VULNERABILITY IN AGRICULTURE: ENERGY USE, STRUCTURE AND ENERGY FUTURES

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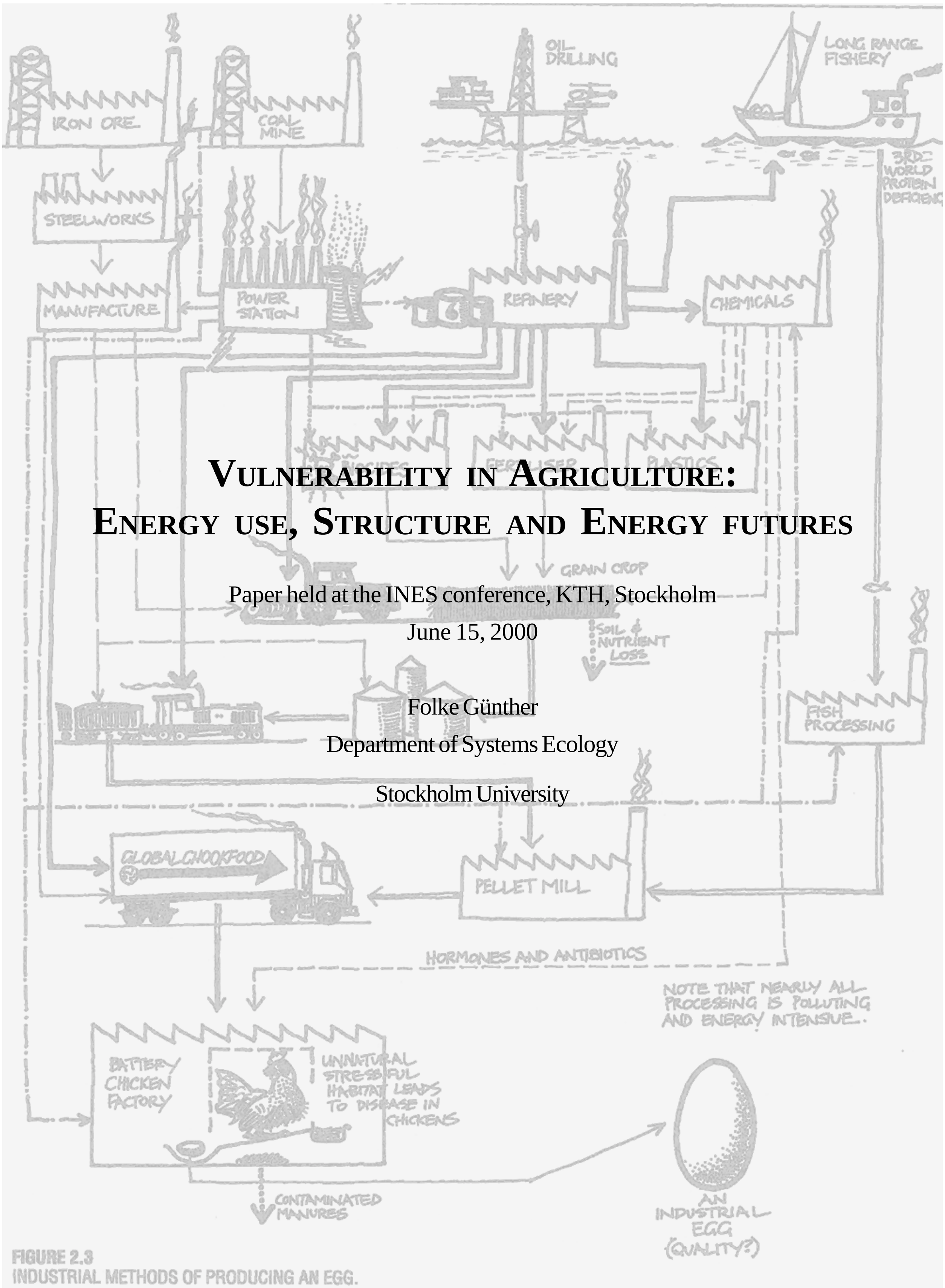


FIGURE 2.3
INDUSTRIAL METHODS OF PRODUCING AN EGG.

ABSTRACT

To fulfil the basic goal of delivering food for the tables of the citizens, modern Western agriculture is extremely dependent on supporting material flows, infrastructure, and fossil energy. According to several observers, fossil fuel production is about to peak, i.e., oil extraction is no longer capable of keeping pace with the increasing demand. This situation may trigger an unprecedented increase in fossil energy prices, which makes the entire food production-distribution system highly vulnerable. The paper starts with a survey of these dependencies. An analysis, based on Swedish official statistics and energy future discussions on Internet, indicates that its sustainability is highly questionable.

To alleviate vulnerability, a type of production-consumption system that diminishes external dependencies is discussed. The system is a type of combined settlement-agriculture structured after the same principles as those occurring in natural, self-organising ecosystems.

In the proposed societal structure, agriculture is integrated with settlements and most of the food needed by the population is produced locally and the nutrients for food production is recycled from households and animals by means of biological processes demanding considerably less mechanical investment and fossil support energy than the conventional type of agriculture.

The energy requirements for the agriculture and food delivery systems in this structure can be calculated to be significantly lower than the current types. The vulnerability of this structure is therefore considerably lower.

Key words: agriculture, fossil energy, infrastructure, social structure, and structural vulnerability

The front-page picture is taken from Mollison, B., 1988. Permaculture, A Designers Manual Tagari publ. Tyalgum, Australia

Introduction

The contemporary Swedish agriculture is one of the most technically advanced and successful in the world. The development of the agricultural practice has led to a situation where a very small part of the population (1992, 0.68%, (SCB, 1994)) is occupied in the agricultural production.

However, this situation is achieved only with a large amount of external support, (Giampietro, 1992). The agriculture has changed from a local activity to a throughput business (Goodland & al, 1992) that is dependent of support from societal functions, energy sources and minerals derived from a large part of the world.

To survive and maintain a food production for the population, the prevalent western European agriculture needs a continuous support of the following types:

1. Faultless and cheap fuel production that will continue in the future.
2. Availability of phosphorus ores that could be extracted to produce fertilisers.
3. A distribution system for fertilisers, animal feed, fuels and agricultural products that function indifferent of disturbances in the society outside the agricultural system.
4. A support infrastructure that can provide renewal and repair of machinery independently of the general industrial climate and future energy prices.

The agricultural system is heavily dependent on services that often are taken for granted, e.g., constantly low energy prices. Therefore, when discussing a sustainable agricultural system, it is important to include the necessary support systems for the entire chain.

The ultimate objective of agriculture must be the provision of food for the human population. However, some of the above mentioned supports associated with the agricultural production are so vital that a failure, e.g. from uncalculated energy price increase, can turn the success of the agriculture into disaster.

This perspective depicts a gloomy picture of the sustainability of this highly productive agriculture and of the society that depends on it for its subsistence.

The aim of this paper is to discuss the capacity and reliability of the support system as it is designed today in Sweden, and, in cases where this capacity and reliability appear doubtful, to discuss how problems can be alleviated.

The dependencies

Dependency on material and industrial energy support

Pre-industrial agriculture was a highly local activity. Most machinery was made locally, and agriculture was operated mainly on different types of locally captured solar energy. Nutrients were collected by means of meadow plants and transported to the fields through harvesting of winter feed, or with manure from feeding animals brought home overnight. The necessary energy for these activities was exclusively derived from the sun.

The main energy input to modern agriculture is not solar energy. It is industrial energy of different types. Parallel with the need for constant input of other necessities, i.e., fertilisers, biocides, animal food, plastics for silage and drugs for treatment of animal diseases, it gives modern agriculture an operation structure similar to a throughput industry. The increased yields experienced by these methods are not due to increased ability of the crops to obtain more solar energy, but rather that some tasks former made by the crops (e.g., extracting nutrients and restraining diseases and herbivores) are done by the farmer, for what reason an increased grain yield can be achieved (Odum, 1971) (Figure 1). Thus, in order to boost rate of output, there is a need for a constant throughput of energy and materials in agriculture. By this, the agriculture

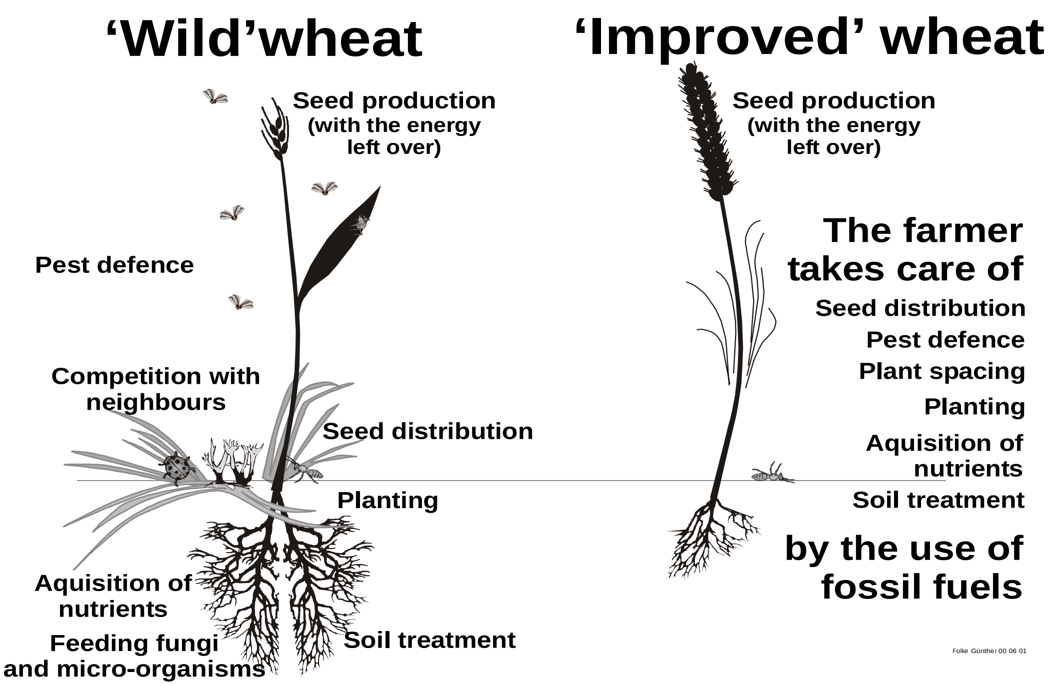


***Figure 1**. The improvement of domesticated plants and animals has often implied an increased dependency on fossil fuels*

becomes highly dependent on different types of industrial support for maintenance, energy and nutrients.

Cheap industrial energy?

In this practice, it is implicit an assumption that the price of the supporting industrial energy, and products will always be so cheap that they will not increase the price for the food produced over what can be paid by the public. This assumption can, however, be questioned.

To produce food, the agriculture of today is heavily dependent on fossil fuels. In the agriculture of developed countries, the input of fossil fuel energy equals, or surpass, the output of food energy for human consumption (Hall et al., 1986; Folke & Kautsky, 1992), for what reason the industrial agriculture can be referred to as a black box for converting fossil fuel energy into edible food energy. The ratio of energy input/output of the Swedish agriculture is about 0.96 (Hoffman, 1995), which is in close concordance with this 'black box' description.

The Swedish agriculture uses over 110 litres of fuel petroleum per hectare per year (SCB, 1994). To this adds the indirect use of fuel for production of pesticides, fertilisers, machinery etc., which easily can be 50% of what is directly used, and, on top of that, the requirements of electricity.

Energy price is hard to calculate. The price for e.g., gasoline at the tank station changes at a daily basis, as the salary for the person who buys it. Therefore, it is hard to say if the energy is 'cheap' or 'expensive'. One way to understand this is to calculate how many hours a person has to work in order to get a certain amount of energy. The result of such a calculation is demonstrated in Figure 2, where the price for gasoline in Sweden is divided with the salary of a 'general' worker in Sweden. Here, it is possible to estimate the availability of energy on the form of gasoline for the worker. The working time needed to purchase one kWh of gasoline in 1995 has diminished to about 0.1 of the time needed about 1920, i.e., the availability has increased ten times.

Peak production

Estimates of the verified amounts of crude oil (DOE, 1993) indicates that its availability is of a relatively short duration, 35 years, to around the year 2035, with the use of these resources today. Against this, it has been argued that new amounts found have always (i.e., lately) exceeded the used amounts, for what

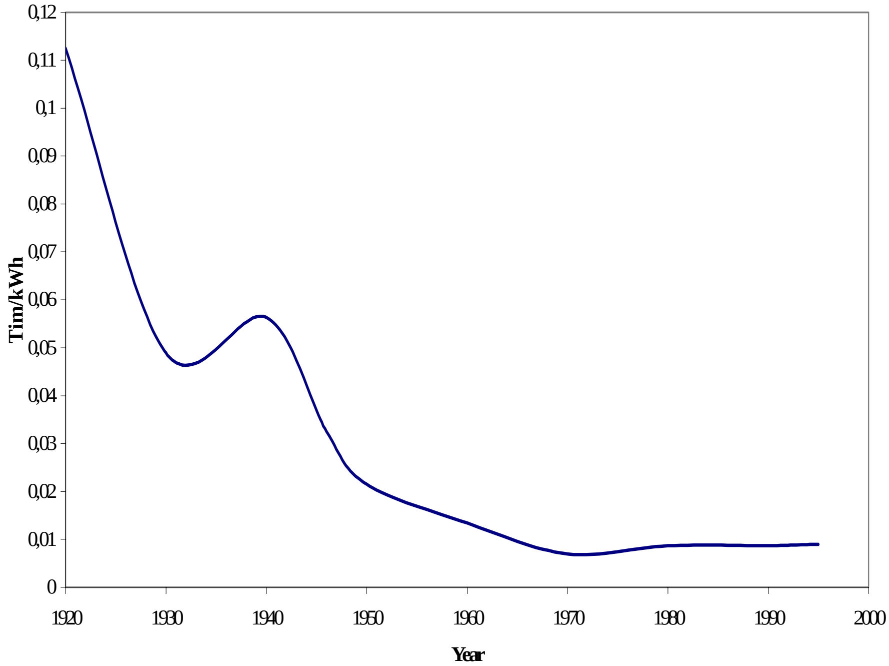


Figure 2*. The working time needed to purchase one kWh of gasoline has diminshed to about 1/10 between 1920 and 1995. Note the increase during WW II. The 'energy crisis' during the 70-ies is barely notable.*

reason the total extractable resources have not diminished. This argument is not consistent with observations.

Masters (1994) published a review of the global findings of oil this century that showed a definite peak in the discovery around 1960 and a definite decline in the discoveries thereafter, simply due to a more thorough knowledge of the subsurface globe. Ivanhoe (1995) referred to the weighted average of the global oil discoveries, a typical bell-shaped curve, as the 'Hubbert curve' (Figure 3).

The extraction of the discovered oil follows a similar curve, but with a lag of about 40 years. Since the peak of this 'extraction'-curve therefore could be expected to occur around 2000, these curves has recently attracted considerable attention, however rather among geologists and engineers than economists. The Australian engineer Brian Fleay, associate of Murdock University's Institute of Science and Technology Policy, maintained on a net site (http://www.hubbertpeak.com/fleay/crunch.htm) the 13:th of March 2000 that the 'crunch' has come, i.e., that the oil extracting countries were not more able to keep pace with the demand. He pointed out that the oil market is very sensitive. The price of crude oil tripled over one year (1999-2000 from $10 to $30 per barrel) due to a 5 % decrease of the output.

In March 27, 2000, the OPEC countries had a meeting to discuss the extraction increase demanded by the consumer countries. A week before this meeting, March 20, C.J. Campbell (2000) published an article in Oil & Gas Journal, where he boldly set up a series of predictions what would happen to the oil market the following months. These predictions are summarised in Table 1, where I have put in checks of what actually happened during the aftermath. Bloomberg Energy, a leading firm in oil market reporting, was used as a source of data and comments.

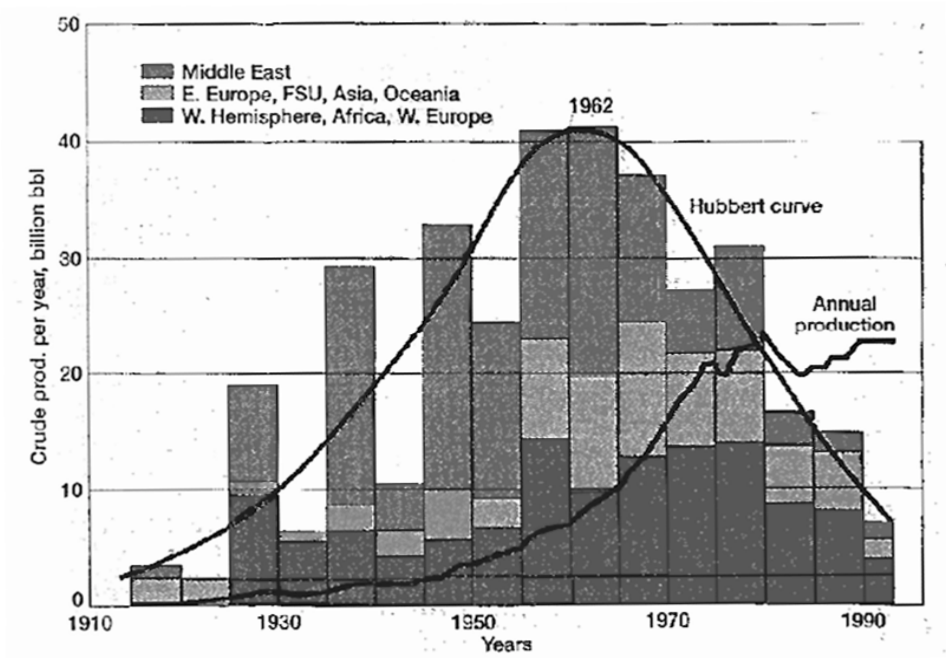


Figure 3. *The 'Hubbert curve' displays the findings of crude oil during this century. The findings follow a bell-shaped figure with a peak around 1960. After that, no major fields are found. The total amount of extracted oil (the space under the curve 'Annual production') can never exceed the space under the Hubbert curve. If the time-lag of the two curves hold, a peak production can be expected 2000 - 2005. (Adapted from Ivanhoe, 1995)*

Table 1. C.J. Campbells predictions from March 20, 2000 and the outcome so far (June 6, 2000)

Check	Date	Campbell's predictions
✔	28/3	OPEC makes some conciliatory noises about raising quotas in response to US pressure, wishing to maintain the illusion that its members can meet demand at will. Norway and Mexico continue to support OPEC within the framework of such conciliatory words, making a virtue of necessity.
✔	29/3 $ 25,3/b, (Bloomberg)	The market takes the hint and marks down the price of oil in an action that feeds on itself as the new flavour of the month permeates the ranks of speculators, hedge funds and derivative specialists searching for a quick buck. Refiners hold back from filling their tanks. Prices collapse to the low $20=s, even perhaps plummeting briefly into the ›teens. People relax in the belief that the wolf has headed back into the forest. The famous flat-earth economists again cheer that market forces reign supreme.
✔	30/5 $ 30.7/b (Bloomberg)	But then a few weeks later, people begin to notice that fewer tankers are arriving. Norway says that storms were responsible. Venezuela speaks of floods. Saddam says he needs a spare part. Mexico claims restructuring. King Fahd leads a delegation of puzzled Senators into the desert to show that all the wells are fully open. The penny finally drops that there is no instant spare capacity in the sense of shut- in wells. The men at their screens start marking up prices. A new upward momentum drives prices through the $40 barrier. When Air Force One makes a new panic tour to Norway, Mexico and the Middle East, it meets ashen faced oilmen saying that they have been working night and day to meet their quotas, but were unable to do so. The world, including OPEC, gradually appreciates that it faces a losing battle in trying to offset the depletion of the large, old, low-cost fields.

To this may be said that June 7, the crude oil prices sank to around $29/b due to a report from Iran that they would boost their output, but the day after, the pices rised to over $30/b again. (Bloomberg)

The inventories of crude oil in the US have sunk about 30% the last year, and are not expected to increase sufficiently during the summer, which otherwise is normal. (Bloomberg)

Yield per effort

The extraction of fossil fuels is an energy intensive industry. To make the energy in fossil fuels available, a certain amount of energy must be inserted as of prospecting, drilling, industrial frameworks etc. These activities are mainly powered by oil. When the quality of the fields sinks, more of the energy extracted need to be invested in the extraction process, i.e. the net energy output will diminish even if the gross energy extraction remains constant. This factor is referred to as EROI (Energy Return On Investment) or, more generally, for any extraction process, YPE (Yield Per Effort).

New resources can therefore be expected to have a lower energetic marginal return, yield per effort (YPE), than those already verified. This will change the 'perfect' bell-shape of the Hubbert curve to one with a steeper slope at the right side, i.e., the availability of the remaining resources will decline because of a decreasing YPE.

The YPE of extracting efforts in fossil fuels have decreased globally during this century. In the lower 48 states of USA, it is expected to fall below 1:1 around 2005 (Hall & al., 1986; Cleveland, 1991). At this point, the petrol cannot longer be considered an energy source, even if it could be extracted for other reasons.

The large reserves of tar sand, which has been referred to as a future oil reserve (e.g., Peter Odell, Visiting Professor at London School of Economics) has an YPE of about 1.5, i.e., two energy units are necessary for the extraction of three.

Energy price

The increasing gap between the extraction of crude oil from the 'producer' countries and the demand from the consumer countries (notably USA and Japan) may trigger an unprecedented increase in fossil fuel price due to the supply - demand effect. If the market base is set in doubt, also the investor's willingness to keep their money in the energy sector may decrease. In such a scenario, the decimal point on the gasoline pumps may move some steps to the right.

Phosphorus ore availability?

To survive, the current (western, industrial, urban-supporting) agriculture also needs a steady supply of nutrients, at least corresponding to the same amounts of nutrients that are steadily exported with the produce. It is possible to obtain nitrogen from the atmosphere by means of leguminous plants, but potassium and phosphorus has no such gaseous phases and must be available in the soil liquid. Potassium is a quite common element and scarcity is therefore rare. Phosphorus, however, is often a limiting element for plant growth, why a constant supply of it is of vital importance for any agriculture exporting produce from which the nutrients are not recycled. This is often the case in the prevailing agriculture. Consequently, to be able to export food, it has to import nutrients, of which phosphorus is vital. For this reason, phosphorus is chosen as a 'standard' nutrient in the discussions of this paper, although its behaviour is somewhat different than other nutrients.

Guano, the supply of available phosphorus that was used to substitute the deficits in the 19th century, was exhausted in about 30 years (Brundenius, 1972; Gutenberg, 1993). Today, the source of phosphorus is mainly rock P, which in most cases is extracted in other parts of the world. These resources are also limited. The estimations differ regarding the supply of phosphate ores worth working. In a literature survey

(Pierrou, 1976) estimates the available amount of phosphorus possible to extract as being in the range of 3,140 - 9,000 Tg, with an extraction rate of 12.6 Tg/year. This gives the resource a lifetime of 249 - 714 years if the assumed rate of extraction is maintained. However, later estimates indicate lower values of supply and higher rates of extraction. Smil (1990) estimates the available ore to about 20,000 Tg, containing of about 13% phosphorus, contrasted to 5% of Pierrou. From the figures of Smil the sources of pure phosphorus can be estimated to 2,600 Tg. Annual uses of phosphorus from these resources are in the report estimated to about 20 Tg P. Calculated from the figures of Smil, the available phosphorus resources may have a life-time of about 130 years at current energy prices.

There is a large uncertainty about both the amount of extractable phosphorus ores and their average content of phosphorus. What is certain, however, is that the extraction of phosphorus ore is an energy demanding process. P mining uses energy resources (18-32 MJ/kg P, depending of product (Smil, op.cit.). As in fossil fuel extraction, the energetic marginal return of phosphorus extracting efforts diminishes (Hall & al., 1986). Considering the possible availability of fossil fuels, this leads to a resource trap, where there is

Table 2. The energy price/YPE trap in the case of phosphorus mining, assuming 5% annual increase in petroleum prices

Year from now	0	25	50	75
Price for industrial energy, SEK/kWh	0,45	1,6	5,5	19
Price for the extraction of phosphorus, assuming a 3,00% annual decrease in YPE., SEK/kg	3,13	34	119	415

a possibility that phosphorus resources currently available will be unavailable in the future (Cleveland 1991). The market price today is about 15 SEK/kg P, and the corresponding energy price for extraction 3.13 SEK. Assuming an energy price increase of 5% and the extraction energy needed increasing annually with 3%, the energy cost for extraction will exceed 400 SEK/kg within 75 years, an increase of two powers of ten (Table 2). The market price in that situation is open for speculations, but it is probable that such prices would significantly limit the current method of phosphorus use. This is clearly an unsustainable situation worth considering.

Transport dependent centralisation

With the fossil fuel based industrialisation and its infrastructure development came the capacity of far-away production and cheap long-range transportation. This creates the possibility of concentrating people in urbanised - industrialised areas. There seems to be a close connection between the availability of cheap energy and urbanisation. Without cheap energy, large cities cannot be sustained. The extraction, refinement and transport of necessary products would otherwise be too expensive, not to talk about the recycling of nutrients (Günther, 1998).

A general principle of all self-organising systems is to change in a direction that enables it to degrade more available exergy (Schneider & Kay, 1994). This principle can explain the substitution of machinery for manual labour, or the transportation of food instead of local production. The availability of cheap energy can thus to some extent explain the growth of cities, as it can also give clues to on other types of centralisation, for example the specialisation of agriculture into large units.

This development has lead to a situation where single households can be associated with large expenditures of cheap energy:

The house

In Sweden, a normal new-built house for a family of four, built according to the Swedish building standards 1980 can be assumed to have a yearly energy use of about 17 000 kWh. However, by applying energy conservation this figure is possible to diminish to below 10 000 kWh. The potential for increasing energy efficiency in the building is thus about 8 000 kWh/ year for a family of four.

The car

Another large energy user of this four-person family is the car. Assuming an average use of the car to 15 000 km/year, using 0.6 - 1 litre of gasoline per 10 km. The more energy-efficient car uses about 9 000 kWh of gasoline/year, the other about 15 000 kWh. Assuming the same indirect energy use in construction and maintenance, the difference is about 6 000 kWh/ year. Thus, the potential for increasing energy efficiency of the car is about 6 000 kWh/year, in the same size range as that of the house.

Food

The energy used for transportation and handling of food is to a large extent unrecognised part of the total per capita uses of energy. In Sweden the use of direct energy for transport and handling of food is conservatively estimated to about 10 % of the total annual energy use (Olsson, 1976). Nils Tiberg (LuTH, pers. comm.) estimates the figure for Sweden to about 60 TWh, or 13 % of the total energy use. Including the energy expenditures in agriculture which in round terms can be estimated to about 1:1, the total energy efficiency would have been about 8:1 1976. Considering the changes in society during the last 20 years, this figure would be worse today. A guess that it is more like the US in 1975, 1:10 (Hall & al, 1986), would not be overwhelming.

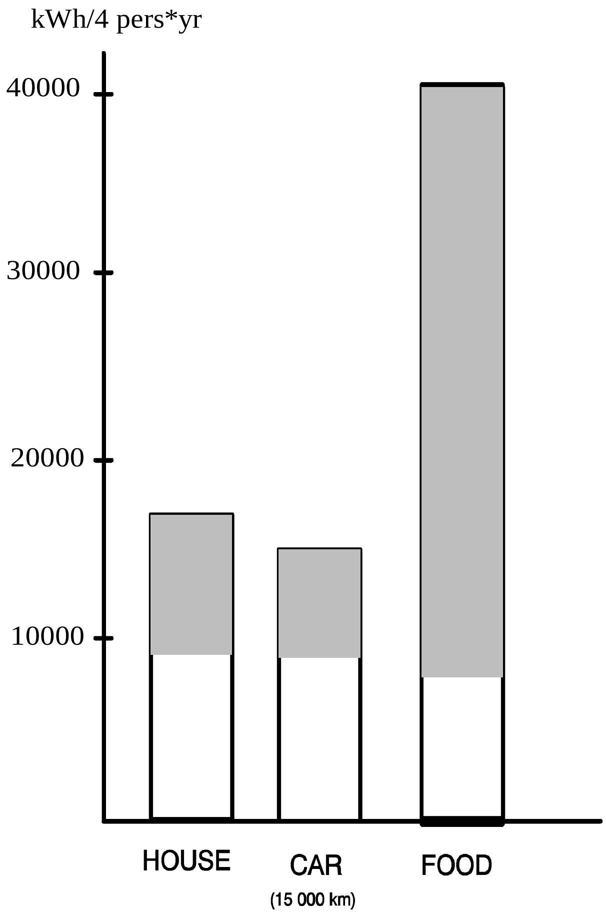


Figure 4*. The energy use of a family of four in Sweden, roughly calculated. The single largest energy user is the food system. Here is also the largest potential for increased energy efficiency (grey part of the bars) to be found.*

It can thus be estimated that the energy yield per effort in food production, transport and handling is about 0,1. This implies that about ten energy units are spent in transportation, handling, packaging, shop maintenance, and so on for each energy unit delivered to the dinner table. A conclusion of this is that for a normal family, the largest single energy use is that for food management and handling. (Figure 4). Assuming a Swedish agriculture similar to the one today, but a more 'local' handling and managing of the food, the energy expenditures for the production of food necessary for feeding this family would be about 4000 kWh for the agriculture and an equal amount of energy for the 'local' handling system. In this case, the potential for efficiency increase would be about 32000 kWh.

Agriculture and vulnerability

The industrialised agriculture is as dependent on the general services from the surrounding society as any other industrial activity. In order to meet a need to increase the economic efficiency of these services, the tendency during the last decades has been to increase the size of the industrial units delivering the services. This is especially typical for the reduction in number of dairies and slaughterhouses. The total number of diaries has declined from about 400 to 58 during the 33-year period 1960-1993 (SCB, 1994). Beside the effects of increased transporting, which will be discussed later, this tendency leads to an increasingly vulnerable structure. A permanent or transient malfunction of one unit, e.g., the outbreak of a disease, a malfunction of the electricity delivery system, some problem in the delivery system for packages, or any other peace or war crisis will, by its increasing share of the whole production, have more severe effect on the food delivery for the population than if a smaller unit was eliminated. This is an example of the effect of reducing the resilience (Holling, 1973) of a system.

The same problem is associated with the system for delivery of other supplement products for the agricultural production, e.g., animal feed, fertilisers, seed grain (Table 3), spare parts for machinery, frozen sperm for insemination. About 90 % of the cows in Sweden are artificially inseminated (SCB, 1994). About 80% of the Swedish milling capacity is situated in the far southeast part of Sweden today (Jordbruksverket, 1991).

The specialisation of the agricultural units combined with their increase in size and decrease in number (Figure 5) and the decrease of the number of service system units has brought about not only an increased transportation range for each unit, but it has also lead to the aggregate effect that a malfunction in one support unit can affect several large production units that in turn produce a large part of the public's total requirement of a product.

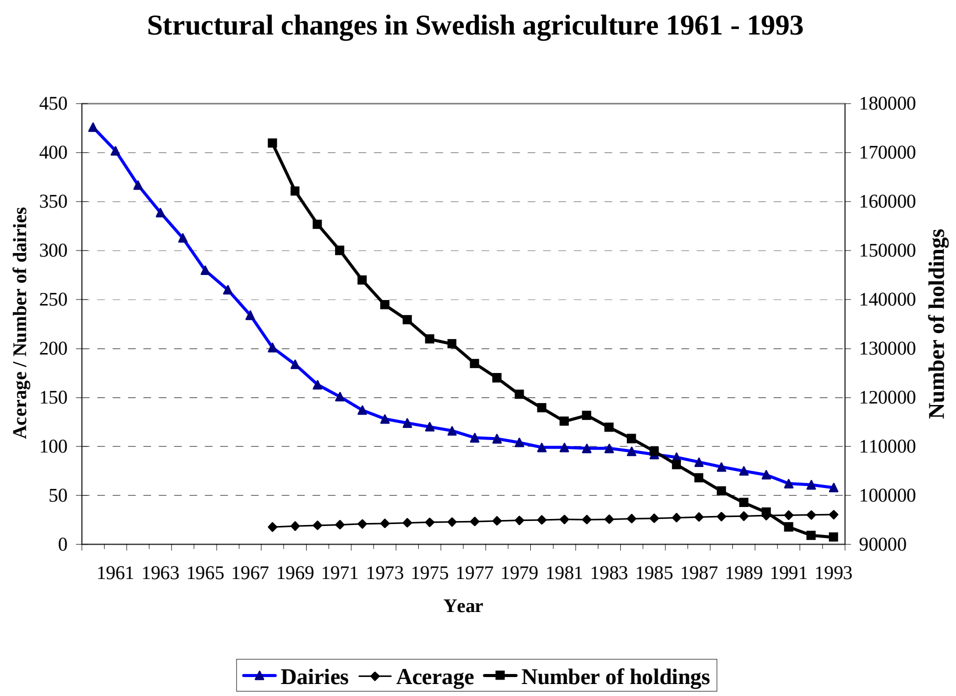


Figure 5. *An increase in vulnerability can be expected with a specialisation of the agricultural units. At the same time as the size of the units have increased, the number of service elements (here: dairies) have diminished.*

To these problems adds a further that is closely associated with vulnerability: With the decrease in number of production and support units, the importance of the distribution system will increase. By that, the transportation lines will be longer and the need for a safe and constant delivery of cheap energy and a well-functioning transportation infrastructure will increase, as the need for accurate and precise distribution. Compared to a system with shorter transportation lines and a higher grade of self-sufficiency, a failure in this system will be more likely to take place and its effects will be more severe. This tendency is general of the modern society, of which the agriculture is a part.

The specialisation of the agricultural units themselves has had the same tendency in decreasing the diversity of the agricultural units. Half a century ago, it was commonplace that a farm not only grew a large part of the feed for the animals, but also that there was a large diversity of animals and plants on the farm. It was common that cows, pigs, horses, geese and chicken could be found on the same farm, together with a variety of crops and refinement procedures. Today, this situation is very rare. The farmers are forced by the increased price for supplement products and the decreased price for their produce to specialise on products that could be produced in large quantities to a low cost per unit. The general economic paradigm has transformed the relation between the farmer and his farm from managing the land to running a company. Various governmental subsidies have, together with the entrainment (Rosser & al., 1993) of firms into a new infrastructure, intensified this process. This specialisation had lead to a decrease in diversity, reduced resilience and, consequently, to an increase in vulnerability of the food delivery system as a whole.

The infrastructure of the contemporary agriculture is created to deal with problems of well-known character, e.g., local demands and malfunctions. However, the feedbacks in the system are slow or non-existing to problems arising on a higher hierarchical level or at a longer temporal scale (Allen and Starr, 1982), i.e., ecological problems or dependencies on future energy access.

Discussion: Potential solutions

In this part of the paper I will propose some measures that can be taken to alleviate the problems of high risk and potential instability of the food supply system. Some benign side effects that can be expected from the alleviation measures will also be pointed out. I will not discuss measures taken within the agricultural system, concerning for example organic farming or agroecology, since such measures have been discussed extensively in the literature (e.g., Altieri, 1987; Pimentel, 1989). Instead, I will focus on the alleviation of the structural problems that have risen as effects of the access to cheap fossil energy.

1. Minimising energy use in transportation

The heavy dependence of transportation in current farming practice can be ascribed to two or three infrastructure modes:

- The fertilisers and other support material for the agriculture are externally produced, often very distantly.
- The agriculture and end-user of the food are separated, often very distantly.
- It is common that feed is produced in another part of the country than the animals.

These transportation dependencies could be diminished radically with a closer integration of agriculture and settlements, and the re-introduction of balanced animal and plant production on the individual farms (Granstedt and Westberg, 1993). The discussion in the first part of this paper indicated that today, about 10 000 $kWh*p^{-1}*yr^{-1}$ is used for food delivery. However, it is not outrageous to expect a decrease of this figure to 2 000 kWh with a closer integration of agriculture and settlements, combined with a strategy for local food management. Assuming that this would be possible for 50% of the Swedish population, the amount of energy thus not needed is about 40 TWh annually at a current energy cost of about 160 billions (10^9) SEK, or 20 billion US$.

Naturally, energy use can also be diminished by different intra-farm technological changes. However, the energy investments in agriculture seem to be of the same range as energy output in food. Increased efficiency of the intra-farm energy use can therefore not be expected to lessen the total energy use more than a part of the industrial energy subsidies used in agriculture today, which is about 18 TWh (Hoffman, 1995).

2. Increasing nutrient circulation

In modern agriculture, the nutrients lost by export are replaced by new, supplied from mineral ores (P, K), or from industrial processes (N). However, this increases the vulnerability of the food system due to the connection with the mining and processing industry and the earlier mentioned problems of material and EROI.

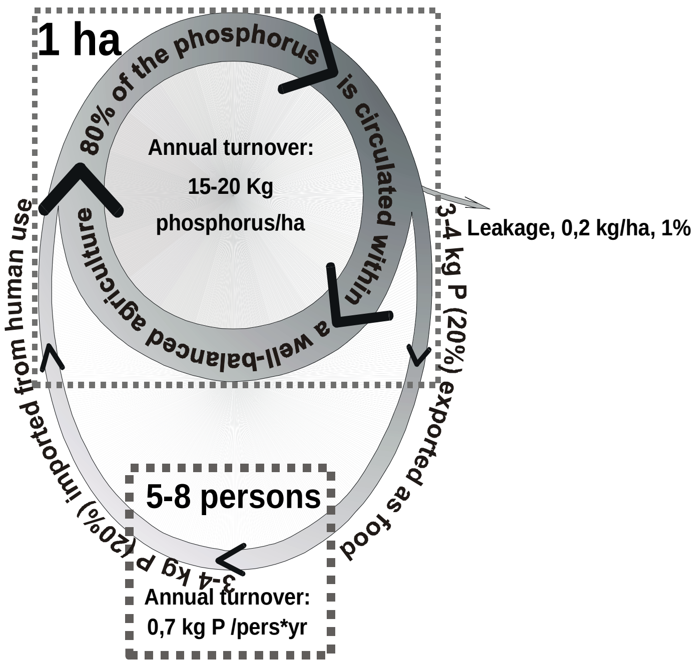
Biological systems, e.g., ecosystems, have offset the problem of source deprivation of essential nutrients.

Mature ecosystems have responded in two ways: For elements that have volatile phases (e.g., C, N, O, S and H) they are transported in the atmosphere and brought down when needed. For elements that in practice have no volatile phases, repeated cycling solves the problem. Characteristics for advanced ecosystems are their abilities to eliminate leakage an export of nutrients almost completely (Stark and Jordan, 1978; Odum, 1973, 1985; Kay, 1994).

Therefore, in order to augment sustainability, it seems to be a good idea to imitate the strategies of long-term surviving self-organising systems. One of the most important of those strategies seems to be the cyclic charging - discharging process of simple elements, the regenerative cycle (Günther and Folke, 1993; Günther, 1994b). In ecosystems, such elements are volatile (N, C, S, O, H) and non-volatile elements (P, K and trace metals). The limiting ones of the latter elements, and those of the former type that carry a heavy energy investment, as nitric oxides, are carefully recycled in such systems (Stark and Jordan, 1978; Odum 1973, 1985; Kay 1994). To attain ecosystem mimicking (ecomimetic) nutrient circulation, two changes are needed in the currently typical agriculture (Figure 6).

- Animal feed has to be produced on the same farm, or in the vicinity, allowing the manure to be returned to the land where the feed are produced. By this practice, 60-90% of the nutrients, at least the non-volatile ones, can be circulated (Granstedt and Westberg, 1993). Nutrients with volatile phases, e.g. nitrogen, can be conserved by anaerobic storage, effective mixing into the soil or other means.
- The nutrients actually exported as human food should be returned as uncontaminated as possible, preferably as human urine and (composted) faecal matter. With the use of source-separating toilets, which do not mix urine with faeces, the urine, containing most of the phosphorus and the nitrogen excreted (see Supplement 1), can be reclaimed easily. The faeces can be composted out of reach for flies during a half to one year in order to eliminate pathogens before the repossession to the fields.

Figure 6*. The phosphorus export from a hectare of balanced agriculture (i. e., one producing food for its animals) equals the phosphorus content of the excrements from 5-7 persons. This means that one person needs about 0.2 hectares of balanced agriculture for the production of the annual food needs.*



Integration of agriculture and settlements

Most of the problems pointed out in the first part of this paper can be ascribed to the unintentional separation of agriculture and settlements that has developed as a side-effect of 'the industrial revolution' the last century. Re-integration of agriculture with settlements would be a way to solve the problems of increased vulnerability and decreased sustainability of the food system. Many of the environmental problems experienced today could also be alleviated by this strategy.

Alleviating the problems at different scale-levels: Micro-scale

To solve the problems discussed in part one, it is necessary to study different scale levels (Allen & Starr, 1982). I will first try to outline how some of the identified problems can be solved on the scale of a single agricultural unit and a small (around 200 people) settlement.

<u>1. Elimination of dependency for feed and nutrients</u>

Assume an agricultural unit that produces both animal and vegetable products. Suppose also, that all the feed for the animals is produced locally. This will reduce the need for import of nutrients by 60 - 90 % (Granstedt and Westberg, 1993). However, the export of essential nutrients in food will still amount to 3-4 kg P/hectares*year. For a long-term survival of the system, this amount must be recycled. A human leaves 0.6 - 0.7 kg P/year in urine and faeces, (Supplement 1). This means that the phosphorus content of the excrement from 5-7 persons equals the losses of phosphorus in food from a hectare of a balanced agriculture (Figure 6).

From these figures, the area of a balanced agriculture needed to support one person is obtained. This area is between 0.23 and 0.15 hectares, which is in agreement with the figure of 0.2 hectare per person calculated from the need of nutrients for a person and a restrained production capacity of an average Swedish agriculture (Günther, 1989). A 40-hectare agriculture can thus support about 200 persons for a majority of their food needs.

Thus, to diminish the acute dependence on outside support of nutrients, integration is needed of both animal feed production and a local settlement with the agriculture as a food producing system. This integration also implies an increased diversity of the agriculture because of the increased diversity of products needed by such a population.

<u>2. Elimination of leakage</u>

The direct leakage of phosphorus, which in this article is chosen as a 'standard' nutrient from an agricultural unit is within the range of 0.2 - 0.4 kg/hectares*year (Brink & al., 1979). By the opening of water streams and re-planting with buffer-strips, a large part of this leakage can be captured (Mander & al., 1991, 1994). Examples of reclaiming methods for the nutrients contained in the biomass can be as compost, biogas sludge or ash. Such buffer strips have also other functions than the capturing of nutrients. In windy conditions, they also have a wind shielding function, by this increasing the yield 15 - 30 % within 15 meters from the vegetation strip. Other benefits of such vegetation are the increased occurrence of predators against insect pests (Andersson, 1990) and bumble bees for pollination (Hasselrot, 1960).

<u>3. Economy</u>

Another problem that was pointed out in the first part was the low income and the decreasing income marginal for the farmers. The extensive handling and transporting system between the producer and consumer is not only energy demanding, it also appropriates a large part of the price for food paid by the end-user, more than 75% (calculated from the figures in LES, 1991, 1993a, b). Furthermore, the price to the farmer represents to a large extent the cost for monetary and material supplies paid by the farmer, about 85% calculated from the figures of Augustsson and Andersson (1995) (Figure 7).

With an increased integration of agricultural units and settlements, a direct trade between the farmer and the consumer can be accomplished. If the farmer is given half the price for food that is paid by the consumer in the shop today, this could six-double his income. By such an arrangement, the consumer can also reduce the cost for the food produced by the farmer with about half, both figures assuming the product price to the farmer is 25 % of the consumer price (which is somewhat high).

Today, the earnings for the farmer are 15 % of his income (Augustsson and Andersson, 1995), i.e., not more than 3.6 % of the market price in the shop. Assuming that the production cost would increase with 30 % because of the increased diversity in agriculture, a fifty-fifty agreement between a farmer and a local settlement would anyhow increase the payment to the farmer from 3.7 % of the shop price to 22 %, i.e., about six times (Figure 7). A rise in payment of that magnitude can be expected to enforce even large changes in agricultural practice.

Medium scale

The implementation of the above-proposed solutions is not incompatible with intermediate size settlements. Three or four settlements with their associated agriculture can form groups of 800 - 1,200 persons and an associated agricultural area of 160 - 240 hectares. If areas also are used for the improvement of local ecosystems, 170 - 260 hectares can be expected to support these people. This population size is large enough for a good deal of the common social infrastructure, as low level schools small service business etc.

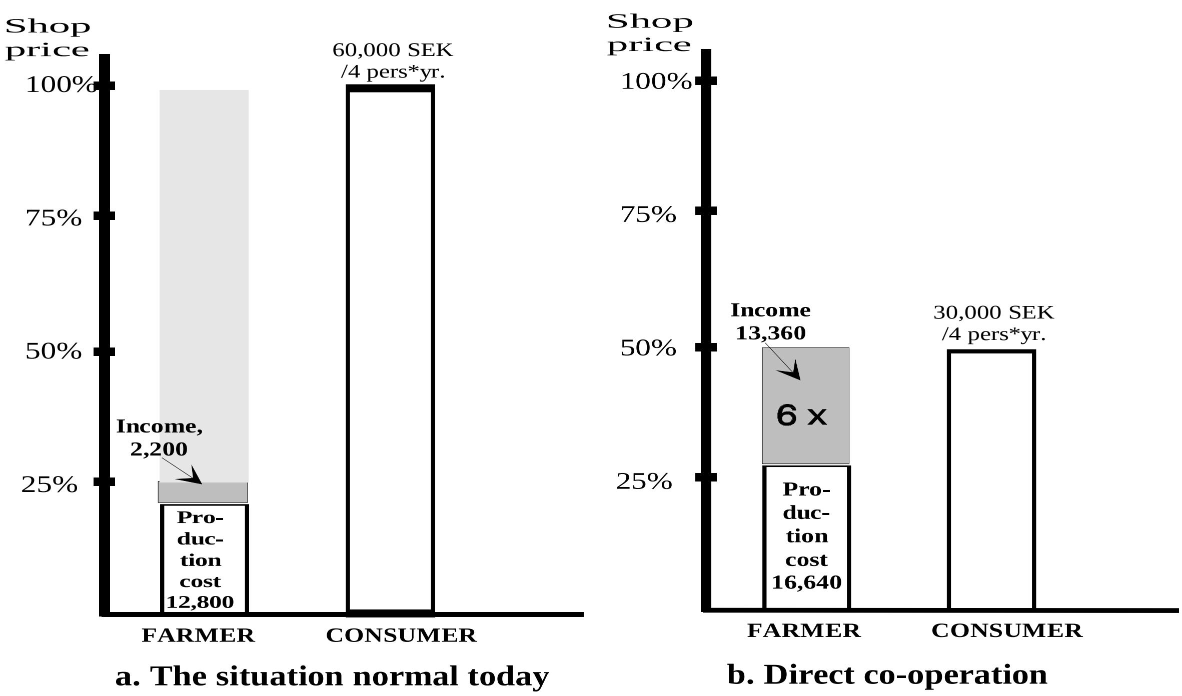


Figure 7. *A direct co-operation between an agricultural unit and a local settlement would be economically favourable, not only to the consumers, but also to the farmer, even if the production cost would increase with 30%.*

It could although be argued that this size of settlement is not enough for the cultural needs of people, and for employment etc., and that this may generate an increased need for transportation. For the sake of discussion, however, imagine an area where such settlement types cover the land. In such an area, not regarding the incidence of lakes, mountains etc., there would be a population density closing to 500 p/km^2, which could be enough for a diversity of social interactions.

Large-scale implementation of the proposed solutions: Ruralisation

Nutrient circulation becomes increasingly expensive with increasing distribution range (Günther, 1994). The energy requirements for distribution of food also tend to increase with quantum leaps when the distribution pathways require extensive packaging and preservation of the products. As pointed out earlier in this paper, providing this energy with fossil fuels tend to increase the vulnerability of the society over the level that can be allowed if only a basic allowance is given to human and environmental security. Therefore, the only ways left, if the goal is to provide this security, is to maintain these flows with solar powered methods and to diminish the external energy requirements to the lowest level possible.

Also, the methods to provide the agriculture with its 'ultimate' raw material, phosphorus, must be changed if the above-discussed level of security is to be attained. To maintain a linear flux of phosphorus through the society over a prolonged time seems both wasteful and insecure.

Therefore, to attain nutrient circulation at the same time as energy support needs are diminished in large societies, a different societal structure strategy in should be applied: Instead of the current trend towards increasing agricultural specialisation combined with urbanisation of the population, a closer integration of farms and settlements would be the goal.

A name for such a strategy is ruralisation, as opposed to urbanisation. This development strategy implies a

successive replacement of houses bound for extensive restoration or rebuilding. Instead of making a new house on the same place, small settlements integrated with agriculture as outlined above are created in the hinterland of the urban area. Many of the different problems outlined above could be alleviated by this strategy.

Summary

In this overview, I argue that agriculture is inflicted with a lot of problems that cannot be alleviated by enhanced agricultural routines, since they are effects of a more general structural change of the society, hence they must be solved with structural solutions. Such problems are

- dependency on industrial energy support
- constant input of nutrients and other materials
- inescapable loss of nutrients, an effect from
- linearity of the nutrient handling system

The problems are aggravated from the following factors:

- ongoing specialisation of agricultural units
- decreasing population working with agriculture
- urbanisation
- a dependency of cheap energy
- the probable increase of fuel price

I argue that such problems, and others, as ecological and social ones, could be alleviated by a successive change into assemblages with a closer integration of agriculture and settlements, thereby:

- minimising industrial energy dependency
- increasing nutrient circulation
- increasing the integration between agriculture and other social activities
- increasing and supporting ecosystem services received

The economical assets of such systems seem to be favourable, especially in the anticipated increase of cost and vulnerability of the current type of agriculture. In the reflection of recent information on fossil fuel access, it is hard to perceive a sustainable society that is not mainly powered by solar energy.

References:

Allen, T. F. H. and T. B. Starr, 1982. Hierarchy, Perspectives for Ecological Complexity. University of Chicago: Chicago and London.

Altieri, M.A., 1987. Agroecology: The Scientific Basis of Alternative Agriculture. Westview Press: Boulder. 227 p.

Andersson, L., 1990. Florans inverkan på åkerns skadeinsekter och deras naturliga fiender. Växtodling: 18. SLU: Uppsala

Augustsson, L. and M. Johansson., 1995. Sektorskalkyl för jordbruket. Jordbruksverket 1995-03-16, Jönköping, Sverige

Booz, A., 1976. Energy use in the food system Federal Energy Administration Washington DC 041-018-00109-3

Brink, N., A. Gustavsson and G. Persson., 1979. Förluster av kväve, fosfor och kalium från åker. SLU publ. 181:4. Ekohydrologi 4. Sveriges Lantbruksuniversitet, Uppsala.

Brundenius, C., 1972. Imperialismens ansikte: 400 år av underutveckling i Peru. Stockholm: Prisma

Campbell C.J. March 20, 2000. The Myth of Spare Capacity. Oil & Gas Journal

Cleveland, C.J., 1991. Natural Resource Scarcity And Economic Growth Revisited: Economic And Biophysical Perspectives. In: R. Costanza, Ed. Ecological Economics: The Science And Management Of Sustainability. Columbia University Press, New York, Oxford, pp. 289-318

Folke C., and Kautsky N., 1992. Aquaculture with its Environment; Prospects for Sustainability. Ocean and Coastal Management 17: 5-24

Giampietro, M., G. Cerretelli and D. Pimentel, 1992. Energy Analysis of Agricultural Ecosystem Management: Human Return and Sustainability. Agriculture, Ecosystems and Environment, 38: 219-244

Goldemberg, J., T.B. Johansson, A.K.N. Reddy and R.H. Williams, 1987. Energy for a Sustainable World. World Resources Institute, Wiley-Eastern.

Goodland, R., H. E. Daly and S. El Serafy, 1992. Population, Technology and Lifestyle: The Transition to Sustainability. Island Press, Washington

Gootas, H.B., 1956. Composting Sanitary Disposal and Reclamation of Organic Wastes. WHO, Geneva

Granstedt, A. and L. Westberg, 1993. Flöden av växtnäring i jordbruk och samhälle. SLU Info 1993:416

Günther, F. and C. Folke, 1993. Characteristics of Nested Living Systems. J. Biol. Syst., 1, 3. 257-274

Günther, F., 1989. Ekobyar, ekologiskt anpassad och resurssnål bebyggelse. (Eco-villages, ecologically adapted and resource saving settlements.) Ekokultur förlag, Borlänge

Günther, F., 1994b. Converting Linear Flows into Cycles: The Phosphorus Flux in the Swedish Society as an Example. Paper presented at the 2nd International Conference on Implications and Applications of Bioeconomics, Palma de Mallorca, Spain,Mars 11-13 1994

Günther, F., 1998. Phosphorus management and societal structure. End report to AFR. Vatten, 98:3

Gundersson. L., C. S. Holling and C. S. Light., 1995. Barriers and Bridges to the Renewal of Ecosystems and Institutions.. Columbia University Press: New York

Gutenberg, P., 1993. Imaging development: Economic Ideas in Perus Fictitious Prosperity. Guano 1840-1880. University of California Press

Hall, C.A.S., C.J.Cleveland and R.Kaufmann, 1986. Energy and Resource Quality. Wiley Interscience, New York.

Hasselrot, T. B., 1960. Studies on Swedish Bumblebees. (genus Bombus Latr.), their Domestication and Biology. Opuscula Entomologica, Supplementum XVII. Lund.

Hoffman, R., 1995 Jordbrukets energibalans - En analys av energiflöden i Svenskt jordbruk 1993 och jämförelse med åren 1956 och 1972. KSLA Tidskrift nr ?? Lantbrukets energibalans - Energiflöden i Jord- och Skogsbruk. Sammanfattning från seminariunm 19/4 1995, Stockholm. Under preparation.

Holling, C. S., 1973. Resilience and stability of ecological systems. Annual Rewiew of Ecological Systems 4, 1-23.

Ivanhoe, L. F., 1995; Future world oil supplies: There is a finite limit; World Oil, October 1995, p. 77-88.

Jordbruksverket, 1991. Programplanen för funktionen Livsmedelsförsörjning m.m. Bilaga A. Jordbruksveket, Naturvårdsverket och Statens Livsmedelsverk.

Kay, J. J., 1994. Some notes on: The ecosystem approach; Ecosystems as Complex Systems In: Proceedings from the 1:st International Conference on Ecosystem Health and Human Health, Ottawa, Canada, June 19 -23, 1994

Leach,G., 1976. Energy and food production IPC Scientific and Technical Press, GB

LES, Livsmedelsekonomiska samarbetsnämndens indexgrupp. 1991. Analys av prisutvecklingen i olika led av livsmedelskedjan. Jordbruksverket. Jönköping

LES, Livsmedelsekonomiska samarbetsnämndens indexgrupp. 1993a. Prisindex på jordbruksområdet. Beräkningsmetoder. Jordbruksverket. Jönköping.

LES, Livsmedelsekonomiska samarbetsnämndens indexgrupp. 1993b. Prisindex på jordbruksområdet. 1980-1992. Jordbruksverket. Jönköping.

Mander, Ü., O. Matt and U. Nugin,, 1991. Perspectives on Vegetated Shoal, Ponds and Ditches as Extensive Outdoor Systems of Wastewater Treatment in Estonia. In: Etnier, C. and B. Guterstam: 1991, Ecological Engineering For Wastewater Treatment Proceedings of the International Conference at Stensund Folk College, Sweden, Mars 24-28.

Mander, Ü, V. Kuusemets and M. Ivask, 1994. Nutrient Dynamics in Riparian Ecotones: A Case Study from the Porijõgi Catchment, Estonia. Paper presented for publishing in the journal Landscape and Urban Planning Elsevier 1994. Proceedings from the European Congress of IALE Agricultural Landscapes in Europe, Rennes, France, June 6-10, 1993

Masters, C., 1994. USGS: World Petroleum Congress

Odum, E. P., 1973. Fundamentals of Ecology. 3rd ed. Saunders, Philadelphia

Odum E.P., 1985. Trends to be Expected in Stressed Ecosystems. BioScience 35: 419-422.

Odum, H.T., 1971. Environment, Power and Society. Wiley-Interscience, New York.

Olsson, P., 1976. Energianvändning i livsmedelsproduktionen. SIK rapport 425 / STU rapport 69:1978

Pierrou, U., 1976. The Global Phosphorus Cycle. In Svensson, B.H. and R. Söderund (eds.). Nitrogen, Phosphorus and Sulfur - Global Cycles. SCOPE: Report 7. Ecol. Bull., Stockholm) 22: 75-88

Pimentel, D. and C. Hall., eds., 1989. Food and Natural Resources, Academic Press INC, San Diego, California.

Rosser, J. B. Jr, C. Folke, F. Günther, H. Isomäki, C. Perrings, G. Peterson and T. Puu, 1993. Discontinous Changes in Multilevel Hierarchical Systems. Systems Research Vol. 11, No. 3, pp. 77-94, ISSN 0731-7239

SCB, 1994. Jordbruksstatistisk årsbok 1994 (Yearbook of Agricultural Statistics 1994). Official Statistics of Sweden, Statistics Sweden. Stockholm

Schneider, E. D. and J. J.Kay, 1993. Exergy Degradation, Thermodynamics, and the Development of Ecosystems. Proceedings of the International conference on Energy Systems and Ecology. The American Society of Mechanical Engineers, Advanced Energy Systems. 10 p. Cracow, Poland, July 1993

Stark,N.M and C.F.Jordan, 1978. Nutrient retention by the root mat of an Amazonian Rain Forest.