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SUBJECT I

ECONOMICS OF ENERGY USE IN AGRICULTURE

Economics of Energy Use in Agriculture*

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UNDERSTANDING ENERGY USE IN AGRICULTURE

The subject of the economics of energy use in agriculture has generally received very little attention from economists in this country. This contrasts sharply with the experience of several developed countries, particularly the US and Canada as well as countries of Europe, where this subject has been extensively researched by economists through a substantial amount of empirical work. Needless to say, field level studies on the economics of energy use in the agricultural sector have to be carried out as a multi-disciplinary exercise where economists have to work hand in hand with agricultural scientists. Perhaps, this has not happened in India to the extent desired, so that the perception of energy use for agricultural activities has generally remained confined to the domain of technical assessments pursued by agricultural engineers and agricultural extension specialists. Some teams, however, have done micro level work on this subject, and a few scattered writings in this field have been briefly reviewed with some insights drawn from them in this paper. However, there are a large number of issues related to energy use in agriculture that go beyond merely the estimation of agricultural production functions that explicitly include energy inputs as a factor of production. Some of these issues relate to a larger definition of energy use, which would include the production and use of inputs such as chemical fertilizers and pesticides.

Another important set of issues that needs to be considered is the fact that agriculture is not only a user of energy but also, in several parts of the world, an important supplier of energy. In several locations, such as the Amazon region of Brazil, where agricultural land is created by cutting down forests, agriculture not only becomes a user of energy in respect of direct use of energy in agricultural operations, but also becomes a major cause of reduction in energy supply, on account of lower production of fuelwood from forest resources. Such indirect effects exist and are seen in other parts of the world also. In the case of the use of chemical fertilizers and pesticides, an important question arises from the reality that the world does not have too much more land to exploit for agricultural operations, simply because the ecological and social costs of expanding crop area into existing forest lands would be unsustainably high. Since the advent of the Green Revolution, therefore, a major focus has been on greater use of fertilizers, pesticides and water including groundwater resources, by which substantial increases in yields have taken place in recent decades. Yet, this approach is now being questioned and serious fears have been raised by several researchers including Lester Brown[1] on the ability of global agriculture being able to feed a rapidly increasing global population. The spectre that he has outlined of a heavily populated China making huge demands on surpluses in agriculture generated in other countries, raises an important question on the limits of use of factors of production such as energy. Lester Brown's analysis

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and predictions may provide a Malthusian view of the future, in that he has not perhaps taken a very optimistic view of technological changes that may occur, particularly through the use of modern biotechnology. Some examples of changes that are possible have been recently put forward, such as in the paper by Shapiro[10] in the *Harvard Business Review*, wherein through a simple diagram he has demonstrated how huge tonnages of energy use can be eliminated through the use of a revolutionary gene developed through research using modern biotechnology. This is reproduced in Figure 1.

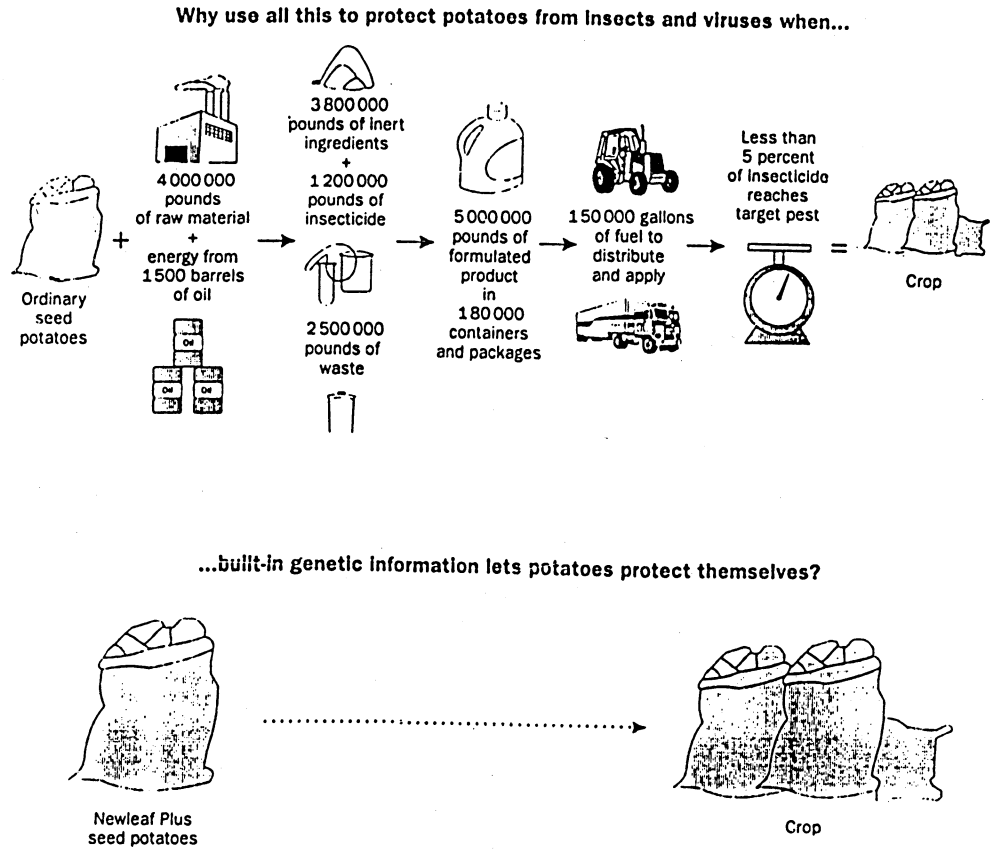

Figure 1

Shapiro's analysis raises still another question about energy use in agriculture, which has hardly been addressed by economists in this country. This question relates to the entire agricultural cycle and the extent of energy to be used right from the stage of production of fertilizers, pesticides and the supply of groundwater to the enormous transport requirements for moving agricultural inputs and post harvest outputs that in a country of India's size and diversity are inevitably large. If the entire agricultural chain was to be analyzed in terms of energy use, the computation could provide some startling results. Such analysis is essential for looking at the implications of current practices and the options available for future policy.

CHANGES IN INDIAN AGRICULTURE AND ENERGY USE

The structure of energy consumption in agriculture in this country has changed substantially, with a huge shift from animal and human labour towards tractors for farming operations and electricity and diesel used largely for groundwater irrigation. This is brought out in Figure 2[12].

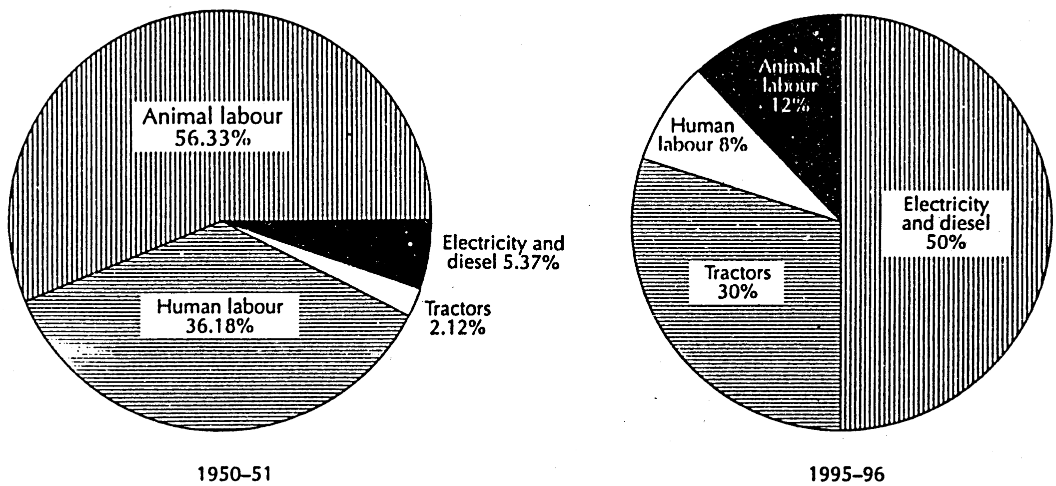

Figure 2 Energy consumption in agriculture

In cumulative terms the use of groundwater for agriculture has grown very rapidly during the past two and a half decades. This is brought out in Table 1[12] which shows that while

TABLE 1. IRRIGATED AREA (MHA) BY VARIOUS SOURCES: 1970-71 TO 1993-94

Source of irrigation	1970-71	1975-76	1980-81	1985-86	1990-91	1991-92	1992-93	1993-94
Government canals	11.97	12.90	14.45	15.39	16.50	16.81	16.50	16.63
Private canals	0.87	0.90	0.84	0.49	0.51	0.49	0.48	0.48
Tanks	4.11	4.00	3.18	3.07	3.32	3.32	3.18	3.15
Tubewells	4.46	6.80	9.53	11.54	14.26	15.17	15.82	16.38
Other wells	7.43	7.60	8.16	8.62	10.09	10.87	11.11	11.39
Other sources	2.27	2.40	2.55	2.65	3.11	3.20	3.21	3.43
Total net irrigated area	31.11	34.60	38.71	41.76	47.79	48.87	50.30	51.45

Source: Fertiliser Association of India (1997), *Fertiliser Statistics, 1996-97*, New Delhi.
Note: Due to rounding off, the total may not tally exactly.

government canals have provided approximately 50 per cent increase in irrigation during the period covered, tubewell irrigation has grown by around 300 per cent during the same period. The result has been a significant increase in total net irrigated area as shown. Matching increases in consumption of fertilizers have also taken place during roughly the same period as shown in Table 2,[12] and similarly increases in use of pesticides have also been significant as indicated by the increase in production during the same period (Table 3[12]). At the same time, major increases have also taken place in the progress of farm mechanization, which implies higher use of energy through displacement of human and animal energy by commercial forms of energy. This is brought out in Table 4.[12]

TABLE 2. CONSUMPTION (MT) OF NITROGENOUS, PHOSPHATIC, AND POTASSIC FERTILIZERS: 1970-71 TO 1996-97

Fertilizer	1970-71	1980-81	1985-86	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97
Nitrogenous	1.5	3.7	5.7	8.0	8.4	8.8	9.5	9.8	9.8
Phosphatic	0.5	1.2	2.0	3.3	2 8	2.7	2.9	2.9	2.9
Potassic	0.2	0.6	0.8	1.4	0.9	0.9	1.1	1.2	1.2
Total	2.2	5.5	8.5	12.7	12.1	12.4	13.5	13.9	13.9

Source: Fertiliser Association of India (1997), *Fertiliser Statistics, 1996-97*, New Delhi.
Note: 1996-97 Provisional.

TABLE 3. PRODUCTION AND CONSUMPTION (TONNES) OF TECHNICAL-GRADE PESTICIDES: 1970 TO 1995-96

Production/ consumption	1970-71	1980-81	1985-86	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97
Production	23501	43262	54922	-	75000	77000	-	-	-
Consumption	24320	45000	-	75000	69840	65530	66690	73120	74810

Sources: 1. *Indian Agriculture in Brief*. Kotharis Deskbook Series, (1993), *The Pesticides Industry*, Kothari Publications, Chennai, p. 19.
2. Covernment of India (1997), *Agricultural Statistics at a Glance*, Ministry of Agriculture, New Delhi.
Note: 1995-96 - anticipated achievement.

TABLE 4. CONTRIBUTION OF VARIOUS ENERGY SOURCES TO FARM POWER: 1991-92

Source of farm power	Number (million)	Total (GW)	Total (%)
Human			
Male	149.20	8.95	7.32
Female	50.80	2.54	2.08
Draught animals	84.00	31.50	25.76
Tractors	1.30	29.10	23.80
Power tillers	0.09	0.54	0.44
Diesel engines	4.60	17.16	14.04
Electric motors	8.30	30.96	25.32
Combines	0.04	1.51	1.24

Source: Tata Energy Research Institute (1995), *Environmental Considerations and Options in Managing India's Long-term Energy Strategy (ECOMILES)*, New Delhi, p. 59.

The question arises whether the trends of the last two and a half decades or so will continue and should be allowed to continue without any changes in policy. Indian agriculture is undoubtedly characterized by a very wide diversity in technology employed. There are still vast areas covered by traditional agriculture with single cropping practices. At the same time there are relatively modern and mechanized farm operations in some parts of the country which also rely on substantial uses of fertilizers, pesticides and vast quantities of water. The policy options available for the country to pursue with regard to energy use in agriculture cover firstly, promoting a significant increase of area under the Green Revolution, employing very high energy intensity agriculture. The second option would be for much better management of marginal farming, which still employs traditional technology and hardly any use of fertilizers or pesticides. Still another approach would be to intensify research in biotechnology as it applies to agricultural operations across the board. The attempt of such research should be to provide agricultural crops with genetic characteristics that minimize the use of fertilizers, pesticides and water, particularly through creating drought resistant and pest resistant crop species, making them suitable for low energy intensive agricultural activity. None of these options is mutually exclusive, and a sound strategy would require initiatives in all three areas.

SOME LARGER POLICY ISSUES

This message comes out powerfully in the work of Lester Brown also. In his recent analysis and projections, as summarized in the *State of the World Report 1997*, Brown suggests that "The shrinking backlog of end-use agricultural technology suggests the need for a dramatic increase in agricultural research." His contention is that even if there is very little prospect of a quantum jump coming from new technology, every new technology that leads even to a small expansion in food supply, could form a valuable part of the total solution. He also advocates the need for price signals bringing about shifts in production of what he calls non-essential crops. For instance, the 5 million hectares of cropland used in the US to produce tobacco could produce 15 million tonnes of grain. Similarly, he feels that the grain used in the US for production of ethanol as an automobile fuel represents a non-essential use. If this was to be phased out, 10 million tonnes of grain could be produced for human consumption. His conclusion is also that the only remaining reserve that can be tapped in a crisis or calamity is the grain that is generally used as feed. He feels high prices of meat would move the worlds rich down the food chain. This would reduce the demand for animal feed, and the same land area could then be used for crops suitable for human consumption. Greater vegetarianism is not only an option to be preferred for direct economic benefits but also for health reasons that in turn would provide further economic benefits. The meat chain is also highly intensive in energy use, right from the production of feed to transport of meat products, involving refrigeration. A think-tank called Redefining Progress[8] based in San Francisco, California has estimated that the money the Americans spend on diet and weight loss schemes adds $32 billion to the US economy each year and $50 billion more is spent on obesity-related health problems. In other words, not only is the consumption of meat with high fat content an energy intensive and economically sub-optimal form of providing human nutrition, but it also has other externalities that need to be taken into account in pricing and taxation measures adopted by governments round the world. The heavy debt incurred by Brazil during the 1970s and 1980s provided a strong incentive for farmers and agribusinesses to clear large areas of Amazonian forests for ranching purposes and export of meat and meat products from Brazil to other parts of the world, mainly North America. If the externalities imposed on the environment in the supply of this meat were to be taken into account, it would be priced totally out of the market and would not have reached the tables of prosperous consumers to the north of Brazil. This would have prevented a large part of the forests in the Amazon region being cut down and reducing the lung capacity of the world in a period when climate change is becoming a serious threat.

Lester Brown states that the 11 warmest years since record keeping began in 1866 have occurred after 1979. This of course was written before the unprecedented summer heat of 1998. The result is frequent shrinking of harvests across the US, Canada and several European countries, the Ukraine and Russia. Against the prospect of feeding nearly 90 million more people each year and increasing incomes round the world the demand for foodgrains both for direct consumption as well as in the form of animal feed to provide larger supply of pork, poultry, beef, eggs and consumption of beer produced from grains would only increase. This also has to be seen against the plateau that has been reached in fishing yields around the world. According to Brown, for the first time in history farmers can no longer count on getting any help from fishermen in expanding the worlds food supply.

The global food pricing system exhibits major distortions, which in the future are likely to accentuate the shortages and scarcities that exist today and thereby reduce the security of food supply that the world had been looking forward to in the past two to three decades. The worst forms of pricing distortions are seen today in the Indian agricultural system. The implication of this is greater use of fertilisers, pesticides and water, all of which would lead to higher intensity of energy use.

Agriculture by its very nature is an energy conversion process. As pointed out earlier, agriculture is not only a consumer of energy but also a producer of energy. Essentially, the process of biomass production of all forms requires conversion of solar energy through the process of photosynthesis. Todays agricultural technology is heavily dependent on petroleum and petroleum products and its derivatives such as used in the production of fertilizers and pesticides. As far as overall energy use is concerned agricultural operations can use both commercial and non-commercial as well as renewable and non-renewable forms of energy. Commercial sources of energy used directly in agriculture include coal, oil, natural gas and electricity. Indirect commercial energy sources are used for production of chemical fertilizers, plant protection chemicals, farm machinery, etc., as well as for transportation of all of these as required for the purposes of agricultural production and supply. In the case of non-commercial forms of energy the sources normally used include human labour, draught animals and vegetative fuels. Indirect sources of non-commercial energy include seeds, organic manure and other forms of biomass. Renewable sources of energy that are now being used in several parts of the world for agriculture include solar, biomass, wind energy as well as draught animals and the waste that they produce.

MANAGING THE TRANSITION

Agriculture is basically a seasonal industry and, therefore, the demand for energy fluctuates dependent on changes in seasons. During certain months of the year agriculture demands large quantities of energy to meet specific requirements such as during the period of sowing, transplantation, harvesting, crushing, etc. Despite the rapid increase in mechanization that has taken place in Indian agriculture, several operations like digging, transplantation, weeding, harvesting and paddy crushing are performed largely by manual workers. It is estimated that India has about 200 million agricultural workers providing 43000 tera joules (TJ) of human energy and 80 million draught animals providing 81000 TJ of animal energy. In the aggregate these two sources provide 0.298 kW/ha (kilowatt per hectare) of farm power. Draught animal power (DAP) by and large still continues to be the main source of energy supply for field operations. Since the introduction of mechanical power in the mid-1970s the use of DAP has been on the decline. Since 1977 a decline in the number of draught animals has taken place from 80.4 million to 73 million even though the total bovine population in the country has increased from 227 million in 1967 to 273 million in 1997. It is estimated that more than 55 per cent of land is cultivated by DAP (with two hectares of command area per pair of bovine animals). Paddy which is grown over 23 per cent of the total cropped area uses approximately 35 per cent of the total DAP energy used in the country. Animal energy per hectare for jute, paddy, onion and potato is relatively high. These crops are grown largely in states with higher DAP density and, therefore, lower levels of mechanization. Along with these changes in the use of DAP for mechanical operations in agriculture there has been a rapid increase of electric and diesel pumpsets, the growth in which has been at a compound rate of 17 per cent and 13 per cent respectively during the last two decades. The result is that the share of the farm sector in power consumption has increased from a mere 3.9 per cent in 1950-51 to close to 30 per cent as currently recorded. In the case of diesel consumption for agriculture the quantity consumed currently is a little over 10 per cent of the total consumption of diesel fuel. Energy for groundwater irrigation is generally not used efficiently in India. This is the result of irrational pricing, which leads to inefficient pumpsets, excessive use of groundwater and in general wastages throughout the entire energy cycle from the stage of power generation to each unit of useful input of water for agricultural operations. The current trend in giving huge subsidies to farmers for agricultural consumption of electricity unmetered and unaccounted for is tantamount to zero marginal cost of each unit of power consumed at the point of end-use. Consequently, there is excessive overuse of energy resources for agricultural purposes. The recent trend in setting up independent regulatory commissions in some of the states and the recent establishment of the Central Electricity Regulatory Commission (CERC) at the centre has led to some optimism that over a period of time electricity tariffs for agricultural use could be rationalised or if subsidies continue to be provided, they would be phased out and reduced over a period of time. The practice of not metering electricity supply to agricultural consumers, since most states have gone over to flat tariff or zero tariff for agricultural uses is an extremely harmful system which is not only resulting in excessive energy use for agriculture, but also rapidly depleting groundwater resources, which over a period of time will only lead to more costly agricultural operations.

It needs to be emphasized that the subject of energy use in agriculture has to be seen within a much larger framework of agricultural policy as a whole. For instance, the question is often asked on what kinds of policy measures would help in those areas where dryland agriculture is practised today. Overall, approximately one-third of the area in this country will remain cultivated through rainfed agriculture even when the entire irrigation potential of the country has been fully exploited. Currently, such areas are characterised by the production of coarse cereals, pulses, oilseeds and cotton. By international standards and as against the potential that exists, these crops currently show very low yields and high degrees of fluctuation of output from year to year. This not only affects overall output by large magnitudes every year, but also has very serious implications for the incomes of farmers, who are generally poor in most of these widespread locations.

The question of rainfed agriculture has received considerable attention in recent years, and several economists and agricultural experts have suggested measures by which farmers can get out of the low productivity trap. Measures that have been suggested include the use of water harvesting methods and soil conservation programmes in most of these areas. On the basis of empirical evidence it can be seen that without minimum moisture any attempts to raise productivity of dryland crops would not be successful. Water harvesting schemes would, therefore, be of critical value, and these may require the use of renewable forms of energy or the harnessing of local energy resources whereby delivery of water wherever harvested can be assured at reasonable cost. There are, of course, implications in this for the provision of credit, which is generally not available to those dependent on this form of agriculture. Livestock development would also be desirable rather than prolonged perseverance with traditional crop production. Some research has also suggested that along with the strategies for water harvesting and soil conservation schemes diversification towards horticulture and livestock production can lead not only to higher income levels for rural households but may also provide help to agricultural workers in terms of provision of biomass energy for meeting their cooking needs. Currently a great deal of time of women and children is spent in collection of fuelwood in locations which are becoming chronic areas of scarcity for supply of biomass energy in general and fuelwood in particular. Higher incomes would also permit investments in proper water storage and pumping devices. It is also necessary to look at the question of supply of energy from agricultural operations. Traditionally, when the pressure of population was low and there were no serious threats on land area that could be devoted to farming, most of the energy needs of the people who depended on agriculture were supplied to a large extent through biomass resources produced either directly or indirectly from agricultural operations.

THE CONFLICT BETWEEN FOOD AND FUEL

At a global level the conflict between food and fuel and the competition for land on which either can be produced is likely to become serious in the coming decade. A recent study carried out by the World Energy Council in assessing global energy perspectives to the year 2050 and beyond found the conflict between food and biomass as a serious issue to be addressed at the global level. The study contended that both for agricultural food production and biomass production for energy, land would be a valuable resource for which both would have to compete. The required expansion of agricultural cropland in order to increase nutrition and to provide food for an additional 5 billion people is estimated to amount to around 250 million hectares, with 200 million additional hectares required in developing countries. This compares to 1440 million hectares currently used by agriculture. The required land area, estimated by this group, for energy biomass production according to one of their scenarios was estimated at 400 to 600 million hectares by the year 2050 and 700 to 1350 million hectares by the year 2100. In an optimistic scenario which assumed a lower bound biomass land requirement, biomass land productivity was assumed to grow to 10 tonnes of oil equivalent per hectare per year with two-thirds being produced in dedicated plantations and the balance being recovered from agricultural residues as well as from better forest management. These additional land areas for both agriculture and biomass are envisaged as being available by the researchers who worked out these projections, but they stretch future land requirements and land use changes to their very ultimate limits. By the year 2100 agriculture which would use 1700 million hectares and biomass production which would use 700 to 1350 million hectares, could require up to 3000 million hectares. This amounts to as much land as is currently covered by forests. Hence, land use conflicts would become a major constraint and are seen as inevitable in the years ahead. If one takes the example of Asia, according to the scenarios that have been developed, the required land for expanding agricultural production and maximum biomass use combined would require the entire potentially arable land available by the year 2100. Because of significant ecosystem changes as well as regional land use conflicts, the future of biomass is in all likelihood going to be constrained, particularly in high density areas, and this is likely to evolve along the cases that are shown in Table 5.

TABLE 5. CURRENT AND FUTURE LAND USE (in 10^6 ha)

Region	Current use			Additional land use			
	Forests	Pasture	Agriculture	Agriculture (2050)	Biomass[c] (2050)	Biomass[c] (2100)	Potential arable land[d]
ICs[a]	1770	1190	670	50	70-100	150-350	N.A.
Africa[b]	630	700	150	95	110-180	140-340	990
Asia	600	880	470	33	160-250	260-340	500
Latin America	890	590	150	72	50-80	140-320	950
DCs	2120	2170	770	200	320-510	540-1000	2440
World	3890	3360	1440	250	390-610	690-1350	

Source: WEC-IIASA Joint Study, World Energy Council, 1995[14].

a. Including OECD, EEU and FSU; b. Including MEA; c. For maximum biomass scenarios (A2 and A3) range corresponds to 4 to 6 toe/ha land productivity by 2050 and 6 to 10 toe/ha by 2100. Lower bounds also assume that 80 percent (2050) and 67 percent (2100) of biomass would be produced in plantations. Higher bounds assume 100 percent plantation biomass. d. UN - Food and Agriculture Organization estimate. (Alexandratos, N. (Ed.) (1995), *World Agriculture Towards 2010: An FAO Study*, John Wiley & Sons, Chichester, U.K.).

CONCLUSIONS

The Indian agricultural system is going through a period of rapid change with greater use of commercial forms of energy and a reduction in the share of muscle energy, both human as well as draught animal power. But in considering the question of energy use in the agricultural sector, a limited view of looking at energy consumption only in farm operations does not serve the interests of larger policy formulation. The growing use of chemical fertilizers, pesticides and water from underground sources, drawn through growing use of commercial energy needs to be considered fully, particularly if future strategies have to be developed to create conditions of sustainable patterns of development. In this context, environmental impacts of growing energy use become an important element in the total picture.

Another issue which is particularly relevant in the Indian case and, with the growing demand for foodgrains, also at the global level, is the fact that agriculture is not only a user of energy, but also a supplier of biomass energy. In a number of locations in this country biomass fuels are the most important form of energy used, and will continue to be so for many decades. At the global level, the conflict between farmland and forest is likely to sharpen in the coming years, and this outlook does raise the spectre of serious problems in food supply as well as large scale damage to ecosystems. Energy questions are, therefore, all pervasive in the foodchain of the world, and if we think only in the context of energy for farm operations, we ignore a large and significant part of reality. Policies must, therefore, come to grips with the linkages between various elements of this entire complex system, wherein energy issues have a far reaching effect beyond farming operations alone.

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