METHODOLOGIES FOR MODELLING OF BIOMASS RESOURCES AND USES

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ABSTRACT

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

INTRODUCTION

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

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

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

SYSTEMS ANALYSIS

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

This model should ideally answer only one question. In the work carried out on Injambakkam village this question was judged to be "How much solar energy can be captured in photosynthetic activity (that is, as biomas resources) and put to use within the village system?" In practice however, by the inclusion of some subsidiary relationships, models can answer many questions.

The process of model formulation is known as simulation. Continuous simulation, applied here is concerned with flows and levels in which each individual entity in the flow is not differentiated from the others, but all are aggravated together; for example the village rice stock, the harvest and daily consumption. An aggregated model, while less informative than a disaggregated, is more robust and reliable.

Systems analysis considers all facets of a situation simultaneously; the interrelationships between component parts of a system rather than the parts themselves. It is therefore an ideal tool for evaluating the merits and demerits of implanting a particular set of biomass oriented technologies aimed at improving the output of a Third World village, district, island or country.

Four crucial issues need to be resolved: What is the best used of bio- and agricultural technologies to raise output? What are the dynamics of change? What level of productivity may be ultimately attainable? What social or economical changes may be needed to make such a self-reliant development possible? To answer these questions, systems modelling has the two merits of versatility and speed. It allows for the examination of a large number of scenarios, each with a different set of initial and/or ensuing conditions.

The process of change over decades can be monitored by the systems modeller in a matter of seconds. To achieve the same spread using solely experimental work in the field would required the setting up and monitoring of a very large number of rural communities, each implanted with a different technological mix. Data collation might take as long as 20 years and the degree of organisation and cooperation sought would be difficult to obtain in the extreme.

DYNAMIC SYSTEMS ANALYSIS METHODOLOGY

To gain some insight into the technique of modelling consider a hypothetical Third World village community (Figure 1). Crops are cultivated on fertile soil. There is woodland, grassland, fallow land, and wasteland plus roads, houses and ponds etc. Some of this waste land has potential for upgrading. In Figure 2 the village layout is stylised, without reference to spatial factors, with all areas of land of the same type being aggregated.

Since the object of the study is to find how a rural community may prosper within a larger system, we have to decide on the boundary between the two. This is called the system boundary, and we can choose, if we wish, to aggregate within or without of that boundary. Within the boundary, flows can be recorded as money, as mass and energy (kilograms of protein, gigajoules of fuel energy, kilocalories of food energy and so on), and as human labour and animal hours of work. In a rural community where much is done without money changing hands it is more useful to ignore money flows. However, if a material good or an activity passes through the system boundary to the outside world it is useful to convert it into money values, and consider the revenue to be spent on purchases. For example, exported rice generates money to buy fertilisers, kitchen utensils, transistor radios, etc.

To project into the future we need to employ a dynamic model in which stocks and flows are linked by a system of differential equations solvable by numerical analysis. Solution of the differential equations is made accessible by the development of specialised computer languages such as DYNAMO and ND TRAN 2 and is given a more mathematical treatment in a subsequent section.

The first step in an analysis is to identify the relevant parts of the system and how they interact. The direction of the arrow indicates the direction of the causation. The sign adjacent to the arrowhead shows whether this is a positive or negative effect. Thus

FERTILISER ————————→ + CROP YIELD

demonstrates that increasing fertiliser application increases crop yields. This is simple statement presupposes a high level of knowledge, which if not available must be researched.

Frequently, the relationship is non-linear. An increasing death rate decreases population. Since a change in population must affect subsequent death rate, we can represent the latter by a causal loop diagram (Figure 3). Causal loops may be positive (+) or negative (-). In Figure 3 the effect of increasing death rate on population is negative. Increasing birth rate resulting in increasing population size leading to increasing birth rate is a positive causal loop.

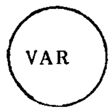
The next analytical step is to decide which elements are flows (called "rates" in system dynamics terminology) and which are state variables (known as "levels"). Levels can be likened to a tank containing a quantity (stock) of water, as opposed to a flow of water through a pipe that enters the tank, which is a rate. Rates have the dimension of units/time whereas levels are measured without reference to time. The flow of water into a tank is illustrated in system dynamics symbols in Figure 4.

It is most important to note the difference between the directions of the arrow in the causal loop diagram and the system dynamics diagram. In the former it shows the direction of the causation, in the latter the direction of flow of material (or information).

Turning to a hypothetical Third World village community we can develop a model for the use of a community biogas generator operating on cattle dung. Nitrogen rich soil conditioner, in the form of the biogas plant effluent will increase rice production. The extra rice straw can be fed to cattle, thus raising dung yields which in turn means more soil conditioner (and of course more biogas) from the biogas generator. The circle is completed. Thus rice productivity is further enhanced. We have therefore identified a positive feedback loop as depicted in Figure 5.

Output does not go on rising forever. Each addition of nitrogen yields less and less increase in output and eventually, after several cycles (seasons) a new level of output is stabilised. It is a simple step from the causal loop diagram to the system dynamics diagram once the level variable has been identified. The digester is the only level variable, to which is associated two rates - the rate of loading dung (IN) and the rate of removal of soil conditioner (OUT). This is illustrated in Figure 6. Here there are some new symbols:

 represents a constant



represents an auxilliary variable - an identifiable variable that is used in the calculation of rate equations

The rice is only harvested once a year so this is represented by a sample procedure illustrated thus:

SAMPLE	
	1 yr

An important part of the system dynamics diagram is the relationship between nitrogen in soil conditioner and rice yield. This model was translated into a DYNAMO program and the results of the simulation are shown in Figure 7.

The biogas plant is brought into production in year 1. Initially the dung is put into the biogas generator instead of being spread on the fields. This has an adverse effect on the next rice crop. In the third year the soil conditioner output, which has approximately twice the usable nitrogen content of directly spread dung, produces an increased rice yield. The positive feedback loop previously described boosts the rice yield in subsequent years until a new equilibrium level is reached (around year 7). The rice yield has increased by a factor of 42%. One should note that a calculation which did not take account of the feedback would have shown only a 12% increase!

One interesting conclusion is that imported fertiliser would have a greater effect than might be imagined. Importing 1.8kg N/ha per year would initially increase the yield by 7% but again, the positive feed-back loop comes into effect and this extra yield produced more soil conditioner for the next year's crop, until a new equilibrium is attained. We can now consider with the aid of a model how one could improve on the performance of the village agriculture.

THE ACQUISITION OF A DATABASE

A simulation model of a real system such as a Third World rural community and its biomass resources can accurately reflect that system only when sufficient relevant data have been acquired. Before projecting into the future via the dynamic systems analysis methodology described above, details of the major parameters of the system (village) must be obtained so that the steady-state village can be modelled at time zero.

These data will include physical, economic and social characteristics of the village and also land area use and distribution pattern, climatic information, demographic details, agricultural practice, crop productivities, livestock ownership, food consumption, energy productivities, livestock ownership, food consumption, energy production and levels and distribution, village imports (such as fertilisers, kerosene and consumer durables) and exports (for example, food surpluses, wood and handicrafts). Ancillary data might consist of occupational patterns, medical information, social organisation and so forth.

The acquisition of such data is often a laborious task, generally entailing personal contact with a large cross-section of individuals from the community, though a village "accountant" may have some of the demographic data. A village survey is most easily accomplished by interviewers who are already known in the village and who have obtained the people's confidence. It is therefore important that the systems modeller makes known his precise requirements to those carrying out the survey in the village. The fact must also be taken into account that some villagers are often unwilling or unable to supply accurate data. Thus the importance of conducting, at least initially, a comprehensive survey is reinforced so that any misleading information which cannot obviously be detected as such is outweighed by the responses nearer to the truth.

Once a model has been constructed for a particular village and any problems in the simulation have been ironed out, then the level of data requirements for similar work on other villages is reduced. This was borne out by the systems modelling experience of the Energy Studies Unit, University of Strathclyde. Initially a highly detailed survey of the Indian village of Injambakkam was conducted by the Murugappa Chettiar Research Centre (MCRC), Madras. The survey consisted of general data on the 211 constituent households of the village to provide a broad perspective followed by a more detailed questioning of 70 selected households (MCRC 1980). Using these data a technocratic model was utilised to simulate the activities of Injambakkam and then used succesfully for the simulation of two Nepalese hill villages, Salme and Tarevir, where the data bases provided were considerably less detailed.

THE MERDA MODEL

The basic model described previously was expanded and implemented using the database for Injambakkam village, Tamil Nadu, India. The model was named MERDA (an acronym for Model for Energy and Resource Development Analysis) and is now a generic dynamic feedback simulation model realised for the computer in ND TRAN 2 language. The ND TRAN 2 package was obtained from Notre Dame University, Indiana, USA and is similar though not identical to DYNAMO software. ND TRAN 2 can be implemented on any computer with an ANSI standard FORTRAN compiler and at least 28 k bytes of store. Hence MERDA could be run on virtually any machine equal to or bigger than a PDP11. In fact MERDA runs on the ICL computer and takes up approximately 15 seconds of computer time at a cost of US$2 each run.

It consists of 111 equations plus 63 data constants and tables and is divided into six major sectors: rice production, legume production, fertilisers, biogas production, financial and the energy sector, to which others can be added if required. The causal loop diagram, Figure 8, illustrates the interactions between the various parameters, including introduced technologies, and Figure 9 the system dynamics diagrams. The numbers and other scenario details are not spelled out here; instead the options available to the model user are given.

Within the rice production sector, two crops of rice are grown each year. It is convenient to look at these separately and then sum the relevant quantities. A stock of rice for each harvest is maintained but depleted by consumption. Each year at the appropriate times each stock is updated by the amount of the harvest according to the yield. Consumption is then calculated to deplete the stock in one year. The yield per hectare is a function of the fertiliser applied by hectare and the total yield is obtained by multiplying this by the rice growing area, taking into account that the whole area need not be used. The total consumption is obtained by summation and accounting for post-harvest losses.

The legume production sector is almost identical to that of rice production except that there is only one crop per year. The production of legumes is initially zero and the modeller provides the starting year.

The stock of fertilisers is provided by dung or digester sludge output; legume leaves; Casuarina leaves; algae; and imports. Fertiliser is counted as its nitrogen content; the other nutrients are assumed to be available in non-limited quantities.

Dung is calculated as a function of the cattle fodder available (crop wastes and grazing). Initially a proportion of this is collected and spread on the fields. When the biogas plant starts operation the dung instead is put in the digester; provision has been made for a different collection efficiency to be used. The digested sludge is then spread on the fields.

Leaves containing nitrogen from the food legumes and Casuarina trees are used as fertiliser when they are brought into production. Algae are started in small ponds and then over a period of time established on the fields, where they fix nitrogen from the atmosphere.

Import levels can be switched on or off at times chosen by the modeller. In the financial sector, the difference between village earnings and expenditure is put in a bank account where it earns a real 2% per annum interest when the balance is positive. When they are in debt the villagers pay a 2% real annual interest rate. Village expenditure for imports includes: fertiliser; wood (can be earnings if there is an export); work energy; biogas plant capital; clothing; extra food, eg fish, milk, eggs, etc. Pumps, both capital and running costs; windmills; Totem (Total energy module for electricity generation and heat reclamation).

The energy sector, as distinct from the biogas production sector, is more closely concerned with heat energy, furnished by fuelwood. The demand for primary energy in the form of heat is calculated as a function of population, with provision for a higher end-use efficiency to be incorporated over a time period chosen by the modeller. Wood harvest is given by the forested area multiplied by the yield per unit area. A change may be made to an energy crop plantation at any time in the simulation. Any deficit in the supply and demand equation is imported and any surplus is exported. If a biogas plant is operating any surplus gas can be used as heat energy (eg for cooking). A limited amount of waste heat from the Totem plant can be utilised here, for heating water only. These last two supplies, if implemented by the modeller, would force an increase in the wood export.

The biogas production sector is more closely related to work energy. The demand for work energy for irrigation is added to that for lighting. Before the biogas plant comes on stream all of this energy must be imported. These imports are reduced by gas production but can never go negative, in which case the excess gas is used in the heat energy sector to substitute for wood. When biogas becomes available the fraction of rice growing area is increased by extra irrigation until 100% is utilised. The number of new pump sets required for this is calculated in this sector.

If windmills are required in a scenario the energy saved by using this method for irrigation is subtracted from the demand. A Totem system, if selected by the modeller, reduces the supply of gas but produces some electricity which is then added to the supply. Some waste heat is transferred to the heat energy sector.

Other sectors can also be included, for instance, population growth can be catered for in scenarios if required - the modeller provides the net annual rate of increase in population. The spatial layout of the village is handled separately here for convenience. All the areas can be altered by the modeller. Indicators of village wellbeing (eg protein intake, solar capture, etc) are calculated for the model output.

The scenarios, sensitivity testing of the model, and results of model simulations have been published elsewhere (Lewis 1984; Slesser et al 1982). Briefly the results indicate that Injambakkam has the potential to utilise its biomass resources to become self-reliant in food and fuel within 5-7 years.

AN ECONOMIC ASSESSMENT OF BIOMASS BASED DEVELOPMENT IN INJAMBAKKAM VILLAGE

Having established the technical feasibility of self-reliant development for the village, a more rigorous economic analysis was made than that performed by MERDA, using a feedback model called ECONOMERDA. Its purpose was to investigate whether biotechnologies such as the biogas plant could develop within Injambakkam and villages like it purely under economic forces, with the rate of introduction controlled by the mechanism of price.

ECONOMERDA is essentially an extension of the MERDA model in which the economic driving force is the desire to have an economic return on capital investment (Figure 10). The opportunity for production and distribution of biogas is vested in an entrepreneur who develops the system only where it is advantageous to him, and if it is viable for him to do so then it should be viable to a village cooperative also.

Essentially livestock dung is bought from the villagers and the post-digestion gas and sludge fertiliser are sold back to them, with the capital required for construction of plant borrowed from a bank at commercial interest rates. The digester has an annual dung throughput of 17.5t. It is assumed that the higher the price paid for dung (base price of Rs 0.1/kg dry wt) then the greater the proportion of available dung will be sold (Figure 11) and when the amount available for digestion exceeds the current throughput capacity another plant is built. The price offered to the villagers for dung is determined by the profitability of the whole operation (Figure 12), while the price at which biogas is sold is notionally 80% of the price of imported diesel fuel. Similarly the price of sludge fertiliser is set at 80% of the price of nitrogen equivalent of imported chemical fertiliser. Profitability is monitored by maintaining a financial balance for incomings and outgoings. Thus the money accruing from the sale of gas and sludge fertiliser increases the balance while the cost of dung purchase, labour and maintenance, interest and repayments of capital decreases the balance.

The biogas is used initially for irrigation until two rice crops per year can be grown on all the available paddy area. Some of the resulting increase in rice production is exported so that the farmers may buy new biogas-operable pump sets without the community going into debt. When the technocractic scenario used for MERDA is incorporated into ECONOMERDA, equilibrium levels for the parameters monitored are reached by year 15.

Over 15 years rice production increases by 240% to improve nutritional standards and export potential. Biogas production, at over 1TJ per annum, is sufficient to irrigate biannual rice crops, with 320 GJ/y surplus for other uses. Solar energy capture more than doubles, the entrepreneur's profit is Rs12,000 (US $1500) per annum, and his return on investment is 40%. However, while this approach to assessing economic viability is clearly a useful one, further hard cost data are needed to improve its credibility.

In addition to the above approach a more conventional cost benefit analysis (CBA) was used to investigate the feasibility of introducing biogas plants into a rural community such as Injambakkam (Armstrong 1983). Essentially CBA is a method of assessing the desirability of public projects where future, as well as current, returns are considered, as are potential side-effects on society. It is based on the notion that an allocation of resources to an investment project should increase social welfare and involves the enumeration and evaluation of all relevant costs and benefits to assess the effect of carrying out projects (in this case the introduction of biogas plants) on the welfare of society as a whole. A favourable verdict is returned where total benefits exceed total costs.

However, many of the assumptions made about social costs and benefits within a CBA are necessarily subjective (value judgements), and are difficult to quantify. Financial analyses of a project aimed at introducing biogas plants to the village indicate that an entrepreneur, or indeed village cooperative, would benefit from such a venture on strictly market price terms. However, a final appraisal using such values does not adequately indicate changes in the villagers' economic welfare. This requires the estimation and use of shadow prices whereby inputs and outputs are valued according to their true resource costs and values to the village, which is the essence of a CBA. Furthermore, CBAs include externalities such as the reduction in pollution caused by burning biogas rather than wood and the reduction in time spent looking for woodfuel, whereas financial analyses take no account of such factors.

In general, the results of the various CBAs were favourable in that the installation of biogas plants in Injambakkam would indeed increase social welfare. Nevertheless these results are highly sensitive to parameters such as the rice yield (since the post-digested sludge acts as a fertiliser in the paddy fields), to biogas yields and to labour costs and so the values placed on these parameters are critically important to the outcome of the CBA undertaken. As in the approach to economic feasibility adopted by utilising the ECONOMERDA model, further hard cost data are also required to increase the credibility of cost benefit analyses.

THE ECCO MODEL - BIOMASS SECTOR

ECCO (Enhancement of Carrying Capacity Options) is a feedback system dynamics model operating at the national level and in such a way that accounting is made in energy rather than money terms. It maintains at all times the essential resource elements of the economy, of which the biomass/woodfuel sector is one. ECCO can be used to explore many policy options amongst which are trade offs between land for biomass energy or food, or between food and cash crops, and has been applied to the case of Kenya.

Carrying capacity is defined as that population, at any moment in time, which can be indefinitely sustained at a given standard of living. It is not a threshold, and can be enhanced by appropriate national development using physical and human resources. The model assesses the overall scale and trend of the economy, sector by sector (eg water, non biomass energy, agriculture, biomass, industry etc) in such a way that each sector grows so as to satisfy the overall resource needs of all the other sectors. Thus if the domestic demand for energy cannot be met by fuelwood from the biomass sector, any shortfall must be made good by the non-biomass energy sector. If it cannot do so then material standard of living falls. Once the long-term physical profile is known conventional economic methods may be used to plan the implementation of each sector.

Figure 13 presents an influence (causal loop) diagram of the model's biomass sector, while Figure 14 is the system dynamics diagram. Data are provided for Kenya by Mwenge International Associates Ltd (MIAL 1984):

Average natural forest yield	1.05t/ha.y; 70 y growing period
Average plantation yield	9.2t/ha.y; 7y rotation
Woodfuel demand	25.5GJ/ha.y

In a country like Kenya the harvesting of biomass by collecting firewood from the forests and woodland is a very important source of fuel to the population. Eighty per cent of Kenya's energy accrues from biomass. In this sector, the harvesting of the natural forest is gradually augmented by the introduction of fast growing energy crop plantations.

Capital formation in this sector is not allowed until after 1985. The desired capital stock is calculated either as that required to meet the household sector energy demand, or to plant the entire forest area, whichever is smaller. A check is made to ensure that the area cleared for new plantations does not provide more than the demand for woodfuel. Capital has to be replaced after the plantation is harvested, so the lifetime of capital stock is set equal to the plantation growing time. Capital is allocated to the harvesting sector sufficient to always maintain the necessary stock to meet the full harvesting level anticipated.

The area to be planted is decided according to the actual capital stock available for planting. This is calculated by dividing this by the capital necessary to plant one hectare. Through a seven year delay, corresponding to the time for the forest to mature, one-seventh of the planted area is harvested.

The biomass stock of the plantation is calculated as the time integral of the growth rate minus harvesting. The growth rate in mass terms is simply a function of the area planted. The harvesting rate is given by the area harvested times the mass per hectare of the mature trees obtained.

All of the forest area currently allocated to energy supply that is not planted is allocated to natural forest. The biomass of this forest is calculated in the same way as for the plantation. The rate of harvesting, though, is determined by the demand for energy in the domestic sector that is not met by the plantation and clearing operations. There is a check made to ensure that if there is no biomass left none is harvested. The yield of biomass from the outside forest area, that is from trees grown on agricultural land, is accounted.

The data for yields and energy inputs will depend on the tree species chosen. If the domestic demand for energy cannot be met from the biomass sector any shortfall must be made good by the (non-biomass) energy sector. The energy and water demands for forestry are calculated under the appropriate sectors of energy and water.

What has been presented here is a methodology for dealing with the biomass (specifically fuelwood) resource of a country, in this case Kenya. It could be applied with equal facility to any African country with a sufficient database upon which to draw. The results are dependent on the data inputs and assumptions made in all other sectors of the ECCO model as well as the biomass sector, and so for this purpose are less important than the methodology used.

DISCUSSION

While this paper has tried to focus on methodologies for the modelling of biomass resources and technologies for their use, the MERDA, ECONOMERDA and ECCO models are policy making tools for development in all aspects of economic activity, whether at the rural community or national level. Indeed to model biomass in isolation from other sectors would be of little use since they are all interconnected in the systems methodology adopted. It would not be profitable for example to attempt to measure biomass energy production to the exclusion of everything else since then there would be no land for food crops nor investment for other activities, and no opportunity for a balanced development strategy. [An exploratory biomass production systems model, BIOMET has recently been developed at the University of Florida with the boundary of the production process taken as the system boundary (Mishoe et al. 1984)]

Clearly, in the African situation, continuous deforestation and falling food production per capita are trends which need to be arrested and reversed. However, investment here may take investment away from the urban/industrial sector of an economy which is why the overall system has to be researched, not merely the agricultural and biomass sectors. It is then left to the politicians and policymakers to decide the priorities for their particular country, such as whether to attempt more food and self-reliance or export-led growth of manufactured goods rather than adopting import substitution strategies.

The models described in this paper can aid the decision process, but they themselves require hard data, data which in many countries are not yet obtainable. Nowhere is hard data more unobtainable than in the production and consumption of the biomass resources so crucial to the economies of developing countries. Modelling is a very useful tool, but as a prerequisite data collection is absolutely vital.

Finally, to fully explain the system dynamics methodology adopted has not been possible in a paper such as this, but interested readers are referred to the texts now available on the subject, particularly to that by Forrester (1973), for a more complete treatment. System dynamics is potentially a very rewarding approach to the process of decision-making not only concerning biomass resources, but in attempting to achieve development goals in all areas of an economy.

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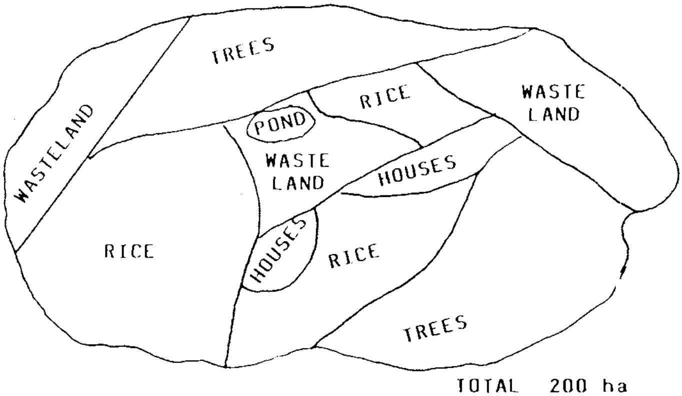


Fig 1. The Real Village System

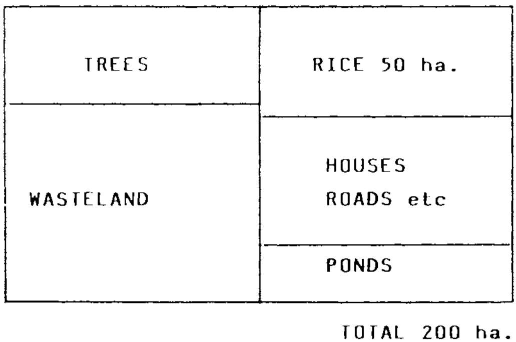


Fig 2. The Modelled Village System

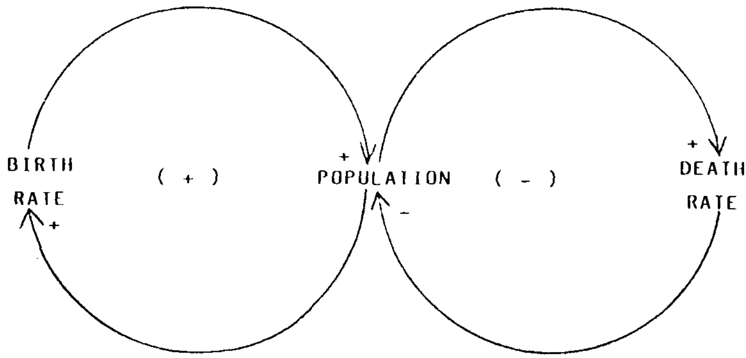


Fig. 3 Causal Loop Diagram of Simple Population Model

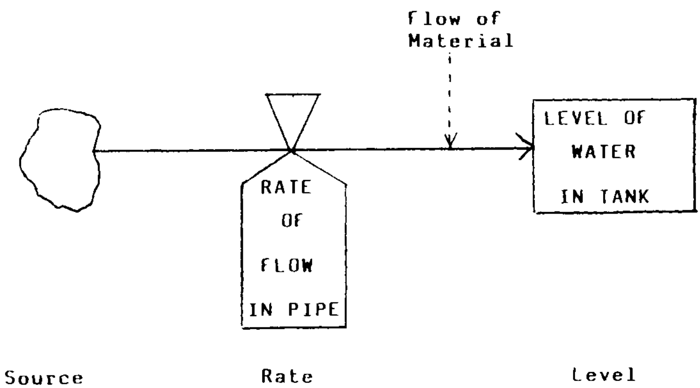


Fig. 4 System Dynamics Diagram

Fig. 5 Rice Production - Causal Loop Diagram

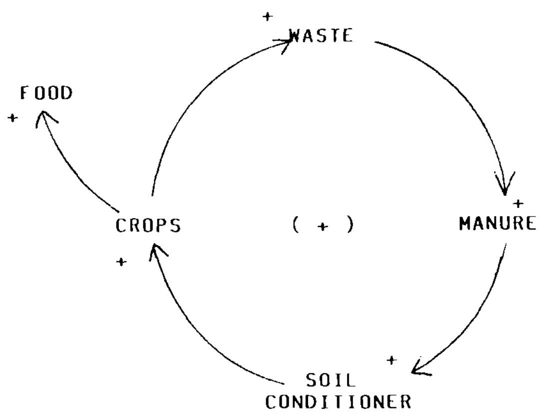


Fig 6. System Dynamics Diagram of Simple Village Model

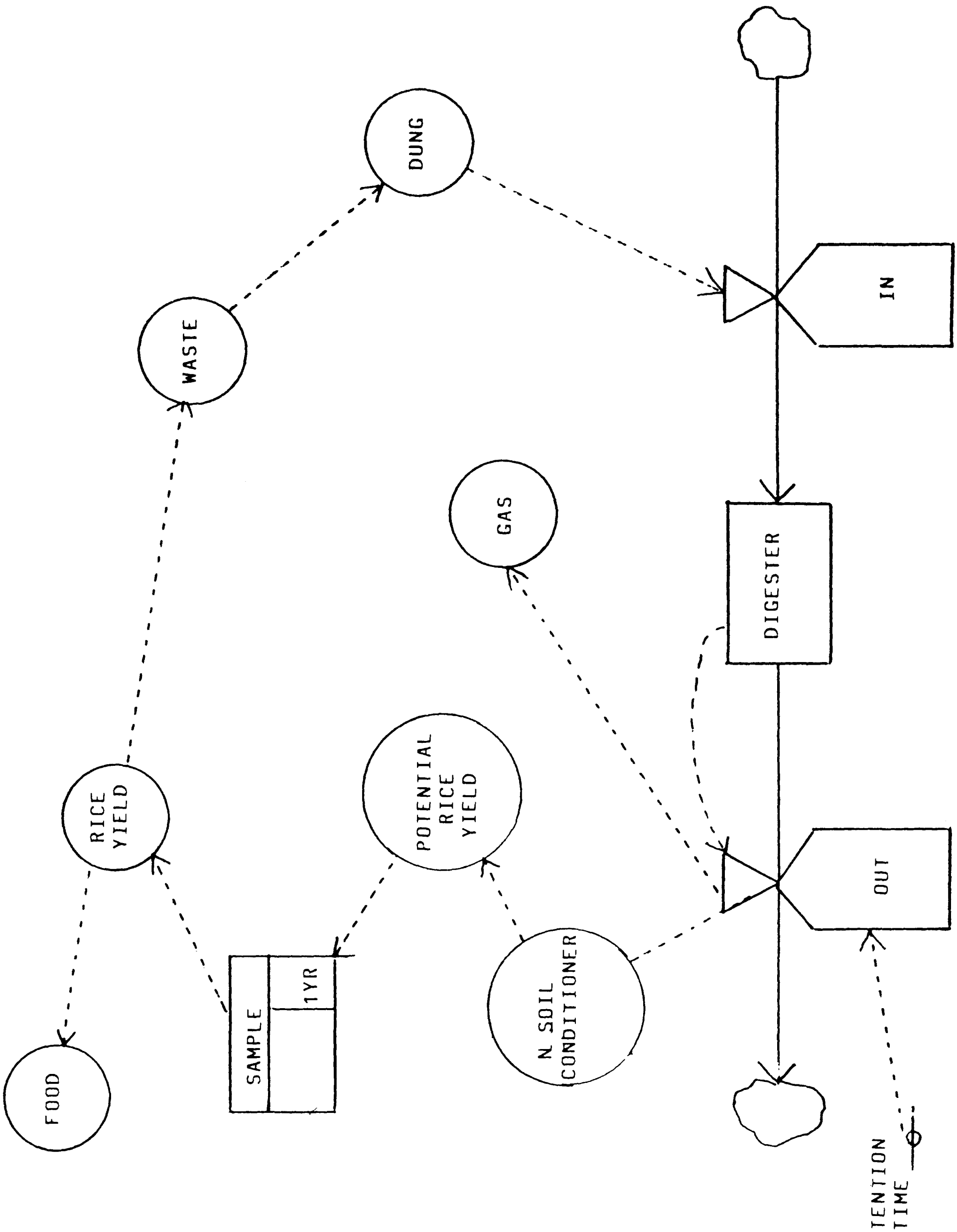


Fig 7. Output of Simple Village Model - Scenario 2: Biogas Plant and Imported Fertiliser

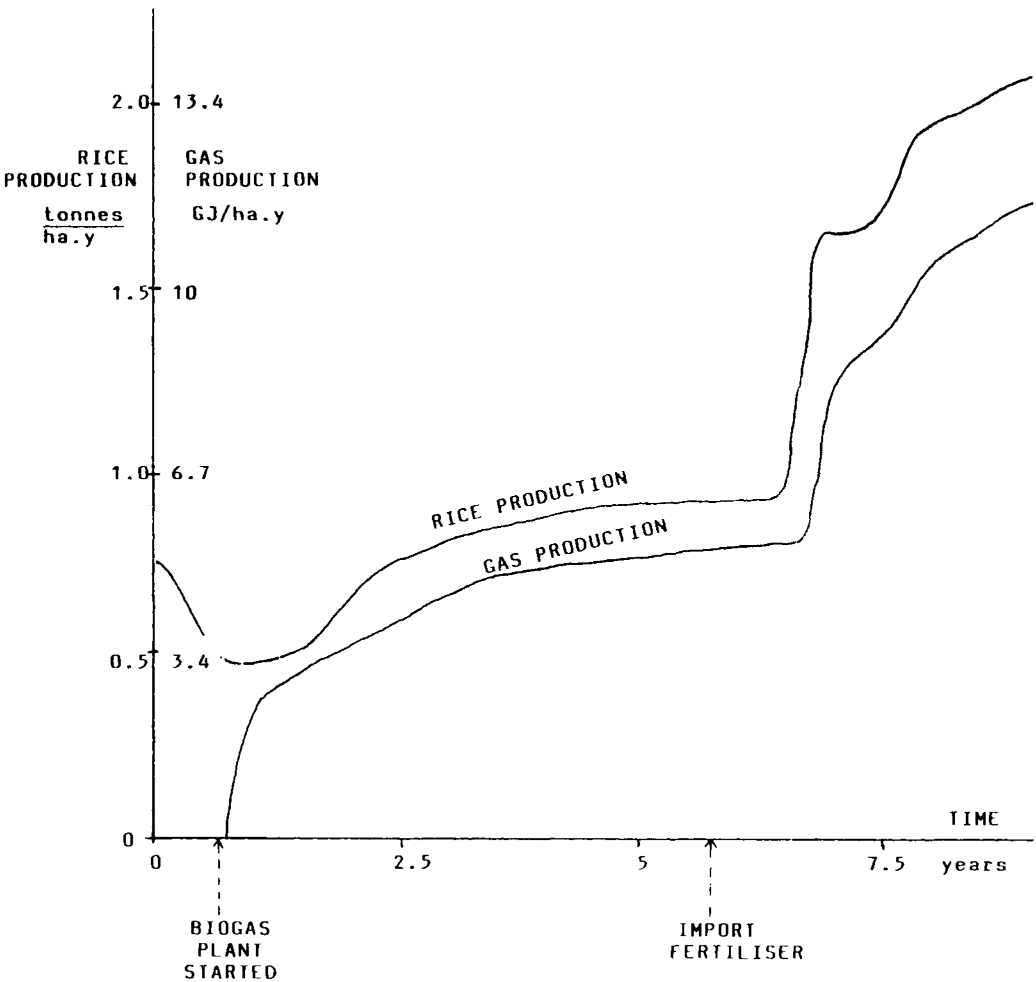


Fig. 8 Causal Loop Diagram of the MERDA model

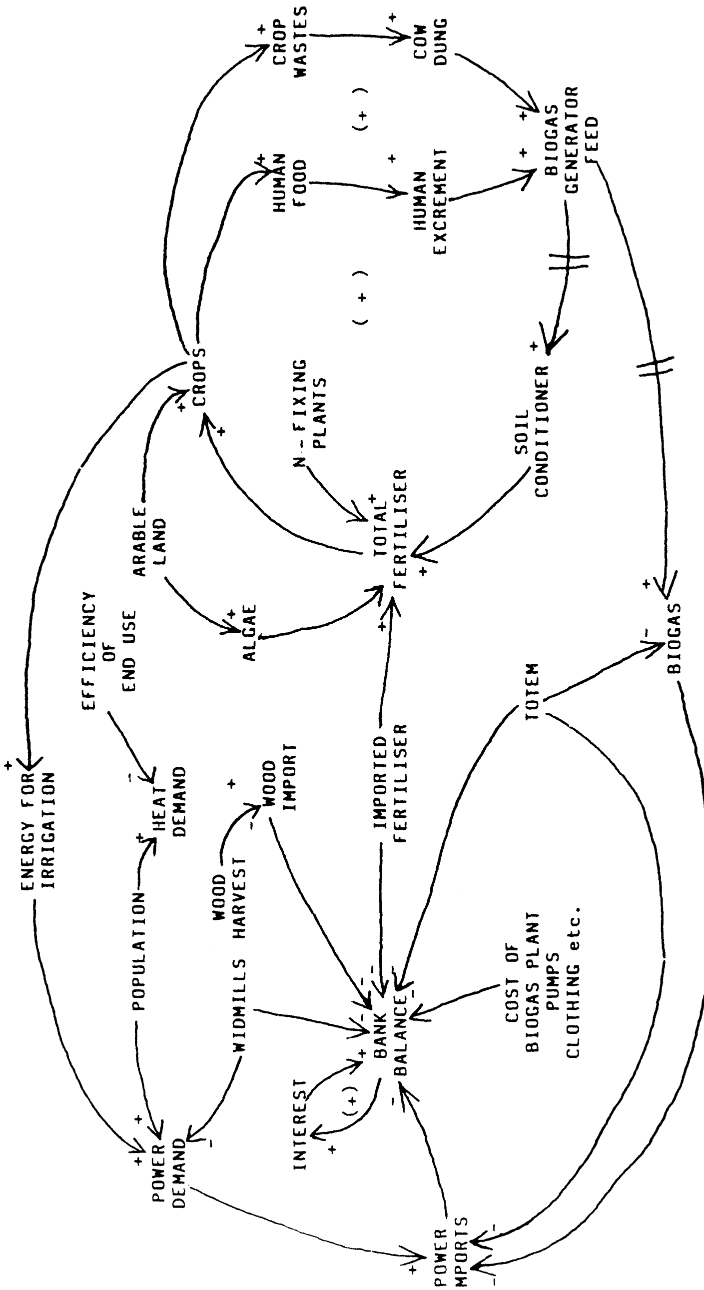
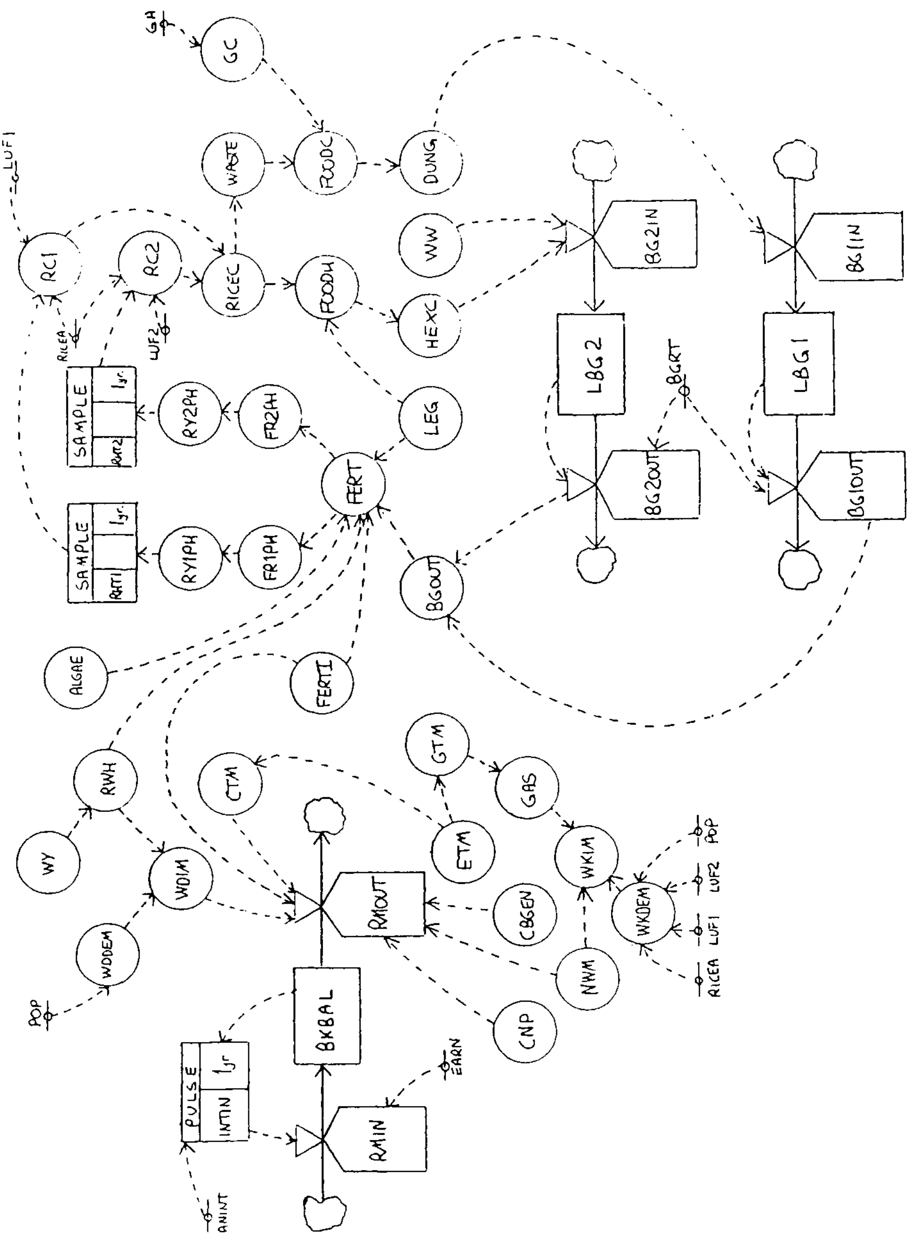


Fig 9. System Dynamics Diagram of MERDA



EXPLANATION OF SYMBOLS (Fig 9)

ALGAE	Algae Production
ANINT	Annual Real Rate of Interest
BGOUT	Total Soil Conditioner Output
BGRT	Biogas Plant Retention time
BG1IN	Input to 1st Biogas Plant
BG1OUT	Output of 1st Biogas Plant
BG2IN	Input to 2nd Biogas Plant
BG2OUT	Output of 2nd Biogas Plant
BKBAL	Bank Balance
CBGEN	Cost of Biogas Generator
CNP	Cost of New Pumps
CTM	Cost of TOTEM
DUNG	Cow Dung
EARN	Village Earnings
ETM	Electricity Production from TOTEM
FERT	Total Fertiliser Available
FERTI	Fertiliser Imports
FOODC	Food for Cattle
FOODH	Food for Humans
FRIPH	Fertiliser for Winter Rice Crop per ha
FR2PH	Fertiliser for Summer Rice Crop per ha
GA	Grazing Area
GAS	Total Gas Production
GC	Grass for Cattle
GTM	Gas to TOTEM
HEXC	Human Excrement
INTIN	Interest on Bank Account
LBG1	Level in Biogas Plant No 1
LBG2	Level in Biogas Plant No 2
LEG	Legume Production
LUF1	Land Utilisation Factor Winter crop
LUF2	Land Utilisation Factor Summer crop
NWM	Number of New Pumps
POP	Population
RC1	Rice Consumption from Winter Crop
RC2	Rice Consumption from Summer Crop
RHT1	Rice Harvest Time Winter Crop (fraction of year)
RHT2	Rice Harvest Time Summer Crop (fraction of year)
RICEA	Rice Growing Area (potential)
RICEC	Total Rice Consumption
RMIN	Money into Bank Account
RMOUT	Money out of Bank Account
RWH	Wood Harvest
RY1PH	Rice Yield per ha in Winter
RY2PH	Rice Yield per ha in Summer
WASTE	Waste from Rice for Cattle Fodder
WDDEM	Wood Demand
WDIM	Wood Import
WKDEM	Work Energy Demand
WKIM	Work Energy Import
WW	Water Weed Production
WY	Wood Yield per ha

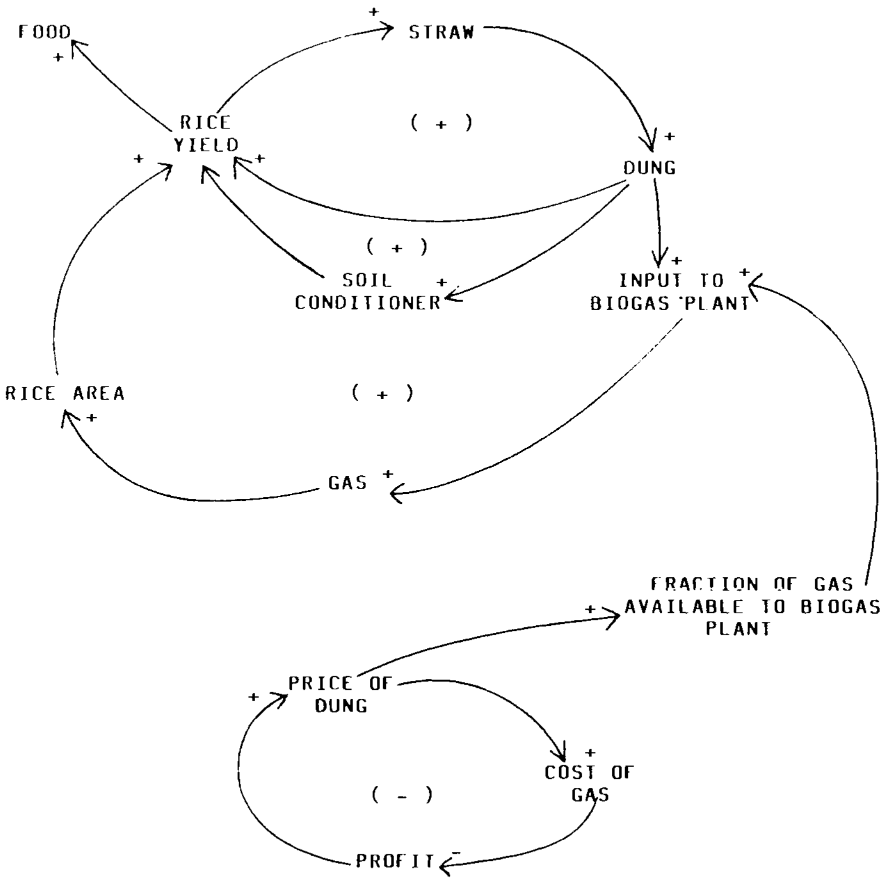


Fig 10. Causal Loop Diagram of ECONOMERDA

Fig 11. ECONOMERDA : Dung Price vs Dung Availability

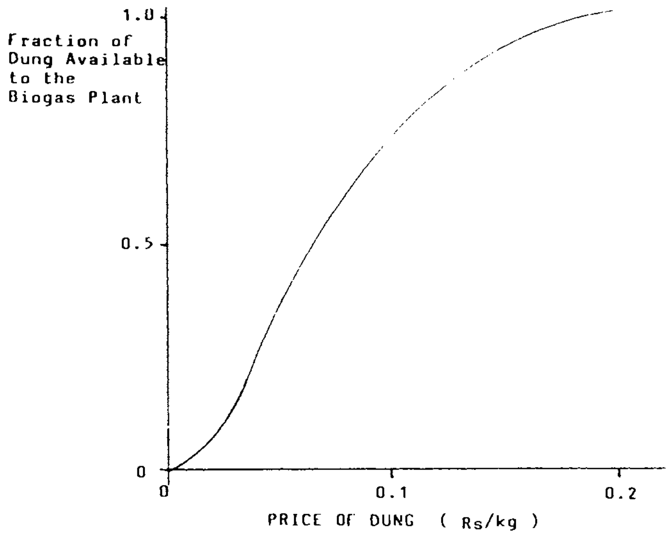
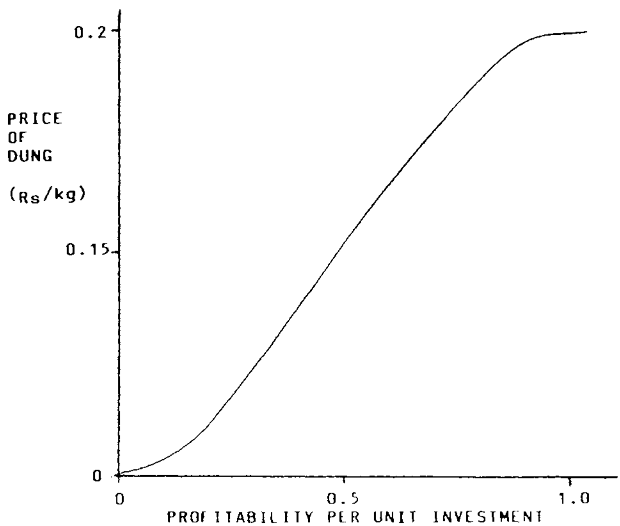
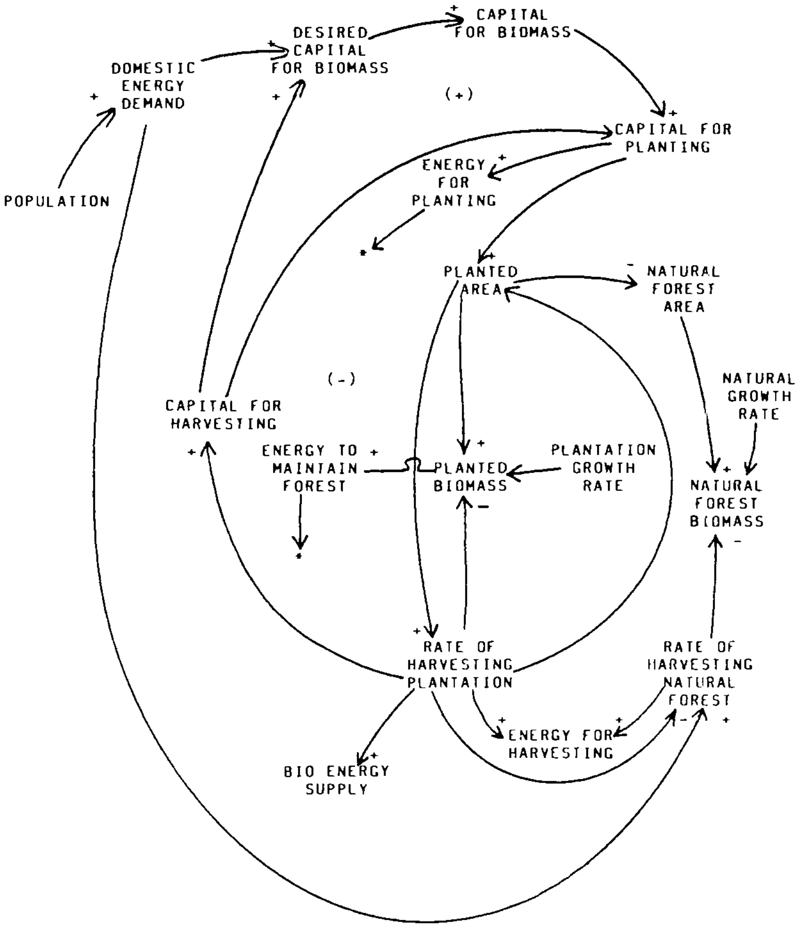


Fig 12. ECONMERDA : Dung Price vs Profitability





* = Link to main model - Energy Demand

Fig 13. Influence Diagram of ECCO Biomass Sector

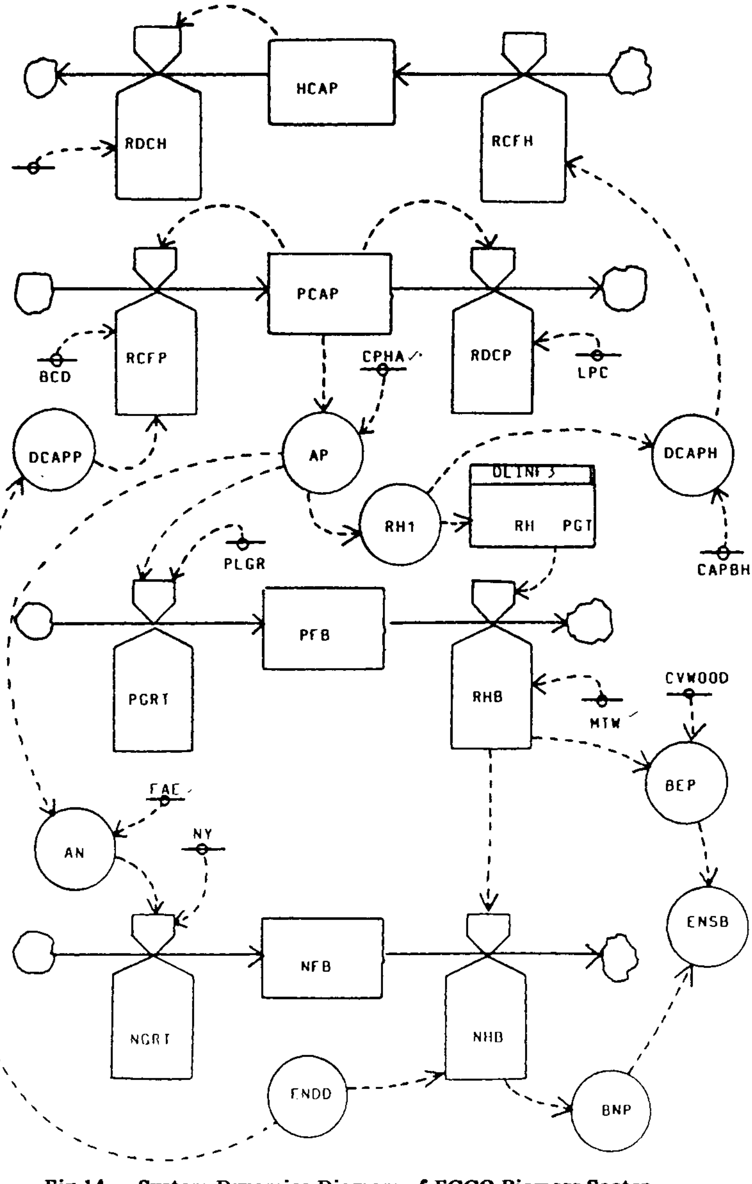


Fig 14. System Dynamics Diagram of ECCO Biomass Sector

EXPLANATION OF SYMBOLS - FIGURE 14

AN	Area of natural forest for bioenergy
AP	Actual area planted
BCD	Desired capital for biomass
BEP	Bioenergy production of plantation
BNP	Bioenergy from natural forest
CAPBH	Capital required for planting
CPHA	Capital required for unit area planted
CVWOOD	Calorific value of wood
DCAPH	Desired capital stock for harvesting
DCAPP	Desired capital for planting
ENDD	Household energy demand
ENSB	Energy shortage in biomass sector
FAE	Total forest area for bioenergy
HCAP	Capital stock for harvesting
LPC	Lifetime of plantation capital
MTW	Mature tree mass per unit area
NFB	Natural forest biomass
NGRT	Natural forest growth rate
NHB	Rate of harvesting natural forest
NY	Natural forest yield per unit area
PCAP	Planting capital stock
PFB	Proportion of forest area for bioenergy
PGRT	Plantation growth rate
PGT	Plantation maturation time
PLGR	Plantation growth rate per unit area
RCFH	Rate of capital formation for harvest
RCFP	Rate of capital formation for planting
RDCH	Rate of capital depreciation
RDCP	Rate of depreciation of planting capital
RH	Actual rate of harvesting
RH1	Future rate of harvesting
RHB	Rate of harvesting biomass