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Energy intensity and productivity in relation to agriculture–Bangladesh perspective

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The energy intensity and overall energetic efficiency of agricultural practices as exists in Bangladesh was determined. Results showed that total energy output increased from 69.87 $GJha^{-1}$ to 82.08 $GJha^{-1}$, with increasing commercial energy input from 17.94 $GJha^{-1}$ to 27.10 $GJha^{-1}$ in the study period of 1990 to 2005. The corresponding increase in energy intensity was 45.67 MJ/US$ (2000) to 54.47 MJ/US$ (2000). Energetic efficiency, calculated as the ratio of total output to input for different crops, using weight factor, decreased from 3.97 to 3.03 in the study period. The energetic efficiency declines with increasing energy input, and the result indicates that input energy increases faster compared to energy output. The mechanization index increased from 64% to 78% in the study period. However, our main goal being maximization of the output per unit agricultural land, the estimated change in efficiency with increasing input can play an important role in choosing the appropriate input for optimum output.

Key words: Energy intensity, productivity, agriculture, Bangladesh.

Introduction

Bangladesh is an agricultural country in respect of number of people involved in this sector. It has remained so, not for its agricultural output but due to the lack of development in industrial sector, and the shortage of natural resources. Although in many countries although there has been enormous development in agriculture through the use of modern science and technology, Bangladesh is still greatly dependent on the traditional equipment and is only making a transition to modern agriculture. However, modern agriculture is becoming energy intensive. The economic activity of Bangladesh is heavily dependent on agriculture in respect to employment, where 48% of the human

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labor is involved. This particular sector contributes only 12.929 billion US$ (2000), which is about 21% of total GDP of 2008. This discrepancy in respect of output per person engaged in agriculture is mainly due to the backwardness in energy use in this sector considering the total energy use, its form and efficiency.

In this study, we have tried to evaluate the role of energy in GDP and the energy intensity; the role of energy in energetic efficiency and the role of energy in agricultural production as food that is energy productivity.

Energy intensity is a measure of efficiency of a nation's economy. High-energy intensities indicate a high cost of converting energy into GDP, while lower energy intensities indicate a higher GDP per unit expenditure of energy. It is usually calculated as unit of energy needed to produce per unit of GDP. The energy intensity in agriculture sector is calculated in three ways. In the first case, we considered the combined contribution of all sub-sectors of agriculture such as crops and horticulture, fishery, livestock and forestry taking into account only the commercial energy (petroleum, electricity and gas) used. In the second case, only the crops and horticulture sub-sectors taking into account the commercial energy used have been considered. In the third case only the crops and horticulture sub-sectors, taking into account all kinds of energy such as muscle power, mechanical power, chemical and bio- fertilizer energy (excluding pesticide, seed and water energy) and all other forms of final commercial energy used in irrigation have been considered.

The efficiency of agricultural practices can be computed in more than one way. Most people have calculated the efficiency of agricultural processes by converting the agricultural product into energy as output, and only the commercial energy in the form of energy from human, animal, machinery fuel, fertilizer, pesticide, irrigation fuel in the form of petroleum and electricity and energy from seed, and that again for a particular crop like rice and wheat (Alam *et al.*, 2005), boro rice (Iqbal, 2007), wheat (Shahan *et al.*, 2008), sugarcane (Mrini *et al.*, 2001) and potato (Yadav *et al.*, 1991). We have calculated the efficiency of agricultural process as practiced in Bangladesh by taking into account the total agricultural product in the form of different kinds of crops such as rice, wheat, maize, jute, oil seed, pulses, vegetable, potato, sugarcane, spices, cotton and groundnut, and their residues, which have been converted into energy as output. The input energy is considered in two ways. Firstly, by considering only the commercial input, and secondly by taking the total energy input, which includes solar energy and the commercial energy. The first approach is important when the aim of the agriculturist is rather narrow and commercially to find out how much agricultural output one receives out of the agricultural investment, without taking into consideration the net output of the cultivated land. In the second approach which we have called the total energy efficiency, the aim is to find out the efficiency of converting solar energy by agriculture as increased through the additional input of commercial energy in the form of energy from human, animal, machinery, fertilizer, manure, pesticide, irrigation fuel (petroleum and electricity), as also from water and seed. We have also calculated the change in these two efficiencies from 1990 to 2005 on the basis of the agricultural practices in Bangladesh.

Many researchers have studied energy intensity and energy efficiency, Hossain and Tamim, 2005 state that in Bangladesh the aggregated energy intensity was 11.42 MJ/US$ (2.45 MJ/US$-ppp) in 1990 and 10.56 MJ/US$ (2.36 MJ/US$-ppp) in 2004. Todoc *et al.* (2003) reported that in Thailand the agriculture sector energy intensity showed an increasing trend until 1997 and it showed a declining trend until 2000. Between 1989 and 1997, energy intensity grew annually by 12% on the average, although sharp declined occurred in 1993 and 1995. Between 1997 and 2000 agriculture energy intensity fell by 19.1% per annum. Schaeffer *et al.* (2005) reported that in Brazil the agriculture energy intensity was 3 MJ/US$-2000ppp in 1980. Mrini *et al.* (2010) determine the energy efficiency of sugarcane in Morocco. Bockari-Gevao *et al.* (2005) determine the energy efficiency of rice in Malaysia. Demircan *et al.* (2006) and Canakci *et al.* (2005) determine the energy efficiency of sweet cherry, citrus, apricot, tomato, cotton, sugar beet, greenhouse vegetable, some field crops and vegetable in turkey.

Previously many researchers have calculated efficiency with respect to different types of crops (Alam *et al.*, 2005) where the inclusion of commercial input is not exhaustive. In fact, with the progress of time, the nature of the commercial input is changing due to modernization of agriculture and the introduction of new devices. We have considered a more exhaustive list of inputs as practiced in Bangladesh in recent time.

The main consideration in this paper has been the goal of maximizing agricultural production from our limited cultivated land. Despite of various shortcomings of the land utilization system, Bangladesh has greatly increased its food grains from 31 million MT to 42 million MT in the whole study period of 1990 to 2005, and achieved self-sufficiency in food production in 2000. It is also found that machinery fuel energy, fertilizer energy, pesticide energy and irrigation (petroleum and electricity) energy consumption in agriculture sector has greatly increased in recent years, and the output of the agriculture also increased though the cultivable land decreased slowly which was 9.78 million hectare in 1990 and has been reduced to 7.32 million hectare in 2005. Under this situation, an energy scenario in agriculture can provide planners and policy makers an opportunity to evaluate the performance of agriculture system in respect to energy input.

Materials and methods

The available up-to-date data from different national and international published sources were used in this study. In those cases, where no published data is available, we have estimated the relevant figures from field survey. Human and animal labor, machinery, electricity, petroleum and fertilizer have been included to estimate the energy intensity. The energy equivalents of these different forms of energy used for our computation have been estimated. Before 1996, the usual practice was to use labor force with lower age limit of 10 years and it was changed to 15 years from 1996. We have calculated the energy supply by human labor accordingly (BBS 1992-2008). To estimate the gross energy input in agriculture, working day of agricultural worker is considered as 207 days per year, with an average 8 hr. work per day (Stout, 1990). The average working hours of an animal in agriculture is considered 360 hr. per year (Ozkan *et al.*, 2004). Since, there is no data available for petroleum (diesel) consumption of the machinery used in agriculture, the total diesel energy input to agriculture was calculated from the petroleum consumed by tractors and power tillers. From field investigations, it is found that a 70-hp tractor consumes 8 L. diesels per hour and its average used on the field is 1140 hr. per year. On the other hand, a 10-hp power tiller consumes 1.75 L. diesel per hour with an 80% loading capacity and its average used on the field is 720 hr. per year (Ozkan *et al.*, 2004). Deep tube-well, shallow tube-well and low lift pump are operated by electricity and diesel. Data on electricity and diesel, used in irrigation were collected from field investigation. It is found that for irrigation, a deep tube-well consumes 1388 KWh electricity per hectare, shallow tube-well and low lift pump consumes 266.4 L. diesels per hector. Chemical energy input data on individual fertilizer materials (nitrogen, phosphorus, potash and zinc); manure and pesticides (insecticide, herbicide and fungicide) were used on the basis of practices. The total energy input from fertilizer was calculated from the chemical energy released by the different element of the fertilizer usage, which is shown in Table 1. The energy contributions from the pesticide were also calculated. The energy contribution from water was estimated by considering the total water needed for irrigation and the energy released per unit quantity of water as obtained from Table 1. To calculate water energy, used in irrigation, it is assumed that 1.33 kg of water is consumed to produce 1 gm of wheat and 0.45 kg of water is consumed to produce 1 gm of rice and other food grains. This amount of water, were also converted to energy equivalent (Acaroglu and Aksoy, 2005). Seed is considered as a form of energy input to agriculture. In this study rice, wheat, maize, jute, oil seed, pulses, vegetable, potato, sugarcane, spices, cotton, groundnut and their residues were considered as output in the energy estimation. Energy output from these products was calculated by multiplying the amount of production and their corresponding energy equivalent. Energy output from the by-products was estimated by multiplying a by-product with its corresponding energy equivalent.

Based on the energy equivalents of the inputs and output (Table 1), the energy input to produce per unit of GDP output (energy intensity), the energy ratio (energetic efficiency), energy productivity and the mechanization index have been evaluated of the period 1990 to 2005 as defined bellow (Demircan *et al*., 2006 and Sartori *et al*., 2005).

$$\text{Energy Intensity} = \frac{\text{Energy Input (MJ ha}^{-1}\text{)}}{\text{GDP US\$(2000)}} \quad (1)$$

$$\text{Energetic efficiency} = \frac{\text{Energy Output (MJ ha}^{-1}\text{)}}{\text{Energy Input (MJ ha}^{-1}\text{)}} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Grain output (kg ha}^{-1}\text{)}}{\text{Energy Input (MJ ha}^{-1}\text{)}} \quad (3)$$

$$\text{Mechanization Index} = \frac{\text{Commercial energy input (MJ ha}^{-1}\text{)}}{\text{Energy Input (MJ ha}^{-1}\text{)}} \text{ X } 100\% \quad (4)$$

Results and discussion

Energy intensity is a measure of efficiency of a nation's economy. High-energy intensity indicates a high cost of converting energy into GDP, while lower energy intensity indicates higher GDP per unit energy use. Energy is necessary for accelerating economic growth and improving the quality of life. There is a large disparity between the life-style of developed and developing countries. An advanced country has higher standard of living and have greater impact on its energy intensity than the countries with a lower standard of living. Thus, the energy intensity reflects the standard of living and the state of the economy. It is usually calculated as units of energy needed per unit of GDP.

Energy intensity

The relationship between energy intensity and economic development has the following pattern- in the initial stage, where agriculture is more conventional, human and animal muscle power plays significant role, energy intensity is lower since the productivity is also low. In the second stage, It is the initial phase of the modernization of agriculture, energy intensity increases

Table 1. Energy co-efficient for agriculture energy sources.

Description	Energy co-efficient	Description	Energy co-efficient
1. Human muscle power	0.1 hp/labor	21. Vegetable	0.88 MJ/Kg
2. Animal draft power	0.25 hp/head	22. Potato	4.06 MJ/Kg
3. Fertilizer, nitrogen	60.6 MJ/Kg	23. Sugarcane	2 MJ/Kg
4. Fertilizer, phosphorous	11.1 MJ/Kg	24. Spices	0.80 MJ/Kg
5. Fertilizer, potassium	6.7 MJ/Kg	25. Cotton	11.8 MJ/Kg
6. Fertilizer, zinc	5 MJ/Kg	26. Groundnut	23.8 MJ/Kg
7. Fertilizer, organic	1 MJ/Kg	27. Rice hulls	13.8 MJ/kg
8. Pesticides, insecticide	145 MJ/Kg	28. Rice straw	19.7 MJ/kg
9. Pesticides, herbicide	200 MJ/Kg	29. Wheat straw	18.9 MJ/kg
10. Pesticides, fungicide	145 MJ/Kg	30. Oil stalks	19.4 MJ/kg
11. Diesel	56.4 MJ/ liter	31. Vegetable stalks	19.4 MJ/kg
12. Electricity	3.6 MJ/ KWh	32. Jute stick	16.91 MJ/kg
13. Water	1.02 MJ/ tone	33. Cotton hulls	19.4 MJ/kg
14. Average solar energy Incidence	65130 GJ/hector = 661.18 J/m2/ sec	34. Cotton stalks	17.4 MJ/kg
15. Rice	14.7 MJ/Kg	35. Groundnut shells	19.7 MJ/kg
16. Wheat	14.7 MJ/Kg	36. Peat	14.6 MJ/kg
17. Maize	15.1 MJ/Kg	37. Sugar cane urgesses	19.0 MJ/kg
18. Jute	16.91 MJ/Kg	38. Cow dung (as fire stick)	12.0 MJ/Kg
19. Oil	22.72 MJ/Kg	39 Others residue	19.4 MJ/kg
20. Pulses	15.10 MJ/Kg	40. Fodder coefficient	2.51 g/day/cattle
		41. Coking fuel co-efficient	4.21 GJ/ day/person
		42. Food coefficient	16 unce/day/person = 0.453Kg/day/person

Sources: Canakci *et al.* (2005), Ozkan *et al.* (2004), Acaroglu (2005), Salokhe *et al.* (1998), Shrestha (1998), Argiro *et al.* (2006), Alam (1991), Mittal *et al.* (1988), Gopalan *et al.* (1978), Reddy *et al.* (2003) and Singh (2002)

because of increased energy investment to develop the infrastructure, application of chemical fertilizer and the introduction of new machineries and techniques and in the preparation of manpower and acquisition of specialized knowledge. In the third stage, energy intensity decreases due to increased efficiency of agricultural productivity through modern technology and efficient utilization of various forms of energy. In Bangladesh we have not been able to go through this third phase transition in either agriculture or industry yet. In the following sections, the sectoral energy intensity is discussed.

Table 2. Agricultural statistics of Bangladesh (BBS 1992-2008, LFS 1995-2006, LS 1998-1999).

	1990	1995	2000	2005
Active human labor (million)	50.15	54.59	39	47.4
Human labor in agriculture sector (million)	33.3 (66%)	34.5 (63%)	20 (51%)	22.8 (48%)
Total cattle (million)	20.98	21.53	23.43	23.78
Workable cattle (million)	9.44	9.69	10.54	10.70
Power tiller (thousand)	120	180	300	480
Tractor (number)	2180	1550	1555	3000
Chemical fertilizer (million metric tone)	1.973	2.026	2.651	3.212
Organic fertilizer (million metric tone)	73.8	73.3	71.9	71.6
Consumption of petroleum (diesel) (million liter)	450.115	589.59	801.872	1010.27
Consumption of electricity (GWh)	594.273	927.13	921.77	1009.08

Energy intensity in agriculture sector

Bangladesh primarily has an agrarian economy and agriculture is crucial for the country's socioeconomic development. Importance of agriculture in the economy of Bangladesh is overwhelming in attaining food sufficiency, poverty alleviation and sustained economic development. It is the single largest sector in our economy. The combined contribution of all sub-sectors of agriculture such as crops and horticulture, fishery, livestock and forestry in GDP was about 21% in the year 2008 and 48% of the total labor force was employed in this sector. However, in 1990, this sector shared high growth rate of about 10%, of which, crop sub-sector contribute about 80% of the GDP and about 57% of the labor force was engaged in this sub-sector. Over the last fifteen years it is found that although there had been expansion of irrigation accompanied by increase of crop production, due to the absence of planned irrigation management, it had adverse impact on environment in some areas of the country. For example, sub-soil water level fall and water became unavailable for long-term irrigation. In addition, until the mid of 1980s, traditional irrigation system with inefficient equipment had been used. After that the application of modern energy, efficient equipment and appropriate technology for irrigation has been introduced.

The historical energy intensity from 1990 to 2008 and projected intensity for the period 2009 to 2035 for the historical GDP growth and energy of the agriculture sector of the country is shown in figure 1(a). It is realized that the energy intensity slowly increased from 1.78 MJ/US$(2000) in 2000 to 11.31 MJ/US$(2000) in 2008. The projected energy intensity is shown to be non-linear up to 2035. The increasing trend of energy intensity in agriculture sector of Bangladesh does not support sustainable development. Schaeffer *et al.,* (2005) reported that in Brazil the agriculture energy intensity was 3 MJ/US$-2000 ppp in 1980.

The government has given importance in crops and horticulture sub-sector of the agriculture sector for overall socioeconomic development of the country. The government of Bangladesh has been promoting this agriculture sub-sector through various supports to farmers for improving the quality and productivity of crops and other agriculture products. Over the years, a significant development of this sector is made through modernization of irrigation system with access to adequate as well as affordable supply of energy and electricity, planned use of ground and surface water, application of fertilizer and use of machinery and high yield variety seeds are essential for accelerating the productivity of crops and high output. As a consequence, the use of mechanical power of machinery is gradually increasing while the muscle power of human and animal are decreasing, shown in Table 3.

The utilization of electric and light diesel oil (LDO) for water pumping and the high-speed diesel (HSD) for motive power in the fields are increasing. It is generally felt that the use of efficient machinery and modern energy in agriculture sector contributes higher productivity and reduces the need of expansion in the quality of land under cultivation. These reduce the pressure on ecosystem conversion that is the requirement of sustainable development in the agriculture sector. The approach of modernization to agriculture has significantly improved the productivity and quality of crops in Bangladesh that can be explained by estimating and analyzing the historical energy intensity of the agriculture (crops and horticulture) sub-sector of the overall agriculture sector.

The energy intensity is difficult to estimate and analyze because a large portion of total utilized energy in this agriculture Sub-sector comes from human and animal muscle power, mechanical power of agriculture machineries, natural gas in the form of organic fertilizer and traditional energy, namely biomass in the form of bio-fertilizer. It is not easy to translate human and animal muscle power, mechanical power of machineries, organic and bio-fertilizer into economic values. The energy intensity in terms of final commercial energy in the form of electricity, gas, petroleum and coal in agriculture sector can be explained easily because of available data and information about the sectoral energy consumption in our national statistics. In order to examine the long-term economic aspect of energy in this sub-sector, it is necessary to compare the energy intensity in terms of all kind of energy and power used.

The estimated historical energy intensity for the period 1990 to 2008 of agriculture sub-sector in terms of total final energy is shown in Fig. 1(b). It is realized from the calculated data that the historical energy intensity slowly increased from 2000 to 2005, which was 10.06 MJ/US$ to 17.59 MJ/US$ and it was 20.11 MJ/US$ in 2008. The gradual incremental growth of intensity is due to the growth of final energy consumption through introduction of machineries for cultivation, electricity and petroleum products for irrigation. The pattern of energy intensity of Fig. 1(b) further indicates that the growth of energy demand in this sector will enhance the productivity of crops and other agriculture products. Thus, the sector may contribute significantly in the overall economy of the country in the long-term future.

Table 3. Energetic parameter in Bangladesh agriculture.

Total cropped area (Thousand hectare)	**1990 (GJ/hectare)**	**1995 (GJ/hectare)**	**2000 (GJ/hectare)**	**2005 (GJ/hectare)**
	14060	***13520***	***14270***	***14107.28***
1. Available human energy input	1.05	1.33	0.62	0.72
2. Available animal energy input	0.16	0.17	0.18	0.183
3. Available machinery energy input	0.69	1.00	1.55	2.52
4. Irrigated energy input	2.31	3.29	3.94	4.89
5. Total physical energy (1+2+3+4)	**4.21**	**5.79**	**6.29**	**8.313**
6. Organic fertilizer (livestock residue) energy input	5.26	5.42	5.04	5.08
7. Fertilizer (chemical) energy input	6.33	8.01	9.45	11.29
8. Pesticides energy input	0.09	0.12	0.19	0.27
9. Total chemical energy input (GJ/hector) (7+8)	***6.42***	***8.13***	***9.64***	***11.56***
10. Seed energy input	0.97	0.98	0.93	0.71
11. Water energy input	1.08	1.15	1.37	1.44
**Total input nergy (without solar energy)	**17.94**	**21.47**	**23.27**	**27.10**
12. Solar energy input	65130	65130	65130	65130
13. Total energy input (with solar energy)	65148	65151	65153	65157
14. Food production (Tone/hector)	2.20	2.31	2.72	2.98
15. Food energy output	23.82	24.6	30.12	30.54
16.Agriculture residue energy output	46.05	49.95	48.70	51.54
17. *Total energy output*	***69.87***	***74.55***	***78.82***	***82.08***

The estimated energy intensity in terms of all kinds of energy used in agriculture sub-sector is shown in Fig. 1(c). In this calculation, we have simply converted all kinds of energy such as muscle power, mechanical power, chemical and bio- fertilizer energy (excluding pesticide, seed and water energy) and all other forms of final commercial energy (petroleum, electricity and gas) used in irrigation, into MJ unit, shown in Table 3. It has been realized that the energy intensity increased linearly from 45.67 MJ/US$(2000) in 1990 to 54.47 MJ/US$(2000) in 1995. After 1995 the energy intensity decreased and in 2000 it was 51.53 MJ/US$(2000), again increased slowly and in 2005 it was 54.47 MJ/US$(2000). The calculated energy intensity shows that economic growth of agriculture (production of crops) has achieved sustainability. The compound growth of energy demand for a long-term basis will not accelerate economic growth of this sub-sector.

The mechanical power of machineries will gradually replace the muscle power of human and animal. As a result, the required number of labor force for this sub-sector will decrease day by day; the excessive labor forces will be absorbed in other economic sectors and contribute to the economy of the country. In the year 1990, the labor force in agriculture sector was 66% of the total labour of the country, which stood 48% in the year 2005. Due to the decline in number of labour force in agriculture sector, the contribution of human muscle power in total energy supply has decreased to 4% in the year 2005 compared to 8% in the year 1990. On the other hand, the contribution of the mechanical power to the total energy supply in agriculture sector was about 4.3% in 1990, which increased to about 10.3% in the year 2005 (Livestock Survey, 1998-1999, and Agriculture census, 1996). The introduction of machinery in agriculture drastically relaxed the required number of labor force that help in improving the productivity of the sector and improving the quality of life of rural people.

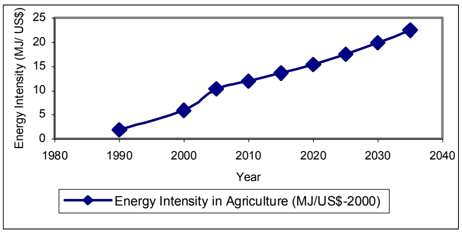
Aggregated energy intensity

The aggregated energy intensity (agriculture, industrial, transport and service) is calculated based on historical data from 1990 to 2008; and it is projected from 2009 to 2035 for the historical compound economic and energy growth of the country. The estimated aggregated energy intensity is shown in Fig. 2. The energy intensity was 7.6 MJ/US$(2000) in 1990 and rose to 19.39 MJ/US$(2000) in 2005. The energy intensity increased to 40.64MJ/US$(2000) in 2035. In Bangladesh, Hossain 2005, reported aggregated energy intensity as 10.56 MJ/US$ (2.36 MJ/US$-PPP) in 2004. The intensity has increased slightly over the years and it becomes only about two folds in the year 2035 compared to 2000. The redeeming feature of low energy consumption with respect to its GDP is that the country’s energy intensity is very low, which is lower than most of the developing countries. This is probably because there would not be any significant structural change in the country’s economy over the study period. On the other hand, the energy intensity shows an increasing tendency over the whole projected period and this open-ended increasing tendency could not support sustainable development of the country.

Mechanization index, energetic efficiency and energy productivity in agriculture

The energy input and energy output from various sources are calculated in per hectare basis. The performance indicators/parameter is shown in Table 3 and Table 4. It is observed that the cultivable area is reducing day by day. The output as product and by-product depend on the level of energy input. It is found that the input as muscles power did not increase in the studied period. However, the input as physical power significantly increased during the same same the period due to only the mechanical energy input for tillage operation. It is seen contribution of mechanical (tractor, power tiller) energy was 16% of the total physical energy in 1990 and it rose to 30% in 2005 as shown in Table 3. Rapid growth of mechanical energy input has made a significant contribution to the total draft energy. In 1990 the draft energy including animal energy and mechanical energy was 0.85 GJ/hectare and it increased to 2.703 GJ/hectare, which has a significant contribution to producing agricultural output. In 1990 the mechanization index was 63.9% and rose to 78% in 2005 that is a 22% increment compared to 1990, shown in Fig. 3. In Bangladesh, Alam *et al.* (2005) reported a mechanization index of 86% in 2000.

In the last decade, the Government of Bangladesh liberalized the policy of importing agricultural machinery (Satter, 1995). As a result, a large number of tractor and power tiller were imported and significant draft power became available. Thus the physical power input level improved significantly as also reported by Alam *et al.* (2005). The figure-3 indicates that the mechanization index increases with increasing energy input/hector and has a tendency to reach the saturation level. It was observed at the beginning of the study period that the share of fuel energy (electricity and diesel) in total physical energy input was 71%, where the share of muscle energy obtained from human and animal was 29%. At the end of the study period, the share of that fuel energy (electricity and diesel) consumption reached 89%. However, there was an increasing consumption of electricity and diesel oil, which significantly contributed to improving the input energy level and consequently an increase in output. It is seen from Table-3 that the fertilizer energy input increased rapidly in comparison with physical energy input. The fertilizer energy input rose from 6.33 GJ/hectare to 11.29 GJ/hectare during the studied period. In addition, energy input from pesticide and water increased uniformly over the studied period and seed energy is nearly constant during this time. Table 3, shows that the fertilizer energy input was increased 1.21-fold during1990-1995, 1.24-fold during1995-2000 and 1.18-fold during 2000-2005. On the other hand, output energy practically did not change during1990-1995, and were slight increasing 1.12-fold during 1995-2000 and 1.03-fold during 2000-2005.



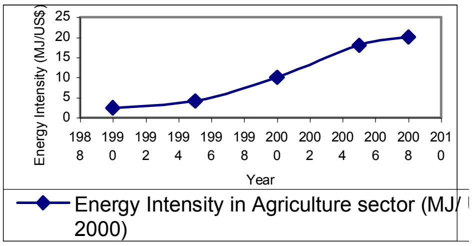


Fig.1(a). Projected energy intensity scenario in integrated agriculture sector of Bangladesh with commercial energy (petroleum, electricity, gas and coal) used.

Fig. 1(b). Energy intensity scenario in agriculture sub-Sector (crops and horticulture) of Bangladesh with commercial energy (petroleum, electricity, gas and coal) used.

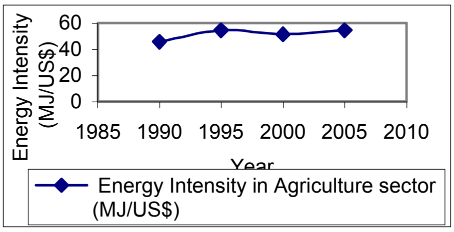
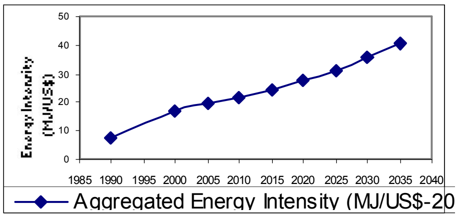


Fig. 1(c). Energy intensity scenario in agriculture sub-Sector (crops and horticulture) of Bangladesh with all kind of energy (muscle power, machinery energy, fertilizer energy, petroleum, electricity, gas and coal) used.



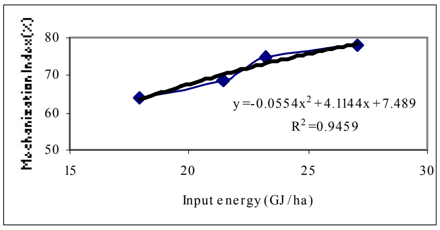
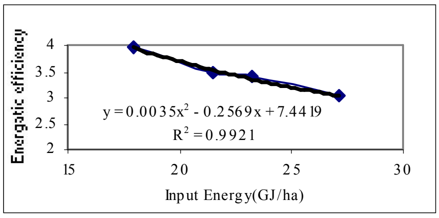


Fig. 2. Aggregated energy intensity of Bangladesh

Fig. 3. Relation between total energy input (GJ/hectare) and mechanization index (%).



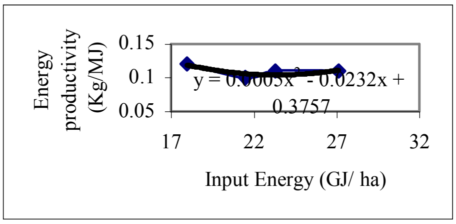


Fig. 4. Relation between total energy input (GJ/hectare) and energetic efficiency.

Fig. 5. Relation between total energy input (GJ/hectare) and energy productivity (Kg/MJ).

Table 4. Energetic parameter and index in Bangladesh Agriculture.

	1990	1995	2000	2005
1.GDP from agriculture (million US$-2000)	4850	4702	5737	6388
2.Energy intensity (MJ/US$-2000)	45.67	54.47	51.53	54.47
3. Energetic efficiency (only commercial energy input)	3.96	3.49	3.39	3.03
4. Energetic efficiency (Commercial energy and solar energy input) (%)	0.109	0.114	0.121	0.126
5. Energy productivity (Kg/MJ)	0.12	0.10	0.11	0.11
6. Mechanization index (%)	63.9	68.5	75	78

The result shows that during 1995-2000, fertilizer-input energy increased to the highest level and the output energy also increased accordingly in the same period. At the end of the studied period, it is observed that the incremental fertilizer energy input is rather insensitive in producing increased energy output, and the energy input for irrigation increased linearly. In the studied period the energetic efficiency (only commercial energy) was 3.96 in 1990 and it was 3.03 in 2005. Singh *et al*. 2007, calculated energy output/ input ratio for wheat as 2.9, 4.0, 4.2 and 5.2 at different locations in India. Alam *et al.* (2005) calculated the energetic efficiency for wheat and rice was 8.10 in 2000 in Bangladesh.

The energetic efficiency declined with increasing energy input/hectare (Fig. 4). This indicates that input energy increased faster compared to output energy. The energetic efficiency (both commercial and solar energy) increased with increasing energy input/hector. So there is enough scope still open to achieve greater solar conversion efficiency through photosynthesis. At present, the conversion efficiency achieved is 0.126% in Bangladesh agriculture, where the achievable conversion efficiency is evaluated as 1% (Alam *et al.*, 1993). The relation between total energy input (GJ/hector) and energy productivity (Kg/MJ) was shown in Fig. 5. In 1990 the production of food was 2.20 tone/hectare and in 2005 it rose to 2.98 tone/hectare that is 35% increase in the studied period. On the other hand the input energy was 17.94 GJ/hectare in 1990 and rose to 27.10 GJ/hectare in 2005, that is, the input energy increased 51% in 2005 with respect to 1990. In 1990 the energy productivity was 0.12 and declined to 0.11 in 2005. This means that 0.11grain output was obtained per unit energy. The energy productivity declined with increasing energy input/hectare and it can be concluded that our agriculture sector is going to its saturation level. Calculation of energy productivity rate is well documented in the literatures such as stake-tomato (1.0) (Esengun *et al.*, 2007), sugar beet (1.53) (Erdal *et al.*, 2007).

The following conclusions can be drawn from this study: Firstly, it has been realized that the energy intensity (considering total agriculture and commercial energy only) increased by 6.35-fold from 1990 to 2008. The projected energy intensity is shown to be non-linear up to 2035. The increasing trend of energy intensity in agriculture sector of Bangladesh does not support sustainable development. Secondly, it has been realized that the energy intensity (considering crops and horticulture sub-sector and commercial energy only) increased by 8-fold from 1990 to 2008. The pattern of energy intensity indicates that the growth of energy demand in this sector will enhance the productivity of crops and other agriculture products. Thirdly, it has been realized that the energy intensity (considering crops and horticulture sub-sector with commercial and non-commercial energy) increased by 1.19-fold from 1990 to 2005. The calculated energy intensity shows that sustainability in respect of economic growth of agriculture (production of crops) is attainable.

In the first case, the energetic efficiency, where only the commercial energy is included, decreased from 3.97 to 3.03 in the studied period. This declining tendency with increasing energy input indicates that input energy increases faster compared to energy output. In the second case, the energetic efficiency, where both commercial and solar energy is included, increased from 0.109% to 0.126% in the study period of 1990 to 2005. This shows that there is enough scope still open to achieve greater solar conversion efficiency through photosynthesis.

The contribution of mechanical (tractor, power tiller) energy was 16% of the total physical energy in 1990 and it rose to 30% in 2005. In 1990 the mechanization index was 64% and rose to 78% in 2005 showing a 22% increment compared to 1990. The production of food increased 35% in the studied period. On the other hand the input energy increased by 51% in 2005 with respect to 1990. In 1990 the energy productivity was 0.12, which declined to 0.11 in 2005. The energy productivity declined with increasing energy input/hectare. It can be concluded that our agriculture sector is approaching to its saturation level in the present trend, unless there is new innovation in agriculture.

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