RURAL CHANGE

The Challenge for Agricultural Economists

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Gower

ULF RENBORG

Energy Analysis of Agriculture
Biology or Economics – a survey of approaches, problems and traps

BACKGROUND: AGRICULTURE IN THE NATIONAL ENERGY SYSTEM

The successive rises in crude oil prices since 1973 and the increased awareness of the risks associated with nuclear power stations – so dramatically emphasized by the Harrisburg incident this spring – have brought the energy supply question to the forefront of economic and political discussions.

This debate is difficult to survey and it is confusing. One reason is that so many questions are at the same time brought into the discussion. Here are some common examples: Economize with finite energy sources! Lower economic growth to save energy! Lower use of nuclear energy to protect man from radiation risks! Lower use of fossil energy sources to protect environment from sulphuric acid fall-out! The claims show a mixture of legitimate requirements, half-truths and mistakes and are often incompatible. Another reason for confusion, even in the educated part of the debate, is the wide differences in background among participants. Of specific interest for this author is that certain science writers[1] and economists come to such different conclusions as to what is meant by a desirable development of energy use in society.

This paper aims at shedding at least some light on this question as it shows up in an analysis of agriculture in the national energy system.

Figure 1 gives a simple picture of agriculture in the national energy system. From this is seen that agriculture uses energy and produces/can produce biomass for the energy system. These are the two roles that agriculture can play in the energy system of a nation.

Figure 2 indicates that agriculture's role in the national energy system varies from country to country. Investigations show that agriculture in industrialized country situations – (1) and (2) – consumes a share of total support energy smaller than its contribution to GNP. In this situation energy saving within agriculture is thus of minor national interest although possibly of some importance within agriculture itself. On the other hand agriculture *can* play an important role as producer of energy

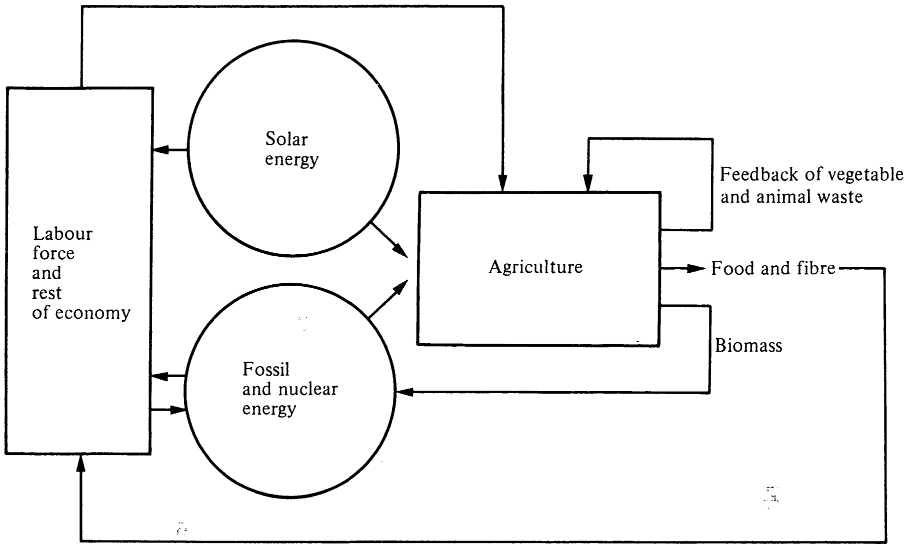


FIG. 1 *Agriculture in the national energy system*

FIG. 2 *Agriculture in four national situations*

	Small acreage of land per caput	Large acreage of land per caput. Ample water supply
Agriculture small part of the economy	(1) Energy saving and biomass production not feasible in agriculture	(2) Biomass production feasible in agriculture
Agriculture large part of the economy	(3) Energy saving feasible in agriculture	(4) Energy saving and biomass production feasible in agriculture

Complicating factor: national supply of fossil energy resources

resources as biomass. This reaches major importance for the nation only when large acreages of land per capita are available. Situation (2) has potentials in boreal temperate zones – USSR, Canada, Scandinavia. In developing countries situations – (3) and (4) – energy saving is important in agriculture where it takes the form of labour intensive production and efficient use of wastes for fuel in situation (3). Biomass production has potentials in situation (4), of which Brazil is a possible example.

A meaningful analysis of agriculture in a country's energy system can only be made against the goals guiding the political decisions in each country. Appropriate goal dimensions are economic growth, low vulnerability of fuel supply, environmental control and solidarity with future generations and developing countries. Countries with different weights in these dimensions and in different situations as of Figure 2 will come up with quite different pictures of agriculture's role in the national energy system. One reason for differences in approaches to analysis of the energy system by science writers and economists may well be the differences in attitudes to these various goals.

ORIGIN OF ENERGY ANALYSIS (EA)

Economists and engineers have well established methods to analyse energy systems like national energy supply schemes, power plants, industrial energy supply plans etc. Investment calculations, input–output studies, studies of price and income elasticities of supply and demand have long been used for these purposes.

In the beginning of the 1970s the effectiveness of these methods were questioned by a group of mainly natural scientists and ecologists.[1] They observed that the processes of industrialization characteristic for economic growth of nations are using increasing amounts of energy and that this energy above all comes from finite resources like fossil fuels (oil, natural gas, coal) and uranium. They also pointed out that the world's crude oil deposits would be rapidly emptied if the industrialization process went on as they observed. This means, they pointed out, that the prosperity of today's industrialized countries have a shaky foundation, not to speak of the prosperity of future generations and that of underdeveloped countries. To this can be added the more and more apparent risks of nuclear power stations. Man's future energy source has therefore to become – and rapidly become, they claim – based on renewable energy sources like direct use of solar energy, or energy from waterpower, wind and production of biomass.

From various scientists in this group were developed alternative methods for analysis of energy systems. An important early contribution came from the ecologist Howard T. Odum (1971). He analysed the energy requirements to build and run energy systems based on finite energy sources and developed a specific language – with flow charts and symbols – by which to analyse these systems. Energy systems have also early been treated by Chapman (1974). Other authors analysed the total energy content – from primary products to final products – in various capital good, cars, buildings, etc. Early contributions in this field was made by Hannon (1972), Makhijani and Lichtenberg (1972) and Berry and Fels (1973). Early studies of energy flow through agriculture have been made by Pimentel et al (1973), Leach and Slesser (1973). An early and important forerunner with thoughts related on thermodynamics and economics is Georgescu-Roegen (1971). He summarizes his criticism of economic analysis in two long articles in *Ecologist* (1975). In 1974 and 1975 at two meetings arranged by IFIAS, The International Federation of Institutes for Advanced Studies, a set of common recommendations for Energy Analysis, here called EA, were formulated (IFIAS, 1974 and 1975). It is clear from these two later documents that EA is a young field of science which is not yet a well-defined discipline. Its practitioners are physicists, biologists and ecologists. It studies "societal use of a single aggregate resource, energy". It traces quantitatively "the changes in the thermodynamic potentials of materials as they pass through successive process stages". One of its goals is to "indicate where reductions in the energy requirements for total processes could be made". These are looked upon as "the pressure points for technological change". Energy is thought of as being provided by fuels or by renewable sources such as solar, fluid or hydro power generation *and also* as the flow of thermodynamic potential associated with the material flows in a process (IFIAS report 9, 1975, pp. 3–4).

It is this EA we are going to study here. We concentrate on EA of agriculture. The reason for economists to do so is twofold. Analysis of energy problems with EA has met serious attention in political circles and official documents (Webb and Pearce, 1975). EA challenges the economic analysis of energy questions.

ELEMENTS OF ENERGY ANALYSIS OF AGRICULTURE

Energy

In EA all inputs into a production process (e.g. wheat or milk production), an energy system (e.g. production of biomass and energy delivery from it) or a sector (e.g. agriculture) are measured as Gross Energy Requirement, GER. For any input GER is the total energy required in all parts of the chain of production processes from primary products (oil, ore, etc.) to the final input as used in the system studied. GER is counted as the free energy of combustion of natural energy sources corresponding to all energy inputs required (IFIAS 1974 and 1975). It is therefore also possible to say that the energy requirement of an input is a direct measure of the withdrawal from the global stock of finite natural energy resources it represents (Nielsen and Rasmussen 1977). Energy inputs from water and nuclear power stations are counted as the corresponding amounts of natural energy resources.

Solar radiation is a natural flux resource from which a flow of energy occurs over extended periods of time. The potential of all energy flux source refers to the maximum average rate of supply of free energy (IFIAS, 1974).

In most EA of agriculture the input and use of solar energy is not counted (for example Pimentel et al, 1973, Leach 1976, Nielsen and Rasmussen 1977). There are three reasons given for this by energy analysts. The first is that EA deals with the use of finite, mostly fossil, energy resources. Solar energy is not, it is said, a technically useful source of energy (Leach 1976). The second is that including solar energy in the study would make it "little more than a study of photosynthetic conversions of solar energy to food energy, and could say nothing about the effects on fuel usage of changes in methods of producing food" (Leach 1976). The third reason is that solar radiation is available in a constant flow for use or non-use, and thus can be treated as a fixed resource.

The third objection to including solar energy does have a meaning in EA of an acre of a specific crop or cropping system (Pimentel et al 1973) and parts of Leach's (1976) cropping budgets calculated per acre. In cases where the whole agricultural sector is analysed none of the objections are valid. This is due to the fact that direct substitution between solar energy and direct energy inputs from finite sources exist, for example in roughage and grain drying in wet and cold climates. Similar substitutions are also possible in choices between low fertilizer inputs on a large acreage or high fertilizer inputs on a smaller acreage to produce a given amount of grain. How solar radiation should be treated in EA of agriculture is obviously determined by the way in which the system under study is specified. It cannot be determined without such a specification.

Factors of production

In cases where energy from solar radiation is not included in EA of agriculture – and these are the majority of cases – *land* is not included as a factor of production in EA. This is also true for the minerals and other primary products, other than fossil fuels and uranium deposits, usually included in land in socio-economic considerations. Phosphate and potassium for fertilizers, iron ore, bauxite limestone and clay, and other basic resources included in buildings, and machines have thus no value in EA. Nor has the alternative value of land for other use. Land is thus in EA counted in its role as deliverer of finite fossil fuel and uranium resources. *Capital* is, as we understand what has been said earlier, only counted as the energy input it represents. Webb and Pearce (1975) have pointed out that in doing so EA does not separate energy inputs into durable capital and into productive inputs for direct use. In doing so EA misses a fundamental characteristic of the meaning of capital, namely that "capital generates a flow of goods in excess of the original value of the capital" (Webb and Pearce 1975, p. 320).

Human *labour* is in EA of agriculture either not counted as an input at all (Leach 1976, Nielsen and Rasmussen 1977, Slesser 1978) or as the metabolizable energy in food (Pimentel et al 1973) or as number of hours of labour (Renborg, Uhlin et al 1975). This situation is confusing and can be traced back to the conventions adopted by IFIAS in 1974 (IFIAS 1974, pp. 46–50). The IFIAS's workshop of 1974 did not solve this problem. It agreed that "the figure of real interest is how much in the way of energy sources was consumed to furnish the life support system of the man that works on the process. . . . However, once this approach is accepted a further problem arises. Does one include in the energy for the life support of the worker, only food, or also his family, house, car, etc?" (IFIAS 1974, p. 46). After calculating through a series of agricultural examples the workshop concluded that energy inputs associated with labour – according to their viewpoints – were of negligible size as compared to other energy inputs in developed and industrial economies but of importance – and as a matter of fact often the only energy inputs – in primitive and low intensive agriculture. Thus the following convention was adopted:

> Where the analysis refers to developed or industrial economies it is not necessary to consider the energy for life-support of manpower. Where the analysis considers low intensity agriculture manpower considerations play an important role in the calculations. (IFIAS 1974, p. 50).

This convention is fatal on two accounts, irrespective of how much energy is associated with labour inputs. First, any comparison of energy use between systems with different intensities simply does not make sense. This can be seen in Leach (1976) where these kinds of comparisons are made on page 8. To be able to make a reasonable analysis of this material Leach consequently has to introduce labour as a factor of production counted in hours on page 9. Second, any comparison over time including a change in technology of the common type which replaces capital for labour requires some way of allocating energy to the diminishing labour input. Pimentel et al (1973) has realized this and made such an allocation. However, by only counting the food input the real nature, also in energy terms, of structural change in agriculture does not show up in their analysis.[2]

It is not possible for this author to come to any other conclusion than that EA has to adopt a new convention regarding the treatment of energy requirement for labour. Approximately the following might be considered: Input of human labour should be accounted for by counting the Gross Energy Requirement necessary to furnish the total life support system – food, family, house, etc. – of the man that works on the process.

Energy flow through agriculture

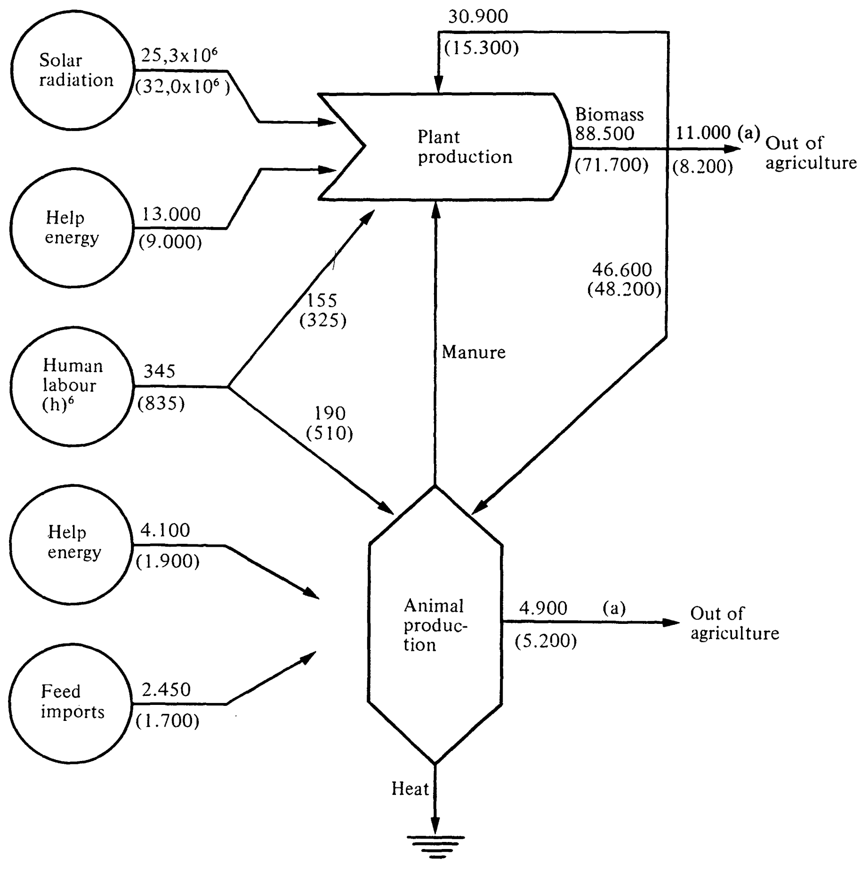
EA can result in pictures of the energy flow through agriculture like the one in Figure 3.

This figure indicates that the flow registered adds features not included in EA conventions. By including solar radiation substitution of fertilizers for land over time is shown. Human labour has been drastically substituted by help energy and imported feed. Indications of waste products, mainly straw, back to the field and of the stream of feed to animal production raises questions as to the efficient use of these products. The same is true for manure and wasted heat, produced by animals. This enrichment of the picture stems from the aim of the EA in this case, to identify points in the agricultural system where research efforts could bring possible improvements. For this use it is less fatal that the output of the system is measured only in energy units. This is very daring, considering differences in protein content per energy unit of various products and in protein quality, for example between vegetable and animal products. EAs of agriculture also seldom push the analysis so far. Either the analysis only covers the input side (for example Nielsen and Rasmussen 1977) or give the products in energy *and* protein units (like Leach 1976).

Energy units or costs?

As we can see from what has been already said EA is a calculation of the technical flow of resources through a system or a production process. The selection of the energy unit to aggregate inputs and outputs includes a distrust of prices formed in a market economy as reliable decision variables by the builders of the EA. Thus for example Slesser says 1975: "Energy analysts believe that it makes sense to measure the cost of things done, not in money, which is after all nothing more than a highly sophisticated value judgement, but in terms of the thermodynamic potentials". Hannon 1975, says that "in the long run we must adopt energy as a standard of value and perhaps even afford legal rights". (Citations after Webb and Pearce 1975.)

Webb and Pearce (1975), also point out that cost calculations – with shadow prices – are in economics also possible without market determined prices. Mäler (1977) points out that it may very well be that today's prices of fossil energy resources underestimate the importance and thus



a) food products for human consumption

FIG. 3 *Energy flow through Swedish agriculture 1956 and 1972 (KWh)* the value future generations will place on these resources if saved for their use. This does not, however, exclude expressing energy flows in cost terms better adjusted to more realistic social costs of fossil fuels. The economists' point here is that EA does not offer a better weighting system.

This can be seen in Figure 3 where energy in solar radiation fossil fuel, electricity, feed inputs with certainly different value in production are measured in the same energy units. It is even more obvious on the output side where vegetable and animal food for human consumption is also measured in energy units.

Criteria of optimality

EA can mainly be used to describe the flow of (finite) energy resources through a system. However, the majority of EA studies include comparisons of energy use between productive processes or production systems. These comparisons indicate prescriptive claims in EA. In the comparisons processes are usually *ranked* according to some measure of output per unit of energy input. This implies that some kind of optimality criterion is visualized in EA and that this includes selection of alternative production processes or systems so as to minimize the use of finite energy resources.

A common ranking measure is the energy ratio (Er) where – in its simplest form – the output of a process or system in energy terms (Eo) is expressed per unit of Gross Energy Requirement (Ei) of the process or system, i.e. Er = Eo/Ei. In studies of the food system Eo generally is expressed as the nutritive energy content of edible food for humans (Leach 1976) or metabolisable energy (Pimentel et al 1973, Slesser, Lewis and Edwardson 1977). Energy ratios are often supplemented (Leach 1976) or substituted (Slesser, Lewis and Edwardson 1977) by ratios showing the produced weight of crude protein per unit of GER.

We understand from this that the ranking criterion is a sheer technical entity. This means that it does not contain any other consumer preference than saving finite energy. As Webb and Pearce (1975) point out this "introduces the idea that energy as a constraint on economic activity is more important than any other constraint" and that selection of policies with low energy input could very well mean that policies with high total resource costs were selected.

As we have seen earlier, EA rejects the price mechanism of the market system to act as signals for supply and demand of energy. With the ranking criterion chosen EA does not replace this system with any signal system of comparable sensitivity. It is also obvious that both Ei and Eo are non-homogeneous entities. Energy sources like oil, natural gas, coal and biomass have values for man in other relative proportions than their energy content. Buildings, machinery and cars also have values in other proportions than the Gross Energy Requirements for their production. The energy content of outputs like wheat and potatoes, beans and fish, meat and eggs also have vastly different relative values in human consumption than their relative nutritive energy values.

Important to note is that energy ratios do not account for the meaning of time in production and consumption. This is closely related to the treatment in EA of optimal use of finite resources, which requires a final section of its own. Our conclusion so far is that EA does not offer an optimality criterion more powerful than other available techniques to allocate scarce resources.

Fossil fuel, biomass and the optimal use of finite resources

Both as user of energy and as potential producer of biomass agriculture has a clear interest in how scarce fossil fuel really is and what is meant by an optimal use of this scarce – and in some time-perspective obviously finite – resource. EA practitioners mean that "economics has no real mechanism for coping with resource depletion" (Leach 1976, p. 4). When we turn to EA for help in economizing with the finite energy resource the only simple answer is: as fossil fuel is a finite energy source the best thing is to use as small an input as possible of it to make it last as long as possible.

As has been pointed out by among others Beckerman (1974) and Webb and Pearce (1975) this answer does not take into account at least four important circumstances.

The first is that all historical experience shows that estimations of current reserves of finite resources have been underestimations. This is the consequence of the fact that calculations of available reserves are based on current prices and that intensified prospecting and lower grade deposits become profitable when scarcity raises prices.

The second is that two important feed-back mechanisms start when supply cannot meet demand. The price will rise and make producers and consumers adjust their demand by decreasing energy consumption and substituting labour for energy. Also the technological development is redirected which in the long run means that the new technique is less energy-consuming than the old.

The third circumstance is that intergenerational comparisons of the utility of energy resources and of welfare are extremely complicated. Beckerman (1974) illustrates this by asking the following question: What is best . . . "that ten million families become better off during one hundred years in the future or that one hundred families become better off during the coming ten million years? How much of the former are we prepared to give up for a very uncertain chance to the latter?" (translated from the Swedish edition). In shorter time perspectives economic theory offers a well developed system for intertemporal addition of inputs and outputs which give more satisfactory results than EA when comparing investments in alternative energy systems.

The fourth point is also put forward by Beckerman (1974) when he asks: "If the finite energy sources will one day be depleted are we then really facing a catastrophe?" Man will then most probably develop new ways of life of a type we cannot imagine today. In earlier situations of this type agriculture replaced the hunter-gatherer culture.

NOTES

[1] I.e. Odum, Pimentel, Slesser, Leach.

[2] Pimentel et al. (1973) associated labour inputs with that part of total food intake which is assumed to be metabolized during working time. This means that the production does not need to pay – in energy terms – for food requirements outside working hours. Nor is it necessary to account for food requirements during childhood and old age, not to mention energy in clothing, housing and private transportation.

This means that Pimentel et al. in their EA hire a naked slave at 18 years of age and dismiss him at 65 and only guarantee his food for his working hours. The consequences of the accounting method are obviously absurd.

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DISCUSSION OPENING – STEWART H. LANE

May I begin by complimenting Professor Renborg on his interesting, important and timely paper. I am sure that the availability of energy and how the limited supplies of it should be allocated are matters of vital concern to all countries represented at this Conference.

In opening the discussion on this paper I should make it clear that I cannot claim any expertise in addressing the issues relating to the conservation and use of energy. However, Renborg's paper has raised a number of questions which I believe agricultural economists will need to give much more attention to in the immediate future. But first let me summarize very briefly what appeared to me to be the main thrust of his paper.

He described the approach used by the biologists (Energy Analysis) in determining the optimum use of energy resources in a society, especially as it relates to the agricultural sector. In the context of their analysis energy refers to the use of finite resources, mainly fossil fuels.

He contrasts this approach with the traditional one used by economists and draws attention to the limitations of the EA approach. He notes especially its disregard of the implications which restriction of energy use will have on the combination of factor inputs (land, labour and capital) and thus on economic efficiency and points out that the fundamental differences in these two approaches result in very different, often conflicting, energy policy recommendations.

Some of the major differences in these two approaches would appear to the following:

Firstly, EA views saving finite energy as the most important economic activity. Thus the rate of utilization of finite energy is the sole criterion by which one measures the desirability of any production process or energy policy. Economic analysis, on the other hand, tends to rely on the price mechanism as the regulator of economic activity. It assumes that consumer preferences operating through the market mechanism will result in the best allocation of resources.

Secondly, EA appears to attach little significance to the concept of time preference. For it the decision rule for energy use is simple and straightforward – "use as little as possible so as to make it last as long as possible". In contrast, Economics converts future income flows to present values. These discounted values are then used as the basis for evaluating alternative resource use patterns.

Thirdly, EA assumes there is little possibility, or at least attaches little significance to the possibility, of developing new and alternative sources of energy. Indeed the significance of a major existing resource (coal) is often minimized because of its deleterious environmental effects. This assumption leads biologists to recommend the substitution of labour intensive production systems for more mechanized systems.

I suspect that economists as a group are less pessimistic than the biologists concerning the possibilities of developing alternative energy sources whether it be nuclear, solar or other forms we are not yet aware of.

In the foregoing brief listing of the main features of the EA and economic approaches for evaluating energy use I have no doubt exaggerated the differences between them. However, I have done so deliberately on the assumption that by so doing, and by presenting them as a dichotomy, it will help to bring the key issues into sharper focus.

My reading of Renborg's paper leads me to wonder whether either the biologist's or the economist's approach is the right one, or whether a middle ground would not be preferable. It is a well known fact that North America uses a disproportionate share of the world's energy resources in relation to its population and to its developed energy resources. Irrespective of whether we can afford to purchase our energy needs at world market prices we are being told that unless we reduce or at least limit our consumption of the available energy supply, our share of OPEC energy supplies will be further curtailed. This suggests to me that factors other than purely market forces are important considerations in determining the allocation and rate of utilization of fossil fuels today.

Similarly, within our national economies we need to examine the criteria which should be used to allocate energy among alternative uses. Can we rely on the interplay of market forces and the price mechanism to do this job or should other criteria be used? For example, in our food system the major share of the energy used is consumed in the food processing and distribution sectors – not in primary production. Should governments intervene to ensure that primary producers receive preferred access to the limited supplies? Should preference be given to grain producers relative to livestock producers because of their greater efficiency in energy conversion?

Agricultural economists will need to address a host of issues related to energy utilization and conservation in the years ahead. It seems safe to assume that energy related issues will be a dominant factor affecting the future pattern of rural change.

GENERAL DISCUSSION – RAPPORTEUR: KWAKU ANDAH

The first speaker felt that the paper had guided the audience to an analysis of the future use of energy but asked if the speaker had included horse power in his analysis. He felt that horse power was very important in energy analysis and if the speaker had not taken account of it then his energy input and output ratio would be incomplete.

Another speaker reminded participants that energy analysis was a special case of the material balance approach and should be considered merely as a tool of analysis. It should not be forgotten that the crucial aspect of energy was that we need energy to adjust ourselves to the catastrophe of energy systems. Professor Renborg was then asked what suggestion he had for the future use of energy with special reference to the ecologist and economist.

The final speaker thanked Professor Renborg for a most helpful paper but felt that agricultural economists (or economists in general) should spend much more time and care in discussing their points of view and the relevance of their skills with other (physical and biological) scientists who appear better able to communicate with each other than with social scientists. In addition to developing an analytical approach to energy problems in agriculture, an approach which can be refined within the profession, was it felt that, as a profession, agricultural economists pay sufficient attention to communicating with other scientists concerned with the energy problem?

In reply, Professor Renborg reiterated that he had only attempted to elaborate what ecologists had been saying and to relate these with the economists' role in solving these problems. He agreed that other considerations like economic and ecologic factors were all important factors in energy analysis. Since individual people have different attitudes one was bound to have different levels of appreciation as to how various factors are involved in energy analysis. He agreed with the discussion opener that market prices today do not adequately take into account the utility for future generations.

Turning to floor contributors, the speaker agreed that horse power was important but note should be taken of the fact that horse power is decreasing in importance in recent years. It is not good analysis to consider production alone but account should also be taken of food processing.

He assured the audience that whenever development takes place we always experience decreasing resources of our energy. In so far as the energy problem is concerned, the speaker stated that attempts *are* being made by agricultural economists not only to communicate with other scientists but also to develop a multi-disciplinary research approach to solving some of the problems of energy.

Participants in the discussion included: Adolf A. Weber, David Torgerson and David A.G. Green.