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The Tightening Conflict:
Population, Energy Use, and the Ecology of Agriculture

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For the time being, the United States and much of the industrial world have achieved very high agricultural production and low food costs on the basis of extremely intensive use offossil energy. Some industrializing countries, such as China, are forced by demographic pressure to follow suit. It is a trap. Such agriculture devours its own base, and the fossil fuel era is drawing to a close, with petroleum likely to be the first to go. The United States, with oil resources amounting to about 15 years' consumption and already dependent on importsfor half its oil, is not very well placed for the transition. China is worse off. The situation calls for a renewed respectfor the natural systems that support agriculture and for population policies that bring demand into line with the ability of the Earth to produce food on a sustainable basis. Mario Giampietro is a senior researcher at the Istituto Nationale della Nutrizione, Rome, and presently a visiting scholar at Cornell University, where David Pimentel is a professor in the College of Agriculture and Life Sciences.

- Lindsey Grant, Editor

In the last half century the technological development of agriculture has dramatically changed the performance of farming. The changes have been both positive and negative: on the positive side a more stable and abundant food supply has resulted; on the negative side more environmental degradation, more dependence on fossil energy, and a lower energy efficiency. Understanding the reason for these changes requires exploring the relationship between technological development, population, natural resources and environmental sustainability for development. For this reason, in this paper we will discuss the use of energy in agriculture and its relation to the performance of the economy (in part I), and the issues of future development, standards of living and a sustainable envirortment related to population pressure (in part II).

Energy, Agriculture and Development

The dual nature of agriculture. Agriculture must be compatible with both society's needs and the natural ecosystem. Rapid population growth and the technical development of society have led to difficulties for farmers worldwide to maintain this dual compatibility. In fact, today farmers face demands for a high productivity as well as environmentally sound, sustainable farming practices.

In rural, developing societies, local environmental constraints historically shaped techniques of production and socioeconomic structures. Agricultural strategies and social activities favored long-term ecosystem sustainability. However, the quality of life reached by traditional farming systems is low compared with that of modern western agricultural systems - short life span, low level of education, and absence of social services, etc. In other words, "subsistence farming systems" are *economically not sustainable* when these societies interact with more developed socioeconomic systems.

The dramatic transformations that have occurred in the economy of developed countries have radically changed their farming strategies. Farmers operating in developed countries abandoned traditional techniques of production to keep their income competitive with that in other sectors of society. This required the adoption of techniques that provide high returns per hour of labor. Therefore, large monocultures which rely heavily on technical inputs resulted. For example, in the United States, the amount of corn produced per hour of labor is today 350 times higher than the Cherokees could raise with their traditional agriculture.

This enormous jump in farmer productivity would not have been possible without large injections of fossil energy and machine power. In fact, the flow of energy input in modern U.S. agriculture is 50 times higher than in traditional agricultural.[1] However, the higher income of modern farmers has a price: high-technology agricultural techniques depend on non-renewable stocks of oil and have negative environmental impacts which lower the sustainability of the agroecosystem. These impacts include soil erosion, reduced biodiversity, chemical contamination of the environment by fertilizers and pesticides, and mining of groundwater. Hence, current intensive agriculture based on heavy technological subsidies of fossil energy is *ecologically not sustainable.*

Energy and Society. Humans transform energy inputs found in their environment into a flow of useful energy used to sustain their social and economic needs. This conversion can be obtained in two ways. First, by transforming food energy into muscular power within the human body; this is called *endosomatic or metabolic energy.* Second, by transforming energy outside the human body, such as burning gasoline in a tractor; this is called *exosomatic energy.* In order to have either endosomatic or exosomatic energy conversions, society must have access to adequate energy inputs.

The two major sources of energy used by humans are solar energy and fossil energy resources. Solar driven or renewable energy sources represent almost 100 percent of the endosomatic and exosomatic energy flows in preindustrial societies; they sustained human development for more than 99 percent of human existence. Fossil or non-renewable energy represents more than 90 percent of the exosomatic energy used in the United States and other developed countries; however, this growing reliance of modern societies on fossil energy started only 150 years ago, or much less than 1 percent of human existence.

Solar and fossil energy sources have different characters. The solar energy captured by photosynthesis is renewable or unlimited in its time dimension, but its exploitation is limited in its rate of flow. This means that if we want to double the quantity of biomass harvested (such as crops for food or cornstalks, fast growing trees, etc. for energy), at a fixed technological level, we need to double the land exploited. To double animal power we need more animals and double the land devoted to fodder. On the other hand, fossil energy is a stock-type resource, that is limited in its time dimension - sooner or later it will be exhausted - but, while the stock lasts, it can be exploited at a virtually unlimited rate.

The access to fossil energy removed the limitation on the density at which exosomatic energy can be utilized, and societies experienced a dramatic increase in the rate of energy consumption. The exo/endo energy ratio has jumped from about 4 to 1, a value typical of solar powered societies, to more than 40 to I in developed countries (in the U.S. it is more than 90 to 1). Clearly, this brought about a dramatic change in the role of the endosomatic energy flow. Endosomatic energy, that is food and human labor, no longer delivers power for direct economic processes. Humans generate the flow of information needed to direct huge flows of exosomatic power produced by machines and powered primarily by fossil energy. To provide an example of the advantage achieved: a small gasoline engine will convert 20% of the energy input of one gallon of fuel into power. That is, the 38,000 kcal in one gallon of gasoline can be transformed into 8.8 KWh, which is about 3 weeks of human work equivalent. (Human work output in agriculture = 0.1 HP, or 0.074 KW, times 120 hours.)

Fossil energy and the food system. More than 10 kcalories (kilogram-calories or "large calories") of exosomatic energy are spent in the U.S. food system per kcalorie of food eaten by the consumer. Put another way, the food system consumes ten times more energy than it provides to society in food energy. However, since in the U.S. the exo/endo energy ratio is 90/1, each endosomatic kcalorie (each kcalorie of food metabolized to sustain human activity) induces the circulation of 90 kcalorie of exosomatic energy, basically fossil. This explains why the energy cost of food of 10 exosomatic kcalories per endosomatic kcalorie is not perceived as high when measured in economic terms. Actually, despite a net increase in the energy and monetary cost per kcalorie of food in the U.S. over the last decades, the percentage of disposable income spent by U.S. citizens on food has steadily decreased and is now only about 15 percent of disposable income.[2]

Based on a 10/1 ratio, the total direct cost of the daily diet in the U.S. is approximately 35,000 kcalories of exosomatic energy per capita (assuming 3,500 kcal/capita of food available per day for consumption).[3] However, since the average return of one hour of labor in the U.S. is about 100,000 kcalories of exosomatic energy,[4] the flow of exosomatic energy required to supply the daily diet is made accessible by about 20 minutes of labor.

In subsistence societies, about 4 kcalories of exosomatic energy (basically in the form of biomass) are required per kcalorie of food consumed. Thus, the total direct cost of the daily diet is much lower in absolute terms, approximately 10,000 kcalories of exosomatic energy per capita (assuming a food supply of 2,500 kcal/day per capita).[5] On the other hand, because of the limited access to fossil energy, the average return of human labor in subsistence societies is low. In such a system up to 5 hours of labor are required to supply the daily diet. In terms of human labor, in subsistence societies the daily diet costs 16 times more than in the U.S. food system.

In countries with a high exo/endo energy ratio, food production no longer provides a direct energy or power supply to society. Food production, however, is still essential to the economy of all nations. Because of the high opportunity cost of human time, there is a strong incentive to lower the human time allocated to the management of the food system. Therefore, technological development in food systems of developed societies is principally aimed at (i) reducing the requirement of labor in food production, (ii) increasing the safety of food, and (iii) reducing the time required for food preparation. Although this strategy of technological development causes an increase in the direct costs of food security, both in production and processing of food, it allows humans to switch a large fraction of their time to other, more productive economic sectors.

For example, in West Europe the percentage of the active population employed in agriculture fell from 75 percent before the industrial revolution (around the year 1750) to less than 10 percent today; in the U.S. this figure fell from 80 percent around the year 1800 to only 2 percent today.[6] The percentage of the total U.S. female population active in the money economy rose from 9.7 percent in the year 1870 to 44.7 percent today.[7] Thanks to energetically expensive, but time-saving food products women no longer have to spend long hours in food-related activities, but can participate in paid economic activities.

Fossil energy and agriculture in developed and developing countries. Modern techniques for farming in developed countries are based on massive infection of fossil energy. This results in lowering the energy efficiency (output-input ratios), and a rapid depletion of non-renewable oil stocks. The two forcers driving this development are (i) the increasing productivity per hour of labor of farmers (=increasing the income and standard of living of farmers, and making available more labor for other ecomomic sectors), and (ii) the increasing productivity per unit of land area (=increasing the total food supply).

Although there are numerous negative effects in terms of environmental sustainability and energy efficiency with modern farming techniques, farmers in developing countries are adopting some of them, especially high yielding varieties, fertilizers, irrigation and pesticides. This adoption, along with more cash crop production, has resulted in some disruption of structures and functions of traditional socio-economic systems. Fossil energy is used to overcome the ecological constraints limiting food output. This has contributed to the widespread relaxation of cultural control on human fertility. Between the end of World War II and 1970, fertility rates rose virtually everywhere in the third world.[9] The rapid growth in the world population is associated with the maximum expansion of fossil energy use.

The increase in birth rates plus the reduction in mortality rates by control of disease resulted in an explosive growth in world population. This resulted in a dramatic shrinkage in the quantity of natural resources available per capita. Under this demographic pressure, developing countries were forced to increase their use of fossil energy in agriculture.

In developing countries, the use of fossil energy has been to prevent starvation rather than to increase the standard of living of farmers and others. Concluding his analysis of the link between population growth and the supply of nitrogen fertilizer Smil[10] makes this point beautifully: "The image is counterintuitive but true: survival of the peasants in the ricefields of Hunan or Guangdong - with their timeless clod-breaking hoes, docile buffaloes, and rice-cutting sickles - is now much more dependent on fossil fuels and modern chemical synthesis than the physical well-being of the American city dwellers sustained by Iowa and Nebraska farmers cultivating sprawling grainfields with giant tractors. These farmers inject ammonia into soil to maximize operating profits and to grow enough feed for extraordinarily meaty diets; but half of all peasants in Southern China are alive because of the urea cast or ladled onto tiny fields - and very few of their children could be bom and survive without spreading more of it in the years and decades ahead."

Strategies of energy use in world agriculture. Different strategies in energy use in agriculture can be found in the U.S.A., Western Europe, Africa and China. Data are presented in Table 1. These differences can be explained in terms of availability of natural resources, population density and standard of living (Table II).

For example, farming systems in Western Europe use heavy energy subsidies in order to keep labor productivity high and also to make maximum use of the limited land. In the U.S., fossil energy is mainly used to boost farmers' productivity (income), and productivity per hectare is not as much a concern as in Europe.

In China, large quantities of fossil energy are used to boost the productivity of the land, because there is little land arable per capita. Agriculture provides the major source of employment in China (67 percent of the economically active population). Therefore, the standard of living of that society is low.

In Africa, little fossil energy is used in agriculture. Thus, the productivity both per farmer and per hectare is low. If the situation remains unchanged, shortage of food will continue to grow as the population increases.

This comparison shows that energy can be used in agriculture to boost the productivity of labor and/or land.

For example, the food energy yield per hour of labor in **Western Europe** is more than 20 times higher than in China, but less than a fifth of that in the U.S. Even though Western European agriculture uses almost twice as much energy as U.S. agriculture per kilogram of cereal produced, the productivity of cereal per hour of European farm labor is lower than in the U.S. For this reason, European farmers require more government subsidies than U.S. farmers to have comparable incomes. The lower agricultural performance in Europe despite higher energy use is due to the limited availability of land (the land area available per farmer in Europe is about 1/7th of that available in the USA).

The effect of demographic pressure can also be seen by comparing the performances of Chinese and U.S. agriculture. **China** has a fossil energy consumption per hectare higher than the U.S. However, this high fossil energy use has the goal of boosting the yield per hectare (increase the food supply) and does not generate an increase in farmers' income (as indicated by the low pro- ductivity per hour of labor). To get approximately the same yield, U.S. farmers work only 10 hours/year per hectare in grain production compared with more than 1,000 hours/hectare for Chinese agriculture.[12] The U.S. economy manages in this way to sustain its farmers at an income level that is almost comparable to that of workers in other U.S. economic sectors, but that is almost a hundred times higher than the income of Chinese farmers.

In this example, again, we can assess the importance of the land constraints: the average area cropped per farm worker in the U.S. is about 64 hectares (ha), compared with only 0.2 ha/worker in China. Where the population density is high, as in China, fossil energy-based inputs are required in large quantities not so much to increase the standard of living, but to increase food yield per hectare. The U.S. enjoyed in the past a fairly low demographic pressure and this resulted in the possibility of using fossil energy mainly to increase the productivity of labor (guaranteeing an acceptable income for farmers). At low population density, fossil energy can be used to guarantee a high income to farmers, and to make workers available for the rest of the economy.

Put another way, if China tried to modemize its society reaching levels of exo/endo energy typical of western standards, it would have to (i) absorb an enormous number of farmers in other economic sectors (hundreds of millions !!), and (ii) further boost the energy consumption in the agricultural sector, since due to the limitation of land (0.09 ha per capita of arable land) Chinese agriculture would face a situation even worse than in Western Europe. A "modernized" Chinese agriculture would be required to provide food for the population, while absorbing only a little fraction of human time, and providing a high income to farmers.

Moreover, it should be noted that when farmers comprise only a small fraction of the population, and society undergoes a massive process of urbanization, the real energy cost of supplying food is shifted from agriculture to the post-harvest section of the food system. In general, 3 to 5 kcal are spent in processing, distribution, packaging and home preparation for each kcal spent in producing food at the farm level.

Such a development would imply not only a formidable flow of energy required to build and run the technological plant required to absorb at least 80 percent of the current Chinese farmers into the industrial/services sector, but also a further increase of energy use in the agricultural sector (well above the western European levels). They might theoretically be able to get such an energy input for a while, by using their coal resources, but they would probably choke themselves on the pollution and induce an environmental impact of enormous dimensions. Furthermore, in case of continued demographic growth, it is also doubtful that it would be possible to further boost the productivity of land (output per ha) to accommodate the increased population. It is well known that, after a certain threshold, energy subsidies (fertilizers, pesticides, irrigation, etc.) have a declining return. "Available long-term comparisons show that in China's Zhejiang and Shandong provinces the typical rice response to additional units of nitrogen application during the 1980s was only 50-60 percent of that of the 1960s, in the Suzhou area of Jiangsu province it was only around one-third, and around Wuxi (also in Jiangsu) there have been no returns at all".[13]

The excessive demographic pressure in China seems to mean that food security, a high standard of living, and respect for the environment are goals almost impossible to achieve at the same time.

Finally, a look at the current performance of **Africa's** agriculture is another source of serious concern. From the low level of fossil energy consumption, it can be inferred that many farmers are still using traditional techniques of production (fallow rotation, a use of land which requires a low population density). Because of the demographic explosion experienced in the last decades, the African situation will get even worse: (i) declining food supplies, because there is too little land per capita and little fossil energy and technology for food production; (ii) increasing poverty, because the limited natural resource, fossil energy and technology available are mostly diverted to their own uses by the few elites; (iii) increasing environmental degradation, because traditional methods of agriculture performed at too high population density shorten crop rotations and further stress the environment.

Actually, all three of these effects are already taking place, and current demographic trends do not leave much hope for positive changes in the near future. Africa has the highest rate of population growth in the world at 3 percent per year, a doubling time of 23 years! In the future the trends appear to be increasing dependence on fossil energy for agricultural production, increasing poverty, increasing deficits in food supply, and increasing ecological destruction.

From the above, it is clear that ecological and human perspectives collide when it comes to technological performance in agriculture. For example, an increase in the output/input ratio can be seen as a positive event on the ecological side. However, this is not always beneficial at the societal level, as illustrated by African agriculture, which has the highest energy output/input ratio but the lowest exo/endo energy ratio and life span. For developed societies, the output/input energy ratios in agriculture are lower than those in Africa, but this allows the labor force to move to other economic sectors. When a society has an exo/endo ratio so low that it is convenient to use labor intensive techniques to save capital and fossil energy, the standard of living is much lower than those considered acceptable in the western world.

The Future: Energy, Population and Sustainability

Limits to the Intensification of Agriculture. The prime resources of agriculture - land, water, energy, and biological resources - function interdependently, and each can be utilized to a degree to make up for a partial shortage in one or more of the others. For example, to bring desert land into agricultural production, it can be irrigated.

However, this can occur only if groundwater or surface water is available, if sufficient fossil energy is available to pump and move the water, if monetary resources are available to buy the required technology, and if the soil is suitable for irrigation and fertile to support crop growth.

Moreover, intensive farming techniques have an impact on the pattern of energy flows in ecosystems. In general, they reduce the capability of an ecosystem to use solar energy for evapotranspiration, gross primary production, and recycling nutrients. This "ecological cost" of agriculture has been overlooked by most economic analyses.

The long-term productivity of agroecosystems depends on the sustainability of natural resources including biological, soil, and water resources. Therefore, an environmentally sound agriculture has limits in its use of these renewable resources. For example, an upper limit exists to the productivity of an agroecosystem.[14] Currently, with most intensive agriculture there is serious land degradation, loss of top soil, chemical pollution, and groundwater mining.

Fossil energy inputs and sustainability. About 330 quads (1 quad = 10^{15} BTU) of all forms of energy per year are used worldwide by humans. A large fraction of this energy, about 81 percent, is provided by fossil energy worldwide each year.[15] Moreover, about 50 percent of all solar energy captured by photosynthesis worldwide is already used by humans, but most of it is captured as food and other agricultural products, which are not included in the 330 quads. That agricultural output is already inadequate to meet human needs for food and forest products.[16] We would be in grim trouble if we had to derive our energy needs from current basic photosynthetic production, as our ancestors did. Given the anticipated decline in fossil fuel use, and the continued growth of human populations, that problem is ahead of us rather than behind us.

The total consumption in the U.S. is 77 quads of energy. This is almost three times the 28 quads of solar energy harvested as crop and forest products, and about 40 percent more energy than the total amount of solar energy captured each year by all U.S. plant biomass.[17] Per capita use of fossil energy in North America (expressed as conventional fossil fuel equivalent) is about 7,000 liters of oil per year or 5 times the world average level!

As noted earlier, large quantities of fossil energy based fertilizers are major sources of nutrient enhancement of agricultural soils throughout the world. Pesticides are also fossil based and their production and use imply a significant consumption of fossil energy.[18] Annual world pesticide use has been estimated at 2.5 million metric tons, of which ' 0.6 million metric tons are used in North America.[19]

Projections of the availability of fossil energy resources are discouraging. A recent report published by the U.S. Department of Energy based on current oildrilling data indicates that the estimated amount of U.S. oil reserves has plummeted. This means that instead of the 35-year supply of U.S. oil resources, that was projected about ten years ago, the current known reserves and potential discoverable oil resources are now limited to less than 15 years' consumption at present levels.[20] Since the United States is now importing more than half its oil, a serious problem already exists.[21] It should be noted that an increased demand of the U.S. economy for oil on the international market could lead to higher prices. This would dramatically affect U.S. agriculture as well as the agriculture of many developing countries already heavily dependent on fossil energy based inputs (mainly fertilizers).

Clearly, there is a room for substitutability among fossil energy sources, and natural gas and coal are expected to increase their share as soon as oil supply will decrease. However, gas supplies are not at all that much better off. Coal is not infinite and it exacts a high environmental cost or a high price to
clean it up.

Increased standard of living and population pressure. The large increases in fertilizers and pesticides used in developed countries are due to the abandonment of traditional agricultural technologies. For some major crops like corn, crop rotations have been abandoned. Now nearly 50 percent of U.S. corn land is grown continuously as a monoculture. This has caused an increase in the number of corn pests and the need for more pesticides to protect the crop. Since 1945 the use of synthetic pesticides in the U.S. has grown 33-fold, yet crop losses to pests continue to increase.[22]

In developing countries, it is population pressure and poverty that push the abandonment of sound techniques of agricultural production, such as fallows and crop rotations. Population growth means shrinking environmental resources per capita (land, soil, water and biological resources), a need for increasing yields per hectare and sooner or later a dependence on fossil energy. When the development of a country at a low exo/endo ratio is prevented by its demographic trap, negative ecological side effects are generated by the increased use of energy in agriculture. Environmental degradation tends to drive down the income of farmers and the available food supply per capita.

Overall, demographic pressure and the search for a high standard of living are forcing increased use of fossil energy while oil and gas stocks are rapidly disappearing.

The population-resource equation and the law of decreasing returns. The population-resource equation can be written as follows:

Natural resources use x Technology = Population x per capita Consumption.

However, the ability of technology to make up for the shortage of natural resources is limited. It is not possible to achieve an unlimited increase in both the population and the per capita consumption by simply adding more technology to the limited endowment of natural resources. The efficiency of a technological process can never be higher than 1, meaning that technological capital should be considered a complement to natural capital rather than a substitute.[23] Technology cannot make accessible more natural resources, such as land and water, than are available; it can only improve the limited efficiency of resource use.

A decreasing return per unit of effort takes place when an intensification of exploitation of natural resources occurs.[24] Moreover, after a certain threshold there is no substitution of technology for natural services. For example, the world fish catch is already close to 100 million tons, and that is thought to be the maximum possible catch from the sea.[25] Improving fishing vessel technologies, as has been done, reduces the fishery stock and leads to decreasing fishery yields. "Maintaining even 80 million tons sustainability will depend upon careful fisheries management, protection and restoration of coastal wetlands, and abatement of ocean pollution-none of which seems in prospect at the moment".[26] Aquaculture is supplying today about 12 million tons but the expansion of this supply is limited by environmental risks and operation costs. A further large increase in human population numbers simply lowers the availability of fish per capita.

Future changes and the potential transition toward sustainability. Currently worldwide there is serious degradation of land, water, and biological resources generated by the increasing use of fossil energy by the world's population.[27] Already, more fossil energy is used than is available in the form of a sustainable supply of biomass, more nitrogen fertilizer is used per year than could be obtained by natural supply, water is pumped out of underground reservoirs at a higher rate than it is recharged, and more minerals are taken out of mines than are formed by biogeochemical cycles. Fossil energy and technology enabled humans to (temporarily) sustain excesses. At present and projected world population levels, the current pattern of human development is not ecologically sustainable. The world economic system is built on depleting, as fast as possible, the very natural resources on which human survival depends.

Clearly, this is a flaw in human logic. Humans must learn how to manage natural resources in a sustainable manner and determine the number of humans compatible with an acceptable standard of living.

A sustainable use of renewable resources is possible only if (i) known environmentally sound agricultural technologies are implemented, (ii) various known renewable energy technologies are put in place, (iii) major increases in energy efficiency are achieved to reduce the exosomatic energy consumption per capita, and (iv) population size and the consequent level of withdrawal of natural resources are compatible with maintaining the stability of environmental processes.

Assuming (optimistically) that the first three points will be achieved in the U.S. in the next decades (with a reduction to less than half of the exosomatic energy consumption per capita), still the "sustainable U.S. economy" mentioned would be possible only with a smaller population than the current 256 million (e.g., about 200 million.)[28] In general, the lower the population density the higher the ratio of natural resources of land, water, clean air, biota, and solar energy per capita, and the lower the cost humans have to pay for these vital services. Agriculture would have more natural nutrients, water, and biological resources. Chemical pollutants would be reduced. With more abundant natural resources per capita, the standard of living for everyone would be improved.

Unfortunately, the actual trend of demographic growth both in the U.S. and world is not toward sustainability (= a population size within the ecosystem's carrying capacity) or optimum population size (= a population size lower than the maximum possible, thus permitting a higher standard of living). U.S. population is projected to rise to 400 million in just 60 years and world population is projected to double to over 10 billion.

Approximately 1/3rd of the world's arable land and forests were lost during the past 40 years due to mismanagement and degradation. Currently, there is only 0.28 ha of arable land per capita with a world population of 5.5 billion people. It is estimated that about 0.5 ha per capita is needed for a diverse and varied diet. With the world population to double to 11 billion people, there will be less than 0. 15 ha per capita in just 40 years (very close to a "Chinese situation"). At the same time, evidence suggests that arable land degradation is increasing as poor farmers burn more crop residues and dung as fuel for cooking and other purposes, instead of returning them to the land.

The threat to food and environmental security created by population growth is clear today. (i) Most of the 183 countries in the world are now dependent in some degree on food imports. Cereal exports that supply most of those imports now come from the surpluses produced in a few countries with relatively low population densities and intensive agriculture (in 1989 the United States, Canada, Australia, Oceania and Argentina provided more than 81 percent of net cereal exports on world markets.[29]) (ii) Some developing countries, like China, already use more fertilizer per hectare than the U.S. This intensive use of fossil based fertilizers is just to help meet food needs in these developing countries. What will a future slowdown of fossil energy consumption (either because of a decline of oil supply or because of growing restrictions on fossil fuel use to limit its environmental impact) mean to both developed and developing countries?

Conclusion

To use a Dutch expression:

> ***"A development policy without a population program is like mopping the floor with the water turned on."***

(-P. Bukman).

At this stage of human development, any serious policy concerned with energy saving, environmental sustainability, increasing jobs, and improving the standard of living has to be based on reducing population pressure. This applies to both developed countries (as the U.S.) and developing countries. The U.S. has a privileged situation in that it can afford to escape the demographic trap in which many developing countries are already struggling. However, it must set the goal of an adequate quantity of arable, pasture and forest land available per capita. This will provide the margin to make agriculture enviromnentally sound. It will offer the option of using some biomass production for energy, and it will reduce the pressure on land, water, air, energy, and biological resources. Such a program is vital if we want to maintain a decent standard of living for future generations.

The level of energy consumption that will be enjoyed by a future "sustainable society" will lie below the one reached today by developed countries (based on the rentless exploitation of fossil fuels) and above the one typical of pre-industrial societies which rely completely on photosynthesis. Renewable energies have to play a major role to substitute for the role currently played by fossil energy. The lower the population density, the lower will be the demand of energy for food production, the lower the environmental impact of agriculture, the larger the choice of possible alternative energy sources and in the last analysis, the higher the probability of achieving an acceptable standard of living and eco-compatibility.

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