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The social cost of energy inputs as a proportion of the value of the total output turns out to be 10.64 per cent in 1961-62, while it has increased upto 29.42 per cent in 1966-67 and it has declined upto 16.15 per cent in 1972-73. This decline can be attributed to the fact that in 1972-73, a large part of fertilizer consumption was met by naphtha-based fertilizer plants. Since naphtha is a cheaper feedstock than electricity, we see a relative decline in the total cost of energy inputs. However, the social cost of energy inputs excluding fertilizer as a proportion of the value of the total output turns out to be 6.1 per cent in 1961-62, 6.4 per cent in 1966-67 and 6.1 per cent in 1972-73. This shows that the social cost of energy inputs excluding fertilizer as a proportion of the value of the total output has not changed significantly.

On the whole, it can be said that the intensity of energy inputs in the agricultural sector of Punjab and Haryana has increased over the years, particularly between 1966-67 and 1972-73. In absolute terms, energy inputs have increased in their use, but the social cost of energy as a proportion of the value of the total output has undergone a relative decline in 1972-73 as compared to 1966-67.

REFERENCES

1. Ramesh Bhatia, "Energy and Rural Development in India: Some Issues," in William Lockeretz (Ed.) : Proceedings of the Conference on Energy and Agriculture held in June, 1976, Washington University, St. Louis, Academic Press, New York (forthcoming).

2. Ramesh Bhatia and Meera Mehta, "Tubewell Irrigation in India : An Economic Analysis of Some Technical Alternatives," *Economic and Political Weekly*, Vol. X, No.52, December 27, 1975.

3. P. D. Henderson: India : the Energy Sector.

4. Fuel Policy Committee Report, 1972.

5. R. K. Sharma: Economics of Tractor Versus Bullock Cultivation, Agro-Economic Research Centre, University of Delhi, Delhi, 1972.

6. Government of Punjab: Economics of Tractor Cultivation and Economics of Production and Cultivation Practices of High-Yielding Varieties of Wheat, Maize and Paddy in Punjab, 1969-72.

7. Central Electricity Supply: All-India Statistics Annuals.

8. Statistical Abstracts of Punjab and Haryana.

AN ECONOMIC ANALYSIS OF ENERGY REQUIREMENTS OF ALTERNATIVE FARMING SYSTEMS FOR SMALL FARMER: SOME PUBLIC POLICY ISSUES

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INTRODUCTION

In recent years the World Food Problem has mandated a search for alternative methods of food production. Special importance has been attached to the general problem of resource-rooted scarcity of agricultural inputs. For example, fossil fuels have been the life line of "modern agriculture" in

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developed countries. Also in developing countries such as India, the Green Revolution technology requires heavy applications of chemical fertilizers and irrigation water, with implications for petroleum (3).*

A country's agricultural policy must be directed to make the most efficient economic use of its indigenous resources(9). Thus, the agricultural development of different countries could be different, yet each the most efficient in its own environment.

Even within a country the method which may meet some criterion for optimality on an individual farm, would not necessarily be prescribed as the optimal agricultural production policy in a macro context, *i.e.*, for an entire nation. For example, inputs may not be available in aggregate quantities to suffice, should everybody take up the same method of production. Besides availability of the resources which provide direct input to production process, differences in the physical and economic environment may themselves dictate variations in the method of production.

For example, in a recent study scientists at Washington University found that the net returns per acre from raising corn were as high when organic techniques were used as with conventional technology, *i.e.*, using large amounts of chemical fertilizers(14). This is a revolutionary finding, indeed, especially in a country like the United States where organic farming was not thought to be competitive with conventional farming. However, this should not be interpreted as meaning that the entire U. S. agriculture could or should revert to organic farming.

The above example has important implications for selecting methods of agricultural production in India. India has varied agricultural resources. It could offer the suitable infrastructure and necessary inputs, *e.g.*, fuel, fertilizer, etc., required for most "modern methods" of agriculture. But the resources from which these are derived are limited in quantity. Further, generally these petroleum-based inputs can only be used advantageously by farmers having large land holdings. Certainly "modern technology" should be used in India wherever it can be employed in an economically efficient manner, both from the standpoint of the individual farmer and that of the entire society.

"Modern technology" has two limitations in India, however. First, it is suitable to large farm holdings as stated above. India has a majority of farm holdings which are very small. Further, the socio-economic conditions in India suggest that the trend toward small farm holding will continue. Second, the petroleum requirements of this technology would place a serious foreign exchange burden on the economy, given India's limited energy resources.

* Figures in brackets relate to references cited at the end.

PURPOSE OF ANALYSIS

The purpose of this paper is to analyse alternative farming systems for a small farmer, in their entirety for energy intensiveness, resource use and economic returns.

A study of the entire farming system rather than looking at its components will also help to shed light on the question of the desirability of animal power vs. mechanical source of power on Indian farms. Human labour is abundantly available on the small farms in India except for some bottlenecks. The study of alternative farming systems will help identify these bottlenecks and their solution. The paper will shed light on farming systems which will improve the standard of living of a small farmer with minimum risk. Finally, the analysis of this paper will provide input for public policy dealing with the development of a small farmer in India with respect to energy intensiveness, resource use and mechanization.

This paper analyses a small farm in India, under assumed conditions and resource endowment, in an attempt to determine how it can effectively recycle its recoverable biological resources to maintain a high efficiency of conversion of potential energy into digestible energy, a problem to which M. S. Swaminathan has alluded in his presidential address to the 63rd Session of the Indian Science Congress (25).

A word of caution is in order. The goal assumed in this analysis is not to maximize the energy use efficiency *per se*, because energy accounting systems do not give a satisfactory theory of value (20, 13). Rather, energy use efficiency is considered only to the extent that it helps to increase food output and real income to the farmer.

A social scientist should also be careful in using a proper measure of energy intensiveness of production processes.[1] The energy embodied in any form of matter should be evaluated on the concept of opportunity cost and not on the energy embodied in its chemical bonds. This is really what we mean by the concept of "useful energy" invoked in this paper. An example of the energy accounting unit based on the concept of opportunity cost can be seen in the unit "million tons of coal replacement(mtcr)" used by the Fuel Policy Committee of the Government of India for evaluating energy use. Public policy issues can be addressed meaningfully only if they are in terms of energy measured in terms of opportunity cost.

Also the addition of energy units from different sources should be done carefully since it does not discriminate between a stock and a flow energy resource. This distinction is very crucial for evaluating the energy vulnerability of a production system. Obviously, the use of a limited stock resource has implications far different from those of a flow energy resource which would be wasted if not captured and utilized.

1. This point can be best illustrated by scrutinising the position, "a kilocalorie is a kilocalorie" no matter the source of its origin. This may be a meaningful concept for a physicist but may not be equally meaningful for an economist.

THE SMALL FARMER, HIS PROBLEMS AND SOCIETY'S PERSPECTIVE

Most alternative policies to raise the income of small farmers face their dual and related problems of capital shortage and inability to bear uncertainty. A farmer's response to uncertainty may even determine his ability to survive. The uncertainties faced by a farmer are classified in the following three categories: management related, price engendered, and natural disasters. Each will be discussed briefly.

Management Related

The farmer must not only buy all the inputs required for modern farming but also provide a high level of management required for modern farming. Both are exceedingly difficult. Generally, a small farmer in India lacks the management techniques required for modern farming. Thus, the response of farm output becomes uncertain even if the small farmer is able to buy the required non-human inputs.

Relative Prices

The more purchased inputs the farmer uses the more his farming operation becomes vulnerable to fluctuations in relative prices of inputs and outputs.

Natural Disasters

Even with the most modern farming technology some natural disasters like a hail or a sandstorm can virtually ruin the crop.

The effect of the types of uncertainty discussed above is that they do little to decrease the cost of farming but they could significantly reduce gross income. Therefore, in order to minimize risk, a small farmer must try to (1) keep expenditures for purchased inputs low as well as (2) use those inputs which are less vulnerable to conditions beyond his control. Not only are these inputs expensive but also they tend to be energy intensive.

Improving the Use of Existing Resources

The prospect of integrating a gobar gas plant with the farming system provides an excellent opportunity for a small farmer to improve his standard of living, yet not accept much additional risk.[2] The farmer gets a 25 per cent subsidy of the cost of gobar gas plant from the government. The rest of the 75 per cent capital is loaned to him from nationalised banks at prevailing rates of interest. The operation of the gobar gas plant is absolutely within the control of the farmer. The benefit of the simple technology of gobar gas plant makes it almost a risk-free venture.

2. The economics of gobar gas plants has been studied by the Khadi and Village Industries Commission (KVIC). Besides several logical fallacies of economic nature in KVIC study (Sanghi and Dekle, 20), we do not believe that the cost-benefit analysis of a gobar gas plant in isolation is meaningful. In Indian conditions, a family size gobar gas plant doe not produce a marketable good. Also the KVIC's study assumes that the supply of dung which is the major input in gobar gas plants is guaranteed. Since there is no stable market for dung in rural India, the supply of dung to the farmer can only be guaranteed by the farmer himself owning enough cattle.

Without a gobar gas plant, a small farmer has no capability to afford a clean and easy to handle energy source for domestic use. In the absence of a gobar gas plant, the farm wife would use dung and firewood (a composite commodity including wood, twigs, and other vegetable material) for cooking. Burning dung destroys almost all of the soil nutrients in it. Moreover, burning extracts only 67 per cent of the useful energy of the dung. In contrast, use of the dung for bio-gas production does not destroy its fertility value, while yielding 150 per cent of the useful energy as compared to that obtained from burning the same amount of dung. The increased efficiencies in the use of dung have significant policy implications for India, especially with regard to foreign exchange.

The use of firewood to supplement the dung for cooking needs has a massive social cost in terms of soil erosion and floods which are a result of denudation of land. Eckholm in his latest book has alluded to the problem of soil erosion in third world countries(7). In India M. S. Swaminathan has estimated that the total annual loss of nutrients from Indian soils is 2.5 million tonnes of nitrogen, 3.8 million tonnes of phosphorous, and 2.6 million tonnes of potash respectively(24).

SAMPLE FARM

We take as an example a farm having 2 hectares of cultivated acreage. A farmer having 2 hectares of operational holdings is defined as a small farmer according to the Small Farmers' Development Agency. We assume that the Basic farming system consists of 2 bullocks and four cows or buffaloes and a Persian wheel system for irrigation. The number of family farm workers available for the sample farm is assumed to be eight. They are used to produce the crops, milk the cows, etc.

We choose HYV wheat-HYV rice rotation as part of the Basic farming system described above. Such a crop mix has heavy input requirements. However, this is the type of crop mix a farmer is likely to choose if he were to use modern methods of farming, *e.g.*, tractor, tube-well, etc.

Table I gives the capital cost and maintenance cost of elementary systems used as inputs in farming.[3] Table II gives the services provided by the elementary systems. Table III gives the input requirements for HYV wheat-HYV rice rotation.

3. In making the analysis the following yields and prices are assumed. Price of N = Rs. 2.50/kg., P = Rs. 2.60/kg., K = Re. 0.70/kg., milk = Re. 1.50/litre, wheat=Re. 1/kg., maize=Re. 0.70/kg., rice = Re. 1.50/kg., HYV wheat yield of 2,200 kg./ha. and HYV rice yield of 2,000 kg./ha. and maize yield of 5,000 kg./ha.

Makhijani and Poole (15) have estimated the production cost (including cost of delivery) of electricity from coal fired electric generating plants at $10/kwh for rural India. We assume exchange rate of Rs. 9.0/$1.0. Therefore, the economic cost of electricity is Re. 0.90/kwh. However, government heavily subsidises electricity rate for rural use. The electricity cost to farmer is assumed =Re. 0.20/kwh.

TABLE I—COST OF ELEMENTARY SYSTEMS

Elementary system	Capital cost (Rs.)	Useful life (years)	Annual operating cost* (maintenance cost Rs.)
Bullock (1)	1,250	10	1,314
Cow (buffalo)	1,250	10	1,314
Tractor (smallest) .. .. 10 h.p. power tiller (2) ..	15,000	10	Annual fixed cost Rs. 4,211. Variable cost (excluding labour cost) per hr. of use Rs. 4·55
Gobar gas plant .. .. .. (60 cu. ft.) (3)	2,300	Variable for different components	530
5 h.p. electric tube-well (4) ..	10,000	10	Annual fixed cost Rs. 2,250. Variable cost per hr. of use Re. 1·00 (assuming 5 kwh electricity consumption per hr. at Re. 0·20 per kwh).

*Throughout this table 15 per cent interest is used in calculating annual cost.

(1) It is difficult to precisely calculate the maintenance cost of draft animal or a milk animal on Indian farms. Below three estimates are given as estimated by three different sources. Again, they are not exactly comparable since the information given in these sources is incomplete for the purpose of comparison as well as they are different years and regions.

(*a*) Michael G. G. Schluter (22) estimates the annual cost (including feed and depreciation but excluding labour and interest) of maintenance of a *desi* buffalo in Surat district in 1971-72 at Rs. 785·70.

(*b*) Ramesh Bhatia (1) estimates the annual cost (including feed, depreciation and interest but excluding labour) of maintenance of a bullock in India in 1969-1970 at Rs. 622.

(*c*) I. J. Singh (23) estimates the price of a bullock and the annual cost (including feed, depreciation and interest but excluding labour) of maintenance of bullock in Hissar at Rs. 1,250 and Rs. 1,725 respectively in 1976. Since Singh's estimates are the latest, we adjust his figures to suit our purpose as described below. Singh estimates that 3 kg. of concentrate mix plus 6 kg. of wheat straw should be fed to a bullock per day of normal work to supply desirable amounts of digestible crude protein. In his cost calculations he uses the price of concentrate mixture at Re. 1/kg. and the price of wheat straw at Re. 0·20/kg. Since we are interested in the economics of the entire farm, we do not consider the cost of feeding roughage (wheat straw, etc.) assuming that it can be generated as a by-product of raising the crop on the farm. For the yields assumed in this paper, two hectares of wheat would yield more than six thousand kg. of wheat straw and two hectares of corn would yield about fourteen thousand kg. of cornstalks and cobs (26). Assuming the yield of rice straw to be equal to that of wheat, a double crop would suffice the need for roughage of six cattle at the rate of six kg./day for one year. We estimate the cost not met by on-farm resources of maintaining a bullock per year equal to Rs. 1,314. This cost estimate includes 10 per cent depreciation, 15 per cent rate of interest and cost of feeding 3 kg. of concentrate per day. Further, we assume that the capital cost and maintenance cost of a milk animal and a bullock are identical.

(2) I. J. Singh (23).

(3) The KVI Commission estimates the cost of 60 cu. ft. gobar gas plant at Rs. 1,575. The latest price available (16) quotes the initial investment for a 60 cu. ft. gobar gas plant at Rs. 2,300. Our cost estimates are based on the method given by the KVI Commission but reflect an increase in the cost of the plant. We also use 15 per cent interest rate instead of 11 per cent used by the Commission.

(4) The cost of electrically driven tube-well is estimated by doubling the figures estimated by Moorti (17) for 1966-67. The wholesale price index in India went up by 100 per cent from early 1960 to early 1970 (Indian Institute of Public Opinion, 8). Our cost estimates are also in the same ball park figure as estimated by Bhatia and Mehta (2).

TABLE II—SERVICES SUPPLIED BY ELEMENTARY SYSTEMS

Elementary system	Services supplied*					
	Tilling	Irrigation	Fertilizer	Fuel	Milk	Transportation
Bullock	2 bullocks till one hectare in 2·5 days (1)	2 bullocks deliver 12 $m.^3$ water from Persian wheel in one hour (2)	One year's dung from one bullock is equal to 19·4 kg. of N, 2·7 kg. P and 13·6 kg. K(3)	One year's dung from bullock when burnt gives 2,94,030 kg. cal. of useful cooking heat (4)		2 bullocks provide 32 miles of transportation in one day (5)
Cow (buffalo)	—	—	Same	Same	1,342 litres a year (6)	—
Tractor (10 h.p. tiller)	One hectare is tilled in 8 hrs. (1)	—	—	—	—	Provides 40 miles of transportation in one day (7)
Gobas gas plant (60 cu. ft.)	—	—	Fertilizer value of digested dung is the same as the fertilizer value of fresh dung (9)	One year's dung from one bullock when digested gives methane worth 4,37,800 kg. cal. of useful cooking heat (9)	—	—
5 h.p. electric tube-well	—	Delivers $68m.^3$ water per hr. (2)		—	—	—

* 1 day is equal to 8 hours of work.
(1) I. J. Singh (23).
(2) T. V. Moorti (17).
(3) Assuming 75 per cent dung is collected, N was calculated from the data given by Makhijani and Poole (15). Estimates for P and K were obtained from Bhatia and Mehta(2).
(4) Makhijani and Poole (15) estimate 5,400 kg. of fresh dung per cattle per year having 20 per cent dry weight. Further, it is assumed that 75 per cent dung is collected, one kg. of dry dung has 3,300 k. cal. (Parikh, 18) and dried dung has a 11 per cent thermal efficiency when burnt for cooking in indigenous ovens (KVIC, 12).
(5) Assuming the speed of the bullock cart to be 4 miles an hour.
(6) Michael G. G. Schluter (22).
(7) Assuming the speed of the tractor to be 5 miles an hour.
(8) Assuming 4,050 kg. of fresh dung can be collected annually per cattle and following Sanghi and Dekle (20).

TABLE III—INPUTS REQUIRED PER HECTARE

Crop	Labour (days)		Irrigation	Fertilizer		
	Annual	Peak		N	P	K
HYV rice	235 (1)	72	·43 m (2)	100 kg. (3)	15 kg.	10 kg.
HYV wheat	101 (1)	47	·39 m. (2)	100 kg. (3)	15 kg.	10 kg.
	Total input requirements for 2-hectare farm having HYV rice and HYV wheat rotation					
	672	144 (Fall) 94 (Sum.)	1·64 m.	400 kg.	60 kg.	40 kg.

(1) The figures are taken from Schluter (22). These figures are higher than the average figures given for Punjab by Roy (19) and Kanel (11). But we feel that the figures given by Schluter correctly reflect the higher input requirements of HYV's. Peak labour denotes the sub-part of annual labour required for harvesting and threshing.

(2) Duggal (6) has estimated the crop water requirement for some areas in Punjab. We assume 50 per cent of irrigation requirement for rice to be satisfied by rain.

(3) Recommended nitrogen application rate for India is given by Donde and Brown (5). Estimates for P and K are given by us.

We assume that the markets for tractor services and irrigation services are not well organized. By this we mean that it is not possible for a small farmer to have a tractor or rent his to a neighbour even if he could buy one. Similarly, the small farmers are unable to buy and sell irrigation water among themselves.

Table IV gives budgets for the Basic farming system, some modifications in the Basic system and some elementary systems.

TABLE IV—COSTS AND RETURNS FROM ALTERNATIVE FARMING SYSTEMS

Farming system	Capital cost (Rs.)	Annual carrying cost (Rs.)	Gross income (Rs.)	Net income (Rs.)
Basic (wheat-rice rotation)	7,500	8,707 (1)	18,907 (2)	10,200
Basic I (30 per cent less rice yield) (3)	7,500	8,707 (1)	17,107 (2)	8,400
Basic II (wheat-maize rotation) ..	7,500	8,707 (1)	19,906 (2)	11,199
Gobar gas* (60 cu. ft. plant) ..	2,300	397 (4) (530)**	644 (5) (2,898)**	247 (2,368)**
Tube-well*	10,000	2,618 (6) (3,906)**	0	0
Tractor*	15,000	6,032 (7)	0	0

*Gobar gas plant, tube-well and tractor are not farming systems. However, they can be added to any one of the farming systems described above.

**Figures in parentheses give economic costs or benefits.

(1) Includes fertilizer requirement not met by dung.

(2) Includes inputed value of 400 miles of transportation assuming alternatively it can be satisfied by tractor at Rs. 4·55 per 5 miles.

(3) Assumes insufficient water delivered by the Persian wheel for summer rice which results in 30 per cent decline in rice yield.

(4) 25 per cent subsidy for a gobar gas plant is provided by the government. Therefore, to estimate the cost to the farmer, interest and depreciation costs are calculated on Rs. 1,725 of capital cost. This works out to Rs. 397.

(5) Dung from six cattle when digested in gobar gas plants yields $2 \cdot 63 \times 10^6$ k. cal. of useful cooking heat. Assuming 95 per cent efficiency of an electric stove $2 \cdot 63 \times 10^6$ k. cal. of useful cooking heat is provided by 3,220 kwh of electricity. Assuming that the farmer has to pay Re. 0·20/kwh, the imputed value of bio-gas to the farmer is Rs. 644. As we have mentioned earlier, the economic cost of electricity is Re. 0·90/kwh. Therefore, the imputed economic value of bio-gas is equal to Rs. 2,898.

(6) Assumes maximum water requirement for crop, *i.e.*, ·86 m./ha. for rice and ·39 m./ha. for wheat is met by tube-well irrigation. This implies 368 hours of tube-well operation in a year.

(7) Assumes tractor is used for 400 hours a year for field operations, threshing and 500 miles of transportation.

The Basic farming system would use 340 bullock days to provide 1.64 metres (m.) of irrigation water from the Persian wheel, 20 bullock days to plough the field twice in a year and 32 bullock days to provide 500 miles of transportation services. Besides the 392 bullock days utilized for the above tasks, 338 bullock days remain which are sufficient for miscellaneous farm tasks such as threshing, etc., leaving enough rest days for bullocks.

For the systems described in Table IV, Table V gives the annual cost of variable inputs directly dependent on commercial energy sources, *e.g.*, fossil fuels and electricity. Column 2 of Table V expresses the cost of variable inputs directly dependent on commercial energy as the percentage of total carrying cost. Figures in column 2 may be regarded as an index of vulnerability of the system to energy problems. Column 3 in Table V gives an estimate of energy requirements from commercial sources for variable inputs for different systems. These figures give an estimate of energy intensiveness of different systems.[4]

TABLE V—VULNERABILITY OF ALTERNATIVE FARMING SYSTEMS TO ENERGY INPUTS

Farming systems	Cost of variable inputs dependent on commercial energy sources (Rs.)	Vulnerability index (1)	Requirement of commercial energy for variable inputs (k. cal.) $\times 10^6$
Basic	823 (1)	9·45%	·996 (5)
Basic I	823 (2)	9·45%	·996 (5)
Basic II	823 (2)	9·45%	·996 (5)
Gobar gas	0	0%	0
Tube-well	368 (3)	14·06%	1·179 (6)
Tractor	1,820 (4)	30·17%	4·547 (7)

(1) Variable cost in column 1 of Table V divided by the annual carrying cost.
(2) Cost of chemical fertilizers; not met by dung.
(3) Cost of electricity to the farmer.
(4) Cost of diesel and lubrication to the farmer.
(5) Davis and Blouin (4) have estimated energy consumption for urea (nitrogen) at 2,805 k.cal./kg., for triple superphosphate (P_2O_5) at 458 k. cal./kg. and for potassium K_2O), at 227 k.cal./kg. The energy requirement for the chemical fertilizer used in our budget is equal to ·996 $\times 10^6$ k.cal.
(6) The energy consumption for irrigation from tube-well is estimated at 1,840 h.p. hours which is equal to $1{\cdot}79 \times 10^6$ k.cal.
(7) 400 litres of diesel is used in tractor. The energy value of 400 litres of diesel is equal to 4.547×10^6 k. cal.

4. For energy calculation in this paper, we only count energy from fossil fuels to be relevant. This is because it is the fossil fuels which are imported by India and they put a heavy strain on India's foreign exchange reserves. Also fossil fuels are stock resources and all other sources of farm energy discussed in this paper are flow (biological flow) resources. We have chosen only to look at the variable inputs for energy calculations. The reasons are (1) it is the variable inputs which have direct relevance to the question of vulnerability of the system to energy problem, (2) an input-output matrix in energy flow terms is not available for Indian economy, *i.e.*, for Indian economy there does not exist a comparable document such as that given for U.S.A. by Herendien and Bullard (10).

The biggest bottleneck in the Basic farming system seems to be the ability of the Persian wheel to meet heavy water requirements of .86 m. for the rice crop. However, in the Basic system we assume the irrigation needs to be only .43 m. for rice. The rest of it being supplied by rainfall. Optimal irrigation requires not only supplying the aggregate amount of water required for the crop but also requires supplying enough water in short intervals at a rate much higher than the average rate of water application(21).

The Basic system I assumes that the Persian wheel cannot supply adequate amounts of water for the rice crop which results in a 30 per cent decline in rice yield. Suppose the farmer is able to invest in and manage a tube-well with the Basic system, then he is able to increase his rice yield from 2,000 kg./ha. to 2,600 kg./ha.; this is a 30 per cent increase in rice yield. Table IV indicates that even with a 30 per cent increase in yield of rice, the net income to the farmer is Rs. 9,382 which is higher than the net return in the Basic system I but less than the net return in the Basic system. However, due to the cost of electricity the economic (social) return is only Rs. 8,094 which is even less than the economic return of Basic system I. The tube-well irrigation is vulnerable from energy price fluctuations and particularly from power failure in India. Thus, it does not seem that the small farmer would find it attractive to own a tube-well, should he be able to afford one. Also, on social grounds there does not seem to be any case to encourage a small farmer to own a tube-well. In the Basic system I, 7,200 kg. of grain is produced using commercial energy in the amount of $.996 \times 10^6$ k.cal., *i.e.*, on an average 138.3 k.cal./kg. The Basic system plus a tube-well can produce an additional 2,400 kg. of grain by expanding 1.179×10^6 k.cal. of commercial energy with a high opportunity cost, *i.e.*, on an average the additional 2,400 kg. of rice is obtained at an energy cost of 491.2 k.cal./kg. which is more than three and a half times the calories required to produce 1 kg. of grain in the Basic system I.[5]

Similar calculation can be done by integrating tractor in the Basic system or a tube-well and a tractor minus two bullocks in the Basic system. In both of these systems the net return to the farmer and society will become smaller than the net returns in the Basic system, Basic system I or Basic system II.

A small farmer can increase his net returns and standard of living by integrating a gobar gas plant with one of the Basic systems. The bio-gas from the gobar gas plant supplies his household with an energy source which is comparable in its cleanliness and ease to use with electricity. The rural household with a gobar gas plant will enjoy a significant improvement in health plus considerable savings in labour over burning dung and vegetable matter for satisfying its domestic energy needs. The farmer will not only be able to return all the soil nutrients in dung back to soil but will also be able to

5. The example considered gives a conservative estimate of the increase in marginal energy requirements for marginal increment in crop yield.

harvest 1.5 times the useful energy over burning dried dung by having a gobar gas plant.

A gobar gas plant with six cattle brings a net income to the farmer of Rs. 2,501 if measured in terms of the full economic cost of electricity to provide the equivalent amount of useful energy as provided by the bio-gas. The net income to the farmer from gobar gas plant is Rs. 247 when he pays only a fraction of the economic cost of electricity. No matter which measure of net income to the farmer from a gobar gas plant is considered, the income to the farmer comes in kind rather than cash. That is to say, the farmer is not free to spend his income from the gobar gas plant as he wishes. From the point of view of pure economic theory the income from a gobar gas plant may result in a smaller increase in utility of the rural household than if the household were free to utilize its income on any commodity or service it desired. However, for a rural household in India the above point does not seem to be very important. Since a rural household in India could greatly increase its standard of living by having a clean energy source for domestic purposes, the lack of its marketability is unimportant. More important, by far, is the fact that the on-farm production of this energy relieves the farmer of the need to pay cash for energy. Hence, the bio-gas plant reduces the vulnerability of the small farmer.

CONCLUDING COMMENTS

An analysis of alternative farming systems for a small farm reveals that the energy requirements for field operations and irrigation, at least for the crops not having heavy water requirements, can be met by the Basic system described earlier.[6] The Basic system is able to supply the input requirements with the exception of chemical fertilizer and seed for a higher level of food production. The Basic system maximizes the use of the farm's biological energy resources. Such a system assures a small farmer a relatively high level of income with a minimum of risk and capital requirements.

Modification of Basic System to Include Tractor

Suppose a small farmer can make as much net income in the Basic system as in a modified system in which the two bullocks are replaced by a tractor. In order to obtain the maximum benefit from the gobar gas plant, the farmer must now substitute two cows or buffalo for the two bullocks.[7] The replacement of two bullocks by a tractor makes the small farmer vulnerable to fluctuations in the price of fossil fuels and tractor breakdowns as well as any mis-

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6. The conclusions of this paper should stand even though the estimates of prices and yields are subject to change.

7. This is true because (1) a 60 cu.ft. gobar gas plant requires dung from at least five cattle, (2) he can maximize his return from gobar gas plant by feeding the dung from six cattle since annual running cost of the gobar gas plant is fixed and it takes six cattle to use up all the roughage (wheat straw, corn cobs, and stalks, etc.) produced on farm. It is crucial to understand that the plant residue *e.g.*, wheat straw, cornstalk, etc., must be first biologically processed by the cattle into dung before the full advantage of its nutrients and energy value could be realised by a gobar gas plant.

management in the centralised distribution systems for fossil fuels and spare parts. It also raises the size of his operation and capital requirement to have two more milk animals as replacement for bullocks.

Public Policy Implications

The analysis of alternative farming systems for a small farmer has important public policy implications of macro nature. The public policy for development of small farms in India should consider the following points:

1. Foreign exchange reserves should not be strained to provide fossil fuels as direct energy inputs to the small farmers if alternative sources of energy are available.
2. The direct use of domestic energy resources of a stock nature, *e.g.*, fossil fuels as well as electricity from fossil fuels, should not be encouraged on the small farms. The operators of these farms can economically recycle their biological resources (flow resource) to satisfy their direct on-farm energy needs.
3. Whenever possible, a farmer should be encouraged to install a gobar gas plant so that he can maximize the use of biological resources for satisfying his energy needs. This will help to reduce the social cost of soil erosion, soil fertility loss and floods which may result from the burning of dung and firewood. The use of gobar gas plants also promises significant improvements in the health of the rural household.

Fortunately, the Government of India has included the establishment of 100,000 gobar gas plants in the country during the Fifth Plan period. The following policies should be considered to expedite the adoption of gobar gas plants:

(*a*) The government should at least continue to give the current subsidy of up to 25 per cent of the capital cost of the gobar gas plant. The government should instruct the nationalised banks to make longer term loans available to the farmer for gobar gas plants than the present maximum of five years. Obviously, this will reduce the cash flow problem of a small farmer and should increase the rate of adoption of the plants.

(*b*) The government should consider giving a subsidy for the purchase of cattle if the farmer is able to utilize them in his farming system and wishes to have a gobar gas plant.

(*c*) The government should charge the full economic (resource) cost of providing electricity for domestic purposes on those farms where gobar gas plants are economically feasible.

(*d*) The government should utilize scarce energy and, hence, foreign exchange resources for agriculture in the following order of priority: (*a*) Fertilizers[8] and (*b*) Irrigation.

(*e*) Even though the physical input requirements, with the exception of part of the fertilizer, seed and agricultural chemicals, for high yields and double cropping can be met by the Basic system, poor management may hinder the realisation of high level of food production. Therefore, the government should give high priority to investing in human resources to improve the management ability of the small farmer.

(*f*) The government should invest in research and development of small power equipment such as small harvestors pulled by bullocks. This will help accomplish harvesting and threshing in time to prepare seed-bed for the next crop. This implies that a highly discriminating mechanization policy should be adopted which will expedite double cropping while minimizing the labour displacement potential of mechanization.

(*g*) Finally, the use of the Basic system described in this paper, after refinement in each agro-climatic region where applied, should be widely encouraged on the basis of employment generated as well as foreign exchange saved. India is fortunate, indeed, to have available to it a farming system that will significantly contribute to the solution of these two important public policy questions.

REFERENCES

(1) Ramesh Bhatia, "Energy and Rural Development in India: Some Issues," in W. Lockeretz (Ed.): Proceedings of the Conference on Energy and Agriculture held in June, 1976, Washington University, St. Louis, Academic Press, New York (forthcoming).

(2) Ramesh Bhatia and M. Mehta, "Tubewell Irrigation in India: An Economic Analysis of Some Technical Alternatives," Internal Report of the Harvard Centre for the Population Studies, Cambridge, Mass., August, 1975.

(3) M. G. Blase and W. J. Staub, "Genetic Technology and Agricultural Development," *Science*, Vol. CLXXII, April, 1971.

(4) C. H. Davis and G. M. Blouin, "Energy Consumption in U.S. Chemical Fertilizer System—From the Ground to the Ground," in W. Lockeretz (Ed.): Proceedings of the Conference on Energy and Agriculture, *op. cit.*

(5) W. B. Donde and W. Brown: Effective Demand for Fertilizers in India, World Bank, Washington, D. C., 1972.

(6) K. N. Duggal: Three Level Optimization of an Irrigated Agricultural Growth System, Thesis, Indian Institute of Technology, Delhi, February, 1975.

(7) E. P. Eckholm: Losing Ground, W. W. Norton & Company, Inc., New York, 1976.

8. The hydrologic conditions and heavy water requirements for crops such as rice may render the Persian wheel ineffective.

(8) "Economic Indicators," *Monthly Commentary on Indian Economic Conditions*, Vol. XIV, No. 11 (167), Indian Institute of Public Opinion, New Delhi, June, 1973.

(9) Y. Hayami and V. W. Ruttan: Agricultural Development: An International Perspective, Johns Hopkins University Press, Baltimore, 1971.

(10) R. A. Herendien and C. W. Bullard: Energy Costs of Goods and Services—1963 and 1967, CAC. Document No. 140, University of Illinois at Urbana-Champaign, November, 1974.

(11) D. Kanel, "Size of Farm and Economic Development," *Indian Journal of Agricultural Economics*, Vol. XXII, No. 2, April-June, 1967.

(12) Khadi and Village Industries Commission: Gobar Gas: How and Why, Directorate of Gobar Gas Scheme, Bombay, India, February, 1975.

(13) M. R. Langham and M. W. McPherson, "Energy Analysis," *Science*, Vol. 192, No. 8 (4234), 1976.

(14) W. Lockeretz, R. Klepper, B. Commoner, M. Gertler, S. Fast and D. O'Leary: Organic and Conventional Crop Production in the Corn Belt: A Comparison of Economic Performance and Energy Use for Selected Farms, Report No. CBNS-AE-7, NSF/RA-760084, Center for the Biology of Natural Systems, Washington University, St. Louis, June, 1976.

(15) A. Makhijani and A. Poole: Energy and Agriculture in the Third World, Ballinger Publishing Company, Cambridge, Mass., 1974.

(16) S. K. Malhotra, Personal Communication, Agent, State Bank of India, PJI Branch, Chandigarh, Punjab, May, 1976.

(17) T. V. Moorti: A Comparative Study of Well Irrigation in Aligarh District, India, Cornell International Agricultural Development Bulletin 19, Cornell University, Ithaca, New York, May, 1971.

(18) K. S. Parikh, "India: Energy in the Year 2001," Indian Statistical Institute, New Delhi, September, 1974.

(19) S. Roy: Effects of Farm Tractorization on Productivity and Labour Employment of Punjab Farms, India, unpublished Ph. D dissertation, University of Missouri, Columbia, December, 1974.

(20) A. K. Sanghi and D. Dekle, "A Cost-Benefit Analysis of Bio-gas Production in Rural India: Some Policy Issues," in W. Lockeretz (Ed.): Proceedings of the Conference on Energy and Agriculture, *op. cit.*

(21) A. K. Sanghi and R. Klepper: An Economic Analysis of Irrigated Farming with Diminishing Ground Water Reserves, Report No. CBNS-AE-8, NSF/RA-760085. Center for the Biology of Natural Systems, Washington University, St. Louis, May, 1976.

(22) G. G. Michael Schluter: The Interaction and Uncertainty in Determining Resource Allocation and Income on Small Farms, Surat District, India, Occasional Paper No. 68, Employment & Income Distribution Project, Department of Agricultural Economics, Cornell University, Ithaca, New York, February, 1974.

(23) I. J. Singh, "Bullocks—The Main Stay of Farm Power in India," in W. Lockeretz (Ed.): Proceedings of the Conference on Energy and Agriculture, *op. cit.*

(24) M.S. Swaminathan, "Agriculture on Space Ship Earth," Coromandel Lecture, New Delhi, February, 1973.

(25) M. S. Swaminathan, Presidential Address delivered to 63rd Session of the Indian Science Congress, Waltair, 1976.

(26) UMC Guide 9331, "Animal Manure for Crop Production, University of Missouri, Columbia, July, 1975.