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1. COMPARATIVE RISK ASSESSMENT OF TOTAL ENERGY SYSTEMS
2. ADVANTAGES AND DISADVANTAGES OF DECENTRALIZATION.

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1. COMPARATIVE RISK ASSESSMENT OF TOTAL ENERGY SYSTEMS

ABSTRACT

The paper discusses a methodology for total impact assessment of energy systems, ideally evaluating all the impacts that a given energy system has on the society, in which it is imbedded or is considered introduced.

Impacts from the entire energy conversion chain ("fuel-cycle" if the system is fuel-based), including energy storage, transport and transmission, as well as the institutions formed in order to manage the system, are to be compared on the basis of the energy service provided.

A number of impacts are considered, broadly classified as impacts on satisfaction of biological needs, on health, on environment, on social relations and on the structure of society. Further considerations include impacts related to cost and resilience, and last but not least impacts on global relations.

The paper discusses a number of published energy studies in the light of the comparative impact assessment methodology outlined above.

2. ADVANTAGES AND DISADVANTAGES OF DECENTRALIZATION

ABSTRACT

A distinction is made between local energy systems (located close to users) and decentralized systems (with decentralized control), and the relative virtues of local versus central systems are discussed for a number of renewable and non-renewable energy sources. The paper further discusses energy distribution systems or "grids", e.g. for electricity, district heating and natural gas transmission. For each energy form, the possible advantage of using a common distribution line system is assessed.

Contents:

COMPARATIVE RISK ASSESSMENT OF TOTAL ENERGY SYSTEMS

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1. INTRODUCTION

The purpose of this paper is to place health impacts of energy systems in the context of a total impact assessment. In many cases health and non-health impacts have commom causes and cannot easily be treated separately. Furthermore, it is useful to have a notion of the relative importance of health and other impacts for different energy systems, in order not to be tempted to draw comparative conclusions on the basis of health effects alone, when a total impact assessment may lead to quite different conclusions.

In the following sections 2 - 5, some methodological elements will be discussed, and in sections 6 - 8 their application to individual energy systems will be taken up. Only examples of such applications will be dealt with, since no complete analyses have yet been performed.

2. TOTAL IMPACT ASSESSMENT

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 are 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 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 extends 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 a 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 of the social environment.

3. RISK CONCEPTS

Risk is a common language word which is used to express at least the following three different concepts:

Direct risk is the probability of experiencing one unit of damage (e.g. the loss of one human life) per unit of time [1]. It can be expressed in the product form

$$\underset{\text{(Consequences/year)}}{\text{direct risk}} = \underset{\text{(events/year)}}{\text{frequency}} \times \underset{\text{(consequences/event)}}{\text{damage}}$$

Social risk is a measure of the implications for a given society of an activity entailing a direct risk specified by frequencies and corresponding damage magnitudes of individual events. Of specific social concern are events with small probability but large consequences. This is a reflection of the different capability of a given society for handling small, frequent accidents (such as automobile accidents) as compared with large-consequence events for wich society is ill-prepared (due to their low probability) or which society is simply uncapable of handling due to its finite resources (e.g. number of hospital beds) or at the extreme due to a collapse of vital institutions (e.g. in case of a major nuclear reactor accident affecting the administrative capital of a small country) [2].

As a crude way of quantifying the social risk it has been proposed to use an expression of the form

$$\text{social risk} = \text{frequency} \times (\text{damage})^p,$$

where the damage is raised to some power p (larger than one), which depends on the structure of the society in question [3].

Perceived risk is the risk of a given enterprise as perceived by the public. It may differ from both the direct and the social risk, and may exhibit short-term fluctuations and may be strongly influenced by coverage in media. It also reflects public confidence/mistrust in authorities and in many cases a large discrepancy between perceived risks and officially stated direct or social risks may reflect a history of previously experienced inaccuracy of official reassurance statements. In this sense, perceived risks would have to be taken seriously in risk assessment. Generally, emotional expressions are of course basic in defining social priorities.

4. COMPARATIVE RISK ANALYSIS

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 includes 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 incommensurable, 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.

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 streching 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 of a methodological approach to comparative assessment of energy systems may be found in [4-8].

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 transport, transmission and use of the energy produced, from the institutions created for management of the supply system, and so on.

Many studies have compared some impacts of different energy systems on the basis of equal energy production, e.g. considering various fuel cycles from resource extraction to the generation of electric power, on the basis of given power production. This would ignore any differences occuring in the further transportation, conversion and use of the energy all the way to the final services provided. The procedure would not catch differences between centralized and decentralized systems in terms of power transmission requirements, and it would not be capable of treating energy systems not based on a simple energy production, such as passive solar houses or systems involving changes in end-use structure leading to the elimination of a certain energy use.

The proper basis for comparing energy systems is thus the service provided by the energy system (the term "end-use" could be applied but unfortunately it is often used for "energy delivered to the final customer", a quantity that may exceed the energy spent on the desired service by a large factor, cf.[9]). In many cases there would be alternative ways of providing the service in question, with different amounts of energy input corresponding to different system design and technology. Energy input may then be substituted by measures leading to a higher efficiency, in which case the impacts of energy provision must be compared to the impacts associated with the measures of efficiency improvement. This can only be done on the basis of an identical service delivered. This concept will be further illustrated in sect.7.

5. MARGINAL AND COMPLETE ENERGY TRANSITION

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). 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.

As the change in energy systems 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.

6. TOTAL IMPACT CRITERIA

The different methodological elements described in the previous sections may be summarized in a "checklist" of impacts to be assessed for each energy system. Such a checklist may take the form suggested in Table I, containing a number of criteria with which a given total energy system may be more or less compatible. The table indicates a scale of compatibility ranging from "highly incompatible" (negatively correlated with) over "neutral" to "highly compatible" (positively correlated with). The set of criteria reflect basic individual and social goals, ranging from biological needs over human relations and concern for the environment to broad questions of international relations and potential conflicts. This allows the energy systems to be checked for their degree of consistency with different types of social and political organization. Some of the criteria directly or indirectly affect health, other ones not.

Furthermore, some of the criteria reflect issues on which there is a general consensus, while other ones probe into cultural and economic organization of society, in some cases providing antithetic criteria, for which simultaneous compatibility of a given energy system would eventually be excluded.

The "degree of compatibility" scale is provided as a first attempt of making the assessment quantitative. Only in a few cases can a truly quantitative impact assessment be obtained in comparable units. The idea of the checklist, which does not in its present form claim to be exhaustive, is to avoid that unquantifiable aspects of the assessment are left out of the analysis.

Many of the criteria formulated in Table 1 are subject to interpretation. For example, item 18 (the energy system's compatibility with having high material standards), may include questions on the possibility of launching demand stimulating campaigns (by the energy-providing utility companies or fuel-selling companies), and item 16 (avoiding redundant institutions and infrastructure) may include questions of the feasibility of stimulating energy efficiency. In many cases, the energy institutions and infrastructure are barriers against efficiency improvements (e.g. high fixed fees for electricity or district heating provisions, combined with low fees proportional to energy use).

7. A HEALTH IMPACT CASE STUDY

In this section, the difference between system comparison based on equal energy production and alternatively on equal energy service delivered will be illustrated by considering occupational health impacts of lighting.

The average U.S. delivery of light amounts to 540 lumen per capita. To provide this an average electrical power input into lamps of 40 W/cap is used [10], corresponding to a primary energy input of about 120 W/cap. The lighting service is likely to be smaller than the lumens delivered from the light bulbs, due to only a fraction penetrating lamp shades and being directed towards useful areas. Assume that the actual lighting service is 150 lumen/cap, a figure that may be high relative to the light made useful when reaching proper surfaces for reading, working and leasure activities, but a figure which recognizes, that also some of the diffuse light from lamps is performing a service in providing a pleasant environment for people.

Table II summarizes the steps involved in providing the lighting service by conventional incandescent light bulbs powered from a coal-fired electricity plant. The table also gives an estimate of health impacts for each step, as provided by [11-12]. The attempt is here to include the manufacture requirements throughout society for each fuel-cycle step, using present (U.S.) industrial structure and bio-medical data. In this sense the health impact evaluation is a "total" one, but it only includes fatalities and work-days lost as a result of injury, not social impacts and mental injuries. It thus does not provide a complete impact evaluation even for the items 2 and 6 in Table I, and not at all for item 8.

In Table III, a similar evaluation is made for a different energy system, proposing to provide the same lighting service by high-efficiency light-bulbs [10], by improved light-guidance to relevant areas (more transparent shades, more reflecting walls, etc.) and to provide the electric power by wind generators feeding into the existing grid. In order to use the same health impact data as for the coal-based system, a "marginal system change" approach was used, assuming that the introduction of wind energy does not lead to institutional changes, and that specific back-up facilities would not be required (corresponding to a wind energy share in the system of up to about 25 pct., cf. [13]).

Fig.1 compares the occupational impacts of the two systems, on the basis of equal (electric) power production and alternatively on the basis of both providing a lighting service of 150 lumen/cap.. Clearly the "equal power production" comparison gives a completely false impression of the relative impacts.

Table II indicates, that the coal-based system has a public health impact that is poorly known, but which may exceed the occupational hazard in magnitude.

Similar comparisons could be made for alternative ways of providing e.g. domestic hot water (for instance, comparing the cycle "nuclear power → electricity → resistance heating → hot water → rejected water" with alternative cycles: "solar collectors → small heat storage → hot water → waste water heat exchanger", etc.) and space heating (for instance, comparing the cycle "fossil co-generation → direct heating lines → existing building" with: "solar rooftop collectors → district heating lines → community heat storage → back through district heating lines → retrofitted building with lower heat requirements", etc.).

8. CRITIQUE OF PUBLISHED STUDIES

A number of studies have been undertaken to compare the impacts of different energy systems, or of different system components. In some studies, cost was the only impact studied, and in other studies, health impacts alone were at issue [14-15,12]. These studies were made on the basis of equal electric power production and they all suffer from the substitution of fairly arbitrary estimates for data not immediately available (with the underlying philosophy that bad numbers are better that no numbers).

Studies attempting to broaden the range of impacts considered, as well as considering alternative ways of a full transition between the present energy system and possible future ones, have tended to restrict most of the impact discussion to a qualitative level [16-19]. Some attempts have been made to systematize the methodology of impact assessment [20,4,7-8]. They have been drawn upon in setting up the set of compatibility criteria described in sect.6.

A few recent studies have moved in the direction of quantitative assessment in some of the impact areas neglected by early comparative studies. Two such studies will be further discussed in this section [21,22]. The range of impact areas covered and the nature of coverage in these two studies is summarized in Table IV. The impact areas of Table I have been lumped together in broad categories for the purpose of Table IV, which gives the relevant item numbers for Table I in parentheses.

The IIASA study considers two World demand scenarios, corresponding to different economic development and different allocation of investments. All possible energy sources are invoked, but with emphasis on nuclear and coal technologies [21,23-24]. The CIS study, on the other hand, constructs a scenario for an all renewable energy system for Sweden, considered to be dictated by a Swedish policy of leaving the best options for a rapid improvement of the situation in the World's poorest countries [22].

Neither study explicitly consider health effects, and the distribution of emphasis on the different impact categories is rather different. While the IIASA study assumes that the present value system will be kept rigidly over the next 50 years, the CIS study explicitly assumes a change in value system towards more emphasis on global solidarity and on placing a ceiling on material consumption in the rich countries. A similar explicit modelling of alternative future value systems were undertaken in the Stanford study [19], and has been suggested in other studies [5,25].

Although Table IV suggests that quantitative indications can be obtained in most of the impact categories, this is clearly not possible for each individual impact item. The importance of unquantifiable impacts have been recognized in earlier studies [26], as has the existence of tresholds in public acceptance of impacts, e.g. an upper treshold beyond which impacts are unacceptable [27].

Satisfaction of biological needs is used in the CIS study to define a minimum of food and energy supply.

The little mention of health impacts in the IIASA and CIS studies is surprising, since the IIASA alternatives rely on nuclear systems with little known but potentially significant risks, in addition to the also little known - but qualitatively well established - health impacts of coal and other fossil technologies, and the CIS study relies heavily on biotechnologies, including forestry and methanol production industries, which may be associated with substantial risks and health impacts.

Environmental issues are discussed in both studies. However, the CIS study is mostly concerned with work and mental environment, while the IIASA study makes a fairly thorough investigation of the possible climate impact of carbon dioxide from fossil fuel combustion (and yet draws the little qualified conclusion, that the indicated temperature rise associated with the fossil fuel use in the IIASA scenarios is unlikely to be a problem). The IIASA study also looks into the pollution aspects and the depletion of resources. On the other hand, no discussion of the broad ecological impact of the envisaged futures is undertaken, and the work and mental environment is not at all mentioned. There could be good reason to mention work conditions, e.g. in coal mines and nuclear reprocessing plants, as well as the impact on the mental environment of the security measures, that today are felt necessary in order to deter nuclear terrorism and sabotage. Clearly, the mainly decentralized energy system advocated by CIS would not have serious problems of this kind.

Only the CIS study embarks on a discussion of the impact of energy systems on social relations. Indeed, this is a central theme of the study, which claims that its energy system is particularly suited for a society with social relations better that those prevailing today, and with work conditions similarly improved, by means of a closer link between consumption and production (i.e. production is directly controlled by peoples desire for consumption, in contrast to the presently detached production structure, which invites production of some products that could not be sold without heavy promotion).

Actually, the CIS study treats all the questions of the structure of society listed in Table I as items 9-19 and 23-24. It specifically explores the goals of a non-competitive society and attempts to construct an energy supply system compatible with such a society. A quantitative assessment is made of the energy saving resulting from the study's proposed move towards a minimum of institutions and infrastructure. On the other hand, small and decentralized systems are preferred only when they are seen to provide clear advantages over larger and more centralized systems. The proposed energy system ensures political independence and its minimum of institutions and infrastructure ensures that any change in policy can easily be made at a later stage. The CIS study comments that the opposite is true for nuclear power systems.

The IIASA study only sporadically deals with questions of social structure. It does treat the development of material standards (through the gross national product indicator), and claims to have deviced energy systems compatible with high material standards. In reality, it has only considered GNP and may in fact represent the trap exposed in the CIS study: creating a growing "structure" taking up more and more of the total GNP, and thus leaving less and less to contribute to real material standard at the level of people. The IIASA study also discusses political independence, particularly in relation to fuel trade.

Both studies estimate the direct cost of each scenario, and in the IIASA study, the principle of minimum direct cost is even used to select the mix of energy sources [24]. The indirect costs are not playing a role for the system choice.

The question of system resilience is only receiving parenthetical attention in the IIASA study, which explicitly assumes a "surprice-free" World development, with presently decided oil production ceilings as the only "political constraint". In contrast, the CIS-study makes a detailed analysis of the technology-chains for each system component, i.e. it keeps track of where the materials and skills come from and which degree of dependency is involved. The preferred energy system of the CIS study are described as sometimes "complex" but never "complicated", implying a mix of small- and large-size systems, a mix of centralized and decentralized systems, but never systems depending on asymmetric relations between regions. The degree of local rooting may be taken as one resilience measure, other aspects being associated with the impacts that occational technical failures may have.

As mentioned, a picture of Sweden in the global development process underlies the CIS study. Key criteria are global elimination of poverty, of asymmetric dependency, of resource and environmental exploitation and of the arms race. By relying on its own renewable resources, Sweden may take away some of the global pressures.

The IIASA study also deals with global relations, but in quite different terms. Its central assumption is, that economic development of the Third World Countries is only possible if there is further economic growth in the rich countries [23]. It is acknowledged, that economic growth as defined by GNP does not adequately represent structural changes, which may occur in different regions, and that the model used does exclude such changes [24]. It is of course precisely these structural changes that the CIS study attempts to model.

In summary, the look into two fairly detailed energy studies has shown, that the full range of impacts suggested in Table is beginning to receive attention, but that their treatment can be approached in quite different ways. While the CIS study tries to investigate an energy system based on an assumed change in value system and social structure, the IIASA study rigidly adheres to the socio-economic system that happens to prevail at present. The IIASA assumptions are probably shared by most political decision-makers today, while the new value system proposed by the CIS-study has a fairly widespread acceptance by the younger generation in many Western Countries. The question is then, whether this generation gets adapted to the views held by the present rulers, as they eventually take over the desicion-making responsibilities, or if the new value system will be replacing the old one along with the generation shift.

Regarding those studies, which proposes to do quantitative comparisons of selected impacts, one should be very careful in drawing conclusions at the present state of the art. In the case of the nuclear energy systems, the most uncertain risk appears to be associated with large reactor accidents. The methodology used by the studies undertaken so far ([14] and related studies, e.g. [28]) has been discredited as incomplete [29,2], and it is not even clear, if the distribution of risk on accident size is correctly assessed or not [2]. Furthermore, the impacts associated with large-area land contamination has only recently been devoted detailed attention [30-31].

Similar criticism can be directed at the impacts associated with the air, water and soil pollution from fossil fuel and wood burning energy systems. The full range on health impacts have hardly been identified, and numerical risk estimates suffer from large uncertainties (cf. e.g. [12]).

More satisfactory is the assessment of occupational risks associated with construction and manufacture processes inherent in energy system equipment and operation. The problem is here, that the calculated impacts are not properties of the energy systems themselves, but of the particular industrial methods by which the systems are produced in given regions and at given times. In this respect, the studies are useful in indicating those areas, where a change in manufacturing process is called for. But in terms of comparative evaluation of different systems one should be very careful in assessing, whether the industrial method underlying given impact figures is essential or not, i.e. if it would be technically and economically justified to use alternative industrial methods with smaller impacts.

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TABLE I. CHECKLIST FOR EACH CONTEMPLATED ENERGY SYSTEM

Degree of compatibility with:	(neutral) − o +
1. Satisfaction of basic biological needs	+---------+---------+
2. Acceptable health impacts	+---------+---------+
3. Ensuring individual security	+---------+---------+
4. Having meaningful social relations	+---------+---------+
5. Having meaningful work activities	+---------+---------+
6. Acceptable accident risks	+---------+---------+
7. Concern for physical environment	+---------+---------+
Specifically: 7a. Climate impact	+---------+---------+
7b. Air, water and soil	+---------+---------+
7c. Mineral resources	+---------+---------+
7d. Biota, ecosystems	+---------+---------+
8. Concern for work and mental environment	+---------+---------+
9. Goals of a competitive society	+---------+---------+
10. Goals of a society based on equity	+---------+---------+
11. Goals of a non-competitive society	+---------+---------+
12. Emphasis on strong division of work	+---------+---------+
13. Goals of a tradition-based society	+---------+---------+
14. Goals of a pluralistic society	+---------+---------+
15. Encouraging democratic participation	+---------+---------+
16. Avoiding redundant institutionalization and infrastructure	+---------+---------+
17. Avoiding power concentration	+---------+---------+
18. Having high material standards	+---------+---------+
19. Having high non-material standards	+---------+---------+
20. Acceptable energy provision share of economy("acceptable cost of energy")	+---------+---------+
21. Acceptable cost uncertainties	+---------+---------+
22. Resilience of energy supply system	+---------+---------+
23. Political independence	+---------+---------+
24. Keeping future development options open	+---------+---------+
25. Minimizing potential for conflicts and wars	+---------+---------+
26. Improving international relations	+---------+---------+
27. Improving conditions for development in the worlds poorest regions	+---------+---------+
28. Overall evaluation being insensitive to uncertainty in individual impact estimates	+---------+---------+

TABLE II. HEALTH IMPACT OF PROVIDING LIGHT BY INCANDESCANT BULBS / COAL POWER STATIONS

Step	Average energy input flux	Impacts	
		Injury (10^{-6} MDL)	Fatality (10^{-9} D)
Mining (surface)	154 W	54[a]	12[a]
Processing/transport	139 W	43[a]	9[a]
Power generation,	126 W		
occupational hazard		67[a]	10[a]
public hazard[b]		?	430^{+1720}_{-430}
Environmental protection (desulphurization)		75[a]	14[a]
Power transmission	44 W	~ 200[c]	~ 40[c]
Institutions & back-up facilities		?	?
On-site installations	40 W	?	?
Light bulbs (incandescant)	40 W	5[d]	3[d]
Light distribution	540 lumen	-	-
Lighting service	150 lumen	-	-
Sum of center estimates:		444	518
(of which occupational:)		(444)	(88)

MDL = Man Days Lost. D = Deaths.

[a] [11]. [b] [12] (Assumes low-sulphur coal and 90% desulphurization). [c] Very rough estimate based on cost of power production and of transmission being similar. [d] [12] (Assuming cost of (3) bulbs is 2$, and using category of "control equipment").

TABLE III. HEALTH IMPACT OF PROVIDING LIGHT BY ADVANCED LIGHT BULBS / WIND POWER

Step	Average energy input flux	Impacts	
		Injury (10^{-6} MDL)	Fatality (10^{-9} D)
Power in wind	12 W		
Power generation	3.9 W		
occupational hazard		29[a]	3[a]
Power transmission	3.9 W	~ 20[c]	~ 4[c]
Institutions & back-up facilities		?	?
On-site installations (incl. transformers)	3.5 W	?	?
Light bulbs (advanced)	3.3 W	35[d]	20[d]
Light distribution (improved)	300 lumen	-	-
Lighting service	150 lumen		
Sum of center estimates:		84	27

Footnotes: cf. Table II.

[d] Assumed cost of advanced light bulb : 15$ (1976-level)

TABLE IV. IMPACT TREATMENT OF TWO ENERGY STUDIES

Impact category	study:	
	IIASA[21]	CIS[22]
Biological needs' satisfaction (1+3)	-	Q
Health (2+6)	-	-
Environment (7,8)	qQ	m
Social relations (4,5)	-	q
Structure of society (9-19, 23, 24, 28)	m	qQ
Cost (20,21)	Q	mqQ
Resilience (22)	(m)	Q
Global relations (25-27)	mqQ	q

Key to treatment given:

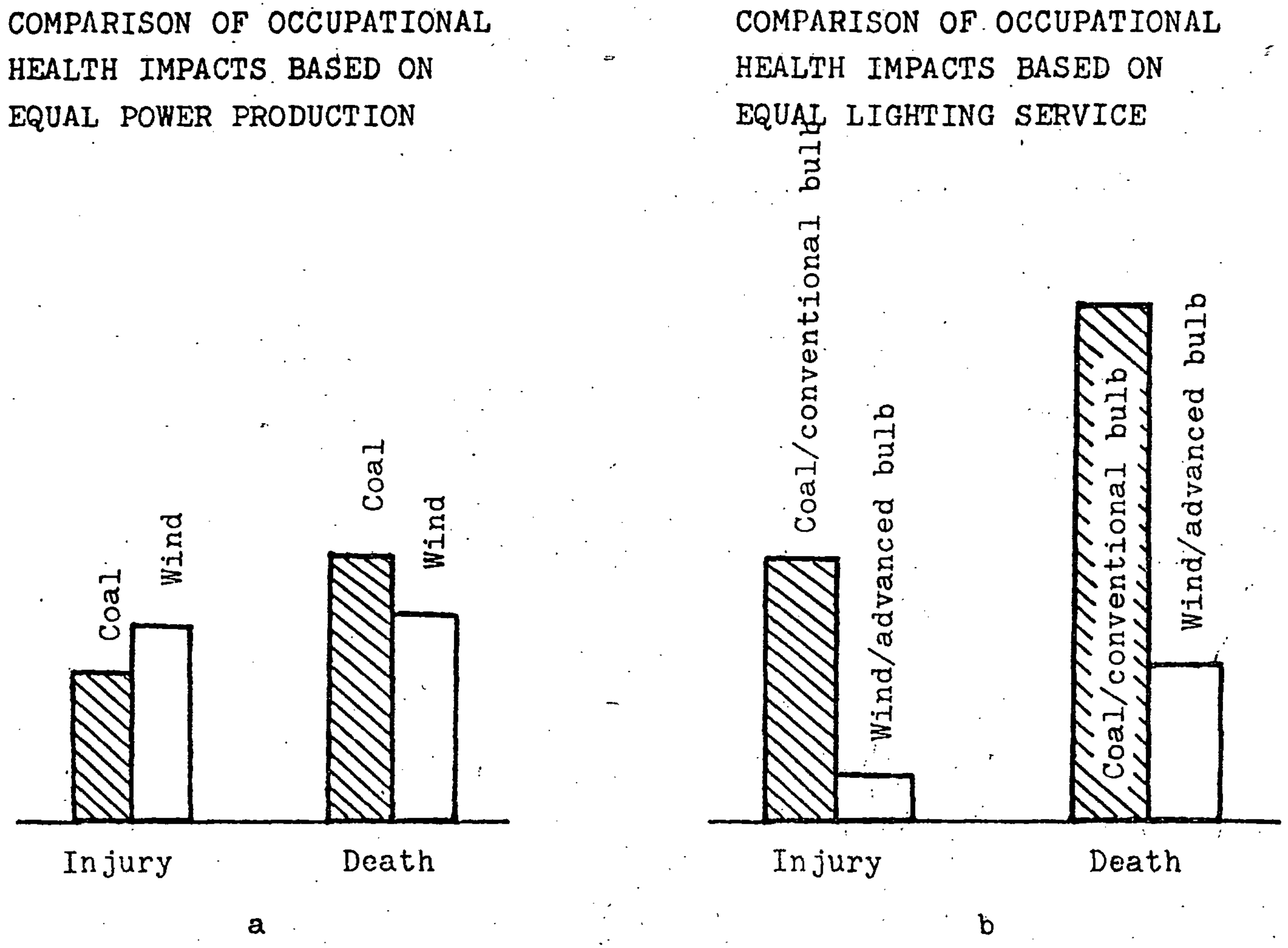
Q = quantitative

q = qualitative

m = mention

\- = not considered (or only sporadically mentioned)

Impact categories give items of Table I included in parentheses.



COMPARISON OF OCCUPATIONAL HEALTH IMPACTS BASED ON EQUAL POWER PRODUCTION

COMPARISON OF OCCUPATIONAL HEALTH IMPACTS BASED ON EQUAL LIGHTING SERVICE

FIG. 1

ADVANTAGES AND DISADVANTAGES OF DECENTRALIZATION

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1. Introduction

The aim of this paper is to discuss relative merits of local and decentralized energy systems, as compared with large, centralized systems. A question of particular importance is, whether the inclusion of a distribution line network is justified or not.

The terms "local energy systems" and "decentralized energy systems" are not entirely identical. A decentralized system is one, which does not depend on a distant "center", or one for which the dependence on a center is weak. The center may of course be the place, where a large energy conversion plant is located, or where fuel is extracted or stored, but the center may also be the locus of control (e.g. a utility company operating a number of dispersed wind turbines placed locally). The concept "decentralization" hence relates to the control structure.

A local energy system, on the other hand, is one located close to the users. Thus "local" relates to the siting of the energy systems as seen from the energy user, i.e. the geographical location of the final step of energy conversion ("end-use").

Questions of "locality" and of "decentralization" may be addressed to each step in an energy conversion chain: resource extraction, refining, conversion, storage and any other handling necessary. Some steps in the chain may be carried out locally, while other steps are done centrally, and the control structure may leave some steps under central control, while other steps may become decentralized.

The discussion of local versus central may be taken up for each energy source, considering different conversion methods and system set-up. However, the optimum solution depends as much on the nature of the services, for which energy is needed, and hence on the energy form required. Questions of decentralization are further related to social and political issues, and the specific discussion of the advantages and disadvantages of various distribution systems is best performed on the basis of energy forms rather than energy sources.

These different aspects will be discussed in the following sections.

2. Local or central systems

An overview of possible layout of energy systems is attempted in Fig. 1. This section will assess local versus central systems with reference to the system components shown in Fig. 1, for a range of different energy sources.

<u>Oil</u> may be found near to energy use sites. Yet, the refining of petroleum products is a well-established large-scale chemical enterprise, i.e. centralized refining has established itself as economically preferable. The dependency involved in centralization of oil extraction and refining is seen as an international problem, but most countries have national refineries, so that utilization of local (and eventually small scale) oil resources would be seen as diminishing the dependency, even if the crude oil has to be transported to a distant but national refinery center and the products back to the local users. Thus the scheme would be of the type shown in Fig. 1(c), with central refining but eventually local extraction. The final conversion is made locally, but the siting of fuel stores is a question of importance. Decentralization of fuel storage has very clear advantages related to supply security and diminished power to the center. The local storage

capacity should be of the order of a year's use in order to allow for substitution in case of break-down of the relations to the center. The net energy yield of petroleum products diminish with the distances of transportation to and from central refineries, and the present size of refineries may not be optimum.

Natural gas differs from petroleum products in that local storage is less easy. Presently, most gas systems have very little storage facility, and the stores in operation are central installations (e.g. in caverns) situated far from most users. Local natural gas systems would be feasible only in cases where the extraction rate can be safely controlled.

Petroleum products and natural gas are in widespread local use, while the use of coal locally has been decreasing (in the highly industrial countries it has almost vanished) for environmental reasons. Instead, coal is being used in central installations, such as large power plants, where control of effluents and use of tall stacks are considered more manageable. A return of coal as a fuel for individual, local users is dependent on the introduction of environmentally acceptable advanced combustion techniques. Fluidized-bed combustion may go some way towards fulfilling this criterion. Further development is needed in the techniques of local handling and storage of coal and related products (lignite, peat), before a return to local coal use can be consciously recommended.

The carbon dioxide release connected with all fossil fuel combustion is increasingly being realized to define the role of fossil fuels as one of filling out a transitional period between primitive use of renewable energy sources and more advanced use of renewable energy sources or of nuclear fuels.

An important but with a few exceptions (Business Week, 1980) neglected possibility is small scale, local use of *nuclear fuels* for power or heat or both. Fission reactors with a thermal capacity below about 100 MW may not have the possibility of socially unacceptable catastrophic accidents, and therefore have the potential of reestablishing confidence in use of nuclear energy, if they can be made economical. They still are open to objections related to radioactive waste management and to linking energy provision to military interests.

Geothermal energy systems are in many cases conveniently located in user areas. Closed loop systems providing heat for district heating lines or for a small power turbine can be made environmentally acceptable in inhabited areas, and storage of energy may not be necessary, since the conversion rate can be controlled (water heat storage can be added in case of cogeneration). The system is thus normally of the simple type depicted in Fig. 1(a).

Small-scale hydro and tidal power can be used to serve local users with electricity. Flow-type hydro installations are of the type shown in Fig. 1(a), while reservoir based systems have a water reservoir situated before the conversion unit. Most small scale installations will only have limited (e.g. diurnal) storage capacity. Tidal reservoirs filled during the inflow period can only be used when the outer water level is sufficiently low, and two-way systems have even more narrow cycle definition. Some small-scale hydro installations could establish long-term storage reservoirs, in which case they could serve as truly local energy systems. In other cases, and this is probably the majority of cases, available power levels will fluctuate, so that the system will have to depend on connections to central power plants, or alternatively will have to install separate storage facilities capable of storing and regenerating electric power (this is the system illustrated in Fig. 1(b)). The availability of hydro-suited locations is such, that only a few users could hope to possess a local energy system. The motivation for dedicating hydro (and tidal) resources to local users is thus weak.

Wind energy use for electric power production is generally characterized by highly fluctuating output and by only very special sites having wind conditions that will make the conversion equipment economical. Thus, like hydro the wind is only in few cases suited as a purely local energy system. However, it can very well form part of a decentralized system, in which dispersed converters feed into a common grid. A common grid receiving contributions from different renewable resources with different time-characteristics clearly exhibits increased viability. These comments on local wind energy systems may not hold for multi-blade windconverters pumping water for irrigation, because here the purpose is not to maximize power production, but to furnish a small, but rather stable level of power output with simple technology. Such systems are thus aimed at being less dependent on siting in good wind regimes.

Direct solar energy converters are highly suited for local installation, because of the high degree of regional uniformity of insolation (i.e. little can be gained by moving the collectors even several hundreds of kilometers away), and because most solar collectors can be mounted on existing structures, such as building roofs or walls. In this way there is a strong, economic advantage of placing the collectors locally rather than centrally, where in the latter case special supporting structures have to be provided. This is true for flat-plate thermal collectors as well as for photovoltaic converters, whereas tracking, concentrating collectors cannot always be accomodated on existing buildings. The direct solar systems are of the type shown in Fig. 1(b), because they all require a kind of storage (or back-up system) after conversion, if they are to provide energy anytime during day or night. While the converters are very suited for local installation, the question of the best location of an associated storage is more complex. One option is clearly a local storage, large enough to make the system autonomous. However, more economical systems may be obtained by provision of a distribution grid and communal or central storage.

Use of biomass for direct combustion or for fermentation (to form biogas or alcohol) is well suited for local implementation, while the more advanced methods of forming liquid bio-fuels are likely to require a chemical plant of considerable size. This is true of methanol production from wood products, by a catalytic process following gasification, and it may also be true for ethanol production, if the energy consuming destillation process is to be replaced by chemical water removal.(Apace Newsletter, 1980). The scope for making these processes economically viable on small scale will have to be considered.

3. Distribution systems

Table 1 gives, for nine different energy forms, an example of a distribution system. Chemicals and fuels may be transported in tubes or in portable containers on ships, trains etc., the preference usually being strongly dependent on the existing infrastructure, the cost of which is often on "a different account". Energy forms such as electricity may be transformed and transported in a different form (e.g. as chemical energy in a battery), as an alternative to a grid. The advantages and disadvantages of a line-based distribution system will be discussed below.

4. Grid or no grid?

Discernable preferences for and against line-based distribution are summarized in Table 2. Such preferences may change with time, and some may at present be in a process of changing.

Electric power is today largely connected with grids. This preference is connected with the utilization of large, central power plants. If future electric power were to be generated by solar cells placed on individual rooftops, the need for an extended grid would become more debatable. Where it already exists, it will probably be kept for emergency back-up, but for newly electrified communities (e.g. in rural development areas), it may be contemplated to construct only a local grid, without interregional connections. Instead, batteries or peak-units based on fuel may be provided for emergency. Even better is a reservoir-based hydro system, if available. If other renewable sources, such as wind and hydro resources not located near use areas are to be exploited, an extended grid would be called for according to the remarks made in section 2. Furthermore, the system stability obtained by interregional grid connections would have to be considered, in a final evaluation. It is not unlikely, that the best solution for presently non-electrified regions would be first to invest in local systems, and postpone the investment in large grid connections to a later phase.

It follows from Table 2, that some energy forms are not presently considered suitable for grid systems. Liquid fuels may be a borderline case, with pipeline transmission sometimes considered feasible. The question marks pertaining to elastic energy rests on the relatively unexplored possibility of hydraulic pressure transmission systems, which has been suggested in connection with wave power and industrial machinery (Ladomatos _et al._, 1979). Compressed air storage systems today use conversion before distribution.

Sensible heat is presently used both with and without grid. District heating lines offer many advantages, such as accepting many different forms of input (e.g. from fuel-based boilers and cogenerating power stations, as well as from local, e.g. solar converters). However, the return on investment in a new district heating system is often lower than investments in insulation, infiltration control and passive solar systems, and as the heat requirement drops, the return on a district heating system further deteriorates. Only for very dense building clusters (such as urban centers)is the grid-based heat distribution system indisputably viable at present. Another thing is, that a number of cultural and practical barriers make it unlikely in many places, that the achievable passive lowering of building heat requirement will be reached in the near future.

5. Economic assessment

In summary, Table 2 shows a considerable scope for local systems without grid connections, but also a scope for decentralized systems making use of a common grid to solve problems of load management, energy storage required by variable outputs from renewable energy converters, as well as for overall supply security.

The most important economic question is one of investment risk. Here there is a clear advantage of systems based on small, modular investments, relative to systems relying on single, large units of investment, even if the total cost is identical. The local and decentralized systems are by nature modular and thus offer the less risky investment policy from the above point of view. This does not answer the question of, whether a common grid (and the implied degree of centralization) is advantageous or not, but the discussion shows, that grid systems offer considerable advantages of supply security, if they are considered as emergency back-up for a decentralized conversion system. In contrast, the grid systems may add to the risk of supply failure, if they are based on large, central converters, that are few in number relative to the size of the load (cf. major black-outs in connection with failure of large electric power stations).

The discussion has indicated a possible strategy in forming new energy supply systems where no system is yet available, in that local conversion systems attaching converters and storage facilities to local grids can provide a viable system, which can then later be made more resilient against loss of load by adding interregional grid connections.

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Table 1. Transmission of different energy forms.

PRODUCT OF CONVERSION SYSTEM	EXAMPLE OF DISTRIBUTION SYSTEM
1. Electricity	Electricity transmission grid
2. Radiative energy	Electromagnetic wave emitter/receiver
3. Kinetic energy (e.g. of inertia, rotation)	Mechanical connection (e.g. oscillating rod)
4. Elastic energy (e.g. compression energy)	Hydraulic pipeline
5. Chemical reaction energy	Separate portable containers for reactants
6. Gaseous fuel	Pipeline
7. Liquid fuel	Portable containers
8. Latent heat	Portable containers
9. Sensible heat	District heating lines

Table 2. Preference of system with or without distribution lines.

ENERGY FORM	WITH GRID	WITHOUT GRID
1. Electricity	+(?)	
2. Radiative energy		+
3. Kinetic energy		+
4. Elastic energy	?	?
5. Chemical reaction energy		+
6. Gaseous fuel	+	
7. Liquid fuel		+
8. Latent heat		+
9. Sensible heat	?(+)	?

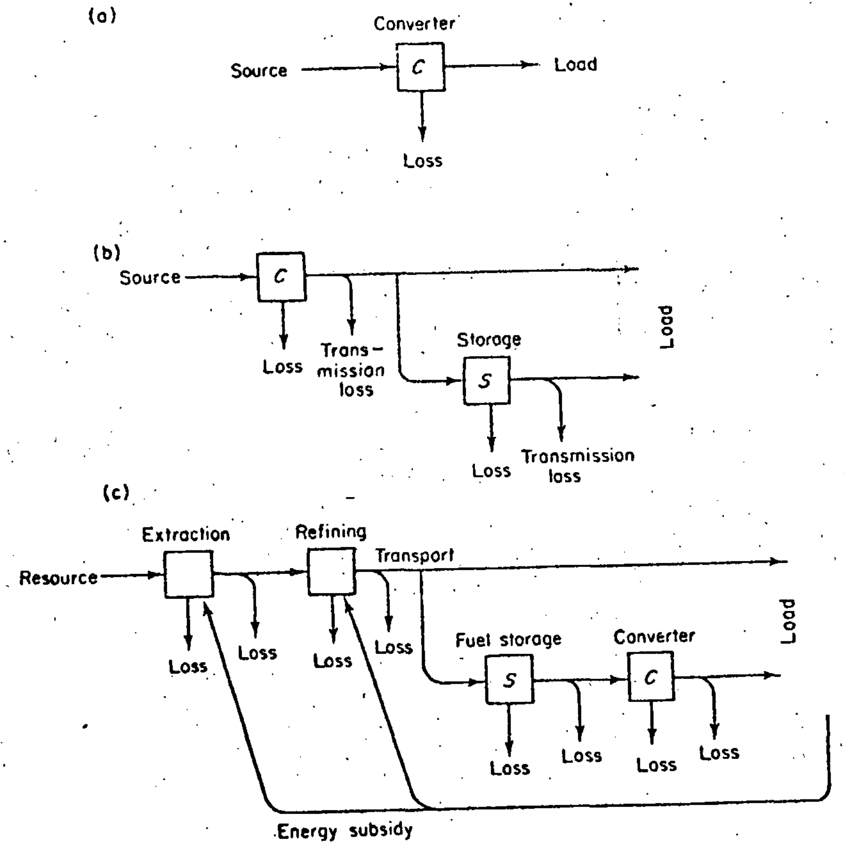

Fig. 1. Energy conversion systems: (a) Simple system, (b) System with storage, (c) Fuel-based system. From Sørensen (1980).

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