FOR PHOSPHORUS	(DIMENSIONLESS)
GF	=	CO-EFFICIENT OF BIOGAS FOR COW DUNG	(GJ/KG)

5. Rural House-hold Cooking Fuel Sub-model

The cooking fuel demand is evaluated on the basis of per capita fuel consumption coefficient. The number of rural population multiplied by the fuel consumption coefficient gives the total biomass requirement. From crop production, the available amount of residue is evaluated by crop specific coefficient. The priority end use of crop residues is animal fodder with by far the greatest share being provided by straw. The number of cattle multiplied by the per unit requirement of fodder gives the total fodder demand to be met by straw residue. Fodder allocation is then deducted from the total residue available. Therefore the balanced portion is used as fuel by means of end use coefficient. Similarly, the product of the number of cattle, the unit production of dung and the end use coefficient for fuel provides the total amount of dung available for fuel.

The felling rate of mature and immature trees from village forest is evaluated by the deduction of summation of fuel component of cattle dung and crop residues from the total cooking fuel demand. Some of the trees are replaced through regeneration but any short fall would have to be made up through replenishment to counteract depletion of the tree stock. Depletion or over cutting is the difference between the felling rate and the regeneration rate. The regeneration rate is evaluated by the product of the regeneration coefficient and inventory of the village forest. Impact of burning efficiency of cooking fuel on tree biomass consumption as well as deforestation as a policy measure is to be investigated.

Village forest inventory (WF)

```
L WF.K=WF.J+DT*(PRR.JK-WCR.JK)
N   WF=IWF
I  IWF=99.3
```

Where,

WF=INVENTORY OF THE VILLAGE FOREST	MILLION TONS
IWF=INVENTORY OF THE VILLAGE FOREST AT THE BASE YEAR	MILLION TONS
PRR=REGENERATION RATE	M. TONS/YR

Regeneration Rate (PRR)

```
R PRR.KL=WF.K*REC
C     REC=0.025
```

WF=INVENTORY OF THE VILLAGE FOREST	MILLION TONS
REC=REGENERATION COEFFICIENT	DIMENSIONLESS

Felling rate (WEC)

```
R WEC.KL=FTB.K/ECT
C     ECT=14.O3
```

WCR=FELLING RATE	M. TONS/YR
FTB=FUEL FROM TREE BIOMASS	PJ/YR
ECT=ENERGY COEFFICIENT OF TREE BIOMASS	PJ/TON

Total cooking fuel consumption (TEC)

```
A TEC.K=PEC*POP.K*RPC
C    PEC=4.44E-6
C    RPC=0.85
```

TEC=TOTAL COOKING FUEL CONSUMPTION	PJ/YR
PEC=FUEL CONSUMPTION COEFFICIENT	PJ/CAPITA/YR
POP=POPULATION	HEAD
RPC=RURAL POPULATION COEFFICIENT	DIMENSIONLESS

Fuel from crop residue (FFS)

```
A FFS.K=NFS.K*SFC*SEC
C    SFC=0.62
C    SEC=18.74E-9
```

FFS=FUEL FROM RESIDUE	PJ/YR
NFS=NONFODDER RESIDUE	KG/YR
SFC=FUEL COEFFICIENT	DIMENSIONLESS
SEC=ENERGY COEFFICIENT	PJ/KG

Non fodder residue (NFR)

```
A NFS.K=ST.K-RFC*CT.K*DY
C    RFC=2.56
C     DY=365
```

NFS=NONFODDER RESIDUE	KG/YR
ST=CROP RESIDUE	KG/YR
RFC=FODDER COEFFICIENT FOR CATTLE	KG/CATTLE
CT=CATTLE POPULATION	HEAD
DY=DURATION	DAYS

Fuel from cattle dung (FDG)

```
A FDG.K=CT.K*DPC*DY*FCD*ECD
C    DPC=2.56
C     DY=365
C    FCD=0.4
C    ECD=13.8E-9
```

FDG=FUEL FROM DUNG	PJ/YR
CT=CATTLE POPULATION	HEAD
DPC=DUNG PER CATTLE	KG/DAY
DY=DURATION	DAYS
FCD=FUEL COEFFICIENT FOR DUNG	DIMENSIONLESS
ECD=ENERGY COEFFICIENT FOR DUNG	PJ/KG

Fuel from tree biomass (FTB)

```
A FTB.K=TEC.K-(FFS.K+FDG.K)

  TEC=TOTAL COOKING FUEL CONSUMPTION          PJ/YR
  FFS=FUEL FROM RESIDUE                       PJ/YR
  FDG=FUEL FROM DUNG                          PJ/YR
```

Burning efficiency of cooking fuel (CEF)

```
L CEF.K=CEF.J+DT*(EGR.JK-ERR.JK)
I   CEF=ICEF
I  ICEF=1

  CEF=FUEL BURNING EFFICIENCY                 DIMENSIONLESS
 ICEF=FUEL BURNING EFFICIENCY                 DIMENSIONLESS
      AT BASE YEAR
  EGR=EFFICIENCY GENERATION RATE              DIMENSIONLESS
  ERR=EFFICIENCY DEGENERATION RATE            DIMENSIONLESS
```

Efficiency generation rate (EGR)

```
R EGR.KL=(DM-CEF.K)/AD1
C     DM=2
C    AD1=10

  EGR=EFFICIENCY GENERATION RATE              DIMENSIONLESS
  CEF=FUEL BURNING EFFICIENCY                 DIMENSIONLESS
   DM=DESIRED EFFICIENCY                      DIMENSIONLESS
  AD1=ADJUSTMENT DELAY                        YEAR
```

Efficiency degeneration rate (EDR)

```
R ERR.KL=CEF.K*EDC
C    EDC=0.025

  CEF=FUEL BURNING EFFICIENCY                 DIMENSIONLESS
  ERR=EFFICIENCY DEGENERATION RATE            DIMENSIONLESS
  EDC=EFFICIENCY DEGENERATION COEFFICIENT     DIMENSIONLESS
```

percentage of area deforestation w.r.t. base year (PAD)

```
A PAD.K=(1-WF.K/WFB)*100
C   WFB=99.3
```

PAD=PERCENTAGE OF AREA DEFORESTATION W.R.T. BASE YEAR	DIMENSIONLESS
WF=INVENTORY OF THE VILLAGE FOREST	MILLION TONS
WFB=INVENTORY OF THE VILLAGE FOREST AT BASE YEAR	MILLION TONS

<u>Percentage of over cutting of village forest (POC)</u>

```
A POC.K=(PRR.JK-WCR.JK)/PRR1*100
C  PRR1=2.48
```

POC=PERCENTAGE OF OVER CUTTING OF VILLAGE FOREST	DIMENSIONLESS
PRR=REGENERATION RATE	M. TONS/YR
WCR=FELLING RATE	M. TONS/YR
PRR1=REGENERATION RATE AT BASE YEAR	MILLION TONS

<u>Additional energy required for sustaining the village forest inventory as base year (AER)</u>

```
A AER.K=FTB.K-TPB
C   TPB=34.83
```

AER=ADDITIONAL ENERGY REQUIRED FOR SUSTAINING THE VILLAGE FOREST AS BASE YEAR	PJ/YR
FTB=FUEL FROM TREE BIOMASS	PJ/YR
TPB=TREE BIOMASS FUEL PRODUCTION AT BASE YEAR	PJ

<u>Equivalent Kerosene required (EKR)</u>

```
A EKR.K=(AER.K/BFR)*KRH
C   BFR=26.43E-6
C   KRH=259.6
```

EKR=EQUIVALENT KEROSENE REQUIRED	KG/YR
AER=ADDITIONAL ENERGY REQUIRED FOR SUSTAINING THE VILLAGE FOREST AS BASE YEAR	PJ/YR
BFR=BIOMASS FUEL REQUIRED PER HOUSEHOLD	PJ/YR
KRH=KEROSENE REQUIRED PER HOUSEHOLD	KG/YR

<u>Per capita fuel from crop residues (PFFS)</u>

```
A PFFS.K=FFS.K/(POP.K*0.85)
```

PFFS=PER CAPITA FUEL FROM CROP RESIDUES	PJ/YR
FFS=FUEL FROM RESIDUE	PJ/YR
POP=POPULATION	HEAD

<u>Per capita fuel from cattle dung (PFDG)</u>

A PFDG.K=FDG.K/(POP.K*0.85)

PFDG=PER CAPITA FUEL FROM DUNG	PJ/YR
FDG=FUEL FROM DUNG	PJ/YR
POP=POPULATION	HEAD

<u>Per capita fuel from tree biomass (PFTB)</u>

A PFTB.K=FTB.K/(POP.K*0.85)

PFTB=PER CAPITA FUEL FROM TREE BIOMASS	PJ/YR
FTB=FUEL FROM TREE BIOMASS	PJ
POP=POPULATION	HEAD

<u>Per capita kerosene required (PEKR)</u>

A PEKR.K=EKR.K/POP.K*0.85

PEKR=PER CAPITA KEROSENE REQUIRED	KG/YR
EKR=EQUIVALENT KEROSENE REQUIRED	KG/YR
POP=POPULATION	HEAD

B.5. QUALITY OF LIFE SUB-MODEL

The quality of life is used here as a measure of performance for integrated rural energy systems.

<u>The Physical Quality of Life (QL):</u>

The physical quality of life (QL) is proportional to the physical quality of life from crowding, food, and bio-gas used for as cooking and lightning energy :-

A QL.K = QC.K*QF.K*QB.K

where QL = PHYSICAL QUALITY OF LIFE (DIMENSIONLESS)
QC = QUALITY OF LIFE FROM CROWDING (DIMENSIONLESS)
QB = QUALITY OF LIFE FROM BIO-GAS (DIMENSIONLESS)
QF = QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)

Bio-gas Utilization Factor (BD):

Biogas utilization factor (BD) is the ratio of generated bio-gas (BG) and bio-gas potential (BP):-

A BD.K = BG.K/BP.K

where BD = BIO-GAS UTILIZATION FACTOR (DIMENSIONLESS)
BG = GENERATED BIO-GAS (GJ)
BP = BIO-GAS POTENTIAL (GJ)

Physical Quality of Life from Bio-gas (QB):

The quality of life depends on the amount of biogas consumed. The non-linear relationship is shown in Figure B-12 :-

A QB.K = TABHL(QBT, BD.K, 0, 0.5, 0.1)
T QBT = 1/1.1/1.15/1.2/1.24/1.25

where QB = QUALITY OF LIFE MULTIPLIER FROM BIO-GAS (DIMENSIONLESS)
QBT = QUALITY OF LIFE FROM BIO-GAS TABLE FIG. B-12)
BD = BIO-GAS UTILIZATION FACTOR (DIMENSIONLESS)

CROWDING RATIO (CR):

Crowding ratio (CR) is the ratio of current population (POP) and the initial population (IPOP) i.e. population of base year 1980 :-

A CR.K = POP.K/IPOP.K

where CR = CROWDING RATIO (DIMENSIONLESS)
POP = CURRENT POPULATION (HEAD)
IPOP = INITIAL POPULATION (HEAD)

Initial Population (IPOP):

Initial population (IPOP) is computed by the summation of initial male child (IMCH), female child (IFCH), male adult (IMMT), female adult (IFMT), male old (IMOD) and female old (IFOD):-

```
A     IPOP.K = IMCH+IFCH+IMMT+IFMT+IMOD+IFOD
C     IMCH   = 21.523E6
C     IFCH   = 20.391E6
C     IMMT   = 21.03E6
C     IFMT   = 18.882E6
C     IMOD   = 3.762E6
C     IFOD   = 4.344E6
```

where		
	IPOP = INITIAL POPULATION	(HEAD)
	IMCH = INITIAL MALE CHILD	(HEAD)
	IFCH = INITIAL FEMALE CHILD	(HEAD)
	IMMT = INITIAL MALE ADULT	(HEAD)
	IFMT = INITIAL FEMALE ADULT	(HEAD)
	IMOD = INITIAL MALE OLD	(HEAD)
	IFOD = INITIAL FEMALE OLD	(HEAD)

Physical Quality of Life from Crowding (QC):

Quality of life from crowding (QC) is assumed to be non-linearly related with crowding ratio which is shown in Figure B-13.

```
A     QC.K = TABHL(QCT, CR.K, 1, 5, 1)
T     QCT  = 1/0.7/0.5/0.3/0.2
```

where		
	QC = QUALITY OF LIFE FROM CROWDING	(DIMENSIONLESS)
	QCT = QUALITY OF LIFE FROM CROWDING TABLE	(FIG. B-13)
	CR = CROWDING RATIO	(DIMENSIONLESS)

Food Ratio (FR):

Food ratio (FR) is the ratio of food per capita (CF) to food per capita (FO) at the base year 1980.

```
A     FR.K = CF.K/FO
C     FO   = 186.79
```

where		
	FR = FOOD RATIO	(DIMENSIONLESS)
	CF = FOOD PER CAPITA	(KG/YEAR)
	FO = FOOD PER CAPITA AT THE BASE YEAR	(KG/YEAR)

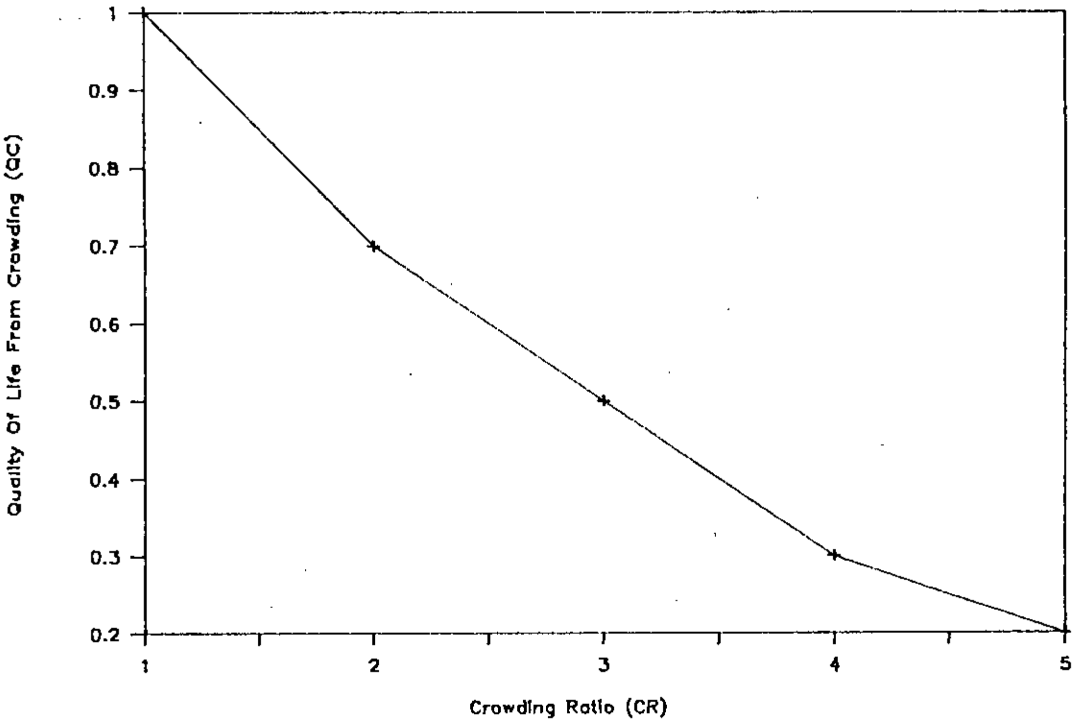


Fig. B-13 Crowding Ratio vs. Quality of Life from Crowding.

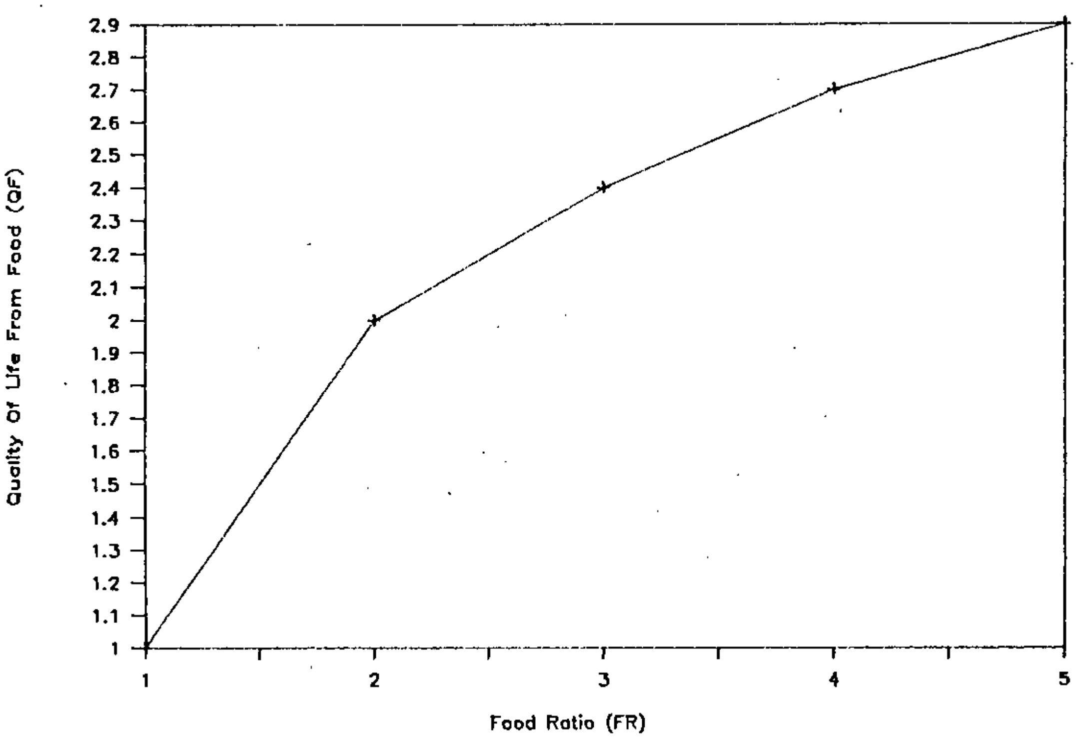


Fig. B-14 Food Ratio vs. Quality of Life from Food.

Quality of Life From Food (QF):

Physical Quality of life from food (QF) is a function of food ratio (FR). The functional relationship is shown in Figure B-14:-

```
A     QF.K = TABHL(QFT, FR.K, 1, 5, 1)
T     QFT  = 1/2/2.4/2.7/2.9

where      QF  = QUALITY OF LIFE MULTIPLIER  (DIMENSIONLESS)
                 FROM FOOD
           QFT = QUALITY OF LIFE FROM FOOD   (FIG. B-14)
                 TABLE
           FR  = FOOD RATIO                  (DIMENSIONLESS)
```

CONTROL STATEMENT

```
NOTE CONTROL STATEMENT
SAVE MCH, MMT, MOD, FCH, FMT, FOD, BR1, BR2, DR2, DR4, DR6,^
     DR3, DR5,  DR7, QL,  GR2, GR4, GR3, GR5, POP, IA, AT, ^
     TF, CF, SF, CT, DC, ED, BG, RU, K1, P1, N1, DG, BRM,  ^
     EP, DIR, IR1, CR1, IM, PA.
SPEC DT = .1/LENGTH=30/SAVPER=1
```

N.B. 1) Source of co-efficients, parameters, and initial values: Alam et al. [88], Bala & Satter [109], and Statistical Year Book [129].
2) Source of Multipliers : Forrester[52], Hsieh[56], Wadhwa[60], Alam et al.[88], and Bala & Satter[109].

APPENDIX-C

PROGRAM LISTING FOR AN ENERGY SYSTEM (IN BASIC) OF A VILLAGE IN BANGLADESH

```
10 DIM D1(10), D2(10), D3(10), D4(10), D5(10), D6(12), D7(12),
   D8(12), S1(10), S2(10), S3(10), S4(10), S5(10), S6(10)
20 DIM CG(10), BT(10), TG(10), Q1(10), Q2(10), Q4(10), Q5(10),
   Q6(10), Q7(10), Q8(10)
30 READ N, N1, N2, N3, N4, N5, N6, N7, N8
40 DATA 48, 6, 7, 11, 10, 7, 6, 8, 6
50 READ FG, CF, GP, PF, CE, CI, GF, YN, DL, YM, WB, ND, KW, PD,
   ED, DA
60 DATA 10, 3.5, 0.025, 0.30, 0.175, 2, 0.73E-3, 4474.32, 2.5, 1,
   200, 365, 0.16635, 328, 0.5, 365
70 READ AR, PN, FU, SF, AT, RF, NF, PF, KF, FC, FR, FA, FB
80 DATA 103, 231, 4.2, 1950, 0.5, 0.1, 0.3, 0.2, 0.1, 14.527E-3,
   42.29E-3, 18.738E-3, 16.06E-3
90 REM MODEL DEFINITION
100 REM AR CULTIVATED AREA
110 REM AT CAPACITY ADJUSTMENT DELAY (CATTLE), YR
120 REM BG BIOGAS PRODUCTION, GJ/YR
130 REM BF BIOGAS POTENTIAL, GJ/YR
140 REM BP BIOGAS POTENTIAL, GJ/YR
150 REM BR BIRTH RATE (CATTLE), DECIMAL
160 REM CI CROPPING INTENSITY
170 REM CM CAPACITY MULTIPLIER
180 REM CN PER CAPITA CONSUMPTION, KG/YR
190 REM CP CROP PRODUCTION, KG/YR
200 REM CR CONSUMPTION RATE, HEADS/YR
210 REM CP CATTLE POPULATION, HEADS
220 REM DF DRAFT POWER, KW/YR
230 REM DG COWDUNG, KG/YR
240 REM DL THIRD ORDER DELAY, YR
250 REM EA FEED ENERGY, GJ/YR
260 REM ED EXPECTED PRICE ADJUSTMENT DELAY, YR
270 REM EH FOOD ENERGY, GJ/YR
280 REM EP EXPECTED PRICE, TAKA/CATTLE
290 REM FD FOOD PER CAPITA, KJ/DAY
300 REM FG COWDUNG, KG/CATTLE
310 REM FL COOKING FUEL REQUIRED, GJ/YR
320 REM GF BIOGAS POTENTIAL (COWDUNG), GJ/KG
330 REM GR POPULATION GROWTH RATE, POP/YR
340 REM KK POTASSIUM, KG/YR
350 REM KW POWER OUTPUT/CATTLE, KW
360 REM NN NITROGEN, KG/YR
370 REM PA FEED PROTEIN, KG/YR
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380 REM PD NO OF DAYS IN A YEAR
390 REM PF FRACTION OF BIOGAS UNIT INSTALLED
400 REM PH FOOD PROTEIN, KG/YR
410 REM PI PRICE PER CATTLE TAKA/CATTLE
420 REM PN DESIRED CATTLE POPULATION, HEADS
430 REM PO POPULATION
440 REM PP PHOSPHOROUS, KG/YR
450 REM PR BIOGAS PRODUCTION RATE, GJ/YR
460 REM RR DEPRECIATION RATE (BIOGAS UNIT), GJ/YR
470 REM RU ENERGY FROM RURAL FOREST, GJ/YR
480 REM R3 CATTLE MATURATION RATE, HEADS/YR
490 REM SM MULTIPLIER (STRAW)
500 REM ST STRAW, KG/YR
510 REM T TIME, YR
520 REM TM MULTIPLIER (TILLAGE)
530 REM TR CATTLE STOCK ADJUSTMENT RATE, HEADS/YR
540 REM YD DEGENERATION RATE, 1/YR
550 REM YM YIELD MULTIPLIER, DEC
560 REM YN YIELD (NORMAL), KG/HA
570 REM YP YIELD DEGENERATION FACTOR, DEC
580 REM YR REGENERATION RATE, 1/YR
590 REM YT YIELD REGENERATION TIME, YR
600 REM QL QUALITY OF LIFE
610 REM QC QUALITY OF LIFE FROM CROWDING
620 REM QF QUALITY OF LIFE FROM FOOD
630 PRINT "SIMULATED RESULTS OF SIMPLIFIED HUQ'S MODEL"
640 REM DATA ON CROPING INTENSITY
650 FOR I = 1 TO N8
660 READ CG(I)
670 NEXT I
680 DATA 2.0, 2.3, 2.6, 2.8, 2.9, 3.0
690 FOR I = 1 TO N8
700 READ BT(I)
710 NEXT I
720 DATA 0.025, 0.0235, 0.0225, 0.0215, 0.0210, 0.02
730 FOR I = 1 TO N8
740 READ TG(I)
750 NEXT I
760 DATA 1988, 1990, 1992, 1994, 1996, 2000
770 REM DATA ON YIELD MULTIPLIERS
780 FOR I = 1 TO N1
790 READ D1(I)
800 NEXT I
810 DATA 0, 0.2, 0.4, 0.6, 0.8, 1
820 REM DATA ON REGENERATION TIMES
830 FOR I = 1 TO N1
840 READ D2(I)
850 NEXT I
860 DATA 0, 8, 20, 45, 80, 120
```

```
870 REM DATA ON EXPECTED CATTLE PRICES
880 FOR I = 1 TO N7
890 READ S5(I)
900 NEXT I
910 DATA 0, 2250, 4500, 6750, 9000, 11250, 13250, 15750
920 REM DATA ON CAPACITY MULTIPLIER
930 FOR I = 1 TO N7
940 READ S6(I)
950 NEXT I
960 DATA 0, 0.75, 1, 1.25, 1.37, 1.45, 1.5, 1.5
970 REM DATA ON CROPPING INTENSITY
980 FOR I = 1 TO N2
990 READ D3(I)
1000 NEXT I
1010 DATA 0, 0.5, 1, 1.5, 2, 2.5, 3
1020 REM DATA ON DEGENERATION FACTOR
1030 FOR I = 1 TO N2
1040 READ D4(I)
1050 NEXT I
1060 DATA 0, 0.006, 0.01, 0.016, 0.025, 0.05, 1
1070 REM DATA ON PRICE OF BEEF
1080 FOR I = 1 TO N6
1090 READ S3(I)
1100 NEXT I
1110 DATA 1, 20, 37, 53, 68, 80
1120 REM DATA ON BEEF CONSUMPTION
1130 FOR I = 1 TO N6
1140 READ S4(I)
1150 NEXT I
1160 DATA 10, 6, 4.5, 3.8, 3.6, 3.5
1170 REM DATA ON DRAFT ANIMAL PER HECTARE
1180 FOR I = 1 TO N3
1190 READ D5(I)
1200 NEXT I
1210 DATA 0, 0.5, 1, 1.5, 1.75, 2, 2.5, 4, 5, 6, 8
1220 REM DATA ON YIELD MULTIPLIER (TILLAGE)
1230 FOR I = 1 TO N3
1240 READ D6(I)
1250 NEXT I
1260 DATA 0.25, 0.52, 0.75, 0.95, 1, 1, 1, 1, 1, 1, 1
1270 REM DATA ON CATTLE INVENTORY
1280 FOR I = 1 TO N5
1290 READ S1(I)
1300 NEXT I
1310 DATA 0, 100, 200, 300, 400, 600, 800
1320 REM DATA ON PRICES OF CATTLE
1330 FOR I = 1 TO N5
1340 READ S2(I)
1350 NEXT I
```

```
1360 DATA 13500, 11250, 6750, 4500, 4050, 2250, 1125
1370 REM DATA ON STRAW PER CATTLE
1380 FOR I = 1 TO N4
1390 READ D7(I)
1400 NEXT I
1410 DATA 0, 1, 2, 3.55, 4, 5, 6, 7, 8, 9
1420 REM DATA ON FOOD MULTIPLIER FOR CATTLE
1430 FOR I = 1 TO N4
1440 READ D8(I)
1450 NEXT I
1460 DATA 0.5, 0.75, 0.9, 1, 1.2, 1.27, 1.31, 1.35, 1.4, 1.4
1470 REM DATA ON QUALITY OF LIFE FROM FOOD PER CAPITA
1480 FOR I = 1 TO N8
1490 READ Q1(I)
1500 NEXT I
1510 DATA 0, 1, 2, 3, 4, 5
1520 FOR I = 1 TO N8
1530 READ Q2(I)
1540 NEXT I
1550 DATA 0, 1, 2, 2.4, 2.7, 2.9
1560 REM DATA ON QUALITY OF LIFE FROM CROWDING
1570 FOR I = 1 TO N8
1580 READ Q3(I)
1590 NEXT I
1600 DATA 0, 1, 2, 3, 4, 5
1610 FOR I = 1 TO N8
1620 READ Q4(I)
1630 NEXT I
1640 DATA 2, 1, 0.7, 0.5, 0.3, 0.2
1650 T=1988: DT=0.25: PO=1121: BG=0: EP=4500: YM=0.9: YN=4693
1660 CP = YN*AR*CI
1670 EH = CP*FC
1680 PH = CP*FR
1690 EA = AR*CI*SF*FA
1700 PA = AR*CI*SF*FB
1710 FL = PO*FU
1720 RU = FL
1730 FD = (CP/PO)*FC*1000000!/DA
1740 DF = (CT*KW)/AR
1750 BP = CT*FG*ND*GF
1760 NN = (CT*FG*NF)/100
1770 PP = (CT*FG*KF)/100
1780 KK = (CT*FG*KF)/100
1790 BR = CT*CE
1800 L1 = BR*(DL/3)
1810 L2 = BR*(DL/3)
1820 L3 = BR*(DL/3)
1830 FO = FD
1840 C8 = PO/AR
```

```
1850 C9 = CP/PO: QF = FD/FO: QC = (PO/AR)/C8: QL = QF*QC
1860 PRINT "YEAR", "POPULATION", "ENERGY(GJ)", "PROTEIN(KG)",
           "FOOD PER CAPITA(KJ/DAY)"
1870 PRINT T, PO, EH, PH, FD
1880 PRINT "YEAR", "CATTLE(HD)", "ENERGY(GJ)", "PROTEIN(KG)",
           "DRAFT POWER(KW/HA)"
1890 PRINT T, CT, EA, PA, DF
1900 PRINT "YEAR", "BIO POT(GJ)", "BIO GA(GJ)", "RU ENERGY(GJ)",
           "RU FOREST(GJ)"
1910 PRINT T, BP, BG, FL, RU
1920 PRINT "YEAR", "NITROGEN", "PHOSPHOROUS", "POTASSIUM",
           "QUALITY OF LIFE"
1930 PRINT T, NN, PP, KK, QL
1940 FOR L = 1 TO N
1950 T = T + DT
1960 FOR I = 1 TO (N8-1)
1970 BK = T
1980 IF BK = TG(I) THEN 2020
1990 IF BK>TG(I) AND BK<TG(I+1) THEN 2020
2000 IF BK = TG(I+1) THEN 2020
2010 NEXT I
2020 SS = (BK-TG(I))/(TG(I+1) - TG(I))
2030 CI = CG(I) + (CG(I+1) - CG(I))*SS
2040 GP = BT(I) + (BT(I+1) - BT(I))*SS
2050 GR = GP*PO
2060 TC = CT
2070 FOR I = 1 TO (N5-1)
2080 IF TC = S1(I) THEN 2120
2090 IF TC>S1(I) AND TC<S1(I+1) THEN 2120
2100 IF TC = S1(I+1) THEN 2120
2110 NEXT I
2120 EE = (TC-S1(I))/(S1(I+1) - S1(I))
2130 PI = S2(I) + S2(I+1) - S2(I)*EE
2140 PT = PI/(WB*0.6)
2150 FOR I = 1 TO (N6-1)
2160 IF PT = S3(I) THEN 2220
2170 IF PT>S3(I) AND PT<S3(I+1) THEN 2220
2180 IF PT = S3(I+1) THEN 2220
2190 NEXT I
2200 FF = (PT-S3(I))/(S3(I+1) - S3(I))
2210 CN = S4(I) + (S4(I+1) - S4(I))*FF
2220 CR = (CN*PO)/(WB*0.6)
2230 BF = CT*FG*GF*ND
2240 PR = PF*(BF-BG)
2250 PE = EP
2260 FOR I = 1 TO (N7-1)
2270 IF PE = S5(I) THEN 2310
2280 IF PE>S5(I) AND PE<S5(I+1) THEN 2310
2290 IF PE = S5(I+1) THEN 2310
```

```
2300 NEXT I
2310 HH = (PE-S5(I))/(S5(I+1) - S5(I))
2320 CM = S6(I) + (S6(I+1) - S6(I))*HH
2330 RR = BG*RF
2340 BR = CT*CE
2350 TY = YM
2360 FOR I = 1 TO (N1-1)
2370 IF TY = D1(I) THEN 2410
2380 IF TY>D1(I) AND TY<D1(I+1) THEN 2410
2390 IF TY = D1(I+1) THEN 2410
2400 NEXT I
2410 AA = (TY-D1(I))/(D1(I+1) - D1(I))
2420 YT = D2(I) + (D2(I+1) - D2(I))*AA
2430 DY = CI
2440 FOR I = 1 TO (N2-1)
2450 IF DY = D3(I) THEN 2490
2460 IF DY>D3(I) AND DY<D3(I+1) THEN 2490
2470 IF DY = D3(I+1) THEN 2490
2480 NEXT I
2490 BB = (DY-D3(I))/(D3(I+1) - D3(I))
2500 YP = D4(I) + (D4(I+1) - D4(I))*BB
2510 YR = (1-YM)/YT
2520 TL = (CT)/(AR)
2530 FOR I = 1 TO (N3-1)
2540 IF TL = D5(I) THEN 2580
2550 IF TL>D5(I) AND TL<D5(I+1) THEN 2580
2560 IF TL = D5(I+1) THEN 2580
2570 NEXT I
2580 CC = (TL-D5(I))/(D5(I+1) - D5(I))
2590 TM = D6(I) + (D6(I+1) - D6(I))*CC
2600 ST = (AR(I)*CI*SF)/(CT*365)
2610 FOR I = 1 TO (N4-1)
2620 IF ST = D7(I) THEN 2660
2630 IF ST>D7(I) AND ST<D7(I+1) THEN 2660
2640 IF ST = D7(I+1) THEN 2660
2650 NEXT I
2660 DD = (ST-D7(I))/(D7(I+1) - D7(I))
2670 SM = D8(I) + (D8(I+1) - D8(I))*DD
2680 R1 = L1/(DL/3)
2690 L1 = L1 + (BR - R1)*DT
2700 R2 = L2/(DL/3)
2710 L2 = L2 + (R1 - R2)*DT
2720 R3 = L3/(DL/3)
2730 L3 = L3 + (R2 - R3)*DT
2740 PN = PD*SM*CM
2750 TR = (PN-CT)/AT
2760 PB = PI
2770 EP = EP + (PB - EP)*(DT/ED)
2780 YM = YM + (YR - YD)*DT
```

```
2790 CP = YN*CI*TM*AR*YM*TM
2800 EH = CP*FC
2810 PH = CP*FR
2820 SI = AR*CI*SF
2830 EA = SI*FA
2840 PA = SI*FB
2850 CT = CT + (R3 - CR + TR)*DT
2860 PO = PO + GR*DT
2870 FD = (CP/PO)*FC*1000000!/DA
2880 DF = (CT*KW/AR)
2890 DG = CT*FG*ND
2900 BF = DG*GF
2910 NN = (DG*NF)/100
2920 PP = (DG*PF)/100
2930 KK = (DG*KF)/100
2940 BP = DG*GF
2950 FL = PO*FU
2960 BG = BG + (PR - RR)*DT
2970 RU = FL - BG
2980 FX = FD/FO
2990 FOR I = 1 TO (N8-1)
3000 IF FX = Q1(I) THEN 3040
3010 IF FX>Q1(I) AND FX<Q1(I+1) THEN 3040
3020 IF FX = Q1(I+1) THEN 3040
3030 NEXT I
3040 QQ = (FX-Q1(I))/(Q1(I+1) - Q1(I))
3050 QF = Q2(I) + (Q2(I+1) - Q2(I))*QQ
3060 CW = (PO/AR)/C8
3070 FOR I = 1 TO (N8-1)
3080 IF CW = Q3(I) THEN 3120
3090 IF CW>Q3(I) AND CW<Q3(I+1) THEN 3120
3100 IF CW = Q3(I+1) THEN 3120
3110 NEXT I
3120 RR = (CW-Q3(I))/(Q3(I+1) - Q3(I))
3130 QC = Q4(I) + (Q4(I+1) - Q4(I))*RR
3140 QL = QF*QC
3150 DZ = DZ + DJ
3160 IF DZ<1 THEN 3260
3170 PRINT "YEAR", "POPULATION", "ENERGY(GJ)", "PROTEIN(KG)",
           "FOOD PER CAPITA(KJ/DAY)"
3180 PRINT T, PO, EH, PH, FD
3190 PRINT "YEAR", "CATTLE(HD), "ENERGY(GJ)", "PROTEIN(KG)",
           "DRAFT POWER(KW/HA)"
3200 PRINT T, CT, EA, PA, DF
3210 PRINT "YEAR", "BIO POT(GJ)", "BIO GA(GJ)", "RU ENERGY(GJ)",
           "RU FOREST(GJ)"
3220 PRINT T, BP, BG, FL, RU
3230 PRINT "YEAR", "NITROGEN", "PHOSPHOROUS", "POTASSIUM",
           "QUALITY OF LIFE"
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3230 PRINT T, NN, PP, KK, QL
3240 DZ = 0
3250 NEXT L
3260 STOP
3270 END
```

APPENDIX-D

List of energy consumption (kwhr/cap)*, life expectancy (LE), infant mortality(IM), literacy rate(LR) and physical quality of life index (PQLI).

Country	Energy Consump-tion Kwhr/cap*	Life Expec-tancy (LE)	Infant Mortality per 1000 (IM)	Lite acy Rate (LR)	Physical Quality of Life Index (PQLI)	Esti-mated PQLI (PQLI)
Upper Volta	8	38	182	7	16	22.85
Nepal	9	44	152	13	27	24.15
Somalia	14	41	177	5	19	29.00
Chad	14	38	160	6	18	29.00
Niger	15	39	200	5	14	29.76
Benin	17	41	149	20	27	31.14
Bangladesh	21	46	153	22	32	33.46
Ethiopia	25	42	162	6	22	35.38
Lao People's D	26	40	175	28	26	35.81
Rwanda	32	41	133	16	27	38.09
Guinea-Bissau	39	39	208	5	14	40.26
Gambia	39	40	165	10	21	40.26
Malawi	46	43	142	22	30	42.08
Nigeria	46	41	157	25	27	42.08
Uganda	47	50	160	35	40	42.31
Togo	56	41	163	16	24	44.24
Equitorial Gui	56	44	165	20	28	44.24
Congo, People'	75	44	180	20	27	47.45
Sierra Leone	81	44	136	10	28	48.29
Kenya	86	50	119	22	39	48.95
Yemen, People'	107	45	155	27	32	51.35
Mozambique	107	44	140	11	27	51.35
Guinea	116	41	175	9	20	52.24
Jordan	119	53	97	32	47	52.52
India	129	49	129	34	41	53.41
Paraguay	136	62	65	80	75	53.99
Pakistan	137	51	139	16	36	54.07
China, People'	146	65	65	60	71	54.77
Western Samoa	155	63	40	98	84	55.43
Honduras	157	55	103	45	53	55.57
Zaire	164	44	160	31	32	56.05
Morocco	164	53	133	21	40	56.05
Angola	169	38	203	12	16	56.38
Bolivia	177	48	157	40	39	56.89
Ecuador	183	60	66	68	69	57.25

Country	Energy Consumption Kwhr/cap*	Life Expectancy (LE)	Infant Mortality per 1000 (IM)	Literacy Rate (LR)	Physical Quality of Life Index (PQLI)	Estimated PQLI (PQLI)
Guatemala	184	53	75	46	54	57.31
Thailand	194	61	89	79	71	57.89
Algeria	200	53	145	26	41	58.23
Egypt	225	53	108	26	44	59.52
Tunisia	226	55	135	32	46	59.57
El Salvador	254	58	55	57	64	60.86
Grenada	260	63	24	76	78	61.11
Iraq	297	53	104	26	45	62.57
Philippines	315	58	80	83	71	63.22
Dominican Rep.	331	58	96	68	64	63.77
Turkey	352	57	119	51	56	64.44
Mauritius	361	63	40	61	72	64.72
St. Lucia	374	63	60	52	67	65.11
Reunion	378	63	44	63	72	65.22
Seychelles	379	65	35	58	73	65.25
Iran	389	57	104	37	52	65.54
Fiji	398	70	41	64	79	65.79
Nicaragua	405	53	110	58	55	65.98
Guadeloupe	458	65	35	83	81	67.33
Martinique	475	65	32	88	83	67.73
Macao	481	58	78	79	69	67.87
Peru	490	56	80	72	65	68.08
Guyana	499	68	50	87	84	68.28
Colombia	499	61	90	81	72	68.28
Malaysia	510	68	41	53	73	68.52
Albania	522	68	87	72	76	68.77
Mongolia	528	61	70	95	78	68.90
Korea, Rep.	535	65	47	88	82	69.04
Cuba	662	70	27	78	85	71.38
Brazil	684	61	109	66	66	71.74
Panama	685	66	47	78	79	71.76
Mexico	707	65	66	74	75	72.11
Lebanon	709	64	59	86	79	72.14
Costa Rica	764	68	38	89	85	72.96
Uruguay	810	69	49	90	86	73.60
Barbados	832	69	28	98	90	73.89
Chile	922	63	56	88	79	75.02
Malta	941	70	14	83	87	75.25
Jamaica	1110	68	20	82	85	77.06
Trinidad & Tob	1117	66	31	92	85	77.13
Argentian	1117	68	59	93	85	77.13
Cyprus	1137	71	27	76	85	77.33
Portugal	1229	69	39	71	80	78.18

Country	Energy Consumption Kwhr/cap*	Life Expectancy (LE)	Infant Mortality per 1000 (IM)	Literacy Rate (LR)	Physical Quality of Life Index (PQLI)	Estimated PQLI (PQLI)
Korea, People'	1457	61	70	85	75	80.05
Venezuela	1581	65	49	82	79	80.95
Hong Kong	1582	72	14	77	87	80.96
Greece	1589	72	23	84	89	81.01
Singapore	1741	71	12	75	86	82.01
Yugoslavia	1865	68	36	84	84	82.77
Romania	2221	70	31	99	91	84.69
Hungary	2261	69	30	98	90	84.88
Spain	2273	72	11	90	92	84.94
Ireland	2552	71	15	98	93	86.21
Poland	2637	71	24	98	92	86.57
Italy	2696	72	19	94	92	86.82
Israel	2774	71	22	84	89	87.13
Bulgaria	3096	71	23	95	92	88.34
Bahamas	3350	66	35	90	84	89.20
France	3429	73	13	97	95	89.46
Denmark	3481	74	10	99	96	89.62
USSR	3831	69	28	100	91	90.68
Netherlands	3978	74	11	98	96	91.09
Austria	4098	71	18	98	93	91.42
Japan	4201	74	9	98	96	91.69
Belgium	4344	71	14	97	93	92.06
Germany, Dem.	4742	72	14	99	94	93.02
Puerto Rico	4814	72	21	89	90	93.19
United Kingdom	4873	72	14	99	94	93.32
Germany, Fed.	5119	71	17	99	94	93.86
Australia	5229	72	14	98	94	94.10
Switzerland	5342	73	11	98	95	94.33
New Zealand	6063	72	16	98	94	95.72
Finland	6222	71	10	99	94	96.01
United States	9344	73	15	99	95	100.48
Sweden	9566	75	9	99	97	100.73
Iceland	10916	75	8	99	97	102.18

Source: Martin M. McLaughlin and staff of the Overseas Development Council, The United States and World Development: Agenda 1979, pp.156-68. Praeger Publishers for the Overseas Development Council New York (1978).

*Source: Department of Economics and Social Affairs, United Nations; "World Energy Supplies.", Newyork 1976.