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BENT SØRENSEN

PLANNING AND POLICY CONSIDERATIONS RELATED TO THE INTRODUCTION OF RENEWABLE ENERGY SOURCES INTO ENERGY SUPPLY SYSTEMS

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The paper deals with elements of a methodology for long-term energy planning with particular reference to the introduction of renewable energy technologies, and a methodology for comparative assessment of energy systems. The discussion comprises technical and economic viability, indirect economy, environmental and social impacts, as well as the influence of uncertainty on the assessment. The role of renewable energy in future energy supply systems is discussed, with separate treatment of the situation in developing countries and in highly industrialized countries. Finally, mechanisms for the mobilization of technical and financial requirements are touched upon.

Background issue paper on

PLANNING AND POLICY CONSIDERATIONS RELATED TO THE INTRODUCTION OF RENEWABLE ENERGY SOURCES INTO ENERGY SUPPLY SYSTEMS

prepared by

BENT SØRENSEN+

for

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+address: Roskilde University Center, Bld. 17.2
P O Box 260, DK-4000 Roskilde, Denmark

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Introduction

1. One feature of the ongoing technological development is an emergence of a range of new energy conversion systems and devices that could form part of such systems. Some of these devices aim at increased efficiency in the use of presently employed energy sources, while other devices aim at tapping novel sources of energy. Among these, the renewable energy sources play an important role. Several among the new energy conversion techniques have been developed to a point, where they are claimed to be technically viable for introduction into current energy supply systems. However, this does not mean, that they are actually introduced. The reason may be lack of economic viability or inertia in moving away from the present types of energy supply systems. Economic viability in itself is a complex issue, involving expected future trends of alternative fuel prices and a political weighting of indirect economic factors, such as supply security, foreign currency expenditure, etc.

2. It follows that a methodology must be established, for the comparative assessment of different energy supply systems. This methodology must reflect the characteristics of the different technological solutions considered, also in cases where the structure of alternative systems is very different. It also must take into account the conditions set by the type of society, in which the contemplated energy systems are envisaged to function. Preferably, a common methodology should be formulated, which would be applicable for societies at different stages of

development, rather than devicing different methodologies for industrialized and developing regions.

3. Once a desirable energy system has been identified, for a given society, the question of implementing such a system must be addressed. The necessary timescale has to be established, and a policy concept would have to be followed by a detailed planning effort. A smooth transition from the present system to the chosen future one could demand a very extended time horison, but the more undesirable the present system is judged to be, the more emphasis may be placed on enhancing the transition. A key element in the planning effort would then be the mobilisation of financial and technical resources for the purpose. In this respect the developing countries would be particularly pressed, because of their need for increased energy supply to ensure the development process. For the developed countries, the need for an expanding supply of energy may be less urgent, or at least the energy growth rate is by most planners expected to become considerably less than the one needed to accomplish development in the poorer regions of the world.

Comparative assessment of energy systems

4. A full comparative assessment of different energy systems must consider all impacts of each energy system on the society, in which it is considered implemented.

Among these impacts are usually some that may be labeled positive, while other ones are labeled negative. Some impacts may be of a mixed character: e.g. the discharge of waste heat to a water body may improve living conditions for some of the flora and fauna of the water body, but may deteriorate living conditions for other parts of the biota. The positive impacts of energy supply is primarily the benefits associated with the tasks, for which the energy is applied. These include production of services and goods. Some of the positive effects may be indirect, through a general stimulation of economic activity, through stabilisation of energy supply or through positive changes in attitudes towards a given society. The negative impacts of energy systems may include the possibility of accidents and adverse health effects, a degradation of the environment and the introduction of undesirable working conditions, as well as indirect impacts on social and mental well-being.

5. Some of the impacts of an energy supply system can be quantified, other ones not. Of the quantifiable impacts, some may be evaluated in monetary units, other ones not. A complete assessment of a given system involves a political evaluation of all the impacts, and a comparative assessment of different system choices involves a weighting of the impacts of the systems against each other. Since the impacts of different systems according to the definition used here may be in-

commensurable, such a weighting involves value judgements, i.e. a political decision. If the subset of impacts lending themselves to economic interpretation is considered in isolation, the term "full costing" is applied, in order to make a distinction from the direct costs alone.

6. A comparative assessment of energy systems must deal with two major obstacles: the existence of unacceptable impacts and of impacts with large uncertainties. The definition of impacts which a society will consider unacceptable should be made open to democratic debate. Examples may be catastrophic accidents of disruptive size and major impacts occuring with a time- or site-displacement (so that other - eventually future - societies would bear the burden without sharing the benefits). Once a society has agreed, which impacts it considers unacceptable, it would accept only such designs of energy systems, for which unacceptable impacts are absent. The problem of uncertain impacts also may be dealt with by excluding energy systems with uncertainty intervals stretching into the unacceptable regions. More problematic is the intercomparison of different systems with large uncertainties of different nature. Again the rules for comparison should in such cases be derived by full public participation, since such rules are necessarily politically debatable. Under the heading uncertainty should also be considered the possibility of future changes in the attitude to selection of acceptable and unacceptable impacts. Elements to the methodological approach to com-

parative assessment of energy systems may be found in chapter 7 of Sørensen (1979), and in the work of the study groups by OECD (1981) and UNEP (1981).

7. In identifying the impacts of a given energy technology, the full energy cycle must be considered: from construction of equipment, inputs of energy and materials, extraction and refining of fuels - if such are involved - through operation under normal and abnormal conditions, to eventual dismantling of the equipment and disposal of any bi-products emerging as a result of the energy conversion scheme. Furthermore, impacts may arise from the use of the energy produced, from the institutions created for management of the supply system, and so on.

From marginal modification to complete energy transition

8. If only a small part of an existing energy system is replaced by a new one, the evaluation of indirect impacts is simplified. In this case, the gross social structure is given, and impacts associated with e.g. energy or raw materials inputs to the new system part may be evaluated using the existing production methods, for which impacts are in principle known or could be measured (except for the possibility of latent time-displaced impacts)(Hamilton, 1980). The impact on employment, balance of foreign payments etc. is similarly

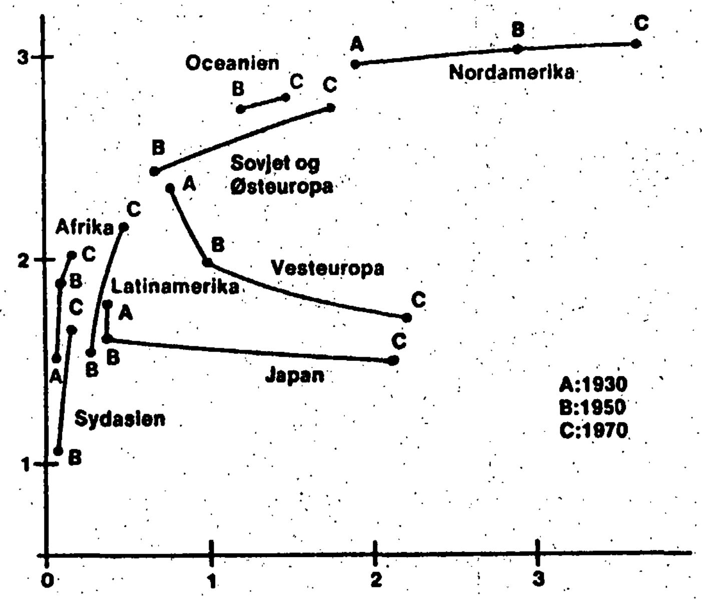
determined, and social impacts - for instance through changes in energy use styles - would be accessible through means such as interview studies.

9. As the change in energy system becomes more than marginal, it would no longer be acceptable to base the evaluation on the present surrounding system, i.e. the presently employed methods of providing process energy, materials, etc. for the new energy technology, and the present social structure as an indicator of the impact, that the new energy technology may have on its surrounding society. As the energy system changes in a major way, new approaches to obtaining energy and materials inputs will come into play. This does not necessarily mean, that each new energy source will provide the energy for its own establishment, because it may furnish other forms of energy than those, which it requires during the construction phase, but the changing mix of energy sources will define the energy inputs drawn upon at any given time. Similarly, a dynamical approach to materials provision, and to social impacts, must be used. This is highly demanding, since it demands a model for the social development to go along with the plan for replacement of the energy system. And, clearly the energy system does not define the social structure (although it may be one factor influencing it), so it may be required to view the emerging energy system in the light of several social development models, in which the same energy

system may give rise to different impacts.

10. Traditionally, the benefits of energy production has been discussed in terms of the gross national product (GNP), noting that in periods of increasing energy usage, GNP has usually also been increasing. To determine, if there is a causal relation, and if so its nature, a more thorough investigation must be made. Fig. 1 indicates the development in energy spent per unit of GNP produced in different parts of the world, during the period 1930-1970. It is noted that the levels reached by Western Europe and Japan are much lower than those of USA, USSR, Eastern Europe and Oceania, and that the specific energy use in Western Europe and Japan has even declined during the period 1950-1970, despite falling fuel prices. Selected figures for the most recent period indicate a new decline in energy use per unit of GNP for industrialized countries, i.e. the effect of more efficient use of energy in response to the sudden price hikes. In other words, the GNP has shown some elasticity with respect to increasing energy prices, at least for some countries. It would be expected, that given some additional time, and means of financing, industry and other energy use sectors could improve energy use efficiency much more, leading to a further "decoupling" of energy use and GNP (Sørensen, 1975; EEC, 1979; Colombo and Bernardini, 1979, SERI 1980).

Primary energy use
per unit of GNP



GNP per capita

Fig. 1. Development in energy-GNP ratio 1930-1970, for North America, Oceania, the Soviet Union and Eastern Europe, Western Europe, Japan, Latin America, Africa and South Asia (Danish Ministry of Commerce, 1975)

11. The gross national product is a measure of those activities in a society, for which money is payed. It thus increases if the same task is performed in a more cumbersome way, provided that the steps involved are part of the money economy. It follows, that living standard (possession of material goods) and goal satisfaction (related to common human goals and to goals specific to individual cultures) will be little correlated with GNP. Growth in GNP may be associated with more wastefull ways of production, with increase of administration and with human settlement types that increases the demand for transportation (cf. Mishan, 1969; Eriksson, et al., 1974). A structural change is society may imply, that the fraction of GNP contributing to living standard and goal satisfaction declines, even if the absolute values of living standard and goal satisfaction may still increase. At the extreme, a GNP increase may be associated with declining real standards. It follows from the definition of GNP, that singular increases in GNP may occur (without increasing standards), whenever some area of activity can be moved from the non-monetary part of the economy to the money economy. E.g. when exchange of money is introduced for activities such as child care, looking after the elderly, household chores, entertainment, etc. (Hvelplund, 1980).

12. Applied to energy use, it follows from the above, that a declining energy use per unit of living standard

or goal satisfaction (if quantifiable!) can be achieved either by improving the conversion efficiency or by changing those parts of the social structure reaponsible for poor translation of energy and other inputs into improved real standards. Such considerations must replace the direct comparison of energy production alternatives, because different energy systems may lend themselves more or less easily to structural improvements affecting the energy end use. Furthermore, it will be relevant to consider as alternatives on one side additional energy production, and on the other side investments in alterations reducing the end use energy, such that the alternatives lead to identical living standard and goal satisfaction. Or more logically to assess the impacts of identical investments in these alternatives, since the assessment of positive and negative impacts is what ultimately defines the goal satisfaction in the broadest sense, including material and non-material goals.

13. The main areas of potential (negative) impacts of energy systems may be classified as related to the physical, the human and the social environment. The physical impacts include modifications of micro- or macro-climate, e.g. caused by carbon dioxide or heat releases, deterioration of terrestrial or marine ecosystem (e.g. by disposal of pollutants) and resource degradation (such as landscape effects of strip-mining). The impacts may be site-displaced (air pollution traveling across national

borders) or time-displaced (migration of radioactive waste or other pollutants from burial site to drinking water sources), and the impacts may depend on complex interactions exhibiting treshold effects (triggering of Arctic ice melting or reversely extension of glaciation).

The effects on individual human beings include health effects caused by work or public exposure. The causes may be safety related (accidents), they may be noxious substances, noise and stress-producing working conditions, and they may be radiation exposure. In the case of accident risks a special problem is presented by events with small probability but large consequences. This extents into the social impacts, since such events present not just individual but additional social risks, if the consequences are disruptive, or if the social risk perception is enhanced by the character of the accident consequences. Examples of impacts on the social environment are modifications in the distribution of burdens laid on different social groups (preponderance of poor people living close to polluting power plant, while the power-consuming high-income groups have moved away), altered employment opportunities, shifts between different types of regional development (e.g. centralized versus decentralized), changes in control structure (establishment of novel institutions, perceived need for anti-terrorist protection of energy installations, etc.), demand on foreign currency and imported technology, modification of supply security (which may mean different things for the individual and for society, resilience meaning access to more than one supply option, in addition to reliability of a given energy supply system). And to conclude the list, any other interference with a society's range of goals will constitute an impact on the social environment.

Technical viability of renewable energy systems

14. In the stream of scientific and popular information on new technology, and in particular on renewable energy technologies, it is often difficult from a first impression to judge, whether the technology described is proven, is close to or far away from technical viability, or even is merely an interesting idea. Only proven techniques for converting renewable energy sources will be dealt with in the following discussion, i.e. devices which have shown technical viability on a realistic scale, but not necessarily devices that have been commercialized, or for which final designs have been reached.

15. Renewable energy conversion system, that have been in use for some time, include flow- and reservoir-based hydro power, steam- or hot aquifer-based geothermal energy for power or heat (geothermal energy is usually counted with the renewable sources, although it derives from an exhaustible - albeit large - reservoir), wind turbines

(such as the conventional horizontal axis rotors), wood-fuel (including charcoal) and flat-plate, concentrating and photovoltaic solar collectors for heat and power. Conversion of manure and organic waste to biogas has functioned for some time, and industrial fermentation of certain crops or crop residues to ethanol is being revived for energy purposes. Other biomass conversion techniques, such as methanol production from wood, has been proven but is not in widespread use. This is also true for tidal energy in suitable bay locations.

16. Energy supply systems based on renewable energy will not approach autonomy unless suitable energy storage devices are made available (cf. Sørensen, 1979, chapter 5-6). Proven storage systems in actual use comprise pumped water, batteries and hot water heat storages, and at suitable locations compressed air storage. Storage using hydrogen, flywheels, chemical phase change and advanced batteries is possible, but not in widespread use. Superconductive storage has been succesfully used in research facilities, but is not otherwise in use.

Economic viability of renewable energy systems

17. The economic viability of one of the renewable energy systems listed above as technically viable should in the most general form be assessed by a total impact comparison of alternatives, under the conditions set

by the society considered, i.e. the full comparative assessment outlined in the paragraphs above. However, one important component in the assessment is the direct cost of alternative means of providing energy. By "direct cost" is meant the life-cycle (of equipment) cost of construction, operation, maintenance, any running materials input (e.g. fuels) and eventually dismantling costs and specifically paid external costs (e.g. for waste treatment or pollution control). This total direct cost is usually given relative to the total amount of energy provided over the life of the equipment, expressed e.g. as fixed \$ (refered to a single year, i.e. uninflated or "real" \$) per kWh or per J (joule). The capital cost of construction is often quoted for energy systems, but it clearly is insufficient to judge upon the viability. By "viability" is often understood competitiveness with some reference alternative, or with the cost of currently provided energy. The latter is a dubious approach, since the very reason for wishing to introduce new sources of energy usually is, that the present system cannot provide the energy needed in the future. If the existing system should be used to assess viability, the marginal cost of the latest unit added should be selected, and if the existing system is based on fuels, a model for the future price development of fuel must be used. It is therefore evident, that a statement on the viability of a new energy system has to be associated with considerable uncertainty. Below, direct energy costs will be estimated for a number of renewable energy systems.

HYDRO POWER

18. Large-scale hydro power installations have traditionally been considered one of the cheapest ways of producing electricity. However, the installation cost is extremely site-specific and depends on dam requirement and on reservoir developing expenditures much more than it depends on the costs of turbines. The physical characteristics of the would-be reservoir may lead to extensive landscape restauration costs and costs of siltation reduction. If the area is inhabited, relocation of people may be required, with both monetary and human costs. If the site is remote relative to existing utility grids, new transmission lines may constitute one of the largest cost items.

19. Production costs at existing hydro power plants in the US range from 0.004 to 0.025 \$ per kWh (1977-prices) (Todd et al., 1977). New installations including site development costs 500-3000 \$ per kW installed power. In Norway the production cost is even lower, selling prices being about 0.01 \$ per kWh (including transmission and overhead costs) (NORDEL 1979). For new plants the cost is estimated as 0.025 \$ per kWh, again including delivery to a block of customers. Fig. 2 illustrates the high viability of hydro plants relative to conventional fuel-based power plants. Small plants (1-10 MW) have about twice the construction cost of the large hydro installations, and mini-size plants (of the order

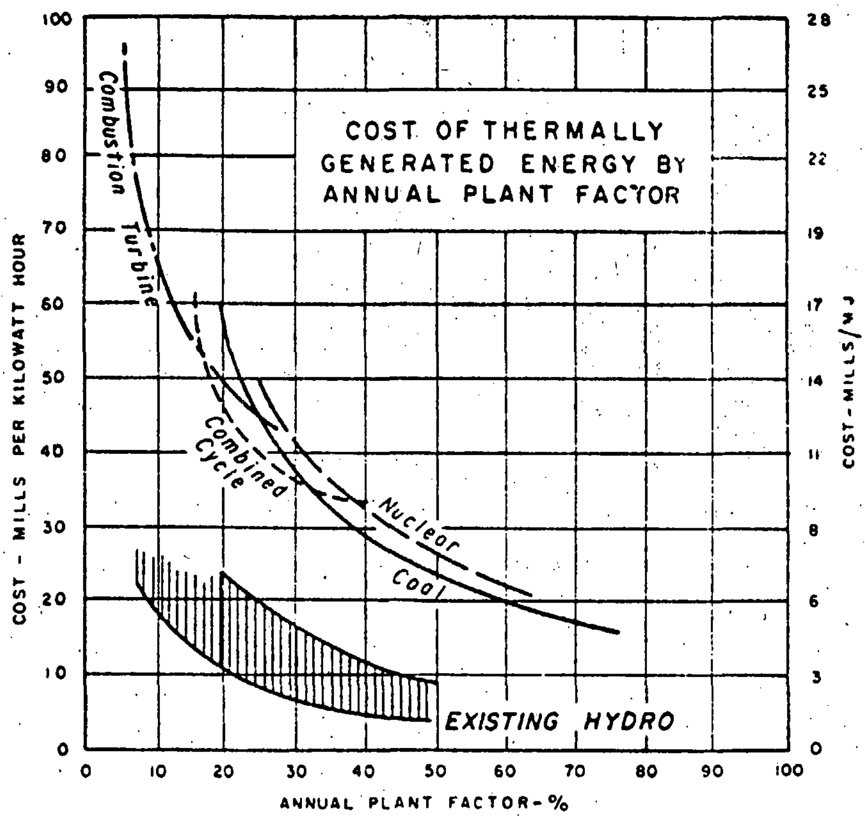


Fig. 2. US costs of thermally generated power and of hydro power as function of plant factor (fraction of year during which plant is operating). The costs are in 1977-$ (Todd, et al., 1977)

of 10 kW) even higher. However, some of the smaller plants are based on river flow or small streams, without intention of regulation. This makes the hydro power production uncontrollable (except that it may of course be switched off) and hence less valuable, but on the other hand the cost may go down substantially, since no reservoir developing costs are involved. If battery or other storage has to be added in order to provide power any time on demand, this advantage will again be upset.

GEOTHERMAL ENERGY

20. Geothermal steam or hot water may be used for electricity production in a thermal power plant, or may deliver heat to a district heating system. The installation costs include those of exploration, of drilling, of the extraction system and the converter, and finally of possible effluent disposal equipment. For many existing plants, effluents are released to the environment, eventually after treatment. The capital cost of such installations is estimated to be in the range of 600 to 1700 $ per kW, leading to a power cost of 0.015-0.043 $ per kWh (UNERG, 1980). In the future, reinjection of effluents may be required, possibly with the requirement of one additional drilling hole. For district heating use, two holes are always drilled, so that the hot water from the well, which typically contains corrosive pollutants, is floating in a closed circuit (Clot, 1977). It is estimated, that plants based on concentrated underground

flows of heat will remain highly competitive with fuel-based alternatives.

WIND ENERGY

21. Table 1 shows a recent assessment of the cost estimates, that can be derived from the present experience with larger utility connected wind turbines producing electricity. The report concludes: "Major progress in the wind power programmes of a number of developed countries now seems to assure the economic viability of large-scale wind power projects over the next few years"(UNERG, 1981). This implies, that viability is ensured relative to a cost of reference above some 0.04(1981-)$ per kWh, which then represent the estimated cost of conventional power generation averaged over the next 20 years (but in fixed prices). The table indicates that cost increases as the turbine unit size goes down. This is not fully supported by the experience with commercial wind turbines in the 50 kW range, for which customers find economic viability ensured today with corresponding power prices being around 0.024 (1979-)$ per kWh (Sørensen, 1980).

22. The electricity-producing wind turbines considered above are considered attached to a utility grid system of which they constitute only a minor fraction (under 25%). For larger share, energy storage is required, e.g. by coupling to an existing hydro power system with sufficient reservoirs, if available. Autonomous systems

TABLE 1.

	Replicate Present Prototypes	Present Types if Mass Produced	Advance Designs if Mass Produced
Large Systems	$0.08 - 0.10/kWh	$0.05 - 0.06/kWh	$0.035 - 0.045/kWh
Medium Large	$0.10 - 0.25/kWh	$0.08 - 0.20/kWh	$0.05 — 0.10/kWh
Medium and Small	$0.15 - 0.50/kWh	$0.10 - 0.20/kWh	$0.05 - 0.10/kWh

Assumptions: Site mean wind speed 6.3 m/s; 18% fixed charge rate; 20 year amortisation period. Quoted costs do not include the reduction possible with tax credits. Mass production implies the manufacture of 100 machines or more. Costs quoted are in 1980 dollars.

Table 1: Wind energy cost estimates and goals, for electric power producing horizontal axis free-stream turbines (from UNERG, 1981)

for remote applications (e.g. in regions without utility transmission grid infrastructure), energy storage or back-up must be provided. The extra cost of a diesel generator for this purpose will in many cases be less than establishing connections to central grid systems, and the wind turbine will be payed for by the fuel it displaces. The same holds for non-electric applications, e.g. for water pumping. If diesel-generators is the alternative, and the fuel price is 0.8 $ per litre, the reference price is 0.5 to above 1 $ per kWh of hydraulic power, the smaller figure applying to diesel sets of larger sizes (25-100 kW) and the higher one to small diesel engines (around 3 kW). The cost of hydraulic power derived from wind generators adapted to the prevailing wind regime is expected to range from 0.25 $ per kWh (hydraulic power) for large units in average wind speeds above 5 metres per second, up to 1.35 $ per kWh for small machines at sites with average wind speeds of 3 metres per sec. At 4 metres per sec. the cost has already dropped below 0.50 $ per kWh (UNERG, 1981).

BIOMASS ENERGY

23. Prices of woodfuel differs considerably between different parts of the world. However, it is used because it is the least expensive alternative at a given locale. Wood-fuel may be in the form of fuelwood (stemwood, wood bunches, scrap wood), charcoal or other collectable re-

sidues, and it may be traded commercially or collected by the users on the commons. The production cost may be taken as the cost of reforestation and management of the bio-resource, independent of whether such a program is actually undertaken. This cost lies in the range of 10-30 $ per ton of dry wood, leading to an energy cost of 0.002-0.007 $ per kWh of thermal energy associated with burning (1976-level, based on Johansson and Steen, 1978). Commercial sales prices of wood in Sweden correspond to twice the upper limit production costs just quoted. It follows that use of wood for energy purposes, including electricity generation, is highly competitive in countries with a large forest area available per capita (e.g. Sweden and parts of New England). In many other areas, the use of land for forestry is in competition with other land uses, and the above costs should be augmented by an amount reflecting the value of the land in alternative applications.

In evaluating the economy of woodfuel, the type of application should be considered. While wood is everywhere used for construction, about 75% of the total wood consumption is in the developing countries (Openshaw, 1978), primarily used for cooking, insect control, heating and process heat, mainly in minor industries. The cost is here from nothing to about 0.01 $ per kWt of burning value, not counting family labour in wood collection for domestic use. Even the upper price quoted may seem very cheap, but often the equipment used for end-use conversion (stove, etc.) has such a low efficiency, that the total cost for a given task is even higher than it would be in the industrialized countries with expensive fuels but efficient equipment.

24. The one-chamber biogas plants in extensive use in India is estimated to cost 340 $ for a plant producing 3 cubic metres of gas per day plus 7 tons of composted manure annually. This yields an energy price of 0.008 $ per kWh of biogas, but about half of this cost is regained by valuing the fertilizer biproduct (Khadi & Village Ind., 1979). A more sophisticated two-chamber design considered in Denmark is estimated to lead to a biogas price of 0.06 $ per kWh, which is considered competitive with alternatives for heating the farm living quarters, with a pay-back period of 5 years (Bro, et al., 1977).

25. Biomass-derived liquid fuels include ethanol and methanol. The largest ethanol production program is in Brazil, where it is used to reduce oil imports, mainly for the transportation sector. Its value is therefore that it displaces imports, because it can be produced with materials (including energy inputs) of domestic origin. At present, the energy inputs are nearly equal to the energy output (Hopkinson and Day, 1980). The biomass basis is sugarcane, and it has been pointed out, that at present sugar prices, Brazil could obtain a

larger positive contribution to the foreign payments balance by exporting its sugar than by producing ethanol (Yang and Trinidade, 1980). However, sugar prices are fluctuating and may decline, whereas oil prices are expected to increase monotonically, so that long-range considerations, as well as supply security aspects favour the decision of Brazil to go on with the alcohol fermentation programme. As for methanol, no large-scale production facilities are operating, but it is expected, that a net energy of 30-50% of the energy in the biomass (wood) can be obtained as methanol, and that a cost around 0.17$ per litre is feasible(Svensk Metanolutveckling, 1978). This corresponds to 0.036 $ per kWh of methanol, which is not competitive relative to the production costs of petroleum products, but is competitive relative to the current sales prices of petroleum products that methanol would be replacing (gasolin and diesel oil), assuming same distribution costs and taxes in the consumer country. The difference is royalties and profits above standard mark-up rates in the oil case.

SOLAR ENERGY

26. Flat-plate rooftop collectors are used to provide hot water and space heating. Current installed system costs are in the range of 200-500 $ per square meter of collector. The energy cost depends on geographical location (insolation, heating need) and usage mode. For

pure hot water systems, heat costs of 0.02-0.05 $ per kWh have been obtained, while for residential space heating and hot water systems, the range is 0.03-0.07 $ per kWh of heat, at different locations in the USA (SERI, 1980). Tax credits have not been considered in these estimates. The solar system provides only part of the needed heat, the fraction being 27-92% for the US examples. Compared with electric heating, all the systems considered above are economical, but relative to other conventional sources of residential heating (such as natural gas in the US), only the installations in the lower end of the cost range are viable, at present fuel prices.

27. Various kinds of concentrating solar collectors may be used for producing heat at temperatures higher than those required for residential heating. Applications are as industrial process heat or for operation of cooling and refrigeration systems. Figure 3 gives an overview of the technologies and their temperature achievements. The collector costs are higher than for flat-plate collectors, and some systems require tracking of the direction to the sun. System costs have been estimated at 500-800 $ per square meter (Brown, 1980), with annual system conversion efficiencies of 30-50%. Improvements in materials and designs are expected to be possible, and they are necessary if economic viability is to be accomplished.

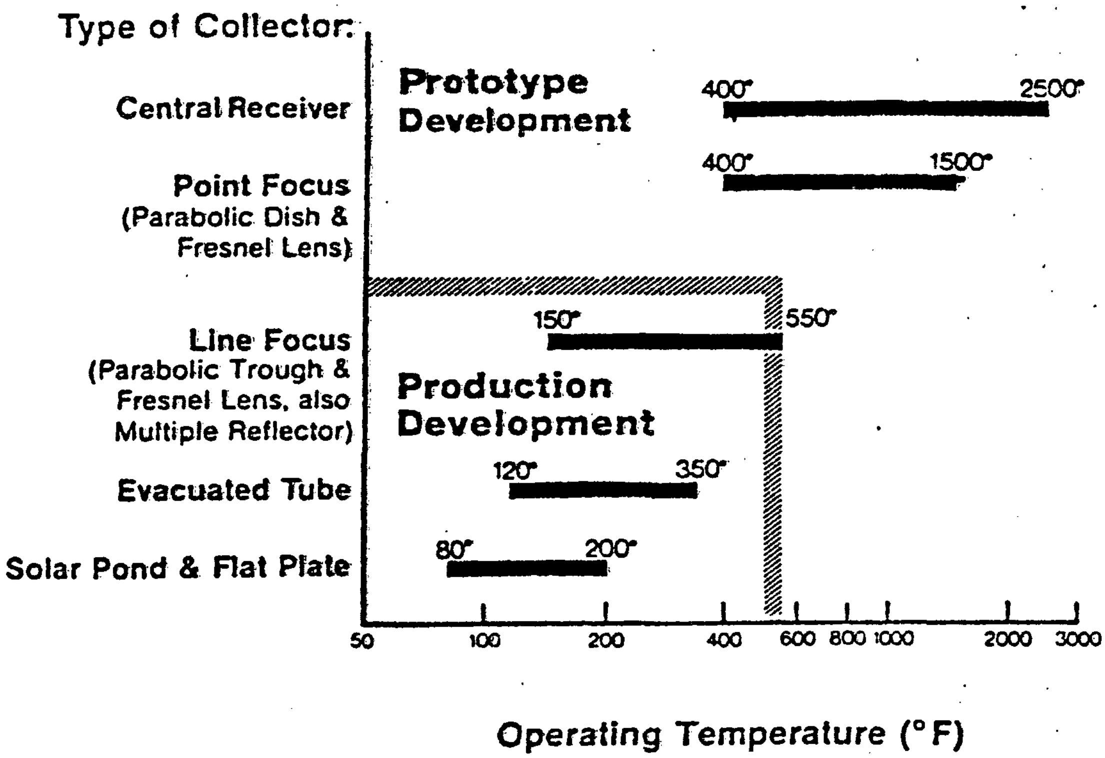


Fig. 3. Practical operating temperature ranges of several types of Solar thermal collectors for industrial process heat (SERI, 1980)

28. Photovoltaic production of electricity is a technology in rapid development. When the terrestrial applications of solar cells (derived from space technology) started to gain momentum in the early 1970'ies, the cost of the cell itself was about 100 $ per watt of peak performance. As illustrated in Fig. 4, this cost has now fallen to below 10 $ per peak watt, and is expected to reach values below 0.5 $ per peak watt towards the end of the present decade. The solar cells may be mounted on rooftops, or may be installed in large utility-type systems on supporting racks. The system costs are presently around 20 $ per peak watt (Fig. 4), but are expected to get below 2 (1980-)$ per peak watt before 1990. Even in this case, the electricity price will be 0.1 $ per kWh or more, because of the low capacity factor (the annual average power level is only 10-20% of the panel peak power). Thus for a while, photovoltaic power generation will only be economically viable for particular applications (e.g. in remote areas, where transport of fuel is expensive and high reliability under unattended conditions is required), but if the cost reduction trends continue beyond 1990, solar cells may be an important component in electric power generation. If it becomes a major component in utility systems, energy storage facilities will be required, as in the case of wind power. At high latitudes the insolation is poorly correlated with power use, so here very sub-

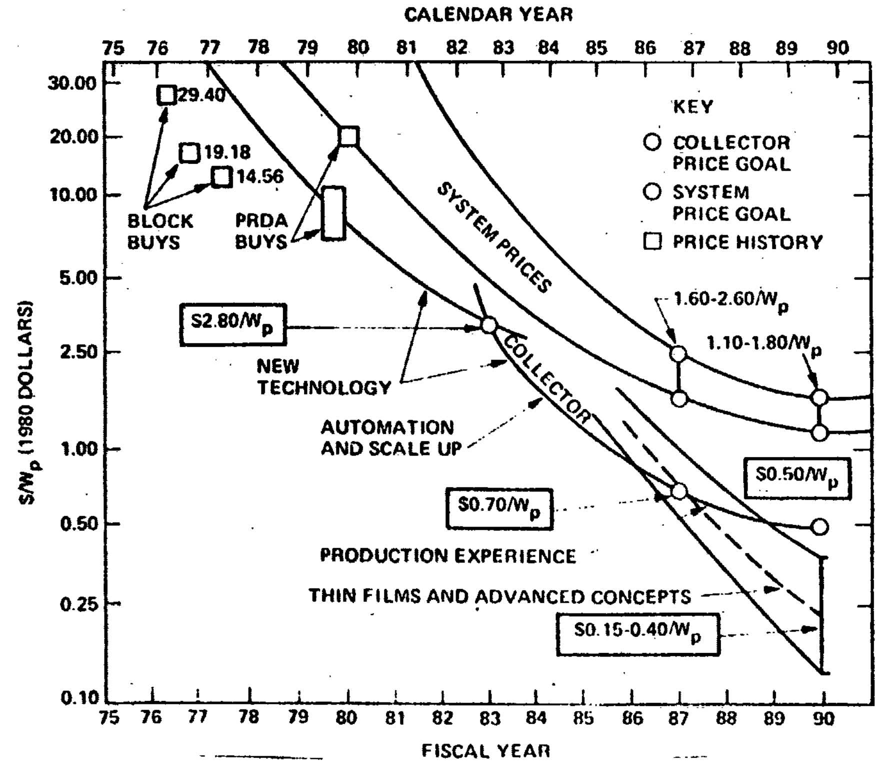


Fig. 4. Achievements and future price goals of the US photovoltaic programme, expressed as $ per peak watt for solar cells alone (lower curves) and for total power-producing systems (upper two curves)(US Dept. of energy, 1980)

stantial storage sizes will be required.

PASSIVE SYSTEMS

29. Building heat comfort can be achieved not only by active energy-providing systems, but also by a number of "passive" measures. Among these are passive solar systems (special collector-walls, windows with insulated shutters, etc.) and load-affecting building components (insulation, air infiltration control and heat exchangers, etc.). For new buildings, passive energy systems can be made part of the design, while for existing buildings, various degrees of retrofitting is possible. The assessment of economic viability for these systems is similar to that of energy supply systems, except that here the annual energy saving is to be compared with the system cost (charge on capital investment plus maintenance and operating costs, if any). Fig. 5 shows the incremental cost of saving an additional unit of annual energy for space heating by retrofit as well as at construction of a new building, under Danish conditions. Measures below the dashed line are economically viable with a capital charge rate of 18% and current residential heat prices (0.045 $ per kWh of input to boiler unit). Fig. 6 shows the result of a similar calculation for an average house at an average location in the USA, considering retrofitting of one-family dwelling. In judging viability of these measures, it should be kept in

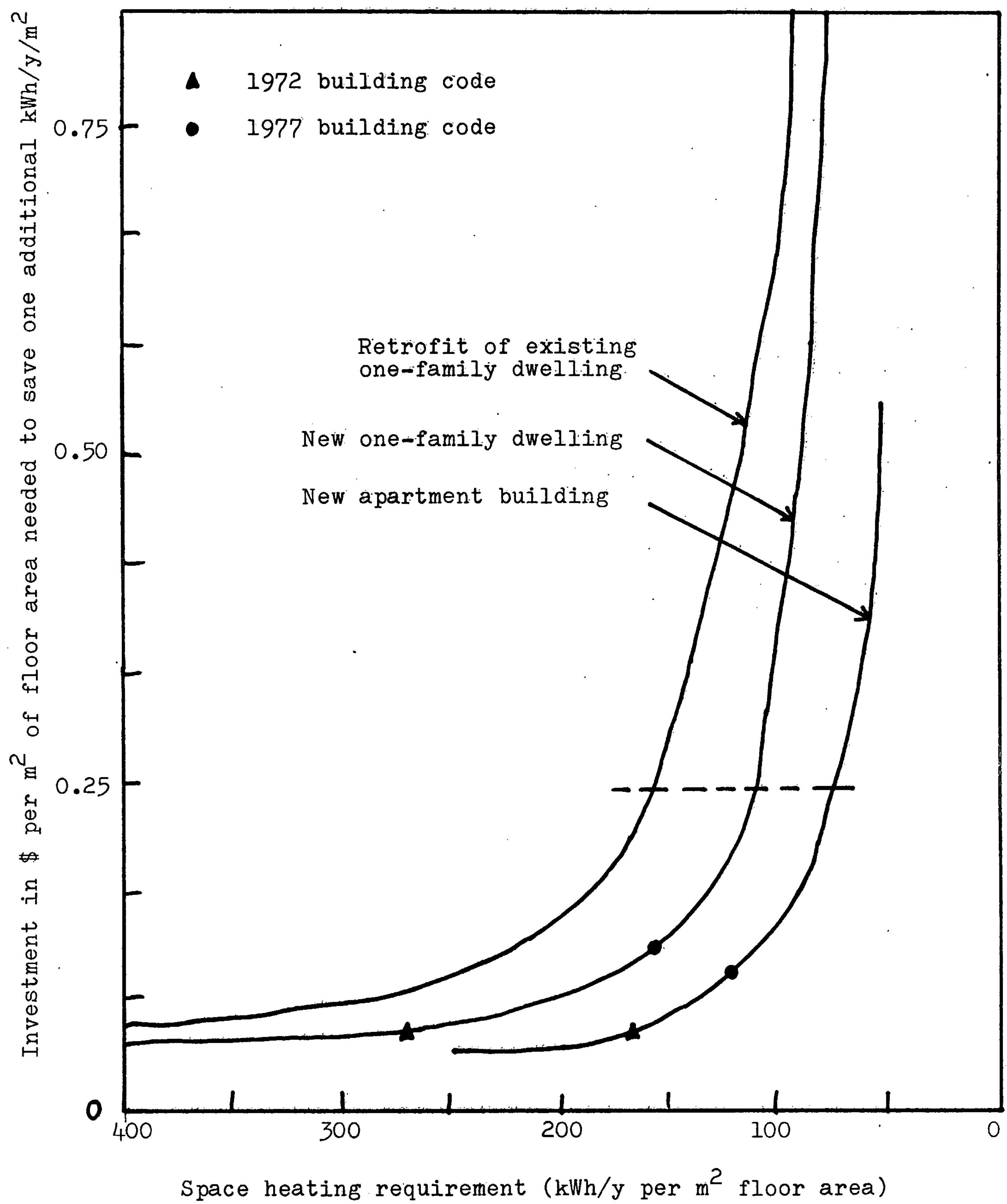


Fig. 5. Incremental cost of saving one kWh/y/m^2 extra, for Danish one-family dwellings (new construction or retrofit) and apartment buildings. The dashed line indicates the capital investment, which at 18% charge will pay for 1 kWh at 1980 prices (based on Nørgård, 1979)

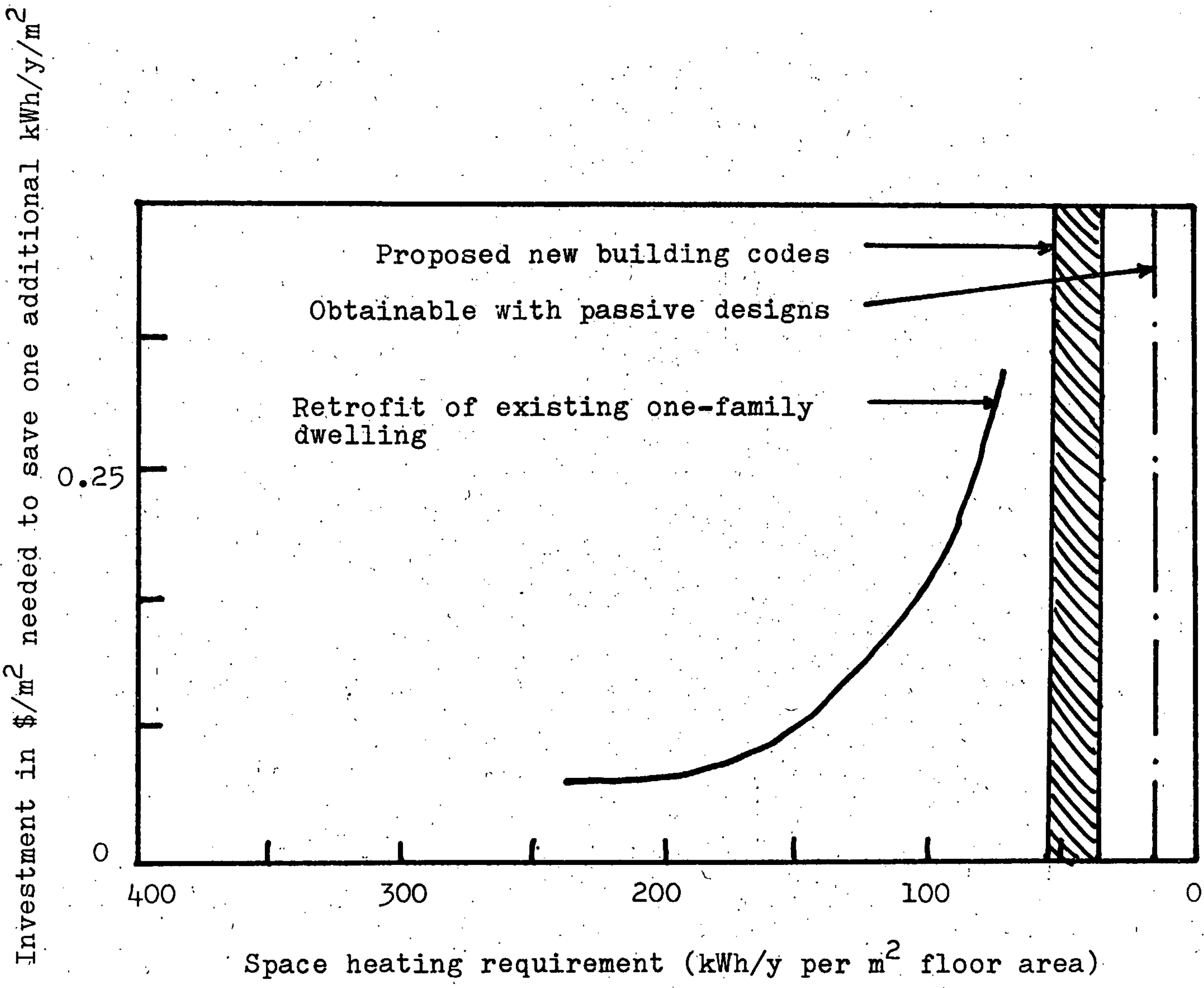


Fig. 6. Incremental cost of saving one kWh/y/m^2 extra by retrofitting of US one-family dwelling on average location (4762 Fahrenheit degree days), the work being done by contractor (based on Rosenfeld et al., 1980 and SERI, 1980)

mind that US fuel prices are hardly half of the Danish values. On the other hand, capital charge rates are also lower.

30. Building heat comfort is not the only area, where an economical assessment has to consider on equal footing the provision of energy and the improvement of efficiency in energy use. Electric appliances can be improved, usually by greater efficiency introduced at the time of replacement (useful life for most appliances being much less than for buildings). Several such measures are economic today (Nørgård, 1979), the same being true for improved mileage of automobiles. Generally the trends of capital investments needed for additional efficiency improvement will look like those of Figs. 5 and 6, as function of the improvement already obtained. In industry there are similar possibilities, with a major area of improvement being associated with cascading of process heat from higher to lower temperature processes. In the same category is also co-generation, where electricity use is combined with heat-generation (what would otherwise be waste heat associated with thermodynamic engines) for use in the plant or as district heating elsewhere (see e.g. Sørensen, 1981).

Possible role of renewable energy in future energy supply systems

31. In order to assess the possible role of renewable energy sources in future energy system, a resource estimate has to be performed. This is attempted in Table 2, giving average energy flow rates for the renewable sources of flow type, but energy contents for sources of reservoir type and for the depletable resources listed for the sake of comparison. The estimates of recoverable amounts are gross figures (not including conversion losses) and they may be associated with impacts (environmental, etc.), which some societies will find unacceptable. The maximum acceptable contribution from renewable resources may therefore be only a fraction of the recoverable amounts, by the technology of conversion presently contemplated.

32. Furthermore, an idea of the future need for energy should be established. The present global rate of energy conversion is on average about 8 TW, corresponding to roughly 2 kW per capita (one TW - terawatt - is 10^{12} watts). In the US, the present rate of energy use is over 10 kW per capita. If the World population stabilizes at 10 billion and they all were to use energy as the present average American, an energy usage rate of 100 TW results. It is not conceivable, that this rate of energy conversion could be achieved with acceptable impacts using presently known technology. The alternative following from the discussion in previous sections is to move towards more efficient use of energy, im-

TABLE 2. ESTIMATES OF GLOBAL ENERGY RESOURCES.

Resource	Estimated recoverable amount	Resource base
Solar radiation at Earth's surface	1000 TW	90000 TW
Wind	10 TW	1200 TW
Wave	0.5 TW	(3 TW)
Tides	0.12 TW[a]	3 TW
Hydro	1.5 TW[a]	30 TW
Salinity gradients		3 TW
Geothermal flow		30 TW
Geothermal heat	50 TWy[a]	1.6×10^{11} TWy
Kinetic energy in atmospheric and oceanic circulation		32 TWy
Biomass (standing crop)		450 TWy[c]
Oil	300 TWy[a], 2500 TWy[b]	
Natural gas	180 TWy[a], 1400 TWy[b]	
Coal	930 TWy[a], 6000 TWy[b]	
Uranium-235	90 TWy[a]	
Other fission resources	10000 TWy[b]	
Deuterium fusion	3×10^{11} TWy[b]	
Present rate of energy conversion	8 TW	

Based on Bent Sørensen: Renewable Energy (Academic Press, London, 1979), and J. Chesshire and K. Pavitt: Ch. 5 in "World Futures" (C. Freeman and M. Jahoda, eds.), Martin Robertson, London 1978.

[a]Estimated recoverable reserves (proven and possible).

[b]Estimated recoverable resources (ultimately minable).

[c]At present.

plying a reduced energy input per capita in the industrialized nations, and an increased input of per capita energy in most developing nations. The resulting average energy inputs in the future would be in the range of 1-4 kW per capita, with the lower part of the range being more likely to be achievable with acceptable impacts. A number of detailed models of how to modify the present use structure and technology, in order to reach such goals, have been constructed (Sørensen, 1981b, IPSEP, 1981).

33. It follows that a vision of the future World may be built around an assumed saturation in population and in energy use, to be reached some time during the next century. Saturation in energy use means that the introduction of new energy-requiring activities at that time is compensated by improvements in technology of conversion. The levels of population and energy use at saturation are more debatable - and conceivably could change modestly with time - but would for the 21st century most likely be a maximum population of 10^{10} people with a maximum energy use totalling 10-40 TW, the most likely interval being 10-20 TW, i.e. between 25% and 250% more than the present value.

Table 2 indicates, that it should be technically possible to cover this level of energy use entirely by renewable resources, without approaching the limits of practical utilization indicated in the table, and leaving room for losses in going from primary energy input to the energy delivered to customers. Elements of a discussion of the economic and social viability of a transition to such an all-renewable energy system will be presented below.

Selected assessments of impact

34. Considering a strategy aiming at improved efficiency of energy use and the introduction of renewable energy sources to gradually replace any non-renewable energy sources in use, a discussion of the impacts on development options can be undertaken. Since the replacement of an energy supply system or the building up of a new energy supply system usually is a slower process than the introduction of modifications in the way energy is being used, it shall be assumed that efficiency improvements are the basic content of short-term policies, but that the effect of introducing new energy supply systems will only show up on a medium or long-term time scale, even if policy decision are made immediately.

Impact on regional development options.

35. In many developing regions, the current energy situation is unstable in several ways: use of firewood for cooking on inefficient stoves and other purposes, for an increasing population, leads to deforestation, which again has a number of negative implications, e.g. on water balance, soil conditions, etc. Use of imported

fossil fuels has lead to serious foreign currency problems, as the cost of these fuels - or at least of oil - has been raised abruptly in recent years. Continued reliance on imported fuels and wasteful utilization of forest resources will in many countries place serious restrictions on the prospects for development.

36. While the introduction of new energy sources, such as solar heat and electricity, wind and hydro power, or development of indigenous resources of geothermal and fossil energy where they are present, will for most developing countries imply deep reliance on imported technology and foreign assistance, if these sources should play a role on short terms, then a gradual development of such options over the medium and long range time scale could be made consistent with essentially keeping open the full range of development options, among which different societies would like to be able to select their preferences.

37. However, this leaves the short-term energy problem to be solved by other methods. Conditions for such solutions are that they are rooted in a mobilization of indigenous resources, and that the import fraction is restricted to mainly transfer of ideas and concepts. The indigenous resources comprise labour, materials and financial means. Although less glamorous than new energy

supply systems, measures to improve the efficiency by which energy is being used undoubtedly have the largest prospect of contributing to relieving the immediate squeeze on the economy of non-oil-producing developing countries. In many parts of the world, cooking is done on stoves with only a few percent conversion efficiency. Improved stoves have been deviced and adapted to the use of materials available in different regions of the world, so that investments are confined to local materials and labour (VITA, 1980). A dedicated implementation program could lead to a 5 to ten-fold improvement in firewood conversion efficiency over a period of about 10 years, for a number of rural areas in the developing countries. This would - in combination with a proper afforestation program - turn the wood resource depletion into a situation with a substantial annual wood surplus in a renewable mode, which could be used for industrial processes and thus contribute to the economic development of the regions.

In areas with both agriculture and animal production, measures to optimize the relative importance of the two can be used in combination with fertilizer and biogas production from manure and residues, in order to achive a self-contained energy- and food-providing farming system. This also would contribute to liberating resources for industrial activities and social development.

Impact on global development options

38. The global energy scene is today dominated by the energy use of the industrialized countries, and relative to its population, the USA is the largest spender of energy resources. Given the squeeze on the presently employed energy sources and the time needed to achieve any sizable impact of new energy sources, it is evident that the inefficient utilization of energy resources in the industrialized world is effectively blocking for development both within these countries and - in particular - for the less privileged countries.

39. The industrialized nations have the technology, the infrastructure and the financial means to implement improvements in energy use efficiency on a short time scale. Numerous studies have demonstrated, that dramatical decreases in specific energy use is compatible with improved living standards, or even are necessary conditions for further improvements in living standard (Nørgård, 1979; Krause et al., 1980; SERI, 1980; Sørensen, 1981b). In ten years, about half of all vehicles and home appliances will have been replaced, and at least 25% of industrial machinery will have been renewed. Thus, a concerted effort to ensure, that the replacing equipment represents the best currently technology, energy-wise, can lead to a sizable decrease in energy demand in the industrialized nations already within the first decade. And, notably, this decrease is not achieved

by "saving", i.e. by refraining from activities, but is an integral part of a new kind of forward development for the already highly developed countries. At the same time, the forces that make the supply of fossil fuels uncertain and motivates further price hikes, will be removed or weakened. This is a condition for reverting the adverse effect of the present oil supply situation on developing economies. Economically, the investments in energy efficiency improvements have much shorter pay-back times than any new supply option, and will continue to have that for at least the rest of this century (i.e. for a long time the "flat part" of curves such as those depicted in Figs. 5 and 6 will apply, and only in the medium to long-range future will the steep part of the curves apply, meaning that new energy sources will be more advantageous relative to efficiency improvements).

Economic uncertainty

40. The cost profiles of renewable energy systems and energy efficiency improvements are quite different from those of conventional fuel-based energy supply systems. For most fuel-based systems, the initial investment is modest compared with the present-value of the running expenses for fuel during the life of the conversion equipment. For renewable energy systems, most of the expenses are concentrated in the initial capital cost of the equipment, due to the absense of fuel expenditure. The difference is illustrated in Figure 7.

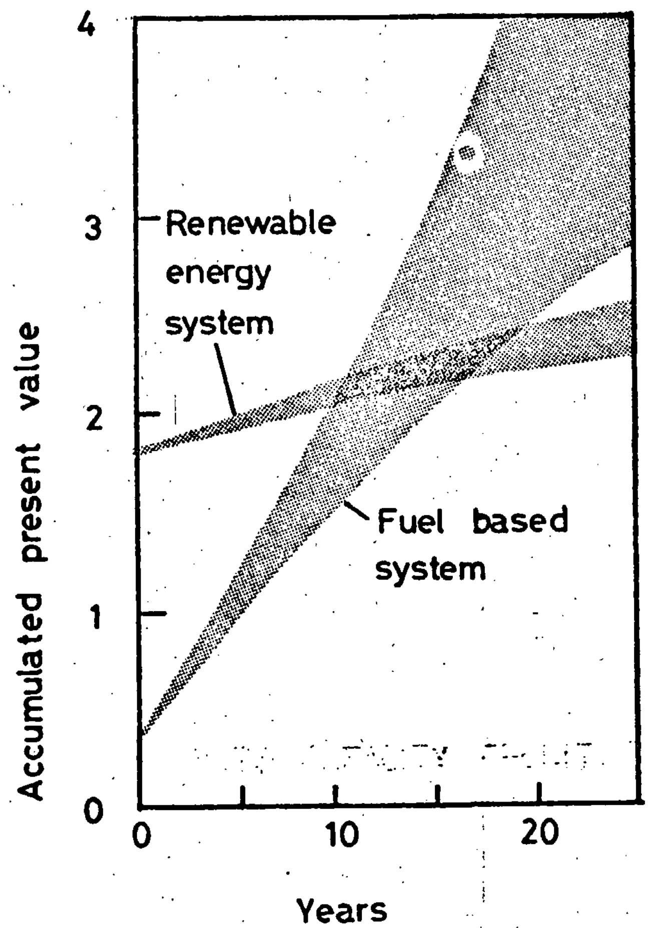


Fig. 7. Profiles of accumulated present-value costs, including capital cost, operation and maintenence and eventually fuel costs, for a renewable energy and a fuel-based energy system. Cost uncertainties are schematically indicated by the shaded regions.

41. Fig. 7 illustrates in a schematical way the influence of uncertainty on the cost profiles of renewable and non-renewable energy systems. The fuel-based systems have large uncertainty intervals, due to the uncertainty of future fuel prices. The uncertainty for the renewable energy system is in the cost of operation and maintenence, which are anyway a minor fraction. One other source of uncertainty would be the life of equipment, which may be rather uncertain for types of technology, for which no lifetime experience exists. This is also true for some fuel-based systems, e.g. nuclear power plants. Most renewable systems are based on components, for which industrial experience is available, but there are exceptions (such as rotor blades for megawatt-size wind turbines).

It follows that renewable energy systems may constitute a way of diminishing the future uncertainty in the cost of energy. Also as far as system resilience is concerned, advantages are obvious. Once the system is installed, energy supply will be dependable and little influenced on alterations in the conditions prevailing in the international markets. The same to a large extent holds for investments in improved energy efficiency, because once the investments are made, the energy supply will be less vulnerable and less dependent on outside conditions. Generally, a lower specific energy use implies a wider range of supply options. For instance, a well insulated house in temperate climatic zones can satisfy its heating requirements from rooftop solar collecting devices, whereas a poorly insulated house cannot.

Medium and long term strategies

42. A major change in the energy supply system of a developed nation is not a trivial operation. Neither is the introduction of such systems in regions with little previous contact with commercial energy supply. This is the reason that a planning effort should be made. It should ensure, that the time scales of various system component introductions are compatible, that the flow of investment assets is acceptable to society, and that the ingredients of the long-range plan is socially acceptable. The construction of plans for energy transitions give the public a realistic possibility to debate the desirability of the futures envisaged, and gives the technical planners and politicians a chance of checking the consistency of the measures to be taken. Once agreed upon, such a plan also gives industries and utilities proper guidelines for making themselves ready for their contributions to the transition.

Goals of renewable energy planning

43. The goals of renewable energy planning are of

course related to the tasks for which energy is used, and to the total impacts that the energy system may have on society. The evaluation of various impacts of energy systems was discussed in the first part of this document. In order to relate energy use to the individual and social goals of a given society, it is important to use a sufficiently disaggregated view on the energy utilization. Some energy statistics do only provide aggregated data, that may not allow a discussion of the relation of energy use to the needs they are supposed to satisfy.

44. Activities in individual households are in most societies the basic instruments of goal satisfaction. The building shell together with clothes provide acceptable biological surroundings, sanitation contributes to health. Supplies of food is brought to the household for preparation, and the living quarters may furnish a frame for meaningful social relations and activities. Other activities are related to institutions outside the household, e.g. for education, public health care and security. Further there are the production sectors, agriculture, construction and manufacturing industries, and the resource industry to provide materials for the production of goods. Finally, a distribution and service sector provide transportation and maintenence services. By division of labour, the relation between components in this structural

framework and the individual or social goals is often made very complex, so that the members of an industrialized society may loose sight of the connection. Indeed, it has often been proposed, that the "structure" has a growth dynamics of its own, and that growth in the public and private sector institutional structure may not necessarily be associated with better fulfillment of goals (Eriksson et al., 1974; Danish Ministry of Commerce, 1975).

45. It follows from the above, that modifications in the structural framework of a given society's way of providing goal satisfaction for its members could well lead to a higher return in terms of goal satisfaction on investments made. One case would be investments in energy systems. This brings us back to the impact assessment, since the expansion of structures that do not contribute proportionally to goal satisfaction may be seen as a negative side-effect of a given development (in some cases the side effect would be increased pollution, in other cases increased vulnerability, etc.). Items that should be on the check-list for assessing energy systems would then include renewability, environmental acceptability and compatibility with social development goals. The last item may of course be taken to include everything, but it does seem useful to single out renewability and environmental acceptability in

an energy context.

Methodology of renewable energy planning

46. The insistence on renewability is a question of obtaining supply security through use of sustainable sources of energy supply. To demand environmental acceptability is connected to putting energy efficiency up front, assuming that environmental impacts would generally be proportional to the amounts of energy converted. More specifically, efficiency includes the socalled "end-use-matching", i.e. to use the right thermodynamical quality of energy for a given task. In this way excessive conversion steps and their associated impacts are avoided.

47. The formulation of a renewable energy plan for any country or region, industrialized or developing, may follow the following steps: First the current energy use is analysed in terms of a breakdown of the energy delivered to various customers on the tasks for which it is serving. This is an analysis of the tertiary (or "delivered") energy. Based on the current energy supply system, a list of secondary energy use (or "produced" energy) is obtained by subtracting transmission and storage losses, and the primary energy use is obtained by adding conversion losses at central conversion plants (electric power plants, bloc heat stations, refineries, etc.). The primary energy inputs are the main concerns

in the supply-oriented planning, that prevailed in the past. In renewable energy planning the interesting quantities are the pieces of tertiary energy use.

48. For each tertiary energy item, reflections must be made on alternative ways of providing the same service. The energy requirement resulting from replacing the current method by the best currently conveivable technology, which is judged to be practicable, would constitute the quantity called "practical net energy" (Sørensen, 1981c). It is a more relevant standard for comparisons than the "physical net energy", defined as the physical minimum of energy required for a given task. The concepts here introduced are illustrated in Fig. 8.

49. To make an <u>energy scenario</u> for some future time, the desired social development must be modelled, and the corresponding requirement for "practical net energy" calculated. Depending on the distance in time, a judgement is then made, as to how far the efficiency improvement or rather the "introduction of best available technology" can be carried, i.e. as to how close to the practical net energy the delivered (tertiary) energy can be taken at the time considered. Then a supply system is chosen (or different possible supply systems are considered), and conversion, transmission and storage losses are added to derive the secondary and primary energy requirement from the tertiary one.

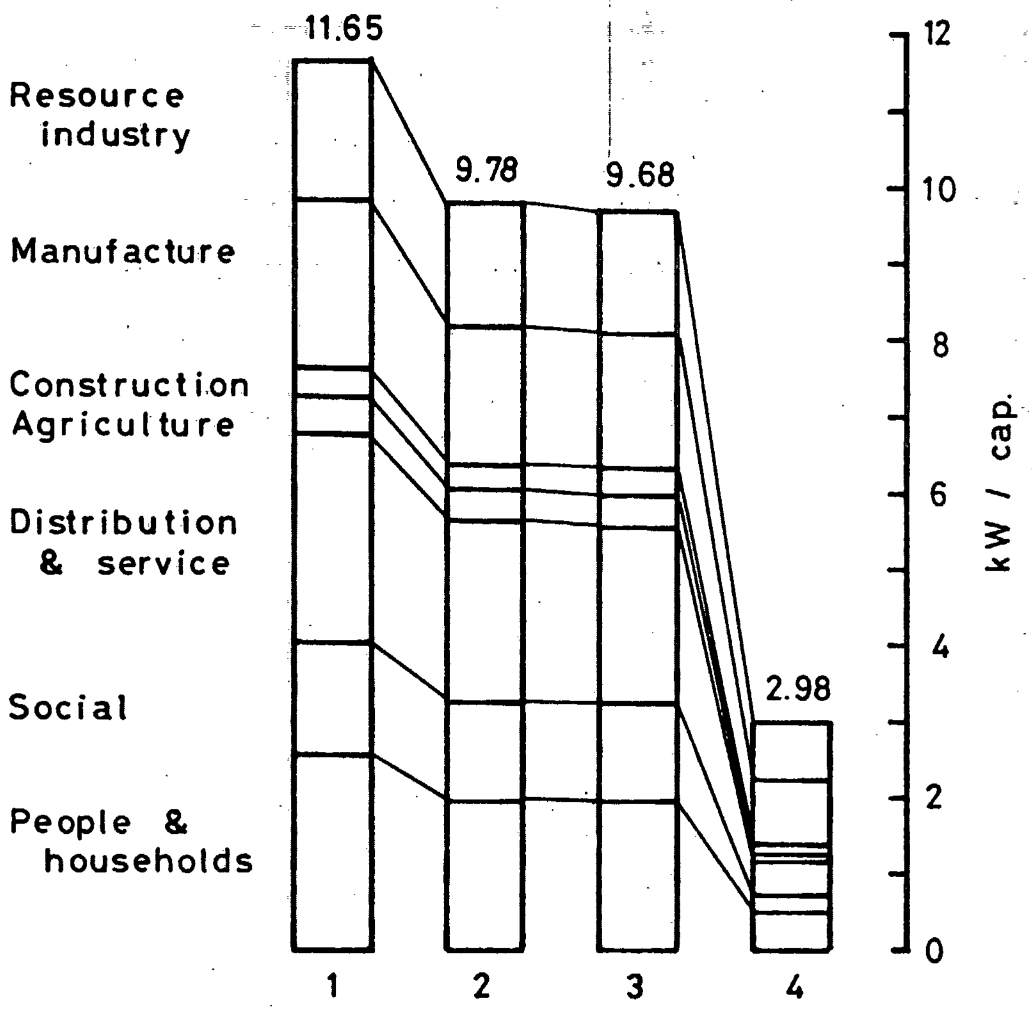


Fig. 8. Analysis of 1974 US energy use structure, in terms of primary(gross), secondary(produced), tertiary (delivered) and quarternary(practical net) energy (from Sørensen, 1981c).

50. In order to make a set of energy scenarios into an energy plan, it must be made plausible, that each scenario can be reached by a smooth transition, and that all the scenarios form a time sequence of connected pictures, each of which demanding only changes from the previous one, which can be realized with the industrial and financial capacity available at the relevant time, and each change consuming the necessary time for establishment of new industrial production facilities, time for products to mature and time for production of the required number of units of each energy conversion, distributing or storage device. Fig. 9 shows an example of a plan claimed to fulfill these criteria, pertaining to Denmark and depicting a transition between the present total dependence on imported fuels and a renewable energy scenario, the interim solution being based of recent oil and gas finds in the Danish part of the North Sea.

Mechanisms for mobilization of technical and financial requirements

51. Both in developing and in industrialized countries, a condition for renewable energy plans to be turned into reality is the creation of suitable technological and financial environments. There are some of the ingredients in the renewable energy plans, e.g. solar rooftop collectors and building retrofits, which may come by public demand, by gradual emergence of viable manufacturing facilities and gradually improved products, that in turn will appeal to larger and larger groups of con-

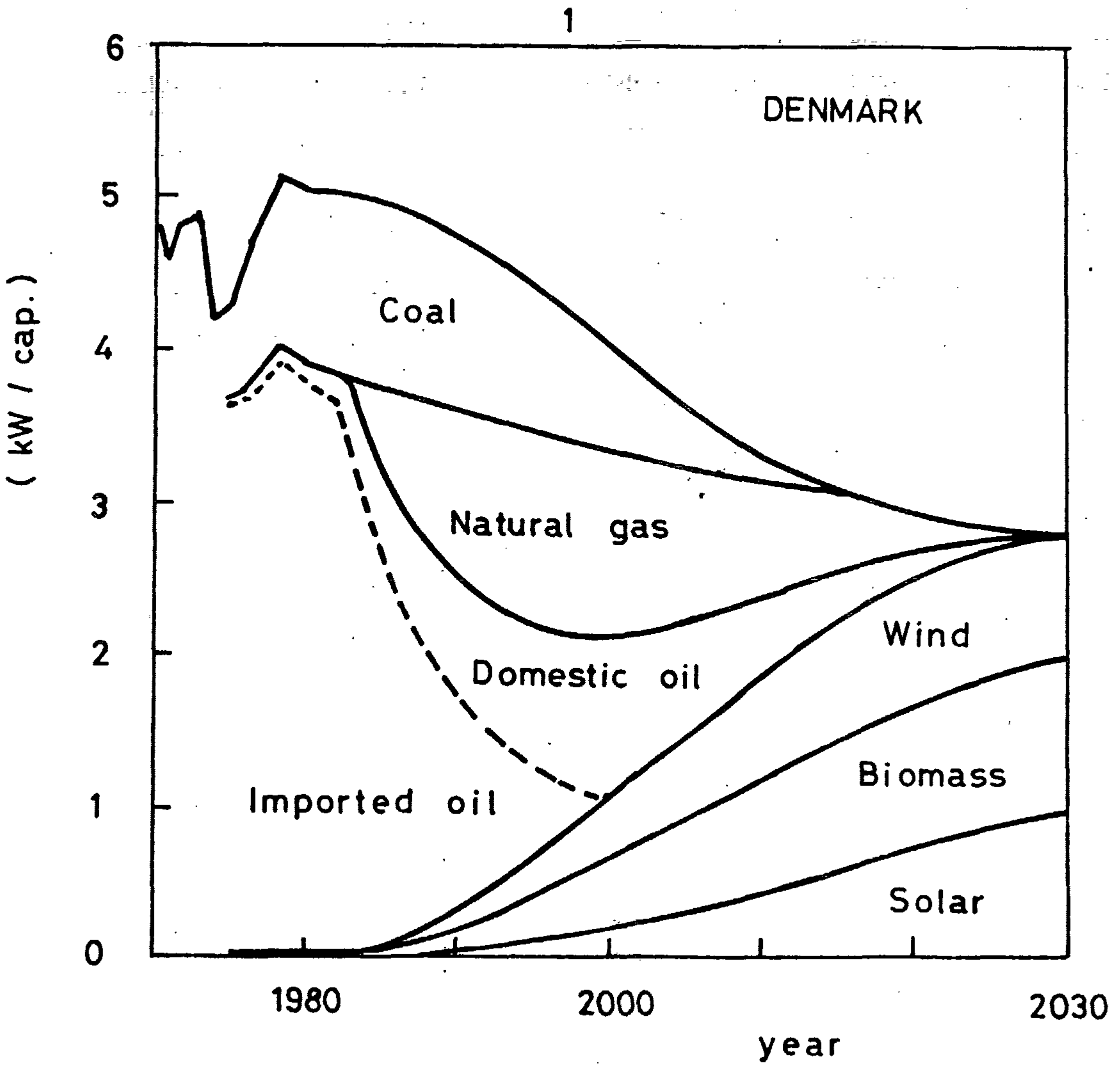


Fig. 9. Summary of a renewable energy plan for Denmark. The quantity depicted is per capita primary energy input, which then is to be distributed on energy use categories (according to quality of energy required). (from Sørensen, 1981b)

sumers. However, combined wind and hydro systems for electricity supply, for example, do not easily emerge without some kind of guided approach. This may consist of government sponsored development programmes, eventually regional or full international cooperation. Further, a mixture of incentives and regulations may be required in order to implement certain elements of an energy plan, e.g. insulation standards or performance of appliances. The interest and involvement of the public is best stimulated by creating very visible demonstration programmes. This is true everywhere but has a particular importance in rural areas of developing countries, where the measures suggested (such as new cooking stoves or biogas plants) will require changes in habits from the people to benefit from them.

52. By insisting on using technologies, that can be supported indigenously, the problem of financing will not necessarily be very grave. In many of the woodfuel areas of the world, where new stoves would be introduced, there is an overemphasis on livestock (being a traditional measure of wealth). This itself creates problems of overgrazing and e.g. poor milk production figures, suggesting a clear benefit from reducing the size of herds. The revenue from selling surplus livestock would in these cases almost certainly be enough to pay for improvements in cooking devices and so on. In those regions where such possibilities are not available, the energy transition

would need some kind of subsidy, from government or international sources. Still, the program must take into account the entire situation in the region focussed at, so that local activities (not necessarily in the energy field) can be drawn into the process, and so that local participation may be ensured . A reciprochal contribution of work and skills, as well as joint leadership, is a condition for a successful program, in which people participate with pride, whether the cooperation is between local population and outside agents, or between regions or nations, as it would often be the case, if optimum utilization of resources and high dependability of the energy system is aimed at.

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