Simulation for Input-Output Energy Structure in Agriculture: Bangladesh

M. S. Alam, M. R. Alam, Nusrat Jahan Imu

***Abstract*—**This paper presents a computer simulation model based on system dynamics methodology for analyzing the dynamic characteristics of input energy structure in agriculture and Bangladesh is used here as a case study for model validation. The model provides an input energy structure linking the major energy flows with human energy and draft energy from cattle as well as tractors and/or power tillers, irrigation, chemical fertilizer and pesticide. The evaluation is made in terms of different energy dependent indicators. During the simulation period, the energy input to agriculture increased from 6.1 to 19.15 GJ/ha i.e. 2.14 fold corresponding to energy output in terms of food, fodder and fuel increase from 71.55 to 163.58 GJ/ha i.e. 1.28 fold from the base year. This result indicates that the energy input in Bangladeshi agricultural production is increasing faster than the energy output. Problems such as global warming, nutrient loading and pesticide pollution can associate with this increasing input. For an assessment, a comparative statement of input energy use in agriculture of developed countries (DCs) and least developed countries (LDCs) including Bangladesh has been made. The performance of the model is found satisfactory to analyze the agricultural energy system for LDCs.

***Keywords*—**Agriculture, energy indicator, system dynamics, energy flows.

I. INTRODUCTION

BANGLADESH is a country with a population of nearly 144.044 million in 2011 confined within an area of 144000 km^2 which makes an average population density of about 976 persons per km^2[1], a figure amongst the highest in the world. About 76% of the people of Bangladesh live in rural areas and mainly depend on agriculture. Almost 60% of the population is cultivators. The country had a rapid population growth rate of 1.47% in 2011 per annum [1]. The country has a very low per capita income as well as energy consumption. Per capita energy consumption of Bangladesh in 2011 was 7.43 GJ per year being one of the lowest in the world against 20.60 GJ per year in India and 320 GJ per year in USA [2] which indicates that the physical quality of life in Bangladesh is extremely miserable. Nearly 19.29% of the GDP [3] is contributed by the agricultural sector, which proves that the Bangladesh economy is predominated by agriculture.

M.S.Alam is with the Electrical & Electronics Engineering Department, Daffodil International University Dhaka-1207, Bangladesh (phone: +8801713109917; e-mail: eeesa@daffodilvarsity.edu.bd).

M.R Alam is with Institute of Energy Technology, Chittagong University of Engineering and Technology, Chittagong 4349, Bangladesh.

Nusrat Jahan Imu is with the Electrical Engineering Department, Daffodil International UniversityDhaka-1207, Bangladesh (phone: +8801783601318; e-mail: imu@daffodilvarsity.edu.bd).

In LDCs like Bangladesh, agriculture is the main source of Biomass fuel as well as one of the main energy consuming sectors too. The energy capture through agriculture in crops and crop residues provide food for people and fodder for draft animals. Cow dung and crop residues are used as fuel for cooking. Sources have been supplemented by the use of coal, oil and electricity in agriculture, transport and household sectors. The most striking feature of energy use in the third world is that the amount of useful work output is poor, which indicates that obtain from the energy they use is relatively small. When the energy inputs to agriculture are increased properly, the energy output per worker and per unit of land increases. Energy obtained from the consumption and sale of crop is, in turn, needed to increase the input to agriculture to raise crop yields and to improve the quality of life of the peasants. The rate with which the LDCs move toward the distant goal of rural modernization is largely determined by the direct and indirect energy flow into agriculture, which may be expected to make up a larger fraction of energy consumption in the future than at present.

With a view to formulate a mathematical model for input energy structure in an agricultural system, an integrated energy flow network with cause-effect relationship [shown in Fig. 1] was initially developed. The network forms the basis for the development of a computer simulation model based on the system dynamics methodology developed by Forester WJ. [4] for policy planning purposes. At the final stage, this model was operationalized by using the available data for Bangladesh.

II. OBJECTIVES

- To assess the impact of energy input in agriculture
- To assess the impact of energy input to generate per unit GDP output and
- To analyze policy options for operating the input energy structure in agriculture.

III. LITERATURE REVIEW

Huq, [5] proposed a more complete and realistic qualitative energy model of an agricultural sector in Bangladesh. This model was based on the concept of control theory. Satter, [6] stated that agriculture concerned with effective energy use into agricultural to maximize production. Pimental et al. [7] reports that the energy intensive agriculture is highly productive, but its sustainability is questionable. Stout and Best [8] remarked that the quality of life in rural areas of developing countries was severely limited by lack of energy needed to produce food. Okurut et al. [9] reported that besides land, farm power was the second most important input for agriculture production. Shrestha [10] analyzed the input output energy and their cost in Nepalese agriculture for the period 1970-1995. Ozkan et al. [11] made a descriptive analysis of energy use in Turkish agriculture for the period 1975-2000. Alam et al. [12] developed a system dynamics model for an integrated energy system for a village in Bangladesh. Alam et al. [13] also developed a system dynamics model for an integrated energy system for farming in Bangladesh. Alam et al. [14] illustrated an energy-flow model for a rural family farming system in Bangladesh. Alam et al. [15] again developed a simulation model for rural household fuel consumption in Bangladesh. In this context, an attempt has been made to develop a simulation model for analyzing the characteristics of energy input to agricultural sector in LDCs.

IV. The Model

Agriculture is essentially an energy conversion process – the collection of solar energy and its conversion through photosynthesis to biomass. Biomass is defined to include all organic matters except fossil fuels. The primary goal of agriculture is to produce balanced food and secondary cash crops, fuel and organic fertilizer.

In early days, the agricultural system involved little more than throwing seeds on the soil and accepting a meager yield to sustain human lives on a subsistence basis. At present, the agricultural system involves a complex mixture of science and technology applied in such a way that the productivity is much higher than with earlier traditional techniques. Currently, agriculture also uses an energy subsidy to enhance yields.

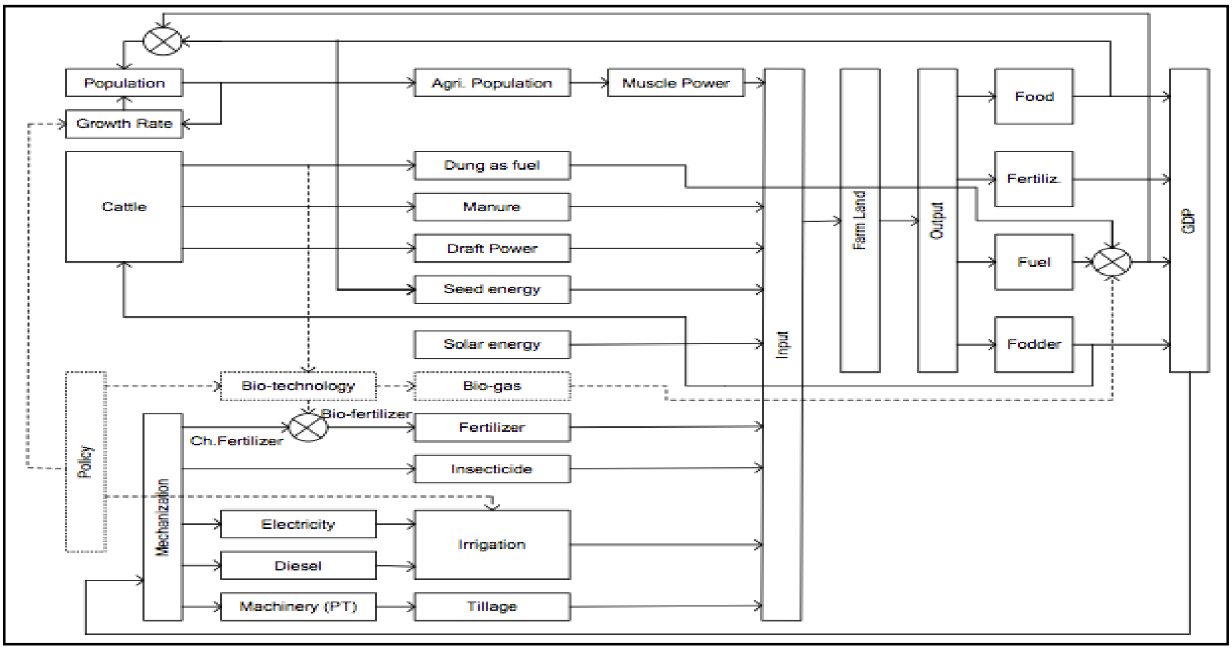

Fig. 1 Model for input-output energy flow in Bangladesh agriculture

The energy flow in agricultural production system consists of several closed loops. Energy feedback for these loops simulates the dynamic behavior of the system. The energy input in the form of muscle power derived from human and animal, draught power from machinery, irrigation, fertilizers and pesticides and the output in the form of food, fuel and fodder link the quality of life for population non-linearity. Therefore, the input-output energy flow in agriculture acts as the mechanism for population control.

The crop production system in Bangladesh deals mainly with the production of food grain and straw. The straw is primarily used for cattle feed and then used for cooking fuel for rural people. 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 cattle as well as from power tiller. So the input energy management can play a vital role to optimize the energy input to produce output in agriculture.

The agricultural production system is evaluated on the basis of either crop production or energy production per unit of land as well as energy input per unit of land. The food demand of large population has been forcing to enhance the incremental food production per unit of land in Bangladesh. Due to limited availability of arable land, the enhancement of food production in Bangladesh depends mainly on cropping intensity, use of high yield variety, fertilizers, irrigation, pest control etc. and therefore investment of capital and technology.

Currently, Bangladesh agriculture receives its input energy such as electricity and fuel in addition to human and animal muscle power for irrigation and tillage operation, and also indirect energy i.e. commercial fertilizer for improving soil fertility and pesticide for pest control. The input energy flow structure in Bangladesh agriculture is shown in Fig. 1. The mathematical model has been developed on the basis of system dynamics methodology using this energy flow structure and has been simulated for the period of 1981 to 2025.

V. Mathematical Formulation of the Model

Muscle power from human and cattle, machine power for irrigation and tillage and latent energy of Fertilizers and Pesticides are the main elements of input energy in Bangladesh agriculture. Each element is to be considered as a sub-model. In population sub-model, the population is a level variable and is presented by an integral equation, in which the growth rate is a function. The growth rate depends on the product of growth rate normal and growth rate multiplier. The multiplier depends on population ratio and is represented by a table function. The population ratio is the ratio of population of a year in the period and population of the base year 1981. The product of active labor obtained from population, muscle power co-efficient and effective working hour per person per year provides the muscle power (GJ). The active cattle population is assumed to be constant over the period. But an account of increasing use of mechanical power for tillage, the appropriation of cattle population for tillage is falling with time. The cumulative product of cattle population, draft power multiplier, draft power coefficient and active working hour per cattle per year provides the draft power (GJ) from cattle. In a similar way the draft power from machine (GJ), electricity for irrigation (GJ), chemical fertilizers (GJ) and pesticides (GJ) used as energy inputs to agriculture has been mathematically formulated. A fraction of food produced as an output has been considered to provide another input (GJ) as seed to the agriculture. Total energy input (GJ) has been estimated using these individual inputs. The total energy output (GJ) obtained from agriculture in terms of food, fodder and fuel as a result of energy inputs has been simulated by the following mathematical model shown in eq. (1), [16]. The model has been calibrated with the input [Y (t) GJ/ha] - output [X (t) GJ/ha] energy in Bangladesh agriculture. Similarly GDP as an output from agriculture has been obtained by the following mathematical model shown in (2) [16]. The model has also been calibrated with input energy [X (t) GJ/ha] – GDP output [Y (t) million $] in Bangladesh agriculture.

$$Y(t) = a + b\,X(t) + cX2(t) \quad (1)$$

$$Y(t) = a + b\ln[X(t)] \quad (2)$$

where t is time in year.

The evaluating indicators such as energetic efficiency (EEA), food surplus index (FSI), fodder surplus index (SSI), cooking fuel surplus (CSI), economic conversion rate (GCR), energy conversion rate (ECR) and solar energy conversion efficiency (SCE) have been formulated mathematically to evaluate the agricultural production system [16].

$$EEA = \left[\frac{TOE}{TIE}\right] \times 100\% \quad (3)$$

$$FSI = \left[\frac{FDA-FDD}{FDD}\right] \times 100\% \quad (4)$$

$$SSI = \left[\frac{STA-STD}{STD}\right] \times 100\% \quad (5)$$

$$CSI = \left[\frac{CFA-CFD}{CFD}\right] \times 100\% \quad (6)$$

$$GCR = \frac{\left[\left(\frac{TIE}{GDP}\right)MJ\right]}{\$} \quad (7)$$

$$ECR = [TIE\ (MJ)/TOE\ (GJ)] \quad (8)$$

$$SCE = [(TOE/SEI] \times 100\% \quad (9)$$

The nonlinear functional relationships are presented through STELLA based on time dependent function. Each equation of the model has been converted into system dynamics flow diagram and then simulated using simulation software, STELLA 8, 2003 [17].

VI. Formulation for Policy Implication

One of the purposes of this study is to identify policy options that affect the input energy to produce unit output in agriculture. To illustrate the use of the model as a tool for policy planning, it was evaluated in both the basic and the policy planning modes over the period 1981-2025. The basic mode corresponds to existing condition, whereas the policy-planning mode corresponds to a policy option that is being tested. The impact of policy options on input energy for the output has been verified through this model. The considered policy options and their outcome are presented heretofore.

A. Policy for Population Control

Bangladesh faced a severe problem in population growth. Population density (976 persons per km^2 in 2011 compared to 657 persons per km^2 in 1981) corroborates the problem. The growing population of the country puts serious pressure on land, water, forests and other natural resources. High population growth (1.47%) increasingly claims land for habitat and infrastructure, which results in reduction in area supporting plants and trees.

These are further reduced to meet growing population's requirement of fuel for cooking, particularly in rural areas. Arable land is already limited and is being further depleted because of population growth. It goes without saying that there is no scope for land area to increase.

As a result, it is an alarming situation to sustain the expanding population in terms of food and fuel. Bangladesh has no way but to control population by reducing its population growth. Accordingly, the Government of Bangladesh has made a plan to reduce the population growth rate to 0.97% in 2025 [18] by way of family planning as well as improving the quality of life through increasing per capita energy consumption. In this study, it has been considered to achieve population growth rate 1% in 2025 as a policy option to be tested.

B. Policy for Irrigation System

The irrigation system in Bangladesh is partly mechanized. Cropping intensity has almost doubled and in some areas it has tripled due to irrigation. Irrigation area increased from 1.6 million ha in 1981 to 4.8 million ha in 2001. The 50.98 $ per ha cost involved in irrigation corresponds to a yield of 4.83 ton per ha. Whereas 32.34 $ per ha in Punjab, 18.35 $ per ha in Andhra Pradesh of India and 17.93 $ per ha in Thailand correspond to yields of 5.28 ton per ha, 4.86 ton per ha and 4.17 ton per ha respectively [19]. Question arises whether Bangladeshi farmer can continue to farm profitably with higher irrigation water cost and be competitive in global market. Excessive pumping with disregard to irrigation management principles, inefficient methods for distribution and application leading to irrigation water wastages and lack of adoption of scientific irrigation scheduling are possible reasons for higher irrigation costs. [19] reported that the efficiency of the Bangladeshi irrigation system for unlined open channels is about 30%. He also reported that the buried type closed conduit system gives an efficiency of about 60-70%. At present each cubic feet per second irrigates about 6-8 ha in an open channel. In a buried pipe irrigation system, it is possible to irrigate about 16-18 ha.

Lack of subsidy in purchasing or operating a system as well as lack of water saving distribution system with comprehensive approach for water resource development for multiple use are main constrains in improving irrigation system efficiency. In this study, the closed conduit system of irrigation has been considered as a policy option.

C. Policy for Fertilizer Use

In Bangladesh, intensive and irrational use of different types of chemical fertilizers and pesticides contaminates harvests, destroys soil quality and ecological balance and increases production costs. As a result, the soil fertility is now under great challenge. Alam et al. [13] proposed an integrated rural energy system and showed that almost 15% of commercial fertilizer might be saved utilizing the full potential of cow dung through biogas technology. In this study, as a policy option use of available cow dung with the use of recommended dose of chemical fertilizer is considered to be used as the input energy from fertilizer.

The mathematical formulation of the basic mode for the model has been presented earlier. The formulation has been appropriately modified for the policy mode.

VII. SIMULATED RESULT

The model incorporates the initial values of 1981 and has been simulated both for basis and for policy mode for the period 1981-2025. The model structure is directly compared to the descriptive knowledge of real system structure and the predicted model behavior agrees with the observed behavior. The simulated results of the model are shown in Table I and Figs. 2 to 10.

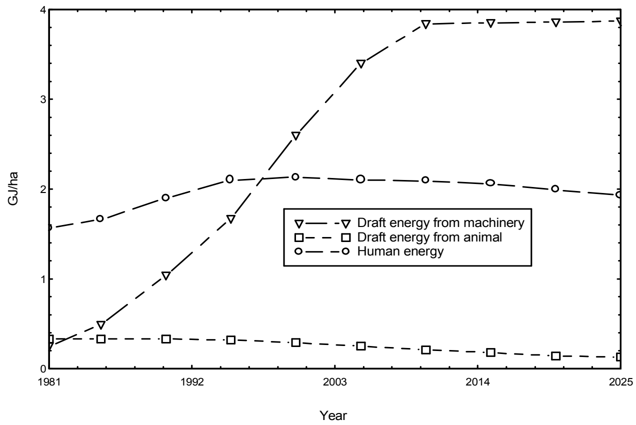

Fig. 2 Simulated results of energy input [GJ/ha] from machinery, animal and human in basic mode for the period of 1981-2025

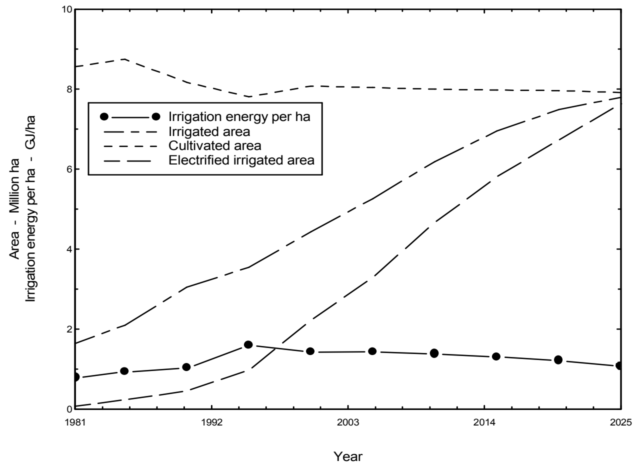

Fig. 3 Simulated results of irrigated area, caltivated area, and irrigation energy per ha in basic mode for the period of 1981-2025

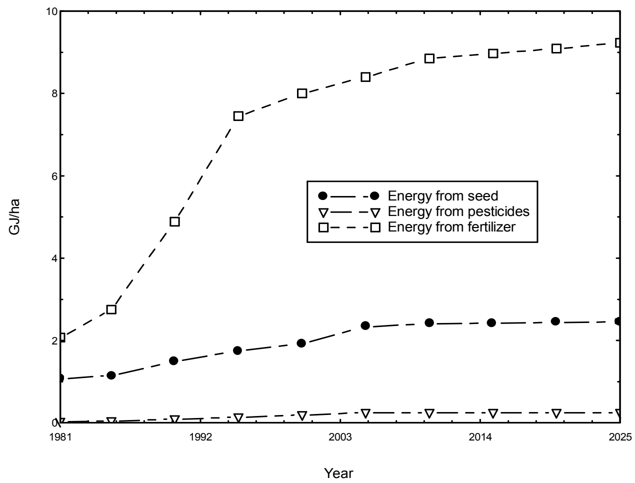

Fig. 4 Simulated results of energy input [GJ/ha] from seed, chemical fertilizer and pesticide in basic mode for the period of 1981-2025

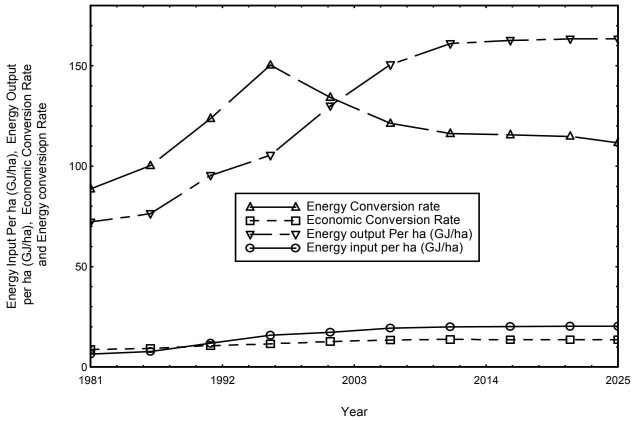

Fig. 5 Simulated results of energy input (GJ/ha), energy output (GJ/ha), economic conversion rate (MJ/GJ) and energy conversion rate (US$/MJ) in basic mode for the period of 1981-2025

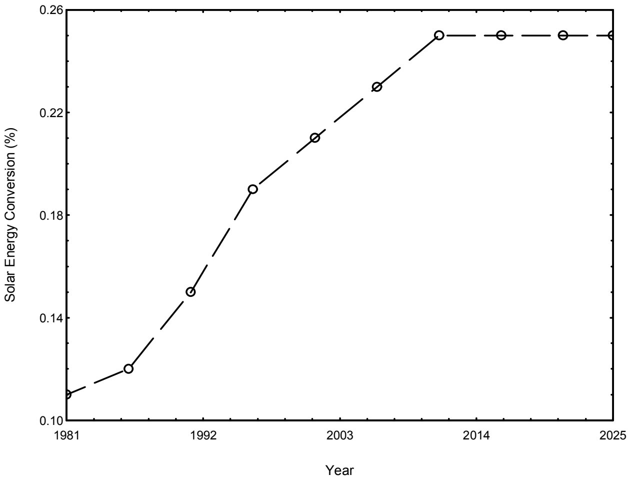

Fig. 6 Simulated results of solar energy conversion efficiency in basic mode for the period of 1981-2025

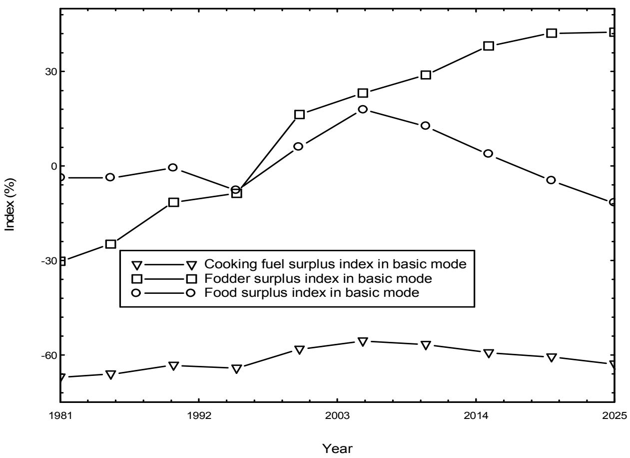

Fig. 7 Simulated results of food surplus index, fodder surplus index and cooking fuel surplus index in basic mode for the period of 1981-2025

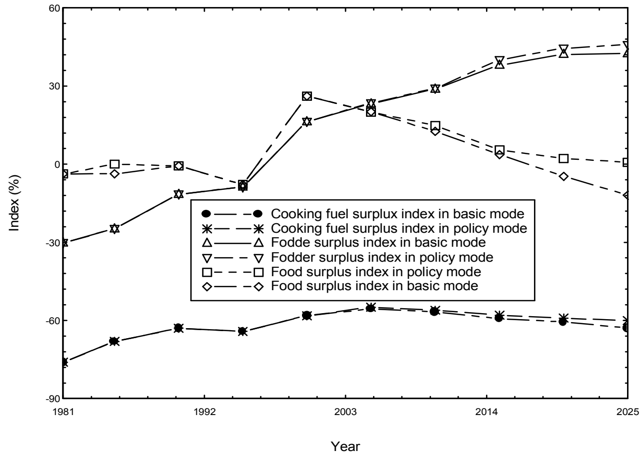

Fig. 8 Simulated results of food surplus index, fodder surplus index and cooking fuel surplus index in policy mode for the period of 1981-2025

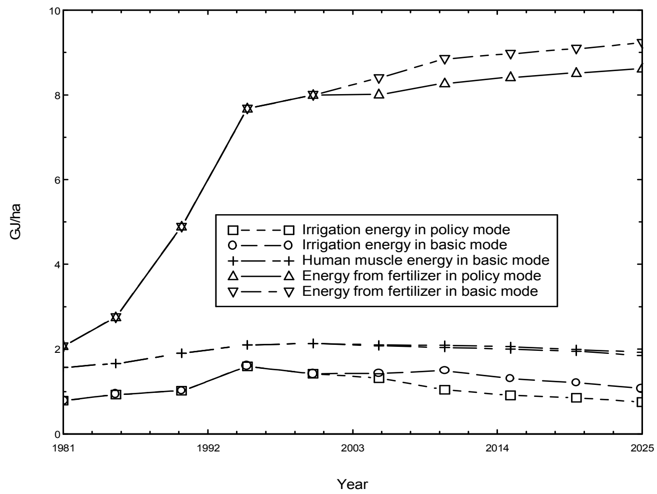

Fig. 9 Simulated results of energy inputs [GJ/ha] from fertilizer, human energy and energy for irrigation in policy modes for the period of 1981-2025

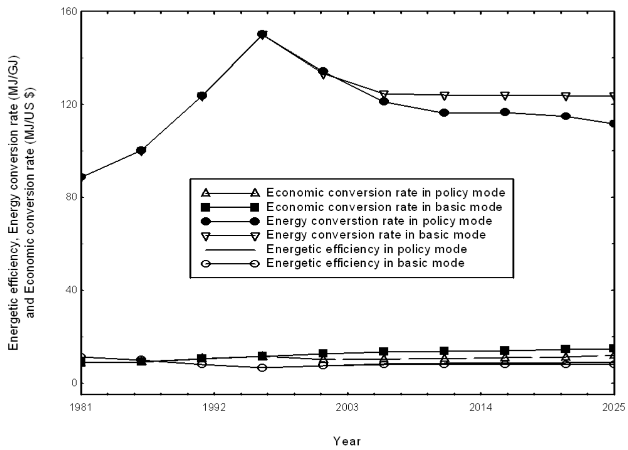

Fig. 10 Simulated results of energetic efficiency, economic conversion rate (MJ/US $) and energy conversion rate (MJ/GJ) in basic and policy mode for the period of 1981-2025

According to the basic mode, total population and active agricultural labor force of the country will increase from 139.5 to 218.12 million and 30.4 to 33.5 million respectively during the period 1981-2025Population growth rate already reduce from 2.1% to 1.47%. Draft power from animal for tilling has also decreased significantly. The draft power is gradually being substituted by machine-operated tillage-power tillers. At the end of simulation period, draft power from machinery will increase from 2.13 to 30.74 million GJ and animal draft power will decrease from 2.83 to 1.05 million GJ. It is found that human muscle power, animal draft power and machinery draft power will be available in the quantity 0.408 kW/ha, 0.10 kW/ha and 0.407 kW/ha respectively at the end of the period 1981-2025 and these will then reach saturation, whereas the optimum requirement of human muscle power and draft power from animal and machinery are 0.30-0.50 kW/ha [20] and 0.373 kW/ha respectively [21]. During the period, total physical power from human, draft animal and machinery will increase 1.87 fold, while the agricultural machinery draft power will increase 14.33 fold which indicates that the mechanization level in Bangladesh agriculture will increase to its satisfactory level. Fig. 2 shows the simulated results for basic mode of energy input (GJ/ha) from human muscle power, animal draft power and machinery power for the period of 1981-2025.

Fig. 3 shows the projection of cultivated, irrigated and electrified irrigated areas along with diesel and electricity use in irrigation in basic mode during the simulation period. Diesel irrigated area is being gradually supplemented by the electrified irrigated area. Cultivated area will decrease from 8.56 to 7.94 million ha. Irrigated area (diesel and electrified) will increase from 1.6 to 7.7 million ha and the irrigation coverage will be 96% of the total cultivated area. During the period the electrified irrigated area will increase from 0.07 to 7.64 million ha and will have to reach its saturation indicating that the mechanization in Bangladeshi irrigation system is moving towards its desired goal. The goal will be achieved at the cost of 15.95 million GJ of electricity together with 1.10 million GJ of diesel energy. The electrical energy input in irrigation was 0.15 million GJ in 1981 and it will increase then to 15.95 million GJ, which is 106 fold with respect to base year.

TABLE I
(A) COMPARISON OF SIMULATED RESULTS AND REPORTED DATA OF ENERGY INPUTS (×1015 J) IN BANGLADESH AGRICULTURE

Year	Energy from human			Energy from animal			Energy from machinery			Energy from irrigation		
	A	B	C	A	B	C	A	B	C	A	B	C
1981	**13.51**	**13.51**	**0.00**	**2.83**	**2.83**	**0.00**	**2.13**	**2.13**	**0.00**	**6.70**	**6.70**	**0.00**
1985	**14.57**	**14.85**	**0.07**	**2.83**	**2.80**	**1.06**	**4.28**	**4.28**	**0.00**	**8.13**	**8.14**	**0.12**
1990	**15.58**	**15.00**	**3.72**	**2.83**	**2.77**	**2.12**	**8.50**	**8.71**	**-2.47**	**8.34**	**8.37**	**0.36**
1995	**16.47**	**16.22**	**1.51**	**2.66**	**2.63**	**1.13**	**12.80**	**13.11**	**-2.42**	**11.92**	**12.20**	**2.30**
2000	**17.22**	**17.12**	**0.58**	**2.35**	**2.32**	**1.27**	**21.30**	**21.42**	**-0.56**	**11.45**	**11.75**	**2.62**
2005	-	**16.94**	-	-	**1.98**	-	-	**30.74**	-	-	**11.37**	-
2010	-	**16.77**	-	-	**1.70**	-	-	**30.74**	-	-	**10.87**	-
2015	-	**16.41**	-	-	**1.47**	-	-	**30.74**	-	-	**10.16**	-
2020	-	**15.91**	-	-	**1.13**	-	-	**30.74**	-	-	**9.63**	-
2025	-	**15.33**	-	-	**1.05**	-	-	**30.74**	-	-	**8.47**	-

TABLE I
(B) COMPARISON OF SIMULATED RESULTS AND REPORTED DATA OF ENERGY INPUTS (×1015 J) IN BANGLADESH AGRICULTURE

Year	Energy from fertilizer			Energy from pesticides			Energy from seed			Energy Input/ha		
	A	B	C	A	B	C	A	B	C	A	B	C
1981	**17.73**	**17.55**	**1.02**	**0.23**	**0.23**	**0.00**	**9.10**	**9.19**	**-0.99**	**6.10**	**6.40**	**0.00**
1985	**24.14**	**23.92**	**0.91**	**0.37**	**0.38**	**-2.70**	**10.10**	**10.13**	**-2.9**	**6.96**	**6.93**	**-0.43**
1990	**40.00**	**39.77**	**0.57**	**0.73**	**0.74**	**-1.37**	**12.20**	**12.10**	**0.82**	**10.86**	**11.11**	**2.30**
1995	**60.00**	**59.91**	**0.15**	**1.15**	**1.18**	**-2.61**	**13.70**	**14.80**	**-8.02**	**15.17**	**15.40**	**1.52**
2000	**64.69**	**64.34**	**0.54**	**1.56**	**1.60**	**-2.56**	**15.60**	**16.82**	**-7.82**	**16.54**	**17.00**	**2.78**
2005	-	**67.61**	-	-	**2.02**	-	-	**18.74**	-	-	**18.52**	-
2010	-	**70.83**	-	-	**2.02**	-	-	**19.33**	-	-	**19.00**	-
2015	-	**71.66**	-	-	**2.02**	-	-	**19.45**	-	-	**19.11**	-
2020	-	**72.41**	-	-	**2.02**	-	-	**19.50**	-	-	**19.13**	-
2025	-	**73.30**	-	-	**2.02**	-	-	**19.50**	-	-	**19.15**	-

TABLE II
COMMERCIAL ENERGY INPUTS TO AGRICULTURE FOR DCS, LDCS AND BANGLADESH [24]

Energy as inputs	DCs		LDCs		Bangladesh		
(GJ/ha)	1972-73	1985-86*	1973-74	1985-86*	1980-81	2000-01	2014-25*
Fertilizer	**8.74**	**14.79**	**1.40**	**4.78**	**2.75**	**8.85**	**9.23**
Pesticides	**0.50**	**0.57**	**0.02**	**0.13**	**0.04**	**0.19**	**0.25**
Machinery	**15.00**	**17.94**	**0.61**	**1.60**	**0.49**	**2.60**	**3.87**
Total	**24.24**	**33.30**	**2.03**	**6.51**	**3.28**	**11.64**	**13.35**

During the period the energy input in basic mode from commercial fertilizer N_2, P_2O_5 and K_2O will increase from 16.06 to 73.30, 1.31 to 5.43 and 0.18 to 2.12 million GJ respectively. The uses of nitrogen and potassium have exceeded their recommended doses (125 kg/ha and 41 kg/ha) since 1994 and from 2007 respectively. On the other hand, the use of phosphorus will always be below its recommended dose (100 kg/ha). Energy inputs from pesticides in basic mode will increase from 0.23 to 2.02 million GJ during the period. The energy input in basic mode from commercial fertilizers and pesticides will increase to 4.13 fold and to 8.78 fold respectively with respect to base year. Seed energy in basic mode will also increase accordingly and that will be 2.12 fold with respect to base year. This result shows that the energy use from commercial fertilizer is unbalanced and unplanned with respect to its recommended dose. As a result, the share of fertilizer to total energy input is 45%. The rate of use of pesticide is increasing rapidly. Therefore, the practice of commercial fertilizer and pesticide use is a threat to the soil fertility as well as to the ecology. Fig. 4 shows the simulated results in basic mode for energy input from commercial fertilizer, pesticide and seed.

Among the findings, Table I shows that the total input energy will vary from 6.4 to 20.2 GJ/ha to produce output from 71.55 to 163.58 GJ/ha and to generate GDP/ha from \$732.0 to \$1400.0. The results also shows that the energy input to produce unit output (GJ) amounts to 85.25 MJ in 1981 and 117.10 MJ in 2025. On the other hand, 8.3 MJ input energy is needed to generate unit GDP (US \$) in 1981 and this need will be 13.6 MJ in 2025. These results show that the intensive energy input will not be accompanied by the expected output increase either in terms of energy or the GDP. Fig. 5 shows the energy input per ha, energy output per ha, energy conversion rate and economic conversion rate would reach saturation at the end of this decade i.e. 2010. Fig 6 shows that the solar energy conversion efficiency will increase with increasing energy input and when energy input reaches saturation in 2015, the solar energy conversion efficiency will become constant at a level of 0.22%. On the other hand, declining trend of energetic efficiency indicates that the increasing rate of energy input is faster than the energy output. Food, fodder and cooking fuel surplus indices shown in per unit basis in Fig. 7 show that the indices other than fodder surplus index indicate that the food and the cooking fuel deficits are ultimately not recoverable. The food production as energy output will reach saturation within 2015. But the population is increasing continuously at a rapid rate.

A comparison of commercial energy input to agriculture of DCs and LDCs including Bangladesh shown in Table II reveals that in comparison to DCs a scope is open to increase energy input to produce output in Bangladesh agriculture. The total solar radiation on the cultivated land of Bangladesh is 46.03 × 109 GJ per year [14]. But the solar energy conversion efficiency in agriculture may be achieved from 0.11 to 0.22% within the simulation period, while the achievable conversion efficiency is 1% [14]. In this context, another scope is still open to increase output of Bangladesh agriculture.

In policy mode, existing population growth rate will reach 1% at the end of the simulation period. It is found that the decrease of population growth rate in policy mode does not affect the energy input due to advancement of mechanization in agriculture. The food, fodder and fuel surplus indices shown in Fig. 8 indicate that food and fodder will be available to meet the requirement up to 2020. If population growth rate in policy mode will reduce further to 0.6%; food and fodder will be then sufficiently available to meet the requirement up to 2025.

Irrigation, fertilizer and total energy input per ha will reduce to 1.54 GJ/ha, 8.3 GJ/ha and 18.26 GJ/ha respectively in policy mode, and these are 2.14, 9.25 and 20.2 GJ/ha respectively in basic mode as shown in Fig. 9. The results indicate that 28% of the irrigation energy per ha, 10.27% of the fertilizer energy per ha and 9.4% of the total energy input per ha will get saved in policy mode to produce the same output as in basic mode.

Energetic efficiency, energy conversion rate and economic conversion rate in policy mode are shown in Fig. 10. In exercise of policy options, it is found that energetic efficiency will improve from 8.09 to 8.96; energy conversion rate indicates that energy input will decrease from 123.61 to 111.63 MJ to produce per unit energy output (GJ) and economic conversion rate shows that energy input will decrease from 14.90 to 12.31 MJ to generate per unit GDP output. It may be concluded that the agricultural productivity will improve with the policies.

VIII. Model Validation

The model for simulation of energy input in Bangladesh agriculture is verified with different sets of parameters. The results as predicted by the model are compared with the reported data [22]-[25]. It is found that the variation between the simulated results and reported results is within 3%, the details of which are shown in Table I. Therefore, the performance of the model is found satisfactory.

IX. Discussion

Energy is supplied to agriculture through tillage, irrigation, fertilizer, pesticides, harvesting and preparation and distribution of food as well as fabrication and operation of farm machineries. In turn, agriculture provides energy as its output to ensure food and fuel for people, fodder for livestock and fertilizer for farmland. It was found that the share of traditional fuel to total energy consumption of Bangladesh in 2001 was about 60% and this had come mainly from agriculture [26]. As revealed from the above results, 0.110 TCF gas-equivalent commercial fuels, being one-fifth of the total commercial fuel, was used to produce the traditional fuel. Agriculture provides cooking fuel for the rural people who constitute 70% of the total population. Agriculture not only supplies more than 50% of the total energy demand of the country, but it also feeds the people.

The results also show that when input energy to agriculture is increased properly, the energy output per unit of land increases. In other words, with appropriate energy inputs the crop can capture solar energy more efficiently to produce more output. Energy need to be increased as an input to the agriculture to raise the crop yields, to extend the irrigation, to increase multi-cropping, to provide machinery draft power, to build roads and hence improve the quality of life of the peasants. In Bangladesh the share of commercial energy in the input energy in agriculture in 1980-81 was 54% and it increased to 74% in 2001. If the trend continues, this figure will rise to 80% by 2025. It shows that the direct and indirect energy flow into agriculture will have to gradually take up a larger share of total energy consumption, which is very significant for rural development of LDCs.

The evaluation of the performance of ongoing methods and future outlook of Bangladesh agriculture shows that the food production has increased but the deficit of fodder, fuel and organic fertilizer has widened as well during the same period though these are the co-products of food. In this context, the analysis of above results shows that the food production during the period 1981-2001 increased 1.7 fold [17], cattle population then reduced by 5% [14] and also due to deforestation the rural forest then got reduced in its inventory by about 4-fold [16]. This indicates that the question of echo system productivity, including biomass production for fuel, fodder and fertilizer, should be considered more broadly. It is always to be kept in perspective that, like most of the LDCs, Bangladesh with its nearly 150 million present population. 1.47% population growth rate (in 2011) small reserve of fossil fuels, and scarce resources for acquiring adequate amounts of conventional, non-conventional, nuclear or non-traditional renewable energy, her rural people is and, for foreseeable future, will be predominately dependent on agriculture not only for food and fuel, but also for fodder and to some extent, for fertilizer and the capacity of the overall echo system to continue to provide these in sufficient quantities is dependent on continued improvements in agricultural productivity with respect to these commodities. The results and discussions described herein indicate that by exposure of the echo system to the injection of energy in the form of chemical fertilizers, pesticides and commercial energy for mechanized irrigation and tillage operation, productivity of the entire agricultural system with respect to food-grains can be expected to maintain adequate level of growth. However, the output of the biomass did not keep pace with food production and the availability of biomass from agriculture has fallen in relation to the needs. It can be said that Bangladesh agriculture has failed to meet the requirements of cooking fuel for rural people and their animal feed. Eventually, livestock and rural population of Bangladesh are going to be serious victims of both fodder and fuel famine.

Some policies over agricultural production system in Bangladesh have been examined in the above stated model considering what type of management and energy flow to be ensured to produce enough food and organic materials for assuring food, fodder and fuel security. It is found in observation of the results in policy mode that it is urgent to reduce the population growth to 0.6% by the year of 2025 and to provide commercial energy input to agriculture along with maintaining soil fertility by controlled use of chemical fertilizers through promoting the use of organic fertilizer. Proper use of cow dung through biogas technology can replace almost 25% of biomass fuel used for rural cooking and 10-15% of chemical fertilizer [14]. Moreover the deficit in cooking fuel would be reduced to half if stove efficiency could be increased from 10 to 18% [16]. Reduced irrigation water misuse and improved irrigation system efficiency can reduce input energy flow in irrigation by at least 30%. The overall agricultural productivity will increase in the policy mode. Eventually, energy input to produce per unit total output (GJ), as well as the GDP, will be reduced substantially. Which will enable cost and energy saving along with ensuring food, fodder and fuel security.

Therefore, the model may be accepted for its satisfactory performance for use with proper modification and adjustment as a computer laboratory for energy flow analysis in agriculture for LDCs.

X. Conclusion

The simulated results lead the following conclusions:

1. Labor force participation in agriculture is significantly decreasing as a result of mechanization;
2. As a result of mechanization machinery draft power overcomes the shortage of draft power in tillage operation;
3. Mechanization in tillage operation as well as in irrigation is moving towards its satisfactory level in context of Bangladesh.
4. Cultivated land is gradually decreasing and irrigated area is increasing and will reach at 96% of the cultivated land at the end of the period;
5. Energy input for fertilizer, pesticides and seed will reach saturation in each case ultimately;
6. Rapid growth of pesticide is alarming;
7. Total input energy ultimately will reach saturation in or around 2010;
8. Energy use from chemical fertilizer is unbalanced, unplanned and irrational with respect to its recommended dose. Moreover, share of energy input from chemical fertilizer is almost 45% of the total energy input;
9. Mode of energy use from chemical fertilizer as well as from pesticides is a threat to soil fertility and ecology;
10. Energy output (Food, Fodder, Fuel and Fertilizer) is highly co-related with energy input;
11. Solar energy conversion efficiency and GDP increase with the increase of energy input;
12. Energetic efficiency is decreasing, which indicates that the increasing rate of energy input is faster than energy output;
13. Energy conversion rate is increasing, indeed the incremental energy input is faster than that of either incremental energy output or of incremental GDP output;
14. Food, fodder and fuel surplus indices indicates that food will be available to meet the requirement up to 2015 in basic mode and up to 2025 in policy mode. Fodder will be

sufficient to meet the requirement for the period both in basic mode and in policy mode;

15. Fuel is available to meet the requirement neither in basic mode nor in policy mode. As a result, the shortage of cooking fuel ultimately leads to deforestation;
16. Proper energy management, energy input would increase ultimately and saturation level of energy input would move to higher level and produce output with the higher energetic efficiency;
17. Due to advancement of biotechnology and genetic engineering, solar energy conversion efficiency will improve and output will increase without increasing energy input;
18. Enough scope is still open in Bangladesh agriculture to increase output with increasing energy input as well as increasing solar energy conversion efficiency and
19. At present, environment friendly and economic energy use pattern for Bangladesh agriculture can be achieved with this study;

Therefore the model may be accepted for its satisfactory performance to use as a computer laboratory for energy system analysis in agriculture for LDCs like Bangladesh with proper modification and adjustment.

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