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2nd Annual Report from the project

LIFE-CYCLE ANALYSIS OF THE TOTAL DANISH ENERGY SYSTEM

Assessment of the present Danish energy system and selected future scenarios, using methods developed in international projects to which this project, performed for the Danish Energy Agency, is linked*

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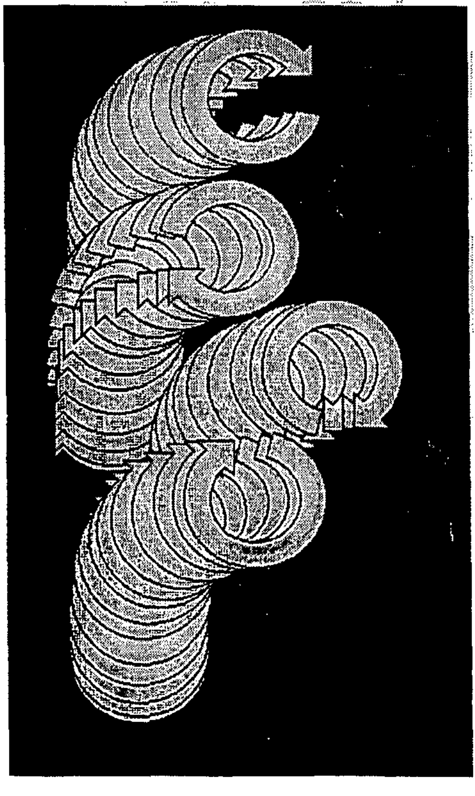
Stefan Krüger Nielsen
Bent Sørensen

* OECD Methodology of Life-cycle Analysis Study
IEA Scoping Study
Japan MITI Technology Assessment Project
USDoE Fuel Cycle Impacts and Valuation Study
EC JOULE Fuel Cycle Externality Study ExternE
EC APAS/RENA Long-term Integration of RE project



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20. January 1996

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Assessment of the present Danish energy system and selected future scenarios, using methods developed in international projects to which this project, performed for the Danish Energy Agency, is linked.
by Hélene Connor-Lajambe, Bernd Kuemmel, Stefan Krüger Nielsen, Bent Sørensen
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ABSTRACT:

This report reflects the work performed on the EFP-94 project during 1995:

* Finalizing the assumptions underlying the two scenarios selected for the future energy system, one being based on a normative requirement of sustainability, the other on "fair market prices", i.e. prices for energy that includes an estimate of social and environmental externality costs (some the most important being those of greenhouse warming) but no other point taxes.

* Carrying out an estimate of physical and practically exploitable levels of renewable energy resources, on a European level.

* Identifying the technologies that will play a role for the energy system over the next 55 years, including production, conversion, transmission, storage and end-use technologies.

* Reviewing current energy use at the end-user, in order to have a consistent basis for modelling future end-use energy.

* Determining the end-use to be covered in the scenarios

* Initializing work on the actual scenario construction, by using aggregate models.

* Reviewing methodology and collecting data on specific impacts for each of the technologies used in the scenarios, based mostly on existing studies but in some cases supplementing with own estimates (e.g. in case of emerging technologies such as solar cells, and for greenhouse warming impacts, based on recent evidence from the 1995 IPCC Second Assessment Study).

The report given here has open ends and chapters to be finished or revised in the final version, due end of 1996. The 1996 work will finalize scenario construction and perform LCA assessment of each scenario. Any omments from readers are welcome!

Fagligt forløb
4. halvårsrapport / 2. årsrapport, EFP-94 projekt 1753/94-0001
Livscyklus analyse af det samlede danske energisystem (nuværende og udvalgte scenarier for fremtidens)
Rapporteur Bent Sørensen

EFP-projektet er en implementering og videreførsel af EC projekterne "ExternE: Eksternaliteter af brændselscykler" (1993-) og "LTI: Integration af vedvarende energi i det Europæiske energisystem på langt sigt" (1995-96), og projektet benytter metoder udviklet i disse projekter og deres forløbere (OECD, IEA, USDoE og MITI). I 1995 har følgende været knyttet til projektet:

cand. et lic. scient Bent Sørensen (EFP, ExternE, LTI: alle dele)
cand. scient. Bernd Kuemmel (EFP, LTI: teknologibeskrivelse og fremskrivninger, drivhusopvarmning og generelt opbygning af database for livscyklus påvirkninger)
Ph.D. Hélène Connor-Lajambe (LTI: energibehovsopgørelse og fremskrivning, identifikation af kvalitative livscyklus-påvirkninger)
stud. tech. soc. Stefan Krüger Nielsen (EFP: scenario-beskrivelse og systemopbygning)
stud. tech. soc. Lene Bager (EFP: assistance med litteratursøgning)

Desuden har prof. Ole Jess Olsen (RUC Institut 4) og adjunkt Anders Chr. Hansen (RUC Institut 8) samt Bent Jørgensen (RUC Institut 2) deltaget i projektdiskussioner.

Som den følgende samling af foreløbige projekt-rapporter og diskussions-bidrag viser, har arbejdet det forløbne år dels søgt at skaffe detaljeret viden om effektivitet og miljøpåvirkninger fra det nuværende danske energisystem, dels arbejdet på teknologianalyse og fremskrivning, som vil tillade samfundsøkonomi og eksternaliteter at blive vurderet realistisk i scenarier for fremtidens energisystem, som benytter teknologier der undergår løbende udvikling og forbedring. En database for sådanne teknologiers økonomi og effektivitet er opbygget, og ventes i 1996 komplementeret med tilsvarende data for livscyklus-påvirkninger. Udover at registrere en række andre arbejder om enkelte energisystemers livscyklus-påvirkninger, har projektet selv set på flere teknologier, der skønnedes at være dårligt belyste i tidligere undersøgelser (fx. solceller).

Scenariekonstruktionen har i 1995 koncentreret sig om generelle forudsætninger, herunder ressource-vurderinger ikke mindst for de vedvarende energikilder, som vil indgå i scenarierne. Dette er sket i europæisk sammenhæng for LTI projektet, men de internationale forhold skønnes også af afgørende betydning for det danske scenarie, som jo skal "spille sammen" med omgivelsernes. Et scenarie baseres på "fair markedspriser på energi", hvilket betyder inklusion af alle eksternalitets-omkostninger, men samtidig eksklusion af "tilfældige" skatter. Metodemæssige overvejelser har spillet en stor rolle i diskussionen af dette scenarie, og en første, oversigtsmæssig implementering er opstillet på europæisk plan. I 1996 vil et scenarie af denne type blive detaljeret for de enkelte lande, og trajektorier og tidslig konsistens vil blive behandlet. Dette skulle tillade konklusioner angående de virkemidler, som eventuelt kunne realisere scenariet.

Delresultater har været fremlagt på en række internationale konferencer, hvorved vi får værdifuld feed-back som kan indgå i den endelige afrapportering. Som foreslået i den oprindelige ansøgning vil al afrapportering foregå på engelsk, for at maksimere synergien mellem de internationale projekter og EFP delen.

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Description of project

Bent Sørensen, January 1996

The state-of-the-art in life-cycle analysis has improved considerably over the last three years. On the methodological side, fairly complete lists of impacts to include have been established (see Sørensen, 1993b), and on the practical side, several energy system components have been subjected to fairly detailed evaluation of a range of externalities. Most of the studies concerned deal with specific energy installations, i.e. a specific technology implemented at a specific time and in a specific location (USDoE, 1992; EC ExternE Project, 1995; World Bank EM Project, 1995; and local implementations, such as Meyer et al, 1994). A few studies aiming at evaluating entire energy systems are underway, e.g. in Switzerland and in the World Bank project. This is also the goal of the present investigation, which will study not only an entire existing system (the current Danish one), but also scenarios for future systems. This may seem very ambitious, but one should remember, that the life-time of energy systems is often very long, and hence a future system could simply be replacing all existing devices with the best ones (in terms of avoiding negative impacts) already on the market today. This is largely the case for the scenarios studied here, as many of the system components have already been developed. However, some of the devices are admittedly at an early stage of development, and the scenario method has been used to prognosticise the future efficiency and optimization of such devices, in order to estimate the impacts of energy systems that are entirely different from the existing ones. With due considerations of the uncertainties in such an approach, we believe that such studies may serve a useful purpose in the political debates over long-term energy planning, an enterprise that must in any case be based on expectations rather than certainty.

The bulk of the project work is taken up by a detailed analysis of all the ingredients and components that may constitute future energy systems, in order to be able to estimate costs and impacts of the entire aggregated system, imbedded in a society that may in several regards be different from the present one. The precise choice of scenarios may be considered of lesser importance, because it would be easy to assess any alternative scenario, once the databases of costs, resources, technologies and LCA impacts are in place. One complication is the possible time and space dependence of impacts. Certainly impacts associated with short-range pollutants depend on the population distribution and physical terrain characteristics at the site of installation, whereas impacts dispersed regionally or even globally will depend less on the actual place selected for the devices involved. For some devices, however, the choice is limited (e.g. decentralized, rooftop based devices), but the sheer number of devices will allow averaging over sites and population distributions.

The following chapters describe each of the issues mentioned. As this is a progress report of ongoing work, some chapters are not finished yet, and many others are in various degrees of preliminary stage.

SCENARIO BASIS

The scenario method - why and how?

Bent Sørensen, January 1996

Most economic theory deals with the past and occasionally the present structure of society. Here it is possible to observe relations between different factors, to construct theories of causal relationship, and to test them on actual data. This type of scientific method is of course borrowed from natural science and particularly from physics. In order to deal with the future, one may invoke the established quantitative relations between components and assume that they stay valid in the future. This allows for "business-as-usual" forecasts, e.g. using econometric models such as input-output matrices to compute the future situation. Because the measured "coefficients" describing relations between the ingredients of the economy vary with time, one can improve the business-as-usual forecast to take into account trends already present in the past development. However, even such trend-forecasts cannot be expected to retain their validity for very long periods (Makridakis, 1990). Actually, it is not even the period of forecasting time that matters, but changes in the rules governing society. These may be changed due to abrupt changes in technology used (in contrast to the predictable, smooth improvements of technological capability or average rate of occurrence of novel technologies), or they may be changed by deliberate policy choices. Assuming of course, that "free will" is a characteristic of human enterprise penetrating even politics. Studies such as the present one, that aims at investigating the action room for alternative changes in policy, including radical changes that are known to have taken place over time horizons such as the 50+ year period considered in this work, therefore have no use of the conventional forecasting method, neither of status-quo or linear trend extrapolation. It is sometimes argued, that econometric methods could include non-linear behaviour, e.g. by replacing the input-output coefficients by more complex functions. However, to predict what these should be cannot be based on studies of past or existing societies, because the whole point in human choice is that options are available, that are different from any past trend, even non-linear ones. The non-linear, non-predictable relations that may prevail in the future, given certain policy interventions at appropriate times, must thus be postulated on normative grounds. This is precisely what the scenario method does. Or rather, it is one way of describing what goes on in a scenario analysis. The conclusion is therefore, that the objective of analysing policy alternatives cannot be reached by conventional economic methods, but must invoke a scenario construction and analysis, one way or the other.

The discussion above explains why we have chosen the scenario method as our tool. It really does not have any meaningful competition. All analysis made to date of long-term policy alternatives are effectively scenario analyses, although they may differ in the comprehensiveness of the treatment of future society. A simple analysis may make normative scenario assumptions only for the sector of society of direct interest for the study, assuming the rest to be governed by trend rules similar to those of the past. One of our scenarios is of this kind. A more comprehensive scenario analysis will make a gross scenario for the development of society as a whole, as a reference framework for a deeper investigation of the sectors of particular interest. One may say that the simple scenario is one that uses trend extrapolation for all sectors of the economy except the one focused upon, whereas the more radical scenario will make normative, non-linear assumptions regarding the development of society as a whole. The full, normative construction of future societies will come into play for a scenario describing an ecologically sustainable global society.

It is important to stress that scenarios are not predictions of the future. They should be presented as policy options, that may come true only if a prescribed number of political actions are indeed carried out. In democratic societies this can only happen if preceded by corresponding value changes affecting a sufficiently large fraction of the society. Generally, the more radical the scenario differs from the present society, the larger must the support of a democratically participating population be. Talking about global scenarios, it has of course to be mentioned, that the world's nations currently enjoy varying degrees of democracy. Most scenarios could be implemented by dictate, including probably the ones we will describe. However, this is a very different type of future, precisely because we see the scenarios as representing "desirable futures", which at our latitudes cannot include any scenario introduced by decree. We shall therefore precede our scenario descriptions by an attempt to indicate the value basis that must gain acceptance in societies embarking on the route to that particular future scenario. Because of the general nature of our scenarios, we will have to dwell at the issue of global development, even if our scenario area is limited to one or a small groups of countries.

Methodology and short history of early energy scenario work

The decision support tool for shaping alternative national policies is the technique known as the scenario method. It basically consists in selecting a few of the possible futures, chosen on the basis of having spurred an interest in the population and by reflecting different values held in a particular society.

As the next step, these futures have to be modelled, with emphasis on the issues deemed particular important: better social conditions, less polluting energy systems, environmentally sustainable processes, societies offering human relationships within a preferred frame, and so on. During this process one must keep in mind, that models are simplified and necessarily inaccurate renditions of reality, and have to be treated accordingly. Models are essentially frameworks for discussion.

One would next have to discuss the consistency of the elements in the models, e.g. as regards sustainability, resource availability, and consistency between different aspects of the scenario. And finally discuss possible paths from the present situation to the scenario future. This would be done for each scenario proposed, as part of an assessment which involves the full apparatus of political debates and decision-making processes.

Central questions to address are who should propose the scenarios and who should stage the debate and decision process. There are clearly many possibilities for manipulation and unfair representation of certain views. Whether a democratic process can be established depends on the level of education and understanding of the decision process, by the citizens of a given society, as well as on the tools used for debate, including questions such as fairness of and access to media. Many developed countries have a tradition for broad social debates, but even in such countries, there are also clear efforts by interest groups or sitting governments to take over the communication means and distorting the process in favour of their own preferred solutions. These institutional questions have to be part of any realistic proposal for a new way of approaching development issues (cf. Figure 1, Sørensen (1995a)).

The first uses of scenario techniques along lines resembling the ones sketched above were inspired by the system dynamics ideas proposed around 1970 by J. Forrester (1971) and H. Odum (1971), building on population models used in ecology (E. Odum, 1963). The basis was linear compartment models described by coupled sets of first order differential equations, originally aimed at explaining feed-back loops to students. Application of these methods to resource dynamics, promoted by industrial magnate A. Peccei and his "Club of Rome", with D. Meadows as science writer (Meadows et al., 1972), spurred a global debate of the finiteness of certain resources, although the actual modelling was far too oversimplified to be credible.

While the system dynamics people claimed to be able to predict catastrophes happening if habits were not changed, the scenario models aim precisely at exploring the alternative policies, that would alleviate any unwanted or unpleasant development. The first ones were primarily aimed at energy production, a subject very much in the forefront during the early 1970'ies: E. Tengström's group at Chalmers Technical Highschool in Göteborg (Eriksson, 1974; Eriksson et al., 1974), and myself at the Niels Bohr Institute (Sørensen, 1975a;b), produced scenarios for sustainable energy systems tied to assumptions of socially equitable and globally conscious behaviour.

These ideas were taken up, e.g. by A. Lovins after his visits to Scandinavia, and widely disseminated (Lovins, 1977). However, his reproduction was not entirely faithful, as he postulated that his scenario was already the cheapest in a conventional direct economy evaluation (clearly an incorrect postulate at the time), and thereby Lovins avoided to deal with all the more subtle questions of tackling indirect economy (i.e. what the standard economic calculations leave out and therefore call "externalities").

The use of scenario techniques were later taken up by the group around T. Johansson at Lund University (Johansson and Steen, 1978), as well as by a number of other groups all over the world (see overview in Sørensen, 1981). The attitude towards such modelling efforts have matured, and today, most modelers realize the need to model not only technical systems, but also the social context, into which the technical solutions are imbedded, the environmental impacts and the implications for global strategies. In other words, the scenarios are seen as more comprehensive visions of future societies, although it is still necessary to restrict the features detailed, in order for the models to remain manageable.

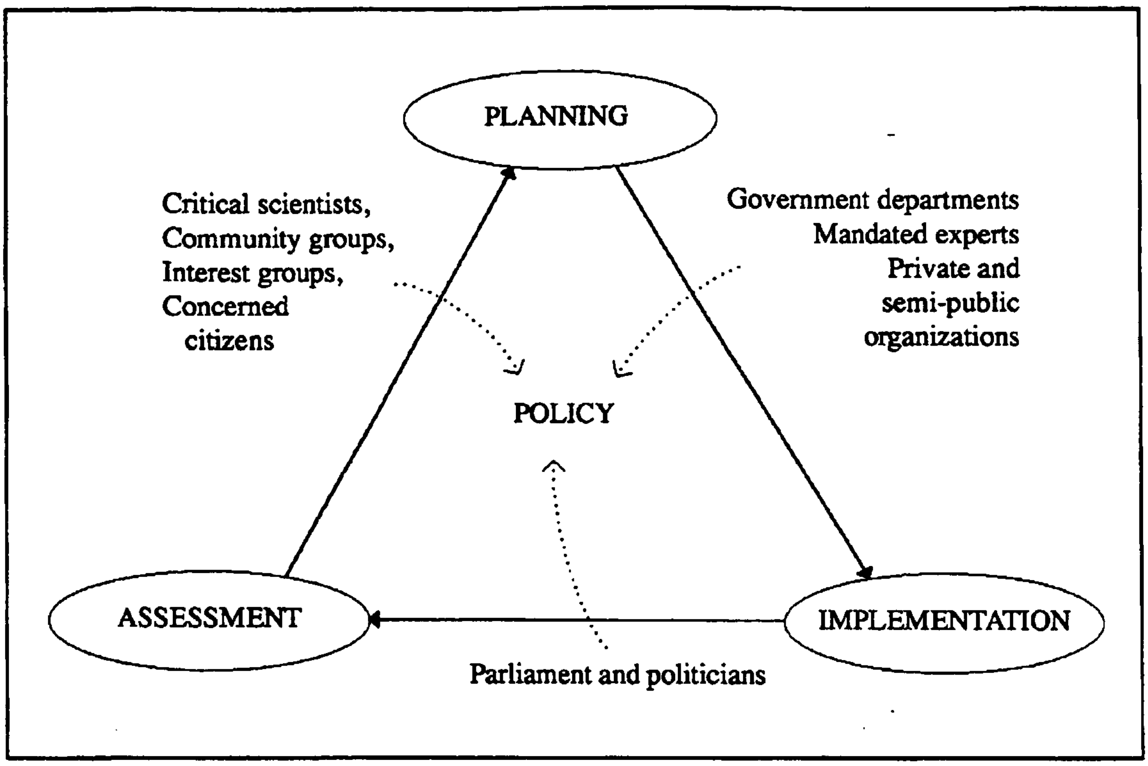

Figure. 1. The actor triangle, a model of democratic planning, decision-making and continued assessment (Sørensen, 1993a).

Overview of other studies

Scenario work for high penetration of renewable energy some time in the 21st century has been performed in several recent studies.One is the Danish Technology Council study of two scenarios for Denmark (Sørensen et al., 1994), reviewed in detail in the 1994 Progress Report (Sørensen, 1995b). Recent Danish studies of energy scenarios may be found in the Danish Department of Environment and Energy (1995) preparatory study for the 1996 Danish Energy Plan. On the European level, we are not aware of any other studies than the present LTI work. However, on the global level, scenario work has been undertaken by the IPCC Second Assessment Report, Working Group II (1995). A continuation of this work has been presented at an IEA Greenhouse Warming Mitigation conference (Sørensen, 1996).Figures 2-7 show the main results of the IPCC scenario work (LESS= Low Emission Supply Systems; cf. Ishitani et al. 1995), while Figures 8-9 show the centralized and decentralized renewable energy scenarios of Sørensen (1996).

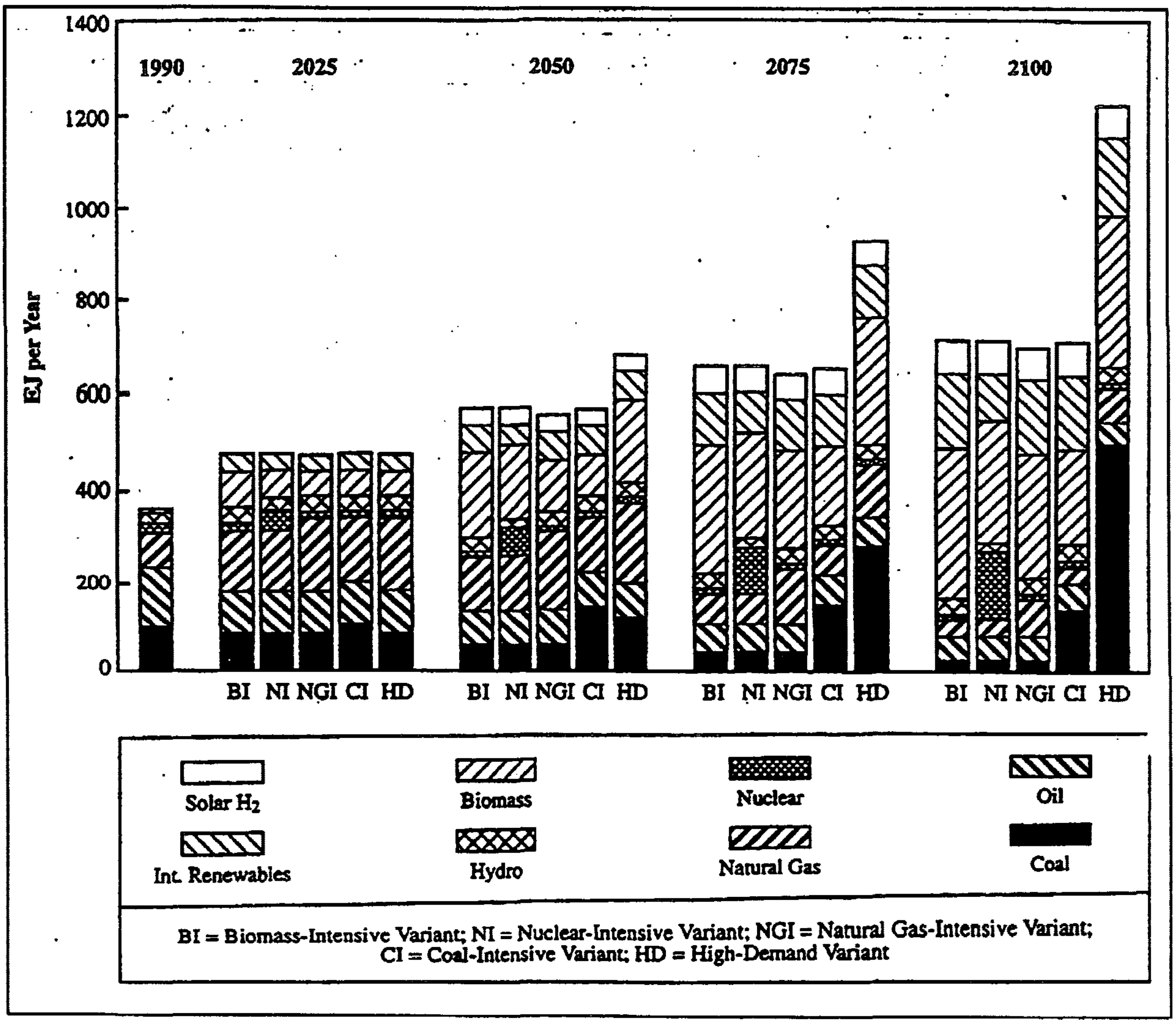

Figure 2. Global primary energy use for LESS scenarios. The scenarios do not have the same energy demand levels (Ishitani et al., 1995).

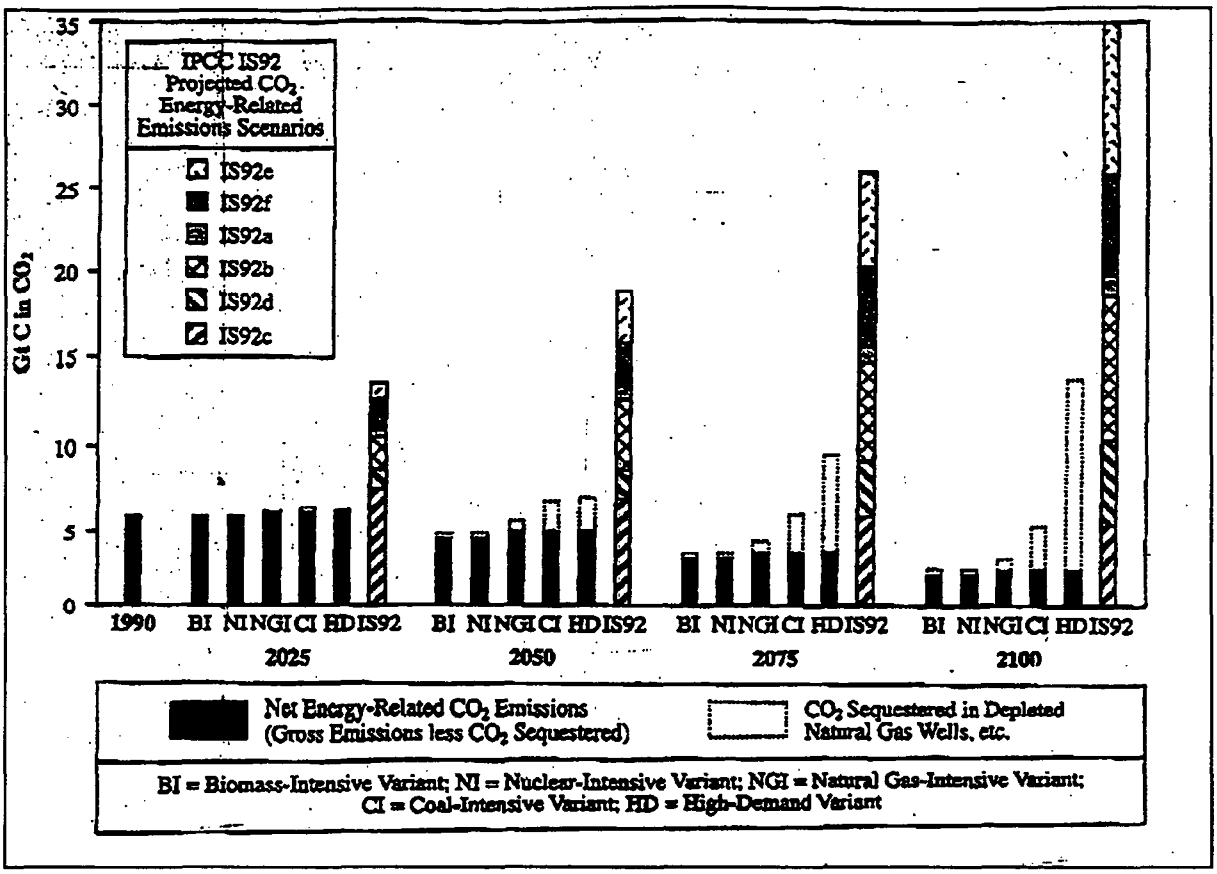

Figure 3. Annual CO_2 emissions from the fossil fuel component of the LESS alternatives, compared with the IPCC IS92a scenario (IPCC, 1992, Ishitani et al., 1995).

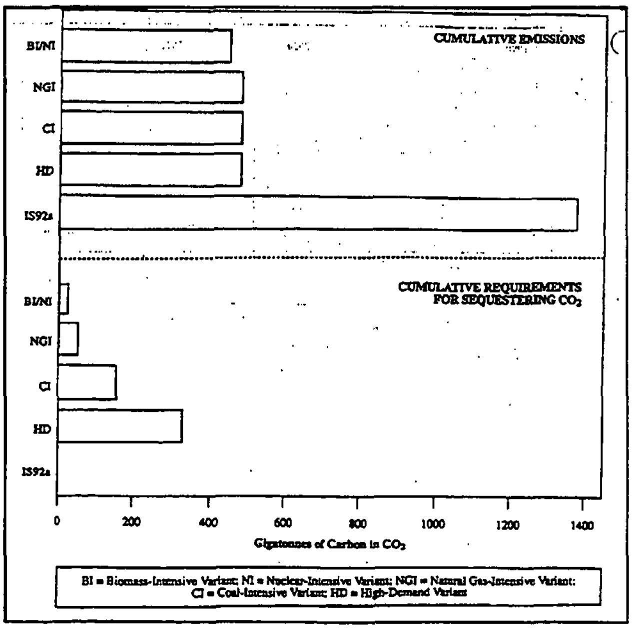

Figure 4. Cumulative CO_2 emissions from IPCC IS92a scenario and LESS scenarios, and CO_2 sequestration requirements (Ishitani et al., 1995).

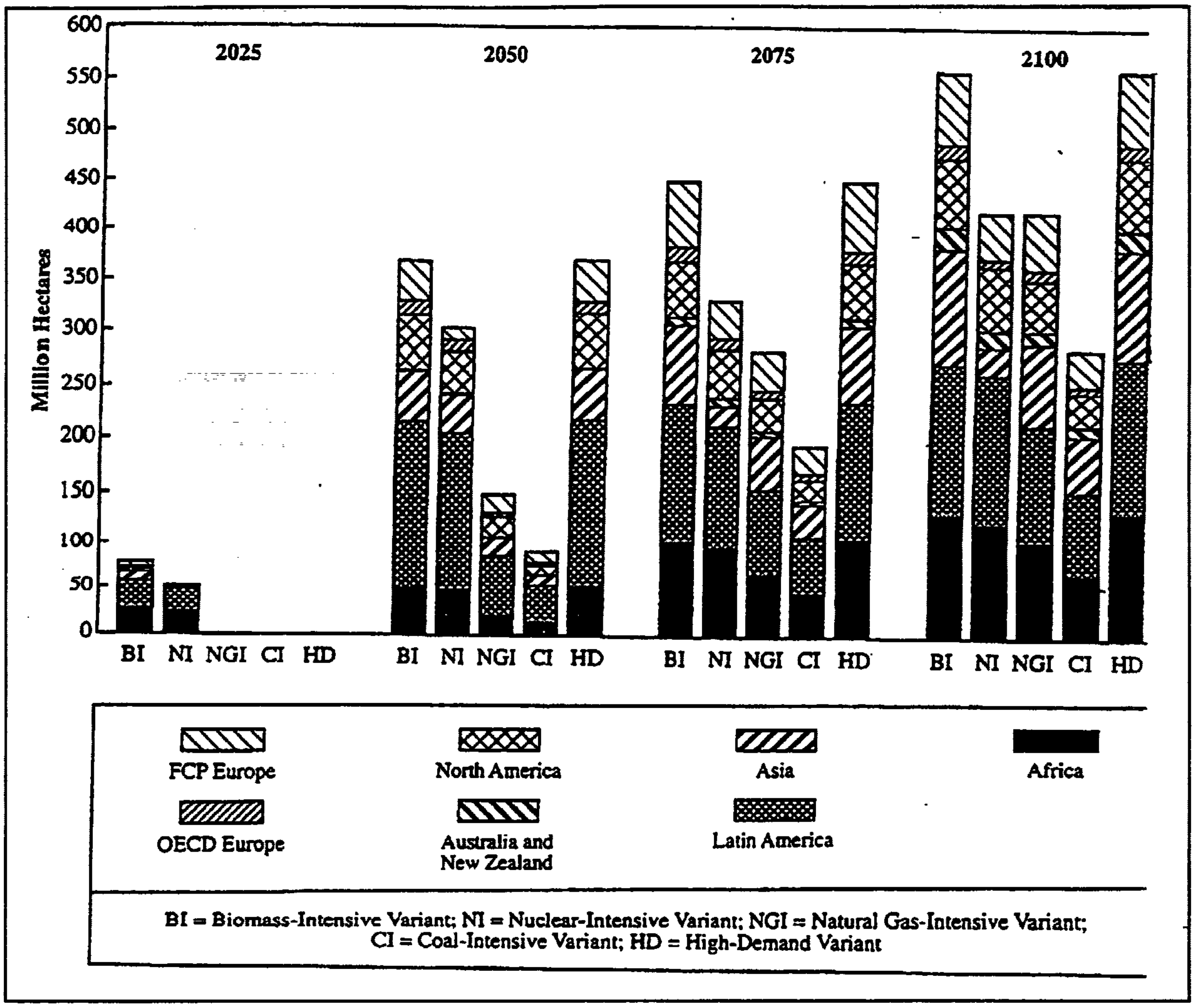

Figure 5. Land areas of biomass plantation by region for alternative LESS scenarios (Ishitani et al., 1995).

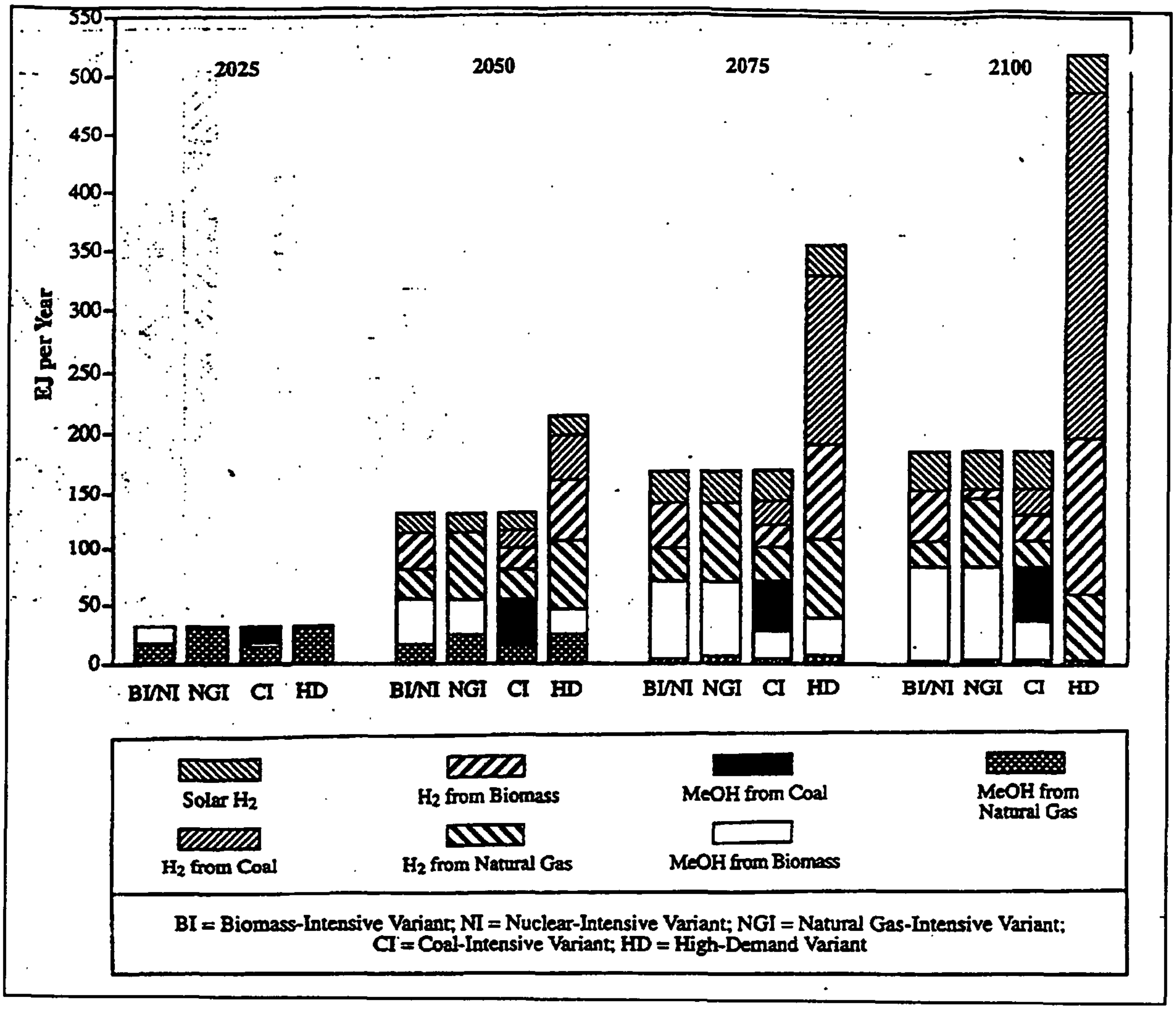

Figure 6. Methanol and hydrogen production from alternative sources for the LESS scenario (Ishitani et al., 1995).

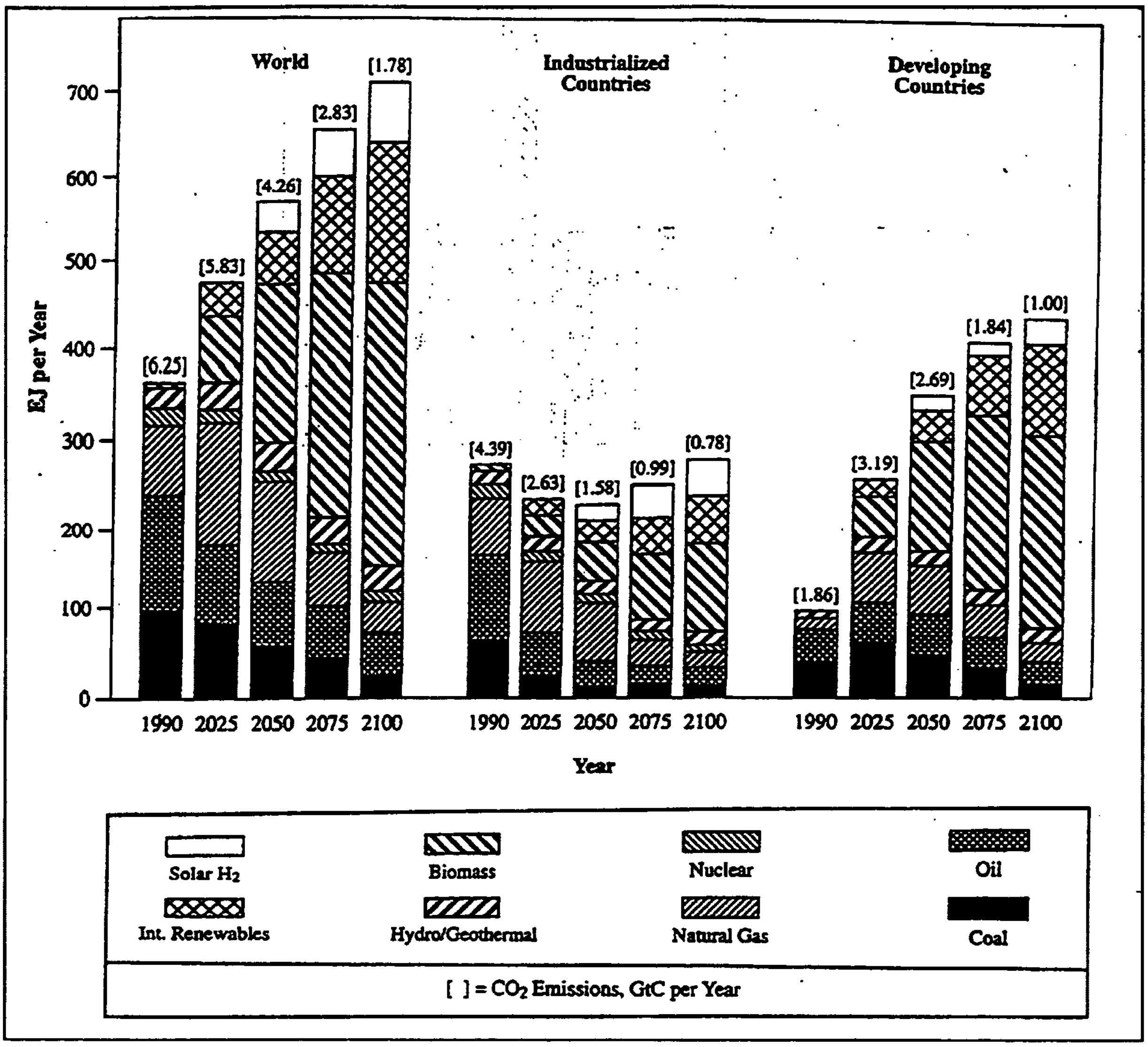

Figure 7. Use of primary commercial energy in the biomass-intensive LESS scenario, for different parts of the world (Ishitani et al., 1995).

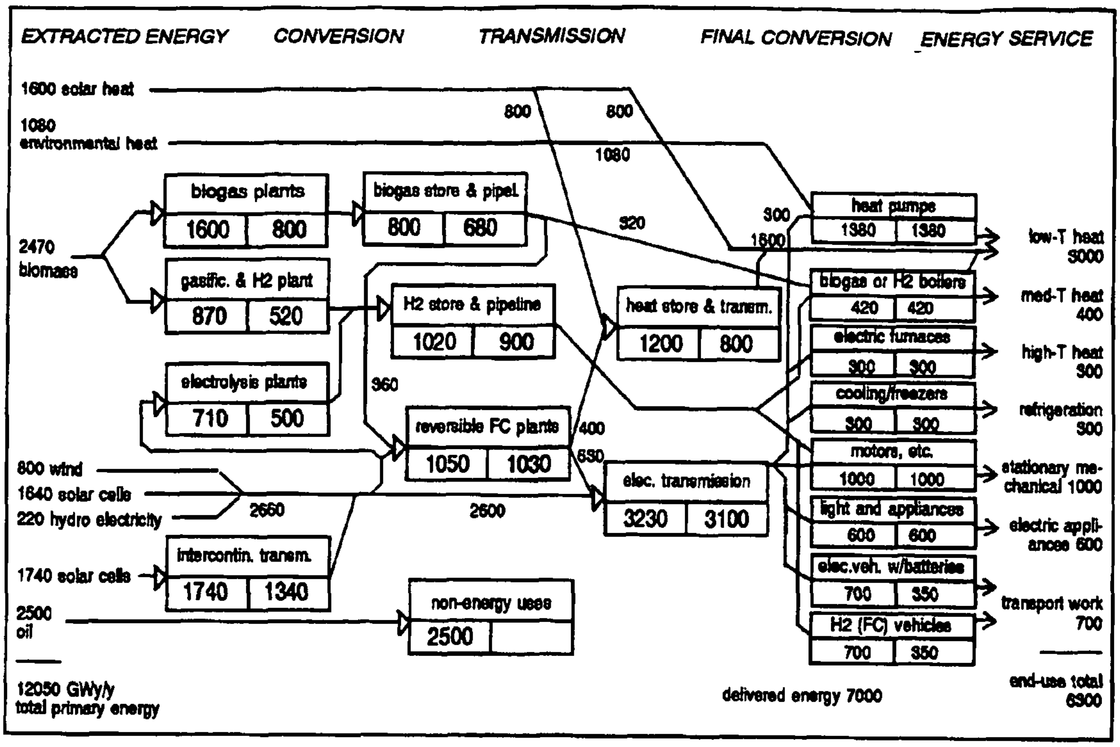

Figure 8. Global 2050 centralized renewable energy scenario (GWy/y; Sørensen, 1996).

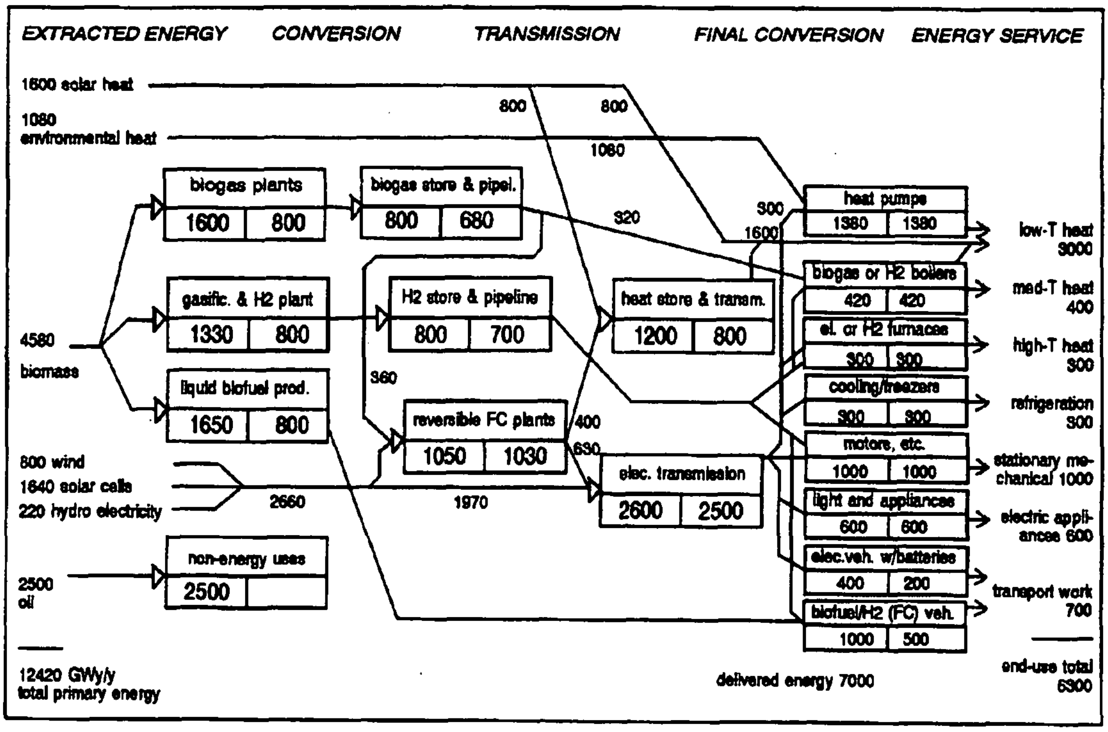

Figure 9. Global 2050 decentralized renewable energy scenario (GWy/y; Sørensen, 1996).

Two scenarios for the mid-21st century

Bent Sørensen

In this project, we are presenting two scenarios for the mid-21st century. One is a scenario based on an assumed transition to environmental sustainability, while the other tries to extrapolate trends and views already present in current advanced societies. Both scenarios are normative, i.e. they describe futures that we think are of general interest, and which may occupy a place in current political discussions about mitigation of adverse impacts of an increased greenhouse effect.

One scenario will assume that trends in current views of the more environmentally conscious fraction of the European population will continue, but that the main mechanisms of societal economy will remain unchanged. There will be changes in prices due to a commitment to establish fair prices in the energy sector, replacing point taxes imposed for reasons of revenue by taxes that can be argued for in terms of externality costs, and the scenario will explore the changes in energy choices derived from such a new price structure.

The other scenario will assume a profound change in the value system of the European population. The argument of sustainability of human activities will be carried very far, and will be used to shape future energy demand as well as energy provision. It is thus assumed that the corresponding environmental values held today only by part of the population will become dominant and will bring about the political will to make radical changes in society. One should however not overlook, that full sustainability is never possible in a society that considers the human settlements as being apart from the environment: Human activities has always and will always interfere with the natural environment, e.g. by transforming large land areas into food-producing agricultural bases, transport infrastructure and settlements. The aim thus cannot be not to interfere with nature, but only to create a human society that in principle could continue to do what it does forever, but accepting the changes in nature (reduction in number of species, for example) that human civilisation entails. Alternatively, one might consider man as part of nature, fighting as any other species to establish his niche on the planet.

The choice of 2050 for the scenario end-point is made, because we want to investige options for a future society, in which most current equipment will have been replaced, leaving the possibility of politicsally influencing the choice of such new equipment. Only in the case of buildings, there will be a fraction left over from the present era. The purpose of this kind of scenario building is to influence policy debates and decisions *today*, by setting tangible goals and directions for current action. No attempt is made to guess the most likely development in the absence of such a debate (which is what economists would call to prognisticize or forecast the future). The aim is to promote conscious policy-making as contrasted to policy by inertia or default (the least pressure solution).

Sociological basis for scanerios, in condensed form

The attitudes characterizing populations of countries, where the level of education and political tradition allow such debates to proceed, may in a simplified and highly condensed form be described by just two arketypes (Sørensen, 1989):

- the concerned citizen
- the audacious citizen

The concerned citizen is worried over the possible side-effects of human activities, whether it is environmental pollution, genetic manipulation or degradation of social conditions. If we cannot overview and understand the consequences of say introducing a new technology, then it is better to forego that technology, to issue a moratorium until we better understand the consequences.

Opposed to this attitude, the audacious citizen says, "Let us take the risk". If something goes wrong, we will deal with that then, and quite likely we shall find a solution, albeit with other unknown consequences. As regards climate change caused by greenhouse gas emissions, the audacious person will say not to worry, as the cost of adapting to any change in climate, should it really occur, may be smaller that the cost of restraining our activities now, or we may be better to deal with the problem, given the progress caused by all the new activities between now and then.

The audacious individuals have produced advances in the past, and they have produced quite a number of problems. Also the concerned persons have made a contribution, although perhaps less spectacular: they have stimulated the development of alternative technologies. In any case, these two groups have existed during the last centuries in most industrialized countries, and they have roughly divided the population in two equally large fractions, with overweight and political influence moving back and forth between the two groups. Probably the debate created by having these two views has been beneficial for the overall development.

Implications for energy scenario formulation

The environmentally sustainable energy scenario of our work is a reflection of the views of the concerned citizen. We have had more difficulty in arriving at a precise definition of the other scenario. There is no point in defining a scenario corresponding to the audacious citizen's views. To satisfy this person, there should be as little planning as possible, no restrictions on development of new technologies and no cost associated with indirect impacts of human activities. We believe that scenarios should represent realistic futures, and the totally deregulated caricature of an ultimate liberalism can hardly be considered interesting by societies, that even when they boast of being liberal still regulate a large number of areas and have no illusions of realistically doing away with most of these regulation (safety of buildings, traffic rules, etc.). The slogan "deregulation" is an argument in a much more restricted debate on whether to marginally increase or decrease regulation.

Then what should the second scenario be? We propose to look at the society, against which we are curently headed, i.e. an extrapolation of the directions of change, that we observe today. This direction is itself a compromise between the political groups of each society, and in our simplified model of social preferences, it is the compromise currently struck between the views of the concerned and the audacious citizens. This choice of scenario has the advantage of being possible a positive one: It might be, that the current political balance between the two views is a fair one, and that the society developed as a consequence of this balance will be the best in dealing with future challenges, including those posed by greenhouse warming. The question we are addressing is then, if this is really so, or if a change in political outlook is required, taking into account some of the considerations made by the concerned citizens.

Global perspective.

The present assignment is to produce scenarios for renewable energy futures for the European Community. It is necessary to complement the European scenarios with at least a sketch of the global development. This includes a view on the population development, the type of activities favoured globally, and correspondingly the demand for resources and the level of international trade with both resources and products.

In order to make the scenarios credible, it is fairly evident that the global development has to be assumed to follow patterns similar to or consistent with the European ones. It would not be sensible in a greenhouse mitigation context to look at a European transition to renewable energy, if the rest of the world goes on burning fossil fuels (this does not mean that there could not be reasons other than greenhouse effect mitigation, that could make it attractive to introduce renewable energy). We shall thus assume, that roughly the same type of policy is persued all over the world, and further that the disparity between rich and poor countries is diminished, because otherwise it is difficult to see, how the polulation growth could be halted (short of nuclear war).

For the environmentally sustainable scenario, which is based on high energy efficiency in the European Union as a basis for introducing a viable renewable energy system, we shall thus assume a similar development of efficient use of energy globally, at the same time as the standard of energy services (as a part of living standards) moves towards a common, global level of an average rate of energy conversion at around one kilowatt per capita. A sketch of the implications of this assumption for the global distribution of primary energy use and end-use delivered services is given in Figure 10, for the planning period 1990-2050. The fair market scenario would then assume a similar development globally, presumable heading towards a picture such as the one shown in Figure 10, but not reaching it so fast, e.g. not within the planning period.

Figure 10 is intended to illustrate one very basic fact in energy planning: The use of primary energy may decline, while the services delivered to the end-users increase. It is based on an estimated difference between primary energy and end-use service, that not only counts conversion losses right until the final conversion, but also reflects on the actual service derived from the end-use conversion. The energy levels depicted on the right-hand side of the picture are meant to represent the lowest possible energy required to deliver a given service, using known (but not necessarily in current use) technology. This includes ideas for providing a given service by other means than those used today (e.g. replacing business travel by video conferencing). Details of the calculation underlying Figure 10 are given in Sørensen (1995a) and (1996). The actual curves in Figure 10 are only for illustrating the point made above. To find the real numbers amounts to constructing the corresponding scenario, which is what we will be doing in the following chapters, for the 15 European countries considered.

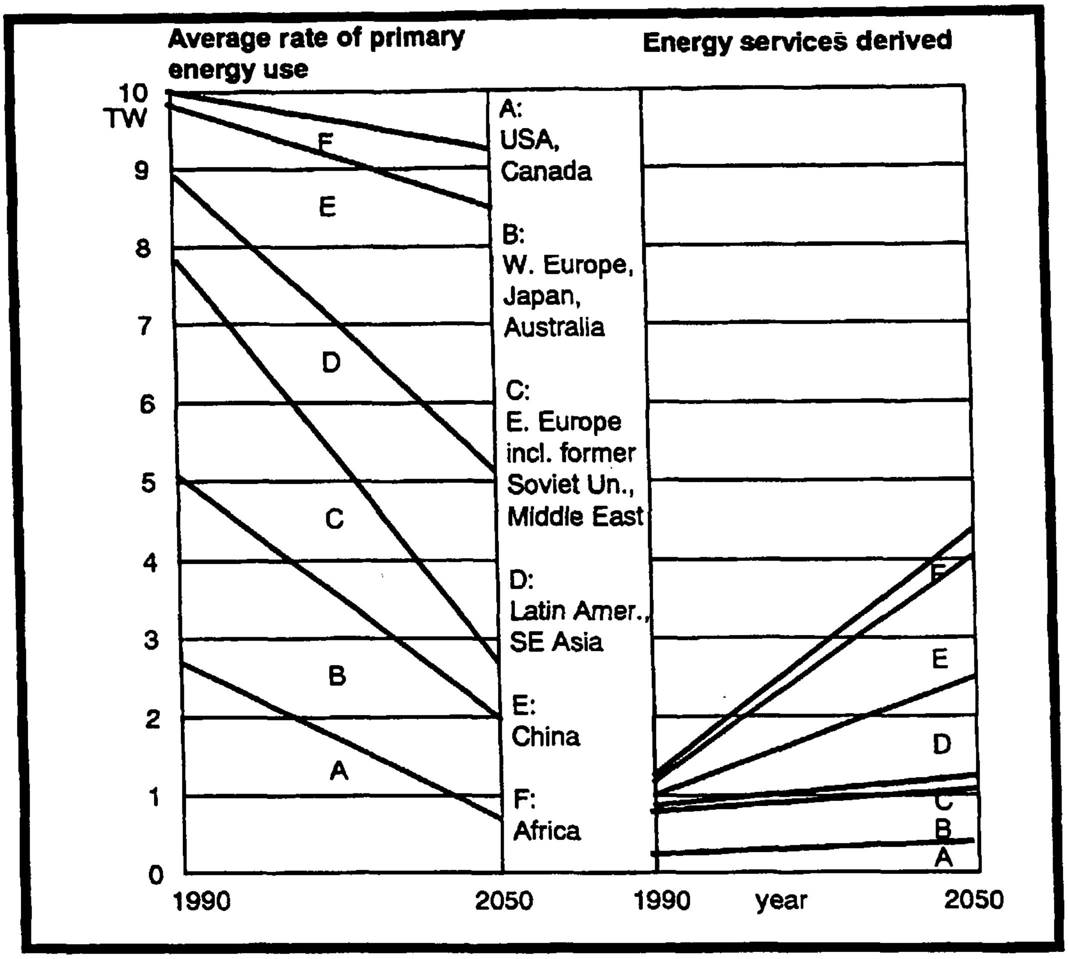

Figure 10. Possible development in primary energy use and in delivered energy service, for aggregated regions of the world (based on end-use efficiency scenarios described in Sørensen, 1995a).

More on scenario development and construction

Stefan Krüger Nielsen

Methodology.

Basically our scenario method is shown in Figure 11. The figure shows the main steps which are to be carried out for each scenario, though the first step, the environmentally sustainable framework, will be common for both scenarios.

As shown in Figure 11 our goal is to reach a sustainable society. In this way the frame of our scenarios will be an "environmentally sustainable framework" that will affect all our concerns and choices for the future society.

We will make two normative scenarios for the future society as a whole. This implies that we will try to describe in very broad terms which changes in society that could possibly lead the way towards two different sustainable societies. We will try to describe which structural changes that could be necessary if the countries in the European Union agree upon taking action to reach a sustainable society.

We will try to translate these assumptions about the changes in society as a whole into some more detailed assumptions of the development of energy related activities in society. This will be used for the estimation of the anticipated end-use of energy which corresponds the anticipated level of activities.

On the basis of the anticipated level of energy use we will construct an energy system that can supply the energy demand.

Finally we will estimate whether we have reached our sustainable goals in any of our scenarios.

In the following we will describe the tasks that are to be carried out in this project in more detail.

Step one: Description of the overall goals of the project and our reason for concern.

I propose that this definition will have to be the same for both scenarios. In this way the goals in the two scenarios will be the same, but the means for getting there will be different.

Sustainability[1]

Our environmental goals can be solved in many ways. Nevertheless we will only consider solutions which can also be considered as sustainable options for the future. In this way sustainability becomes the frame of our approach.

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[1] This is inspired by Jørgen Birk Mortensen, Økonomi og bæredygtig udvikling (Economy and sustainable development), EVA's årsrapport 1991 (in danish), Jørgen S. Nørgaard, "Integrated environment and energy planning", Physics laboratory, DTU, 1991.

We think that a definition of sustainability will be needed in this project. As we all know the word sustainable has been used in many fashions about almost everything. One could say that the expression covers the whole scale from saying exactly nothing to being a very strict definition of each of the Earth's inhabitants environmental space[2].

The most widespread definition of sustainability is probably that produced by the so-called Brundtland Commission. This definition covers several aspects. The basic concept is the principle of all nations of the world having equal access to the same amount of resources[3] and of not preventing the next generations from having the same access to resources as we have today. At the same time there are some ecological and societal demands which should be observed.

Respect for the coming generations

An important aspect of sustainability is respect for the generations that are to be born after us. Our generation should not live in such a way that it conflicts with the chances of survival for the future generations. Future generations should have equal access to the Earth's resources. So we will have to change our lifestyle considerably.

Living by this principle of respect for the coming generations means that our utilization of renewable resources is not allowed to grow faster than the reproduction of those resources. In principle the same will be the case for the non-renewable resources. This leaves us with the question of how much non-renewable resources our generation can be allowed to use.

In principle non-renewable resources should not be used at all. This calls for structural changes in society that will assure that as many substances as possible are recycled, re-used or reproduced and where the use of non renewable resources are substituted by the use of renewables as far and as fast as possible.

Equal rights for the Earth's population

There should be equal access to the Earth's resources for all people on earth. This implies that we have to smeer out the differences between rich and poor, e.g. the differences between developing countries and industrialized countries and even between rich and poor people within the countries. The allocation of resources and environmental loads should in principle be based on a per capita basis

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[2] One definition of "sustainable space" have been made by Friends of The Earth for the "Sustainable Europe" project. They have calculated the environmental space per capita on earth. One example is that they have calculated the amount of energy that each person can use without violating some sustainable and ecological principles.

[3] A definition of resources will be needed.

for the worlds population[4].

Summary

Our definition of sustainable development could be as follows:

1. Renewable resources should not be used faster than they are reproduced. (One could add: Or substituted by some other resources which gives the same amount of welfare.)

2. Non-renewable resources should not be used. (One could add: Or substituted by some other resources which gives the same amount of welfare. This would allow for a substantial use of fossil fuels now while producing renewable energy technologies for the future. These renewable energy technologies could be seen as a fair substitution for the amount of fossil fuels used).

3. The pollution should not be omitted at a higher rate than it is absorbed by the natural environment.

4. The access to resources and the environmental loads should be allocated equally on a world basis.

Environmental loads per capita on earth

As it will be too complicated to assess all potential environmental problems due to energy consumption[5] we will make an environmental goal which is more simple. The goal will be to reach a reduction in CO_2 emissions derived from energy production in the EU countries by at least 80% compared to 1990. This goal is actually probably in the low end if we reach for a stabilization of CO_2 in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system in 2050. For example Niels I. Meyer estimates that the actual needed reduction might be in the range of 98% considering that there will be 10 bilion people in the world in 2050, i.e. a doubling of the present world population, if the allocation of CO_2 emissions were equally distributed on a per capita basis in the world as a whole[6].

Sustainable space per capita on earth

One way to make our sustainable goals a bit more operational is to calculate the sustainable space per capita on earth. We have not got the time for calculating the environmental space per capita for all activities in society, but we have talked about adopting the goal of reaching an energy end-use level of about 1 kW (tertiary energy) on average per capita on earth. This seems to be a level that has

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[4] Of course this definition does not take geographic considerations into account. One major problem might be that people living in cold regions of the world needs more heeting than people living in warm regions.

[5] Especially considering the environmental damages occurring at all levels in the energy conversion chain from the extraction of resources to the final end-use of energy (see figure 2)

Meyer, Niels I., "Sustainable energy scenarios for the scandinavian countries", in "Renewable energy", Vol3, no.2/3, pp. 127-136, 1993.

been agreed upon as sustainable by different green organisations (according to Bent). Maybe this goal will only be reached in the sustainable scenario, but it ought to be the goal of both scenarios.

Step two: Modelling the end-use of energy in 2050

As a first step of our scenario method we should come up with some consistent basic assumptions for the future. The challenge of this step is to describe which societal changes that will be desirable for the future. This description will of course depend on the problems that we see in our present society[7].

As our aim is to present two possible and different pictures of the energy system in the future society we will only try to describe the possible future changes in society that will possibly influence the energy sector. We will not try to describe all societal changes[8]. Basically we will try to describe some solutions which will solve some of the problems in our recent society that we have described in our goal definition.

The societal changes that will be described are mostly structural changes in different economic sectors such as industry, service, domestic, transportation and land-use due to some anticipated changes in the populations norms and behaviour. These basic assumptions of the anticipated activities in society will create the basis for our calculation of the final demand for energy end-use in the different economic subsectors.

The end-use approach

For simulating the future demand for energy we will use the so-called end-use approach[9]. This implies that we will determine the end-use service needs in 2050 and hereafter work backwards through the energy conversion chain (see figure 12) to calculate the primary energy needed for providing the net energy input needed for attending the energy services in question. Basically this

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[7] Of course many problems occur when describing these future developments as the consequences of the interactions between different societal developments are not easy (impossible) to foresee. Nevertheless, we should in some way try to explain the probability of the consistency of the chosen basic assumptions.

[8] This also contributes to the problem that we do not know whether the changes that we choose will affect other parts of society which we are not dealing with.

[9] The end-use approach is a so called bottom-up approach. By this approach the physical stock of end-use technologies and the changing energy intensities of those are modelled directly. In this way it is possible to estimate the end-use technologies future energy use. The bottom-up approach is the opposite of the so called top-down approach, which means that the energy use is assumed to be directly correlated to the economic development, possibly only corrected for the assumed improved efficiency of the end-use technologies and development in population. The advantage of a bottom-up approach is that by using this demand-oriented approach the energy is valued for the services that it provides not for the amount of energy used for attaining these services. A demand-oriented energy plan can be aimed at meeting the end-use demands in the most efficient manner. (Sørensen et. al, 1994, Sørensen 1983, Sørensen 1980, Nørgaard 1991, Benders 1994, Robinson, 1982, Brooks 1983).

method consists in calculating the energy losses due to energy conversion and transmission. One example of the losses of energy through the energy chain is given in figure 13 (Sørensen 1980). **[Substitute this with the spaghetti chart for the energy chain in EU12.]**

The level of activities in the future society is generally estimated by choosing certain levels of activities which we think will be consistent with our sustainable goals for the future. These goals for the future society will create the frame for all our basic assumptions about the anticipated level of activities that will be desirable[10].

The future end-use service level per capita will be determined by translating our basic assumptions about the populations future activities into an anticipated level of energy sevice needs per capita. This implies that we will propose which changes in activities that will be needed in the different economical subsectors such as the industry-, service-, land use- and domestic sector due to the populations changing behaviour and demand for goods and services.

The future end-use energy consumption level will hereafter be determined from some anticipated demographic and physical parameters such as the future population and some assumptions about the future amount of end-use technologies and their respective energy intensities.

Generally there are three stages of calculation which will be necessary to model the final future energy demand[11]:

1: Calculation of the end-use demand for energy in the base year (1990) and estimates of the potentials for lowering energy demand by using more efficient end-use technologies.

2: Prediction of the future energy service level.

3: Transformation of the future service level into final future energy demand.

These stages will be explained thoroughly in the following.

1: Calculating the end-use demand for energy in the base year 1990 and the potentials for using more efficient end-use technologies.

As a first step it will be necessary to determine the energy end-use level in the base year 1990 in all the 15 countries in the EU. We will desaggregate the economy into relevant subsectors and thereafter divide the energy demand in those subsectors into a series of end-use categories. The desaggregation into subsectors and end-use categories will be problematic as the normal statistics are not always

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[10] All in all we ought to reach a level of about 1 kW per capita.

[11] See for instance Teknologinævnet, Benders or Nørgaard.

devided into the same subsectors as are relevant for our study[12].

This kind of matrix ought to be made for each country, but we will probably only make it for one northern and one southern country.

Besides these data we need to know the potential for delivering these existing end use services with less end-use of energy. This can be done by estimating the energy intensity of different existing end-use technologies which can provide the same energy service and by choosing the best available (advanced efficiency) technology on the market presently to substitute old more energy intensive end-use technologies. Besides this we can assume that some of the end-use technologies which are close to commercialization will also be available.[13]

The data on efficiency advances possible for the end-use technologies will allow us to estimate how much energy that will be necessary for providing different kinds of end-use services compared to the average technology used today.

Finally we need to have some cost figures of different technologies and energy fuels. These data are important as we will try to optimize investments in energy technologies, especially in the market scenario. It will be necessary to get data for the prices on energy fuels and energy production technologies without recent subsidies and taxes. We will also have to estimate the social costs and benefits of different kinds of energy.

2: Prediction of the future energy service level.
The second step will be to assess the energy service level in 2050 according to our basic assumptions about how we would like society to be in 2050. Basically we can assume whatever we want about the changes in human activities in the future society. Nevertheless we will not make wild guesses but try to describe two societies which are both more desirable than the one we have today from our point of view and at the same time a possibility. This indicates that we will choose societies which we think can possibly be reached without saying whether it is likely to happen.

3: Transformation of the future service level into final energy demand.
When we have decided which level of energy services that will be necessary in the society in 2050 we will have to assess how much energy that will be needed by the end-use technologies to supply those energy services. At this point the important parameters are the kind of end use technologies that provides the energy services and the energy intensities of those.

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[12] For further information on these problems see Sørensen, 1983.

[13] We operate with three categories of technology:
Average technology used, best technology sold on the market and advanced efficiency technology which is close to commercialization (as seen in Nørgaards "Low electricity Europe").

The energy services can be provided by less energy than today as we expect that all end-use technologies will be more energy efficient in the future. The problems at this stage is to assess, 1) which technologies that will apply the energy service in the future as many unefficient technologies can be substituted by less energy intensive technologies, 2) Which level of intensity that can be reached for each technology and 3) how fast the old technologies will be substituted or made more efficient.[14]

Step 3: Designing the energy supply system.

After having assessed the anticipated future end-use of energy we will have to consider how to build up an energy supply, conversion and delivery system that can supply the anticipated level of energy for the end-use technologies. We will consider how this energy supply system can be put together so that the energy production is not violating our goals for a future sustainable society. This means that we will assess which kinds of energy supply technologies that should be used according to our environmental and sustainable goals.

Emphasis will be put on selecting energy supply technologies which are resource efficient and low polluting seen from a life cycle perspective, although the most important parameter when choosing energy technologies is the cost, especially in the market scenario. We will try to estimate the social costs and benefits of the energy supply technologies so that we can choose the cheapest solutions.

Another parameter which might be taken into account when choosing energy supply technologies is that we might give high priority to the most decentralized units in the sustainable scenario. This implies that we in some cases might have to choose technologies which are really not the most desirable from a resource and environmental point of view.

Step 4: Assessment of the environmental impacts from the production, distribution and use of energy in 2050.

The last step of the scenario work will be to evaluate whether we have accomplished our environmental and sustainable goals. How much pollution and resource use is caused by the energy production, transmission and use?

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[14] However the third point is only interesting for the technologies that are not substituted within the year 2050 at this point of the assessment. This is the case because at this point of the assessment we only want to assess the final end-use consumption for the year 2050. Later on as we are to make trajectories as to show how the transition can possibly happen it will be very interesting to discuss how fast the end-use technologies are going to be substituted or made more efficient (e.g. by insulating the existing stock of houses or repairing existing public heating systems).

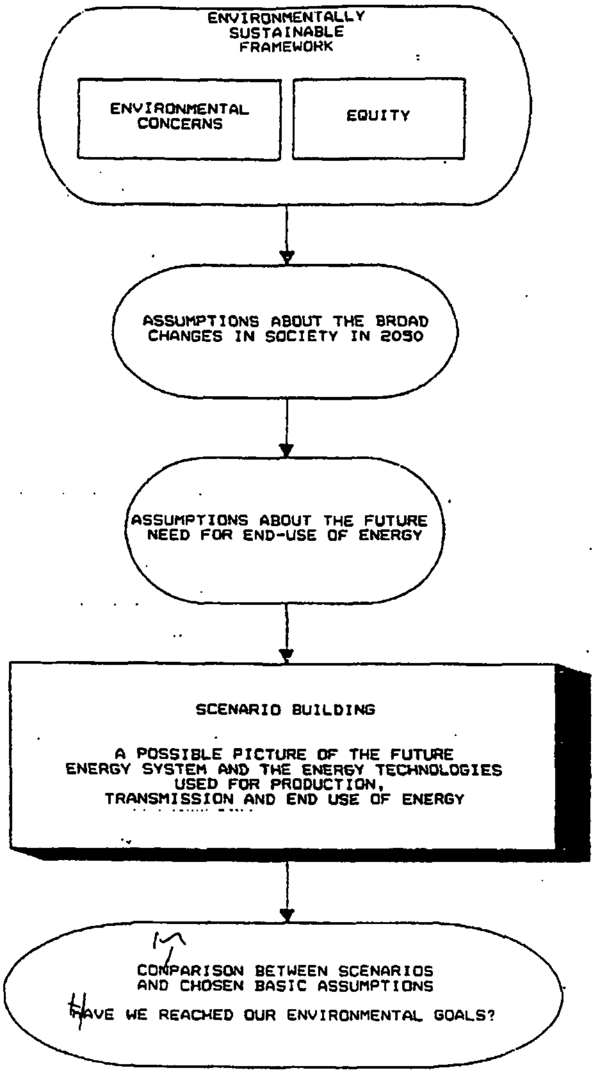
ENVIRONMENTALLY SUSTAINABLE FRAMEWORK
ENVIRONMENTAL CONCERNS
EQUITY
ASSUMPTIONS ABOUT THE BROAD CHANGES IN SOCIETY IN 2050
ASSUMPTIONS ABOUT THE FUTURE NEED FOR END-USE OF ENERGY
SCENARIO BUILDING
A POSSIBLE PICTURE OF THE FUTURE ENERGY SYSTEM AND THE ENERGY TECHNOLOGIES USED FOR PRODUCTION, TRANSMISSION AND END USE OF ENERGY
COMPARISON BETWEEN SCENARIOS AND CHOSEN BASIC ASSUMPTIONS
HAVE WE REACHED OUR ENVIRONMENTAL GOALS?

Figure 11.

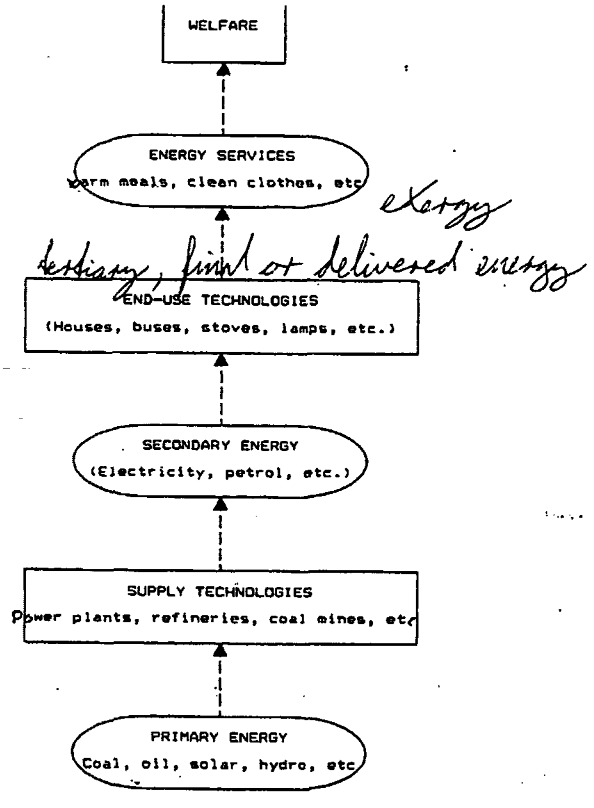

Figure 12. Based on Nørgård (1991).

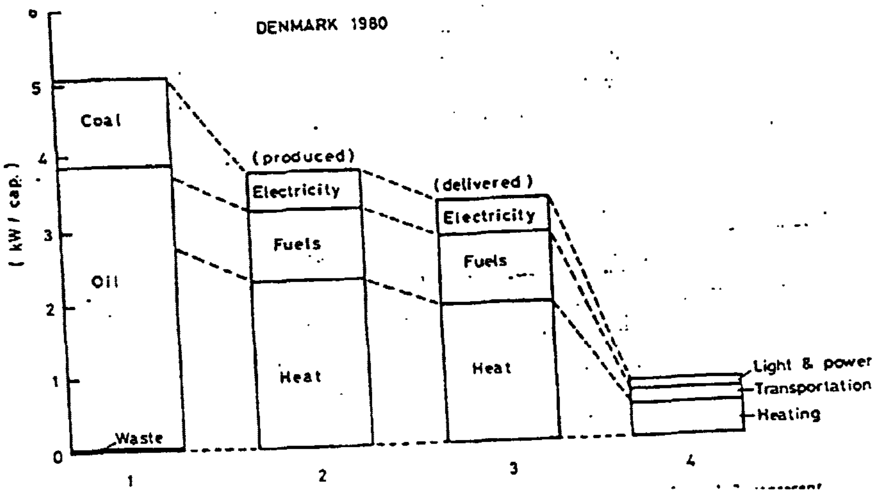

Figure 13. Per capita energy use in Denmark. Colums 1,2 and 3 represent primary, secondary and tertiary energy, while column 4 indicates final energy service (Sørensen, ...)

Development of European societies in the fair market scenario.

Stefan Krüger Nielsen

As described in the method we will describe our basic assumptions of the future fair market scenario in words. This is just to create a picture of the future society which will influence our choises for the future populations anticipated activity level. First we present some more general assumptions that have influence on energy use in society as a whole. Later we describe the possible technical advances in different societal subsectors and our assumptions for future activity growth in these sectors.

Internalization of the social costs of energy production and transmission and use.

[this section to be reworked]

We assume that the main driving factor for the implementation of technologies used for producing, transmitting and using energy will still be the cost in the future. Though we assume that all social costs will be estimated when putting a price on energy. This means that the energy market will be a fair market without any subsidies or taxes on energy besides the fair pricing, e.g. the internalization of all external costs connected to the use of energy. We assume that these price mechanisms will be more important than other factors such as recent institutional and political barriers to the open and fair market.

In our market scenario we assume that the externalities of energy production will be internalized into the economy. **How: Taxes recirculated to the energy sector, constant level of taxes or extra revenue for financing of energy investments (Renewable energy technologies).**It has often been pointed out that the social benefits and losses of the externalities from energy production should be adequatly represented in the economy. The problem is that negative externalities such as environmental impacts caused by conventional energy production plants based on fossil and nuclear fuels are not priced in the evaluation of the social costs and benefits of the production. At the same time the social benefits such as the positive externalities from alternative renewable energy production are not represented in the economy.

The result of internalizing the externalities of energy production into the economy will without doubt make renewable energy sources more competitive because of the severe environmental problems caused by traditional fossil- and nuclear fuel-based power plants.

The same principle will have to count for other energy sectors of transmission and transport as well as conversion until the end use. Full costs of transportation would without doubt change todays structure of the transportation sector. Some of the transported goods and people would change transportation mean to less polluting transport modes and maybe new more efficient technologies would be demanded by the consumers.

How to integrate all social costs in the pricing of energy production.

In the market scenario we assume that the energy prices will include all social costs and benefits from energy production. At the same time we expect that all existing taxes and permanent subsidies on energy production will be removed.

When we are to calculate the costs of each energy unit derived from different energy sources we need to know the 1990 production price including all social costs. Nevertheless it is obvious that it is practically impossible to assess all social costs due to energy production. Therefore we adopt estimates of social costs from all kinds of energy use and production given in the literature.

However, life cycle analysis of the different fuel cycles gives different estimates of the external costs of energy use and production because of the choices that are built into the system borders of every analysis[15]. Just to mention a few examples:

* There seems to be a tendency not to assess the cost of finite resources with respect for future generations.
* The costs are often seen in a short term time perspective by economists (5-10 years at the most)
* How is it possible to price non-reversible environmental damages or depletion of non-renewable resources?
* The pricing of human lives?
* Discovered problems which are not quantifiable?
* Future problems which are not yet discovered?[16]

The list is endless, and it is obvious that putting a price on the social costs of energy production is, like all other aspects of the economy, very uncertain. The uncertainty is very high in this kind of calculations. Nevertheless, the argument for counting at least some of the externalities into the social costs is that if we do not do this we set the price to zero.

What we will do is to find the literature studies that exist today and at least count the price given in those very preliminary studies into the pricing.

With the exclusion of todays existing taxes and subsidies it is quite doubtfull whether the energy prices are going to be much more than doubled....This rises the question whether we will be able to introduce renewable energy technologies which are yet far from being competitive. When Mannheim have delivered their assessment of different fair energy prices it will be possible to give a more accurate picture of how far different technologies seems to be from competitiveness.

Technology level.
The important thing in the market scenario is to show how far we can possibly get with the implementation of renewables and energy efficient end-use technologies in a market driven society. We assume that only those technologies which are indeed competitive under the economic circumstances

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[15] See Hohmeyers figures presenting different cost estimates, Olav Hohmeyer, Lecture notes from 5 seminars in the danish technical university, spring 1995.

[16] Hohmeyer: "We have only seen the top of the iceberg", seminar at the danish technical university, spring 1995.

defined for this scenario will be implemented into the energy system. None of the renewable technologies which are not competitive will be proper alternatives in the market scenario. There will definitely be problems connected to the inclusion of technologies that are not close to competitiveness today but probably will be within 2050. This is especially the case with possible new highly effective storage facilities, reversible fuel cells based on hydrogen and renewable energy technologies like for instance photovoltaics.

The good thing about making such a scenario is that we can be sure that the allocation of investments is optimized and that we do not put great emphasis to technologies which might fail in the end. On the other hand there is a danger that if we only include the most competitive technologies we might not be able to integrate a proper amount of renewables.

About being too optimistic: There is a danger that we are maybe too optimistic with the expectations for the future competitiveness of photovoltaics and fuel cells. Such technologies are possibly not going to be competitive without great emphasis on the research, development and demonstration of those technologies.

The world population in 1990 and projection till 2050.

The future distribution of the worlds population growth is an important parameter when making an energy scenario for Europes future energy use. According to our sustainable goals the environmental loads should be more fairly allocated than today. As the future population growth is mainly going to happen in other parts of the world Europe will have to reduce the CO_2 emissions by at least 80% to stabilize the amount of CO_2 in the atmosphere.

The Eurostat projections for the worlds future population only seem to go to 2025. I have found some long term projections of the worlds population in The World Bank and the UN statistics. These projections goes as far as 2050 and 2150 respectively. Here I have only listed the projections until 2050.

As seen in the figure below I have chosen the UN long range population projections as they give projections with three different assumptions on fertility, low fertility, medium fertility and high fertility. The medium fertility projection is almost equal for 2050 (10019 million) to the projection made by The World Bank in 1993 which ends up with the number 10055 million

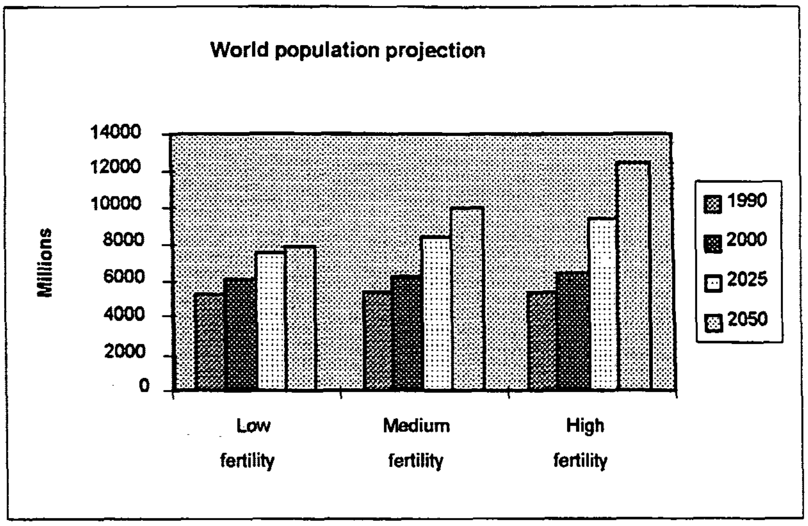

Figure 14, from United Nations, "Long range world population projections, two centuries of population growth 1950-2150", New york, 1992.

The population growth will probably not be equally distributed all over the world. As seen in the figure below the main growth will probably appear in other regions of the world. The population of Africa is expected to rise by more than a factor 3.5 and the population in India and other Asia is expected to double by 2050 compared to 1990. As a result of this major growth in other regions of the world Europe's share of the worlds total population will fall from 9,4% in 1990 to 4,9% in 2050. EU15's share of the worlds population can be calculated to 6,9% in 1990 and 3,7% in 2050.

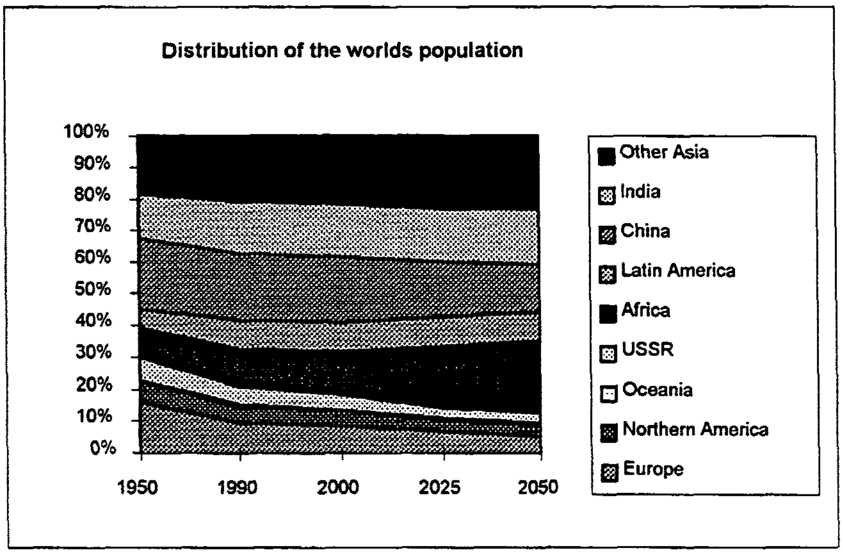

Figure 15. based on United Nations, "Long range world population projections, two centuries of population growth 1950-2150", New york, 1992.

As these other regions of the world will have substantial population growth and also should be allowed to have substantial economic growth there will be a higher pressure on EU to use less energy and emit less CO_2. The whole idea of sustainable development is built on the principle of world equity and respect for future generations which partly means that the industrialized world should use less resources than today. As for the CO_2 discussion the industrialized countries ought to emit at least 80% less CO_2 into the atmosphere[17].

Europe's population in 1990 and projection to 2050.

It is necessary to estimate Europe's future population as the population growth will be an important parameter influencing the future energy consumption level.

Europe's population has increased since 1960. Nevertheless the natural growth rate has decreased while the net migration growth rate has increased in the same period. As seen in the figure below the net migration increase was bigger than the natural increase in 1990.

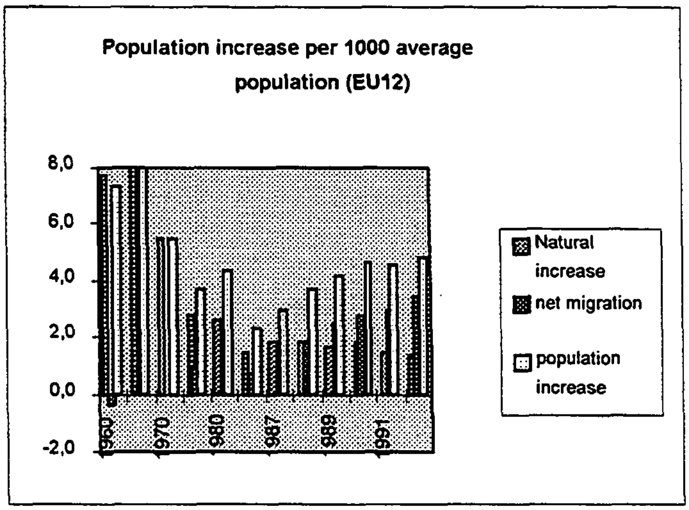

Figure 16. Source: Eurostat demographic statistics 1994.

The long range population projections for EU15 seem to estimate that the population of Europe will continue to grow in the following years, but somewhere after the year 2025 the total population is expected to fall so that the population will be almost the same in 2050 as now.

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[17] IPCC ?????.

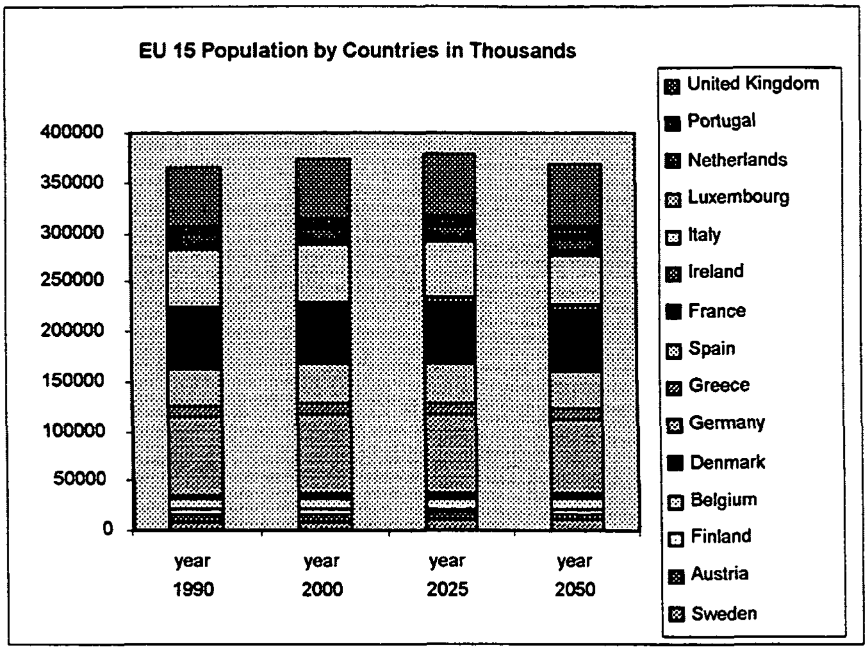

Figure 17. Source: World Bank, "World population projections 1992-1993".

We assume that the population in Europe will actually develop according to this projection from The World Bank, even though the net migration might increase drastically in the future as the population in the rest of the world explodes. As it is very likely that the pressure on Europes borders from immigrants and fugitives will rise we assume that EU15 will make migration quotas so that the population rise equal the population projections from The World Bank.

Finally the population pyramid of the EU15 is changing. In the years to come it is expected that the total amount of people will be more equally distributed in all the age groups up to 75 years of age, i.e. there will be a higher share of elderly and children compared to 1990. At least this is what is expected for the next 20-30 years.

Changes in peoples norms and habits.

We assume that the ecological trends that we see in todays values will continue and increase in the future. People are aware of the environmental problems connected to human activities, and a high level of information and education has secured that people are more concerned about this issue than in 1990.

The market.

We assume that the level of trade will be higher in 2050 both within the EU15 and in the world in general. Though, some of the trade seen today might not be there as transport is about twice as expensive.

There will be a great need for food globally as the world's population double. In countries with high economic growth, such as China, there is a big potential market which makes the prices on crops go up considerably. Therefore there are competing interests for the excess crop lands in Europe which has been taken out of agriculture due to more intensive agricultural production methods. Europe has decided to use some of the excess land for food production for exports and some of it for crops for energy purposes.

The other markets in the rest of the world are assumed to follow the trends in the European economy, which means that they also internalize all external costs into their pricing. In regions where this is not true, their exports will be taxed when entering EU.

Best proven energy efficient technology and its implications for energy end-use in different economic sectors and projections of the future energy service level.

[Calculate the cost of efficiency: Only use those technologies which are economical compared to the fair market price on delivered energy.
At which rate will these appliances be implemented: At least when the appliances does not function any more, but it will often be economically sound to substitute those earlier.]

We will try to estimate how much energy would actually have been needed in 1990 if the most energy efficient existing end-use technologies had actually been used for rendering the end-use energy services of 1990. The general picture tells us that if all the end-use technologies which are now in use were replaced by the most efficient existing technologies we could actually achieve the same amount of welfare (energy services) while the actual amount of delivered energy needed could be **2-3-4?** times lower than it was in 1990.

As described in our methodological chapter we assume that most of the end-use technologies used in 1990 will be replaced before 2050. Only some end-use technologies with very long life times are assumed to be in use beyond 2050, e.g. building shells which have life times of up to several hundreds of years and about 100 years life time on average. We only assume that the most energy efficient technologies already known today or those that are technically feasible within the next 10-20 years will come into play before 2050. As it is quite unrealistic to imagine that further advances in technological development in the next 55 years should not create even more efficient technologies we think that our estimates are rather conservative. However, it is evident that future governmental market regulations are aiming at the promotion and mass production of efficient end-use technologies to ensure that they are fully developed and achieve a large penetration rate in society. History has shown that not all efficient technologies are bought by the energy consumers. In a fair market society the government and the institutional framework in the energy field will have to promote those energy efficient technologies which are economically viable from a social cost perspective.

Besides the need to replace todays energy intensive end-use technologies with more efficient ones there will also be a need to improve the energy efficiency of end-use technologies with very long life times. Those technologies are not assumed to have a static energy intensity throughout the period. One example is that even though the building shells can last for more than 100 years the roofs, windows and technical installations will have to be replaced several times within the life time of the building shell as those technologies have relatively shorter lifetimes. It is only natural to assume that the energy efficiency of the building shells will be improved by better insulation and new facades at the time when the other installations have to be replaced anyway.

However, society is not static. Even though the energy intensity of all physical activities is improved by substituting most of the present end-use technologies with more energy efficient ones the energy use in society will grow if the societal demand for energy services grow. In the fair market scenario we assume that there will be a substantial growth in the demand for energy services in all societal sectors. We have not had the intention to extrapolate historical growth in activities into the future, but rather to assume that a certain growth should be set as a ceiling, not a target for the growth in energy related activities. These ceilings have been chosen quite pragmatic and reflects between 30% and 200% growth in different societal activities until 2050 compared to 1990. Even with such substantial growth rates it will be possible to use less tertiary energy than in 1990 and to meet most of the demand with renewable sources such as wind, hydro, biomass and solar supply technologies.

RESOURCE ESTIMATION

Stefan Krüger Nielsen

Renewable sources

A number of renewable resources will be assessed here, along with estimates of the fraction of the potentials that may be practically useful under certain assumptions. For a more complete discussion of the origin and physical magnitude of the resources see Sørensen (1979); Jensen and Sørensen (1984).

Renewable energy potentials of the world.

The following tables are taken from Joel Swisher et. al., "Renewable energy potentials", in "Energy" Vol. 18 no.5 pp 448-453, 1993.

Table 1. Estimation of maximum technical potentials of renewable energy sources in 2030 (TWhe/year).

Region	Hydro	Geo-thermal	Wind	Solar	Oceans	Biomass*	Energy crops and plantations	Forests
Canada	590	0	2165	0	20	319	800	0
USA	600	370	1082	1800	0	1347	2433	0
Mexico/Central America	327	159	148	252	0	458	167	575
Andean countries	1270	0	148	162	0	333	389	3833
Brazil	751	0	148	324	0	1028	667	5175
Southern Cone	325	0	492	162	30	250	211	0
Nordic countries	320	0	116	0	0	181	333	0
Western Europe	**561**	**267**	**232**	**144**	**30**	**694**	**211**	**0**
Eastern Europe	170	0	23	0	0	375	144	0
Former USSR	3830	328	1293	432	150	1111	1933	0
Japan	132	194	0	49	54	0	83	0
Australia/New Zealand	84	190	541	288	0	236	267	0
China	2170	222	492	846	0	1278	444	0
India	205	0	295	1368	17	1403	211	196
Four Tigers	14	0	8	36	0	28	0	0
ASEAN	820	285	49	306	0	569	189	1679
Other Asia/Pacific	570	0	148	882	0	1014	489	924
Middle East	70	11	20	342	0	0	0	0
North Africa	18	11	30	216	0	83	44	0
Sub-Saharan Africa	700	32	148	756	0	1333	1333	3672
Total	13527	2068	7625	8370	247	12125	10333	16055

* Data from Hall (1991), assuming a conversion efficiency of 50%.

Table 2. Estimates of practical potentials of renewable energy sources in 2030 [TWhe/year]

Region	Hydro	Geothermal	Wind	Solar	Oceans	Biomass*	Energy crops and plantations	Forests
Canada	354	0	1400	0	20	211	233	0
USA	360	370	700	300	0	889	734	0
Mexico/Central America	196	86	95	42	0	303	84	178
Andean countries	762	0	95	27	0	220	100	1187
Brazil	451	0	95	54	0	678	536	1603
Southern Cone	195	0	318	27	30	165	105	0
Nordic countries	192	0	75	0	0	119	103	0
Western Europe	**437**	**267**	**150**	**24**	**30**	**458**	**211**	**0**
Eastern Europe	102	0	15	0	0	248	59	0
Former USSR	1149	177	836	72	150	733	354	0
Japan	89	194	32	9	0	0	55	0
Australia/New zealand	50	103	350	48	0	156	81	0
China	1302	120	318	141	0	843	60	0
India	123	0	191	228	17	926	62	196
Four Tigers	8	0	5	6	0	18	0	0
ASEAN	492	154	32	51	0	376	103	1679
Other Asia/Pacific	342	0	95	147	0	669	17	924
Middle East	42	6	13	57	0	0	0	0
North Africa	11	6	19	36	0	55	40	0
Sub-Saharan Africa	420	17	95	126	0	880	720	1101
Total	7077	1499	4931	1395	247	8003	3603	6868

*Data from Hall (1991), assuming a conversion efficiency of 33%.

Potentials for renewable energy production in EU15.

On-shore wind potential in EU15.

In the table below is listed the installed wind capacity of the world and prognoses of the development in the next five years according to a study delivered to the Danish Energy Agency in december 1995. As can be seen in the table the installed capacity in the European countries is expected to grow to four times the installed capacity in 1994 in 2000. However the physical and technical potential for the exploitation of wind energy in Europe is enormous in the longer term. Several studies have given estimates of this potential in European countries.

Table 3: Accumulated installed wind capacity and prognose for the future annual installed capacity in the world [MW].

Accumulated installed capacity and prognose for the future annual installed capacity in the world [MW].

	Accumulated installed capacity at the end of 1994	1994 installed	1995 prognose	1996 prognose	1997 prognose	1998 prognose	1990 prognose	2000 prognose	Total installed capacity 1995-2000
USA and Canada	1722	100	50	150	150	200	200	200	950
South and Central America	10	4	25	40	50	100	100	100	415
Total America	1732	104	75	190	200	300	300	300	1365
Denmark	539	52	75	75	75	100	100	100	525
Finland	3,6	3,5	3	4	10	10	10	10	47
Germany	632,2	306	400	200	200	150	200	200	1350
Greece	35,8	1,3	10	40	40	50	50	50	240
Italy	22	7	10	10	20	20	20	20	100
Rep. Ireland	8		10	20	20	30	30	30	140
Netherlands	162	30	40	50	50	50	50	50	290
Portugal	8,5		5	10	10	10	10	10	55
Spain	72,6	16	90	100	125	125	150	150	740
Sweden	40	10	15	15	30	30	40	40	170
UK	170,5	40,5	25	150	100	100	150	100	625
Other European countries*	27,6	4,3	10	30	30	100	125	125	420
Total Europe	1721,8	470,6	693	704	710	775	935	885	4702
China	29,4	17,8	15	100	100	150	150	150	665
India	201	141	400	400	400	500	500	500	2700
Other Asian countries**	7	0,3	10	10	10	50	50	50	180
Total Asia	237,4	159,1	425	510	510	700	700	700	3545
Australia and New Zealand	6,2			10	10	20	20	20	80
Northern Africa***	13,5	5,3	10	30	30	50	50	50	220
Middle East****	24	2,2	5	5	10	10	20	20	70
Former Soviet Union, SNG-countries			5	5	10	10	20	20	70
Total new capacity for the year		742	1213	1454	1480	1865	2045	1995	10052
Accumulated installed capacity in the world at the end of the year	3734		4947	6401	7881	9746	11791	13786	

*Other European countries=Belgium, Czech, Slovakia, France, Norway, Austria, Schwitzerland and other east european and baltic countries.

**Other Asian countries=Korea, Japan, Malaysia, Indonesia, Thailand, Vietnam and others.

***Northern Africa=Egypt, Ethiopia, Libya, Tunesia, Algier, Marooko.

****Middle East=Jordan, Syria, Israel, Saudi Arabia, Iran, Irak.

Source: BTM Consult Aps, "Undersøgelse af konkurrencen på det internationale vindkraftmarked", 1995.

Grubb and Meyer[1] have estimated the potential exploitable wind resource in Europe under certain conditions, i.e. assumptions on the availability of land and efficiency of wind turbine technology. Only on-shore wind potentials are estimated in the main assessment but estimates for the offshore potentials in Denmark, United Kingdom and Sweden are mentioned as well.

Essentially the estimate of the potential for wind energy is subdivided into three assessments.

The gross electrical potential is estimated by assessing how much electricity that can be derived from the meteorological wind resources given in the European Wind Atlas with assumptions on the future technological advances of wind turbines[2] and their space needs[3]. Basically this assessment is based on the assumption that each wind turbine aquires a certain space and have a certain efficiency, i.e. it can convert a certain fraction of the total amount of the wind's energy into electricity.

The gross electrical potential is substantially bigger than the so called first order potential, which represents the gross electrical potential excluded the positions which are undisputably not presently available for wind turbines, e.g. in cities, forests and unreachable mountanious areas, etc...

The second order potential represents a further reduction of the area available for wind turbine siting when considering that other land use interests are conflicting with the implementation of wind turbines. The exclusion of land area due to conflicting interests are based upon social, environmental and land-use constraints which depend on political and social judgements and traditions which vary from country to country. Therefore the calculation of the available land for wind turbines is very uncertain and can change with time as traditions and political regimes are changing. Grubb and Meyer have generalized the available space potentials in European countries on the basis of the current situation in Denmark, U.S.A. and the Netherlands. They have based their assumptions on exclusion factors on land-siting studies in those three countries. The general assumption is that these studies represent estimates of reasonable exclusion factors in areas with different population densities. Therefore these exclusion factors have been used for the estimation of the available areas in all European countries according to the actual regional population densities of these countries.

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[1] Grubb, Michael J. and Niels I Meyer, "Wind energy: Resources, systems and regional strategies", in "Renewable energy - Sources for fuels and electricity", edited by Thomas Johansson et.al., Island Press, 1993.

[2] Future technological assumptions of wind turbines is here assumed to be as follows: Hub height above ground = 50 meters, Rotor diameter = 50 meters, total conversion efficiency = 26% (turbine efficiency of 35% x array and system losses of 25% = 26%).

[3] Average turbine space need assumed to be 10D*5D. D= rotor diameter.

Table 4: Grubb and Meyers assumed reduction factors which reduce the available land area for wind turbines in Europe due to environmental and land-use constraints.

Country	Actual population density [Inhabitants per km^2]	Used for European regions with population densities of [Inhabitants per km^2]	First order exclusions of land area in EU depending on population density	Second order exclusions of land area in EU depending on population density
Contigous U.S.	3,14	0-75	1,6	4
Denmark	20	75-150	17	65
Netherlands	360	>150	30	150

Source: Grubb, Michael J. and Niels I Meyer, "Wind energy: Resources, systems and regional strategies", in "Renewable energy - Sources for fuels and electricity", edited by Thomas Johansson et.al., Island Press, 1993 and Niels I. Meyer, "Wind power technologies and potentials - overview paper for ESETT '91, Milan, 1991.

As can be seen in the table below Grubb and Meyer estimate the EU15's on-shore wind resources to be something like 147 TWh per year according to their assumptions on the technology used and the available area for wind turbines.

Table 5: On-shore wind electric potentials in Europe [TWh/year]

Country or region	Gross electrical potential	First order potential	Second order potential
DK	780	38	10 +OFFSHORE:10
UK	2600	760	20-150 +OFFSHORE:200
NL	420	16	2
ECa	8400	490	130
N		32b	12c
SE	540d		30e of which offshore: 23
FI		30f	10f
EU15 Total onshore potential			147

a: Exclusion factors as for Denmark.

b: For the whole Norwegian coast including small cliffs.

c: Using only the best sitings along the coast.

d: Includes southern Sweden only, and only areas with mean annual wind power densities higher than 450 watts per m^2 at 100 meters height. Offshore sitings at 6 to 30 meters depth and more than 3 kilometres from land are also included.

e: About 7 TWh per year at land and 23 TWh per year off-shore.

f: Including some offshore sitings.

Another study conducted by A.J.M. van Wijk, M. van Brummelen, J.P. Coelingh and E.A. Alsema[4] gives another estimate of the technical potential for on-shore wind energy in Europe. Their estimate is based on other exclusion factors than Grubb and Meyer's estimate. They have estimated the site potential as 4% of the fraction of land with wind speed above 5,1m/s (50% of total land area excluded)[5], excluded inaccessible areas which are assumed to be 41% of the residual area[6]. The potential has been calculated on the basis of assumtions of an installed capacity of 8,3MW per km^2 and an average capacity factor of 23% (2000kWh/kW/year). As seen in the table below the resulting technical potential (even though it is called technical potential it is comparable to Grubb and Meyer's definition of a second order potential as areas which are under social and environmental constraints are excluded) is higher than the second order potential (147 TWh/year EU15) estimated by Grubb and Meyer.

Table 6: van Wijk et. al's assumed reduction factors which reduce the available land area for wind turbines in Europe due to environmental and land-use constraints.

Site potential [km^2]	Exclusion areas with wind speeds < 5.1 m/s at 10m height; Exclusion of inaccessible areas (mountains, arctic or dessert); 4% of remaining area available (based on siting studies from U.S.A. and the Netherlands)
Technical potential [kWh_e/year]	Installed capacity of 8,3MW per km; Average capacity factor 23% (2000 kWh/kW/year)

Source: A.J.M. van Wijk, M van Brummelen, J.P. Coelingh, E.A. Alsema, "Solar and wind electricity in OECD-Europe.

Both of the above mentioned estimates of wind electric potentials in Europe tend to underestimate the potential in those areas where the wind conditions are above 5,1 m/s at 10m height. The same is probably the case in regions with lower wind speeds where the areas with wind speeds below 5,1 m/s are excluded for economic reasons. The numbers for Central Europe and the Mediterranian countries are probably quite realistic while the potential in Scandinavia, the coast of France, and especially areas in Ireland and United Kingdom which are very windy could be higher than presumed in these studies as the average wind speeds in many areas in these countries exceeds 5,1m/s.

We have chosen to use van Wijks estimate for our fair market scenario. This means that the potential shown in the table above is assumed to represent the societal acceptable limit for exploitation of wind energy in EU in 2050. When the installed capacity reaches this level we expect that the social costs of wind energy will rise as the socially acceptable level has been reached.

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[4] A.J.M. van Wijk, M. van Brummelen, J.P. Coelingh, E.A. Alsema, "Solar and wind electricity potential in OECD-Europe", 1994.

[5] Private correspondence between Bent Sørensen and van Wijk in december 1995.

[6] Private correspondence between Bent Sørensen and van Wijk in december 1995.

Table 7: On-shore site and technical potential for wind in EU15.

	Total land area [10^3 km^2]	Potential wind class >=3 [10^3 km^2]	Site potential [km^2]	Technical potential [GW]	[TWh/year]	W/cap 2050
AT	84	40	200	2	3	47
BE	31	7	280	2	5	57
DK	43	43	1720	14	29	655
DE	357	39	1400	12	24	37
FI	337	17	440	4	7	152
FR	547	216	5080	42	85	155
GR	132	73	2640	22	44	518
EI	70	67	2680	22	44	1174
IT	301	194	4160	35	69	156
LU	3	0	0	0	0	0
NL	41	10	400	3	7	50
PT	92	31	880	7	15	153
ES	505	200	5160	43	86	250
SE	450	119	2440	20	41	499
UK	244	171	6840	57	114	207
EU15	3237	1227	34320	285	573	178

Source: A.J.M. van Wijk, M van Brummelen, J.P. Coelingh, E.A. Alsema, "Solar and wind electricity in OECD-Europe.

Offshore wind potential in EU.

Large scale exploitation of wind energy by land based wind turbines is likely to be limited by environmental and social constraints like discussed in the text above. In some countries like Denmark, Germany and the Netherlands the debate has already started whether there are too many wind turbines covering the landscape. Therefore it is of great interest to explore the potential of generating electricity on wind farms offshore.

Several reports have described the offshore potential in single European countries. Estimates can therefore be found for at least Denmark, Germany, Italy, the Netherlands, Sweden and the United Kingdom. For a further introduction to these studies see Germanischer Lloyd and Garrad Hassan (1995)[7]. Nevertheless these studies have been limited to single countries and the methodologies used are not comparable. Therefore the European Commission has ordered a report which describes the offshore potentials in the eleven EU12-countries which have coastal areas appropriate for exploitation of offshore wind energy. This report is the first one which gives estimates of the offshore potential in 11 EU countries.

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[7] Germanischer Lloyd and Garrad Hassan, "Study of Offshore Wind Energy in the EC", JOULE I (JOUR-0072), Verlag Natürliche Energie.

As Luxembourg and Austria do not have any coastal areas the report only misses Sweden and Finland which we need to have estimates for. However the offshore potential in Sweden has been estimated by Grubb and Meyer (See table above). Of course there are some major discrepancies between the methodologies used by Grubb and Meyer and Germanischer Lloyd, but we have chosen to use Grubb and Meyers estimate for Sweden. As we have no estimate for Finland we assume that there will be no offshore wind turbines in Finland.

The estimates in the Germanischer Lloyd report are based on several crucial assumptions about the constraints for offshore sitings available for wind turbines. Natural physical constraints taken into consideration are water debth, sea bed slope and distance from land. Besides this some man made constraints reduce the amount of available siting positions. These are traffic zones, military operation zones, pipelines and sea cables, oil platforms, conservation areas and country borders. The constraints considered in the Germanischer Lloyd project are the ones found in navigational charts. The result of this simplified way of estimating physical and man made constraints is that this project tends to overestimate the available energy from offshore wind turbines by a large amount. However it was not possible to go more in debth with the constraints within the frame of the Germanischer Lloyd project as it would probably have required consultation of thousands of persons with interests in the respective sea areas in the EU11.

Generally far more constraints are considered in the national accounts of each countrys offshore potential. One example is that a study estimate the UK's possible offshore siting potential to be around 11849 km2 with a possible electricity production of 134 TWh per year. The Germanischer Lloyd gives an estimate of 71948 km2 and 986 TWh per year.

Furthermore the different estimates are based on different assumptions about the possible future wind turbine technology. In the Germanischer Lloyd report a wind turbine with 100m diameter and rated at 6MW is taken into account. Inter machine spacing is 1km. Array losses are assumed to be 0 and the availability 100%.

The results in the Germanischer Lloyd report are given in the tables below. The report gives estimates of the potential yearly electricity production from turbines placed at sea areas with up to 40 meters water debth and up to 30 kilometers distance to the shore line.

Table 8: United Kingdom, offshore potential [TWh/year].

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	177	187	188
20	332	401	426
30	538	708	774
40	626	879	986

Table 9: Ireland, offshore potential [TWh/year].

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	31	31	31
20	73	78	79
30	139	156	158
40	153	179	183

Table 10: Denmark, offshore potential [TWh/year].

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	97	113	120
20	206	287	331
30	256	403	490
40	260	423	550

Table 11: Germany, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	29	32	32
20	78	127	155
30	95	175	216
40	99	187	237

Table 12: Netherlands, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	49	52	52
20	72	91	102
30	75	110	136
40	75	110	136

Table 13: Belgium, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	6	6	6
20	8	14	15
30	8	16	24
40	8	16	24

Table 14:France, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	97	101	102
20	181	221	232
30	231	333	367
40	267	403	477

Table 15: Spain, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	25	25	25
20	54	56	56
30	80	88	89
40	121	136	140

Table 16: Portugal, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	6	6	6
20	18	18	18
30	24	24	24
40	45	49	49

Table 17: Italy, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	17	17	17
20	58	67	67
30	89	115	120
40	109	141	154

Table 18: Greece, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	17	17	17
20	42	43	43
30	63	64	65
40	88	92	92

Table 19: EC, offshore potential [TWh/year]

Maximum water debth [m]	Maximum distance from land [km]		
	10	20	30
10	551	587	596
20	1121	1402	1523
30	1597	2192	2463
40	1852	2615	3028

We assume that there will be less constraints to the availability of areas at sea than is the case on land. We assume that at least 20% of the Germanischer Lloyd potential will be exploited in 2050 in the fair market scenario. For Sweden we have adapted Grubb and Meyer's estimate. The second order potential for offshore wind electricity production in 2050 is listed in the table below.

Table 20: Assumed second order offshore electrical wind potential in EU15 in 2050 in the fair market scenario (=20% of Germaniscer Lloyds total offshore potential).

	[TWh/year]	[W/cap] in 2050
AT	0	0
BE	4,8	54
DK	110	2483
DE	47,4	73
FI	na	na
FR	95,4	174
GR	18,4	217
IE	36,6	977
IT	30,8	70
LU	0	0
NL	27,2	195
PT	9,8	100
ES	28	81
SE*	23*	280*
UK	197,2	359
EU15	628,6	195

Source: Germanischer Lloyd and Garrad Hassan, "Study of Offshore Wind Energy in the EC", JOULE I (JOUR 0072), Verlag Natürliche Energie.

* Grubb, Michael J. and Niels I Meyer, "Wind energy: Resources, systems and regional strategies", in "Renewable energy - Sources for fuels and electricity", edited by Thomas Johansson et.al., Island Press, 1993.

As can be seen from the tables above the offshore potential is truly enormous in the waters of the European Union. However, as it is the case for land based wind turbines there are many obstacles which have to be overcome to realize a high penetration of offshore wind turbines in Europe. Only very few experiences have been made until now with offshore wind parks. Further investigations of the future production costs of electricity generated by offshore wind turbines and siting potential will have to be carried out. When it comes to a large scale implementation of the technology in a fair market scenario this will only happen in places where offshore wind generated electricity is cost competitive to the fair price of other renewable or fossil electricity production technologies.

Biomass.

Estimates of the actual amount of primary energy from biomass used in EU15 today varies. According to Hall[8] it was in the range of 1,8% of EU12's total primary energy consumption in 1989.

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[8] Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Like it is the case with the estimates for the other future renewable potentials in EU15 there is a very high uncertainty as to estimate which amount of primary energy from biomass that can possibly be used for energy purposes in 2050. According to Hall different estimates range from 2 to 20 EJ per year in OECD Europe compared to the approximately 2 EJ already in use in 1990. Hall (1994) estimate that the total OECD Europe potential will be in the range of 9,0-13,5 EJ in 2050 depending on the use of land areas for plantations and the specific energy yields of those plantations and the amount of recoverable residues from the agricultural sector[9]. Hall has gathered estimates of Europes future biomass potential from 11 recent studies[10]. As seen in the table below the estimates given in these 11 studies varies a great deal.

Table 21: Estimates of potential biomass energy supplies (not imported) in Europe after 2000, both residues and energy cropping are considered.

Region	Year	[EJ]	Remarks	Author
Europe	2010	8,0	"Accessible reserves potential" and traditional biomass	Dessus et. al. 1992
Western Europe (17 countries)	>2000	8,2-5,1	"Potential"	Hall et. al. 1992
Western Europe	2030	7,9-9,9	"Practical potential" and "maximum technical potential"	Hall et. al. 1992
Western Europe (17 countries)	>2000	8,0-10,3	"Potential"	Swisher and Wilson 1993
Western Europe (17countries)	>2000	15,2	"Potential"	Hall et. al. 1993
Europe (W, E and C Europe)	2050	10,5	"Supplies"	Johansson et.al. 1993
Europe (OECD)	>2000	4,2	"Potential"	NUTEK 1993
Western Europe (19 countries)	2030	26,4	"Gross technical potential"	Grassi and Bridgewater 1993
EU12	2010	4,7	"Full potential penetration"	ESD 1994
EU12	2005/-10	2,9	"Realistic potential"	Action Plan 1994
Western Europe OECD (19 countries)	2050	9,0-13,5	"Potential"	Hall 1994

Source: Hall, David, "Biomass energy options in western Europe (OECD) to 2050".

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[9] Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994 and Hall D.O. and J.I. House, "Biomass energy in Western Europe to 2050", Land Use Policy, 12(1) 37-48, 1995.

[10] Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", printed in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Potential recoverable residues from agriculture and forestry for energy production in 1990 and assumptions for 2050.

Torsten Reetz from Wuppertal Institute has estimated the potential recoverable primary energy from biomass in EU15 in 1990. This potential can change considerably in the future as described below.

Table 22: Potential primary energy from biomass residues in 1990.

	Straw [PJ]	Biogas [PJ]	Wood removals [PJ]	Wood residues [PJ]	Total [PJ]	Total [W]	1990 [W/cap]	2050 [W/cap]
AT	17,5	25	5,4	15,3	63,2	2E+09	260	275
BE	6,1	34,6	7	2,9	50,6	1,6E+09	161	160
DK	22,1	28,6	3,6	2,3	56,6	1,79E+09	349	355
DE	110,6	142,1	55,6	49,4	357,7	1,13E+10	143	152
FI	12,8	12,2	3,5	110,2	138,7	4,4E+09	882	836
FR	197,8	212,9	39,7	70,3	520,7	1,65E+10	293	264
GR	15,1	11,9	7,1	12,4	46,5	1,47E+09	146	152
EI	6,5	44,6	2,5	1,6	55,2	1,75E+09	500	409
IT	63,5	90,4	40,4	32	226,3	7,18E+09	124	142
LU	0,5	1,3	0,3	0,4	2,5	79280822	210	215
NL	4,2	66,7	10,5	1,4	82,8	2,63E+09	176	165
PT	3,9	22,1	6,9	14,1	47	1,49E+09	144	134
ES	46,7	88,2	27,3	75	237,2	7,52E+09	193	192
SE	17,4	18	6	133	174,4	5,53E+09	646	590
UK	68,8	130	40,3	11,4	250,5	7,94E+09	138	127
EU15	593,5	928,6	256,1	531,7	2309,9	7,33E+10	200	199

Source: Torsten Reetz and Harry Lehman, Wuppertal Institute.

As can be seen in the table above the potential accessible primary energy content from straw (593,5), biogas/manure(928,5), wood removals(256) and wood residues(531,9) in EU15 in 1990 amounted to 2309,9 PJ per year. The question is if the size of these sources will change in the future. For example, Hall[11] estimates that there will be 3800 PJ for Western Europe (OECD) just from recoverable residues from crops, forests and dung. This number is 1500 PJ higher than Torsten Reetz's estimate.

There are a whole range of factors which might have influence on the total future amount of biomass residues recoverable for energy production. The amount of oven dry (OD) biomass from straw, wood removals and wood residues per ha varies with the specific yields of different types of plants and the specific climatic and soil conditions in the area in question. Animal dung varies with the amount and kind of animals in question. Therefore the estimation of potentailly recoverable biomass residues in

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[11] Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", printed in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

the future is very dependent on the type and size of land use in question, climatic and soil conditions and the nutrition preferred by Europe's inhabitants.

The agricultural area in Europe is expected to be smaller in the future. Different land use studies estimate that between 30-40 Mha could possibly be taken out of agriculture in the future if the recent subsidies for agriculture are cut and agricultural productivity rises[12]. According to Hall the area used for growing cereals in OECD Europe decreased 3,4 Mha between 1980 and 1990 while the average cereals yield per ha increased from 3,5t to 4,5t. The resulting cereal production per capita increased 13,1% in the ten year period[13]. If recent subsidies are cut and the cereal productivity increases the area used for agricultural purposes is expected to be smaller in the future. Therefore it will be fair to assume that the amount of recoverable straw from the agricultural sector will be smaller.

Other factors can influence the actual recoverable straw potential in 2050. If the land use becomes more intensive, e.g. if a higher amount of biomass is harvested per ha there might be a potential to increase the amount of straw. However, according to Sanderine Nonhebel the production increase of the past have not been an increase in the amount of recoverable straw but rather an increase of the grain yield. As can be seen in the table below the total amount of biomass above ground has remained fairly constant since the middle of the last century for winter wheat. The length of winter wheat straw has decreased while the amount of grain has increased. One solution to get more biomass for energy purposes from straw residues could be to promote new types of crops with longer or thicker straws as to increase the amount of straw per amount of grain.

Table 23. Characteristics of winter wheat varieties introduced in different time periods (data from Austin et.al., "Genetic improvement in the yield of winter wheat: A further evaluation", Journal of agricultural science, 112: 295-301, 1989.)

Period of introduction	Above ground biomass [t/ha]	Grain yield (85%dm) [t/ha]	Harvest index	Height year base [cm]
1830-1900	15,0	6,0	0,34	145
1900-1920	15,5	6,6	0,36	134
1950-1970	14,8	7,9	0,45	96
1980-1085	15,9	9,5	0,51	78

Source: Nonhebel, Sanderine, "Comment on "Biomass options in Western Europe (OECD) to 2050"", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

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[12] IPCC:"Energy supply mitigation options" review draft 1994, Hall, David O. et.al., Biomass for energy: Supply prospects, in Renewable Energy - sources for fuels and electricity, edited by Thomas B Johansson et.al.,

[13] Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Another factor which will influence the future productivity of recoverable straw is the need to shift to ecological farming methods in the future. The present high yields in EU15 are obtained due to high input levels of fertilizer abd the use of pesticides. A yield loss of 10-20% due to lower use of fertilizers and pesticides is therefore to be expected, when a higher share of the agricultural sector changes to ecological farming methods.

Furthermore the preferred nutrition of the inhabitants in EU15 will have influence on the future agricultural production of cereals and meat. If for instance people eat more meat there will be more manure, but less potential for cereal food production, recoverable residues and energy crops.

All in all we assume that there will be taken some land area out of todays agriculture due to more intensive farming methods and removal of todays heavy subsidies in the field. This land area can be used for different purposes, where especially biomass plantations and energy forests will be of interest for the energy sector. We also assume that the total potentially recoverable primary energy content from animal manure, straw, wood residues and wood removals will be the same in 2050 as the figures calculated for 1990 by Torsten Reetz as seen in Table 23.

Assumptions for the amount of primary energy from biomass grown in plantations in 2050.

The two most obvious constraints to biomass energy supplies from plants grown in plantations are the amount of land area available for growing biomass and the specific biomass yields on this land. In the table below is listed the land use patterns in EU15 in 1990 according to the FAO statistics. As can be seen there are already today large land areas covered by permanent meadows and pastures which are potentially available for cultivation with biomass for energy purposes.

Table 24: Land use in EU15, 1990 [1000 ha].

	Total area	Land area	Arable land and land under permanent crops	Arable land	Land under permanent crops	Permanent meadows and pastures	Forest and woodland	Other land
BE+LU	3310	3282	819	805	14	671	699	1093
DK	4309	4239	2571	2567	4	217	493	958
DE	35695	34931	12414	11971	443	5618	10393	6506
FI	33813	30461	2436	2436	122	122	23222	4681
FR	55150	55010	19248	17989	1259	11380	14811	9571
GR	13199	12890	3934	2871	1063	5255	2620	1081
UK	24488	24160	6657	6607	50	11180	2400	3923
EI	7028	6889	943	940	3	4692	343	911
IT	30127	29406	12088	9098	2990	4850	6737	5731
NL	3733	3392	930	902	28	1096	300	1066
AT		8273	1505	1426	79	1995	3227	1546
PT	9239	9195	3173	2373	800	849	2968	2205
ES	50478	49944	20325	15560	4765	10200	15645	3774
SE	44996	41162	2826	2826	0	556	28020	9760
EU15	315565	313234	89869	78371	11620	58681	111878	52806

Source: "FAO yearbook - production", 1991.

According to Hall several studies estimate that 30-40 Mha of todays agricultural land could be set aside after 2000 as all present subsidies to agriculture are removed and the intensity of land use increase. Hall finds that this will likely be the case even if all Europe's agriculture becomes ecological[14]. IPCC estimate that 15 Mha could be used for energy plantations already in 2000[15]. Hall estimates that 33 Mha could possibly be used for energy

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[14] Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

crops in 2020. In the longer term between 10-15% of all EU15's usable land might be available for biomass plantations, e.g. 10-15% of all arable land areas, land covered by permanent meadows and pastures and forest and woodland[16]. We expect that some of the areas which will be taken out of agriculture and some of the areas already taken out in 1990 will be used for growing different kinds of biomass for energy production, e.g. energy crop plantations and more forests and woodlands compared to 1990. In the table below is listed our assumptions for the available areas for biomass plantations in the future.

Table 25. The total amount of land area potentially available for biomass production in EU15 in 1990 and assumption for the amount of land used solely for growing biomass for energy purposes in EU15 in 2050 in the fair market scenario [1000 HA].

	Arable land and land under permanent crops	Permanent meadows and pastures	Forest and woodland	Total land potentially available for biomass production	15% of land potentially available for biomass production in 1990 is assumed to be used solely for energy purposes in 2050
BE+LU	819	671	699	2189	328,35
DK	2571	217	493	3281	492,15
DE	12414	5618	10393	28425	4263,75
FI	2436	122	23222	25780	3867
FR	19248	11380	14811	45439	6815,85
GR	3934	5255	2620	11809	1771,35
UK	6657	11180	2400	20237	3035,55
EI	943	4692	343	5978	896,7
IT	12088	4850	6737	23675	3551,25
NL	930	1096	300	2326	348,9
AT	1505	1995	3227	6727	1009,05
PT	3173	849	2968	6990	1048,5
ES	20325	10200	15645	46170	6925,5
SE	2826	556	28020	31402	4710,3
EU15	89869	58681	111878	260428	39064,2

Source: FAO yearbook, production 1991.

Besides the available space for energy plantations in 2050 it is also necessary to estimate the specific biomass yield per ha in 2050. The specific biomass yield varies for different kinds of crops grown by different farming methods under different climatic conditions.

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[15] IPCC:"Energy supply mitigation options" review draft 1994.

[16] Hall, David O. et.al., Biomass for energy: Supply prospects, in Renewable Energy - sources for fuels and electricity, edited by Thomas B Johansson et.al.

According to Hall the aim of EU's biomass programme is to obtain 12 ODt/ha which amounts to a primary energy content of 240GJ/ha from energy crops from plantations on average in EU in the next century. This is considered feasible as an average in EU but requires greatly enhanced research efforts. Hall estimate that it will be possible to reach an average yield of 10 ODt/ha in 2020 and 15 ODt/h in 2050 in EU[17]. However these estimates for the average yields from energy crops are quite optimistic. Sanderine Nonhebel estimate that 10 ODt/ha on average will only be possible in United Kingdom, the Netherlands and Germany today. In southern Europe and in Finland a more realistic estimate is 3-5 ODt/ha[18]. This is partly true because of poorer physical growing conditions in southern areas due to water shortage and partly because of less developed agricultural practices in southern Europe. As long as this situation is not improved much lower yields than predicted by Hall will be needed possible to obtain in Southern EU. The theoretical potential for biomass yields is higher in southern EU than in the north western parts where the highest amounts of biomass yields are obtained presently. However this potential of higher yields in southern EU can only be obtained under irrigation. Water for this irrigation must be obtained from areas outside the growing region since the annual regional precipitation is not sufficient. This requires large investments in infrastructure[19].

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Scan in figure here! Winter wheat production in EU.

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[17] Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

[18] Nonhebel, Sanderine, "Comment on "Biomass energy options in western Europe (OECD) to 2050"-", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

[19] Nonhebel, Sanderine, "Comment on "Biomass energy options in western Europe (OECD) to 2050"", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

As seen in the tables below the choice of crop type is essential for the amount of energy which can be obtained per ha.

Table 26: Biofuels for transport.

	Ethanol from wheat	Ethanol from beet	Rape Methyl Ester	Methanol from wood	Electricity from wood
Net. energy yield [GJ/ha]	58,4	200,6	48,9	158,1	209,9

Source: Hall, David, "Biomass energy options in Western Europe (OECD) to 2050", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Table 27: Ethanol yield from carbohydrate-rich plants

Raw material	Carbohydrate [t/ha]	Carbohydrate [%]	Ethanol [l/t]	Ethanol [hl/ha]
Beet	40-50	16	90-100	38-48
Sugar cane	50-100	13	60-80	35-70
Maize	4-8	60	360-400	15-30
Wheat	25	62	370-420	8-20
Barley	2-4	52	310-350	7-13
Grain sorghum	2-5	70	330-370	7-18
Potatoes	20-30	18	100-120	22-33
Sweet potato	10-20	26	140-170	16-31
Cassava	12-15	27	175-190	22-23
Jerusalem artichoke	30-60	17	80-100	27-54

Source: World energy council, "New renewable energy resources - a guide to the future", 1994.

Table 28: Ethanol yield from ligno-cellulosic products

Raw material		Dry matter [t/ha]	Ethanol [l/t]	Ethanol [hl/ha]
Softwood	(dillute acids)	9-15	190-220	18-31
	(concentrated acids)	9-15	230-270	22-38
Hardwood	(dillute acids)	9-15	160-180	15-25
	(concentrated acids)	9-15	190-220	18-30
Straw	(dillute acids)	1,5-3,5	140-160	2-5
	(concentrated acids)	1,5-3,5	160-180	3-6

Source: World energy council, "New renewable energy resources - a guide to the future", 1994.

Table 29: Energy balances for biomass production on plantations in the U.S.A. Data from Turhollow & Perlak, “Emissions of CO_2 from energy crop production”, in Biomass and Bioenery, 1, 129-135, 1991. [GJ/ha]

Energy input	Hybrid poplar 1990	Hybrid poplar 2010	Sorghum 1990	Sorghum 2010	Switchgrass 1990	Switchgrass 2010
Establishment	0,14	0,14	1,29	1,29	0,39	0,39
Fertilizers	3,33	3,33	8,87	12,69	5,26	7,38
Herbicides	0,41	0,41	1,82	1,82	-	-
Equipment	0,17	0,17	-	-	-	-
Harvesting	7,31	11,69	3,72	8,24	5,47	8,41
Hauling[b]	2,40	3,07	3,81	6,90	2,79	3,60
Total energy input	13,76	18,82	19,51	30,94	13,91	19,79
Energy output[c]	223,74	366,30	232,75	528,50	157,50	252,00
Net energy ratio[d]	15.3	18,5	10,9	16,1	10,3	11,7

b. The energy required to transport the biomass 40 kilometers to a biomass processing plant.

c. Yields net of harvesting ad storage losses for present (future) production technology are assumed to be 11,3 (18,5) tones per hectare per year for hybrid poplar (with a heating value of19,8 GJ per tonne), 13,3 (30,2) tonnes per hectare per year for sorghum (heating value of 17,5 GJ per tonne), and 9.0 (14,4) tonnes per hectare per year for switchgrass (heating value of 17,5 MJ per tonne).

d. The net energy ratio = (energy output - energy input)/energy input.

Table 30: Tree productivity for short rotation forestry. Data from CIEMAT & GRASSI. [ODt/ha/year]

Eucalyptus	10-15
Poplar	12-20
Willow	8-15
Robinia	6-15
Conifers	5-6
Ailanthus	6-15
Acacia	4-12
Platanus	8-20

Source: Thermie Programme Action, “Energy from biomass - principles and applications”.

Table 31: Herbaceous energy crop productivity. Data from CIEMAT & GRASSI. [ODt/ha/year]

Sweet sorghum	20-30
Miscanthus	20-30
Jerusalem Artichoke	20-25
Cynara	15-20
Kenaf	>20

Source: Thermie Programme Action, "Energy from biomass - principles and applications"

Table 32. Energy yields from energy crops

Type of culture	Yield of solid matter [t/ha]	Primary energy [GJ/ha]
Maize		
cobs	6,8-8,6	101-128
rest of plant	5,5-7,5	82-111
total	12,3-16,1	183-239
Bulk wheat (wheat for fodder)	6-8	89-119
wheat grain	6-9	89-134
straw	12-17	178-252
total		
Sugar millet		
young plants	20-25	297-371
slightly older plants	15-30	223-446
Topinambur		
(knot) lump	15-20	223-297
rest of plant	10-15	149-223
total	25-35	371-520
Fodder sugar beet		
beets	15-20	223-297
leaves	4-6	59-89
total	19-26	282-386
Chicory		
beets	10-15	149-223
leaves	3-5	45-74
total	13-20	193-297
Whole peas		
grain	2,1-4,3	31-64
Field bean		
grain	2,1-3,4	31-50
Whole rape seed		
seed	2,7-3,6	40-53
rest of plant	5	74
total	5,7-8,6	85-128
Sunflower		
Achäne	2,7-3,6	40-53
rest of plant	4-6	59-89
total	6,7-9,6	99-143

Source: Thermie, “Biomass-technologies in Austria - market study”, 1995.

In the table below is listed our assumptions for the available amount of primary and produced energy derived from biomass grown in plantations in 2050. As can be seen the average yields in EU are assumed to increase considerably in the years to come.

Table 33. Assumed biomass yield in plantations in the fair market scenario in 2050 (assuming 1 ODt=20GJ, and 33% conversion efficiency, and with crucial assumptions on the amount of oven dry (OD) biomass matter produced per ha in different coutries. Yields are scaled according to the figure above taken from Sanderine Nonhebel).

	Assumed average biomass yield per ha on plantations in 2050 [tOD/ha]	15% of potentially available land for biomass production is assumed to be used solely for energy purposes [1000 ha]	Total assumed primary energy production from biomass grown in plantations in 2050 [TWh]	Primary energy [W/cap 2050]	Final energy [W/cap 2050]
BE+LU	17	328	31	340	113
DK	17	492	46	1049	350
DE	15,3	4264	362	556	185
FI	6,8	3867	146	3169	1056
FR	11,73	6816	442	807	269
GR	7,7	1771	75	887	296
UK	16,6	3036	280	508	169
EI	16,2	897	80	2148	716
IT	5,4	3551	107	243	81
NL	17	349	33	236	79
AT	10,2	1009	57	895	298
PT	2,6	1049	15	152	51
ES	5,1	6926	196	571	190
SE	9,4	4710	245	2978	993
EU15		39064	2117	657	219

Solar thermal potential on available roofs in EU15.

For our estimation of the possible energy produced by solar thermal installations on roofs of non-residential and residential buildings we have until now only included a coverage of a certain fraction of the demand for hot water and space heating in households and the service sector. Later on we will include some more solar thermal installations to cover some of the demand in industry too. The reason for not having included the demand in industry is that we do not yet know how much energy that is spent for room heating and hot water in the industry in EU. However we might be able to estimate this demand from the data given in the ISI-data base on space heating shares in industry.

As solar thermal is already presently cost competitive in southern Europe (ES, GR, PT, IT), we assume that the demand for hot water and space heating in 2050 will be covered entirely by solar thermal installations on roofs. For central European countries (BE, DE, LU and NL) there is a lower coverage of the total energy demand by renewable sources than in northern and southern countries. Therefore those countries will have a higher incentive to install solar thermal collectors. We have included a

50% coverage of the demand for hot water and space heating in those countries. In the residual countries (AT, DK, IE, FI, SE and UK) there is a high potential to exploit the cheapest renewable sources in those areas namely hydropower, wind and biomass and those sources will be able to cover a large share of the total demand for energy in 2050. Therefore the penetration of solar thermal installations is assumed to be very low in those countries. Only 10% of the demand for space heating and warm water will be delivered by solar thermal installations in 2050 in these countries.

Table 34. Demand for hot water and space heating in 2050.

	Households	Service sector	Industry	Total	GWh/year	share that should be covered by solar thermal	GWh/year	W/cap
AT*	246			246	15725	0,1	1572	25
BE	220	57		277	24408	0,5	12204	139
DE	198	71		269	175413	0,5	87707	135
DK	204	7		211	9325	0,1	933	21
IE	163	33		196	7353	0,1	735	20
ES	51	6		57	19415	1	19415	57
FI*	233			233	10740	0,1	1074	23
FR	80	94		174	95139	0,75	71354	130
GR	66	3		69	5878	1	5878	69
IT	137	1		138	61025	1	61025	138
LU	261	89		350	1132	0,5	566	175
NL*	180			180	25128	0,5	12564	90
PT	72	3		75	7281	1	7281	75
SE	147	46		193	15840	0,1	1584	19
UK	162	27		189	103638	0,1	10364	19
EU15	140	38		178	574326		294256	91

I have not calculated how much roof space that will be left for PV's after the installation of solar thermal collectors has been carried out. The reason is that I think that it will be easier to calculate when we get the new version of Wuppertals PV database on diskette. I have E-mailed Torsten Reetz and asked him to bring it on diskette for the meeting in Paris!!

PV potential.

The residual suitable roof space toghether with the facade space which is suitable for PV's is potentially available for installation of PV installations. I assume that this residual space will be enough to produce the electricity assumed in the table below, but we will see when I have calculated the space needed for the solar thermal installations.

Table 35: Total PV potential in EU15 now and in the future if all available roofs and facades are covered with PV systems (with gradually improving future system efficiency) and assumed penetration of the technology in 2030 and 2050 [GWh].

	1990 potential [GWh]	2000 potential [GWh]	2010 potential [GWh]	2030 potential [GWh]	2030 assumed penetration factor	2030 assumed prod. [GWh]	2050 potential [GWh]	2050 asumed penetration factor	2050 assumed prod. [GWh]	2050 assumed prod. [W/cap]
ES	121291	152061	163066	188071	0,15	28211	210084	0,75	157563	459
FR	99033	129671	139109	160309	0,15	24046	179187	0,75	134390	245
GR	28777	37711	40437	46644	0,15	6997	52099	0,75	39074	460
IT	115690	150898	162218	186108	0,15	27916	208744	0,75	156558	355
PT	30717	40249	43162	49781	0,15	7467	55607	0,75	41705	427
AT	16924	22179	23784	27434	0	0	30641	0,1	3064	48
BE	16430	21534	23089	26637	0,05	1332	29248	0,4	11699	133
DE	143100	187542	201096	231985	0,05	11599	259091	0,4	103636	159
DK	9272	12153	13032	15032	0	0	16789	0,1	1679	38
FI	9760	12786	13713	15815	0	0	17668	0,1	1767	38
EI	7286	9547	10237	11806	0	0	13189	0,1	1319	35
LU	680	889	954	1101	0,05	55	1229	0,4	492	152
NL	25161	32981	35362	40801	0,05	2040	45561	0,4	18224	131
SE	17862	23405	25100	28946	0	0	32336	0,1	3234	39
UK	86186	112968	121126	139751	0	0	156062	0,1	15606	28
EU15	728169	946574	1015485	1170221		109663	1307535	0,527719	690011	214

The potentials in table 35 can only be realized if all roofs and facades available for solar panels in EU15 are covered by PV's. This is of course not possible as some of the space is needed for solar thermal installations and as PV installations will only be economically competitive at the end of the time frame of this scenario, whereas solar thermal installations will be cost competitive to fossil fuels much earlier (already is in southern countries).

We use a high penetration factor (75%) in southern EU countries (ES, FR, GR, IT, PT) where the technology is assumed to be competitive already around 2020. In central EU countries (BE, DE, LU and NL) where the technology is assumed to become cost competitive around 2035 we use a more modest penetration factor of 40%. In the residual countries (AT, DK, FI, EI, SE and UK) we use a low penetration factor of only 10% as those countries have very high potentials to exploit cheaper renewable sources as hydro, wind and biomass.

Hydro power potential.

Hydropower is presently the most fully developed renewable energy resource worldwide with about 256GWhe/year installed capacity generating about 2240TWhe/year by hydropower plants in 1990.

According to Swisher et. al. the maximum technical potential is almost 7 times as big (around 13527 TWhe/year)[20].

As can be seen in the table below there are yearly fluctuations in the amount of hydro electricity actually produced in EU15.

Table 36. Yearly hydro power production of 15 EU countries [GWh]

	1990*	1991**	1991$	1992**	1993***
AT	31517,3	31401	31700	34890	36750,8
BE	232,6	232,6	226,1	348,9	232,6
DK	0	0	4	0	0
FI	10815,9	13141,9	13000	15119	13607,1
FR	53381,7	56870,7	61302	67919,2	63732,4
DE	17328,7	14653,8	17825	17328,7	17677,6
GR	1744,5	3140,1	3170	2209,7	2326
EI	697,8	697,8	739,6	814,1	814,1
IT	31633,6	42216,9	42347	42216,9	41402,8
LU	116,3	116,3	72	116,3	116,3
NL	116,3	116,3	60	116,3	116,3
PT	9187,7	9071,4	8899	4652	8489,9
ES	25469,7	27330,5	24065	18956,9	24423
SE	72571,2	63267,2	62344	74432	74664,6
UK	5117,2	4535,7	3468	5466,1	4303,1
EU15	259930,5	266792,2	269221,7	284586,1	288656,6

Sources: *="Energy balances of OECD countries 1990-91", IEA.
**="Energy balances of OECD countries 1991-92", IEA.
$= "Water Power and Dam Construction Handbook 1993".

***="Energy balances of OECD countries 1992-93", IEA.

As can be seen in the table below there is still some additional potential to install new hydro power plants in most EU15 countries. However many European countries already find it difficult to expand their hydropower capacity because of environmental restrictions and competing uses for rivers and water. According to Swisher et. al. most of northern Europe have almost stopped increasing hydro development due to environmental concerns[21]. Therefore we assume that there will not be installed additional big hydropower schemes in Europe. However there is still a considerable potential for installation of new small hydro schemes.

We assume that the same amount of electricity from hydro power plants will be generated in 2050 as in 1991 according to the data in "Water Power and Dam Construction Handbook 1993" in 1991. The

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[20] Joel Swisher et. al., "Renewable energy potentials", in "Energy" Vol. 18 no.5 pp 448-453, 1993.

[21] Joel Swisher et. al., "Renewable energy potentials", in "Energy" Vol. 18 no.5 pp 448-453, 1993.

data in the matrix below are based on the actual production in 1991. The data for 2050 are based on the 1991 data from "Water Power and Dam Construction Handbook 1993" and adjusted for the expected population size in 2050. As can be seen in the table above 1991 does not seem to be an exceptional year compared to the mean production in the period 1990-1993.

Table 37: Potential and actual hydro power generation in EU15 [GWh/year].

				In operation		Under construction	Planned			
	Gross theoretical hydropower potential	Technically feasible hydropower capability	Economically feasible hydropower capability	Total installed capacity [MW]	Total annual generation	Probable annual generation	Probable annual generation	Total annual generation [W]	W/cap 1991	W/cap 2050
AT	150000	75000	53700	10600	31700	400	9000	3,62E+09	469	496
BE	800	600	500	93,5	226,1	0	0	25810502	3	3
DK	120		70	9,5	4	0		456621	0	0
FI	46000	19700	19700	2640	13000	159	582	1,48E+09	298	282
FR	266000	72000		24982	61302	161	0	7E+09	124	112
DE	120000	27000	20000	3589	17825	500		2,03E+09	*26	27
GR	84000	25000	16000	2574	3170	983	2680	3,62E+08	36	37
EI		1180	1180	226	739,6	12		84429224	24	20
IT	150000	65000	65000	14260	42347	1202	3255	4,83E+09	84	96
LU	125	120	40	28	72		23	8219178	*22	22
NL	700	200	130	30	60	0	30	6849315	0	0
PT	32150	24500	19800	3069	8899	1457	1458	1,02E+09	98	91
ES	150360	65600		14055	24065	600	1150	2,75E+09	**71	70
SE	200000	99000	95000	16318	62344	97		7,12E+09	832	759
UK	9300		5200	1136	3468	25		3,96E+08	***7	6
EU15									84	84

Source: Water Power and Dam Construction "Handbook 1993". *=1990. **=1992, ***=1987-1991.

Additional small hydro potential.

Besides the production from existing hydro plants in 1990 we assume that the additional small hydro potential in EU15 will be fully exploited in 2050. The expected power generation from these additional small hydro installations according to the "Water power and dam construction handbook 1993" is listed in the table below.

Table 38: Additional small hydro potential in the future is expected to be fully exploited.

Country	Additional Small Hydro Capacity MW	Additional Small Hydro Potential GWh/a	Additional W/cap 2050
A	1037	3100	48
B	0	0	0
DK	0	0	0
FIN	244	1200	26
F	30564	75000	137
D	604	3000	5
GR	1624	2000	24
IRL	0	0	0
I	21888	65000	147
L	0	0	0
NL	65	130	1
P	2242	6500	67
ES	38313	65600	191
S	0	0	0
UK	131	400	1
TOTAL	96712	221930	69
NOR	1966	8000	

Source: International Water Power & Dam Construction - Handbook 1993, own calculations

Hydro storage potential.

Table 39: Storage capacity in Europe 1991 and additional Potentials.

Country	1991 Existing max. Hydro Storage Size GWh	Additional max. Hydro Storage Size GWh	Total Hydro Storage Size GWh
A	1526	149	1675
B	13	0	13
DK	1	0	1
FIN	380	35	415
F	3597	4401	7998
D	517	87	604
GR	371	234	605
IRL	33	0	33
I	2053	3152	5205
L	4	0	4
NL	4	9	13
P	442	323	765
ES	2024	5517	7541
S	2350	0	2350
UK	164	19	183
TOTAL	13480	13926	27406
NOR	3834	283	4117

Source: International Water Power & Dam Construction - Handbook 1993, own calculations

Summary

Table 40. Total production derived from renewable sources in 2050 [W/cap in given country].

	On-shore wind el.	Offshore wind el.	Biomass residues assuming 33% conversion efficiency	Biomass from plantations assuming 33% conversion efficiency	Hydro power el.	Add. small hydro power el.	Solar thermal heat (reflecting demand rather than resources)	PV el.	Total energy production in 2050 from renewable sources
AT	47	0	92	298	496	48	25	48	1053
BE	57	54	53	113	3	0	139	133	552
DK	655	2483	118	350	0	0	21	38	3665
FIN	152	n.a.	279	1056	282	26	23	38	1856
FR	155	174	88	269	112	137	130	245	1311
DE	37	73	51	185	27	5	135	159	671
GR	518	217	51	296	37	24	69	460	1672
IE	1174	977	136	716	20	0	20	35	3078
IT	156	70	47	81	96	147	138	355	1090
LU	0	0	72	incl. in BE	22	0	175	152	421
NL	50	195	55	79	0	1	90	131	601
PT	153	100	45	51	91	67	75	427	1008
ES	250	81	64	190	70	191	57	459	1361
SE	499	280	197	993	759	0	19	39	2786
UK	207	359	42	169	6	1	19	28	832
EU15	178	195	66	219	84	69	91	214	1117

Table 40 is based on the indivudual estimates in the preceding sections, and the usage considered practical according to the discussion earlier.

Non-renewable resources

Bent Sørensen

The UN Intergovernmental Climate Panel's Working Group II has in its forthcoming Second Assessment Report estimated both renewable and non-renewable energy source technical potentials. These are given in Tables 41-42. One notes that the technical potential of renewable resources is higher than the ones given in the preceding section, due to the global perspective used and lack of omission of sites set aside for other uses by the human community. The potential for non-renewable energy sources displays the finite character of these resources.

Table 41. IPCC estimate of renewable energy technical potentials (IPCC, 1996).

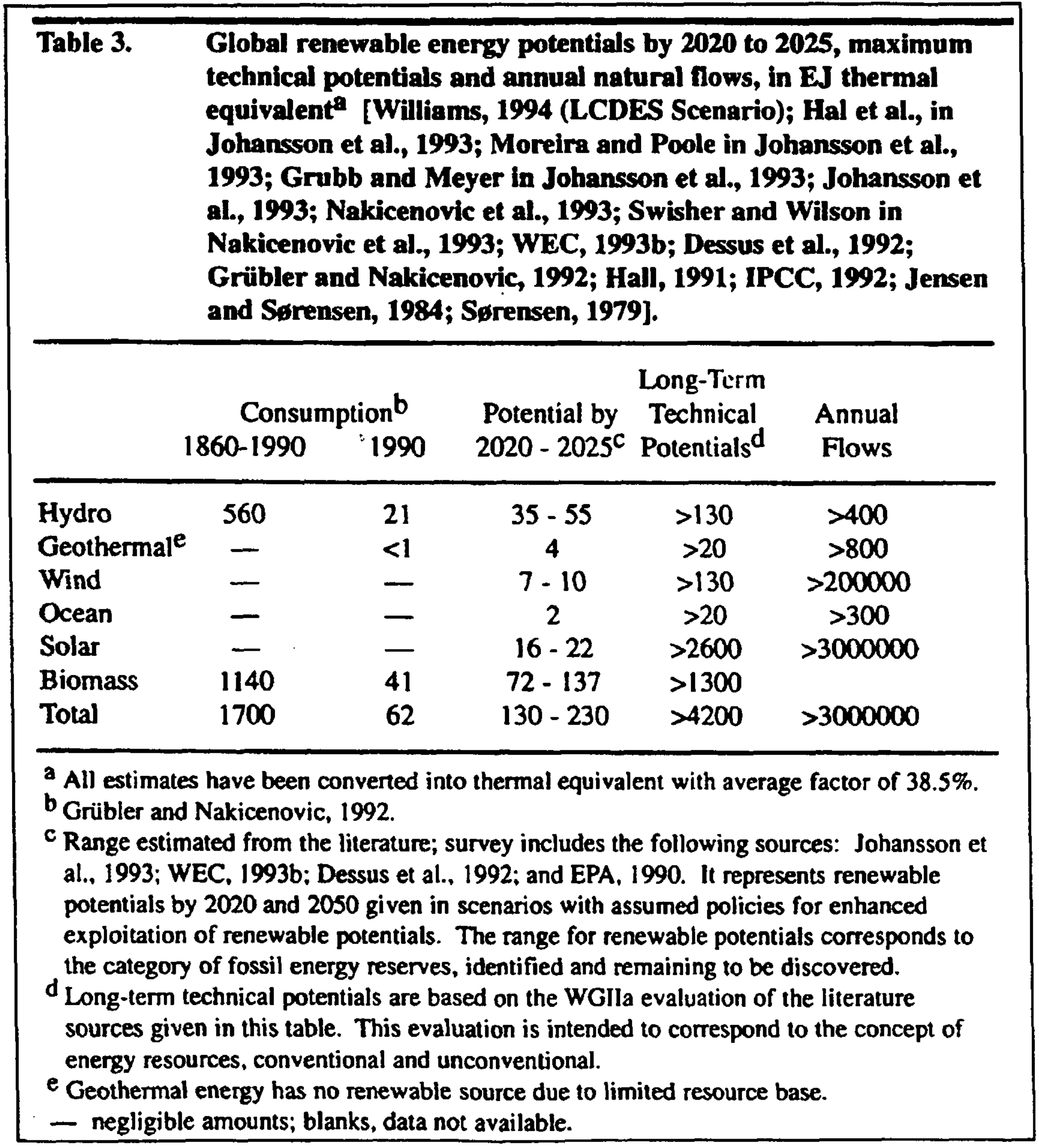

Table 3. **Global renewable energy potentials by 2020 to 2025, maximum technical potentials and annual natural flows, in EJ thermal equivalent[a] [Williams, 1994 (LCDES Scenario); Hal et al., in Johansson et al., 1993; Moreira and Poole in Johansson et al., 1993; Grubb and Meyer in Johansson et al., 1993; Johansson et al., 1993; Nakicenovic et al., 1993; Swisher and Wilson in Nakicenovic et al., 1993; WEC, 1993b; Dessus et al., 1992; Grübler and Nakicenovic, 1992; Hall, 1991; IPCC, 1992; Jensen and Sørensen, 1984; Sørensen, 1979].**

	Consumption[b] 1860-1990	1990	Potential by 2020 - 2025[c]	Long-Term Technical Potentials[d]	Annual Flows
Hydro	560	21	35 - 55	>130	>400
Geothermal[e]	—	<1	4	>20	>800
Wind	—	—	7 - 10	>130	>200000
Ocean	—	—	2	>20	>300
Solar	—	—	16 - 22	>2600	>3000000
Biomass	1140	41	72 - 137	>1300	
Total	1700	62	130 - 230	>4200	>3000000

[a] All estimates have been converted into thermal equivalent with average factor of 38.5%.

[b] Grübler and Nakicenovic, 1992.

[c] Range estimated from the literature; survey includes the following sources: Johansson et al., 1993; WEC, 1993b; Dessus et al., 1992; and EPA, 1990. It represents renewable potentials by 2020 and 2050 given in scenarios with assumed policies for enhanced exploitation of renewable potentials. The range for renewable potentials corresponds to the category of fossil energy reserves, identified and remaining to be discovered.

[d] Long-term technical potentials are based on the WGIIa evaluation of the literature sources given in this table. This evaluation is intended to correspond to the concept of energy resources, conventional and unconventional.

[e] Geothermal energy has no renewable source due to limited resource base.

— negligible amounts; blanks, data not available.

Table 42. Non-renewable ressource estimates (IPCC, 1996)

Table 2. **Global fossil and nuclear energy reserves, resources, and occurrences, in EJ [Nakicenovic et al., 1993; WEC, 1992a; Grübler, 1991; MacDonald, 1990;Masters et al., 1991; Rogner, 1990; BP, var. vols.; BGR, 1989; Delahaye and Grenon, 1983].**

			Reserves				Resources			
	Consumption[a]		Identified	Remaining to be Discovered at Probability[b]			Currently Recoverable	Recoverable w/ Foreseeable Tech. Progress	Resource Base (Reserves + Resources)[c]	Additional Occurrences
	1860-1890	1990		95%	50%	5%				
Oil										
Conventional	3343	128	6000	1800	2500	5500			8500	>10000
Unconventional	—	—	7100					9000	16100	>15000
Gas										
Conventional	1703	69	4800	2700	4400	10900			9200	>10000
Unconventional	—	—	6900				2200	17800	26900	>22000
Hydrates[d]	—	—							>800000	
Coal	5203	91	25200				13900	86400	125500	>130000
Total[e]	10249	288	50000	>4500	>6900	>16400	>16100	>113200	>186200	>987000
Nuclear[f]	212	19	1800		2300		4100	>6000	>14200	>536000

a Grübler and Nakicenovic, 1992.
b Masters et al., 1991.
c Resource base is the sum of reserves and resources. Reserves remaining to be discovered at probability of 50% are included for oil and gas.
d MacDonald, 1990.
e All totals have been rounded.
f Natural uranium reserves and resources are effectively 60 times larger if fast breeder reactors are used. Calculated from natural uranium reserves and resources (OECD/NEA and IAEA, 1993) into thermal equivalent for once-through fuel cycle with average factor of 1700 kg per EJ thermal or 4440 kg natural uranium per EJ of electricity (16 kg natural uranium per TWHe electricity).
— negligible amounts; blanks, data not available.

Sustainability requirements

Bent Sørensen

In selecting the practical potential of the renewable energy resources used in the scenarios, a fundamental requirement is that of sustainability. This means that the scenario system in principle must be sustainable indefinitely. For use of direct solar radiation, wind and wave energy, this is usually considered fulfilled, because any use implies an ultimate conversion is into low-temperature heat, just as the natural processes do in the absense of human intervention. For geothermal energy, the resource consists of a renewable part (replenished by solar radiation onto the Earth's surface), and a non-renewable part derived from flows of heat from the interioe of the Earth. Experience from geothermal power stations in areas of geothermal steam shows that these resources can often only be exploited for a very limited period of time (50-100 years). This implies that renewable geothermal energy is restricted to low-temperature heat stored in surface-near geological formations. For derived solar sources such as biomass, sustainability places a substantial set of requirements on their exploitation: The growth of plants or raising of animals must be sustainable, i.e. for the plants by returning enough nutrients to the soil to permit perpetual use, and by farming in general by employing practices not depending on unbalanced flows of the many materials involved in biological production. Also soil structure must be preserved, such as porosity and composition of top soil layer. In practice, full sustainability is hardly ever achieved, but some agricultural practices come sufficiently close to allow us to consider them as sustainable. As regards the carbon removed from the plants, it is of course originally fixed from carbon dioxide in the atmosphere. In some cases, a shift reaction is used to transfer the energy from carbon to hydrogen (which then serves as the energy carrier in subsequent uses), but also the hydrogen can be considered as recycled through the water cycle.

TECHNOLOGY TRENDS AND ASSUMPTIONS -

Primary conversion technologies

Stefan Krüger Nielsen

Cost estimates of different kinds of energy production now and in the future.

In this chapter I have gathered the estimated present and future production prices of energy produced by different energy supply technologies presented in the technology descriptions of the "Long term integration of renewables into the european energy system" project. For all renewable sources the production price is estimated. For conventional electricity production the fair market price including externalities has been estimated, using preliminary values of the social costs estimated in the project (cf. Chapter on Life-cycle Analysis below). **[estimates for the external costs of renewables, especially for different kinds of biomass technologies and other fuel cycles which might be important, to be inserted based on Mannheim data].** In the fair market scenario we will give preference to those supply technologies which can supply the energy cheapest, i.e. those who have the lowest price when considering both production, storage and transmission costs inclusive the external costs connected to the respective fuel cycles.

Conventional electricity production.

The price for delivered electricity produced in conventional plants using coal or gas has been estimated in the technology description on conventional technologies written by CIRED. They have chosen two technologies which might possibly be representative for the future choise of technology in EU15.

Table 43: Assumed production prices for electricity produced by coal and gas in the fair market scenario (1990-ECU)

	CCGT	PCC(SP)
Investment cost per kW [ECU]	851	1629
Investment cost per kWh [mECU]	8,4	15,9
Operation cost per kWh [mECU]	3,5	6,9
Fuel cost per kWh [mECU]	37,1	17,5
Production cost per kWh [mECU]	49	40,3
Global warming [mECU]	65	130
Other externalities [mECU]	20	20
Fair price including externalities [mECU]	**134**	**190**
CO2 [g/kW el.]	439	873

CCGT: Combined Cycle Gas Turbine.

PCC(SP): Supercritical Pulverised coal combustion; electrostatical dust remover, gas desulphurization, low NOx emission burner, selective catalytic reduction.

Source: CIRED, "...

We assume that these two technologies will be the futures winning technologies, in the sense that they represent the supply technology choises of the future for conventional electricity production using coal and gas as fuel.

By adding the external costs of electricity production to these production costs we can calculate the future electricity price in the fair market scenario. We take an externality estimate of 150 mECU per kWh electricity derived from coal and 85 mECU per kWh electricity derived from gas. These prices are the ones used in the fair market scenario.

Are these externality costs within a political acceptable range? Are they in line with the main stream of scientific studies on externalities? Our chosen level for the fair market price is very high due to one extreme parameter, namely the cost of global warming. If global warming is not accepted by politicians as a big problem they will probably not like our scenario approach.

Cogeneration:
See next section.

On-shore wind turbines.
The cost of electricity produced by small wind mills is estimated to be around 42 mECU per kWh in 1990 and 32 mECU in 2050. Electricity produced by mega watt wind turbines is more expensive and is estimated to cost 112 mECU per kWh in 1990 and around 40 mECU in 2050.

The production cost of land based wind turbines is estimated to be lower than the fair market consumer price on electricity produced in conventional coal and gas fired plants already now and throughout the time frame of the fair market scenario.

Offshore wind turbines.
Niels I. Meyer estimates that future production costs of electricity generated by offshore wind turbines will have the same cost as on-shore wind today. Experiences from a wind park off the shore of Vindeby in Denmark show that the present prototype installations have installation costs which are twice as high as todays installation costs on shore. However upscaling of the size and effectiveness of wind turbines will probably make the price go down[1]. **[The production costs are only 35-40 % higher in the first danish offshore wind park according to recent TEKSAM PhD thesis, insert these data and reference].**

Photovoltaics.

The production cost of electricity from photovoltaics is estimated as shown in the table below:

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[1] Meyer, Niels I, "Wind power technologies and potentials, Overview paper for ESETT '91, Milan, October 21-25, 1991.

Table 44: Cost per kWh electricity produced by grid connected PV solar panels [1990 mECU].

	1990	1995	2000	2010	2030	2050
EU15	420	352	294	206	101	50
South EU	370		260	180	90	40
North EU	560		390	270	130	70

EU15 source: The technological description.

South and north EU source: Olav Hohmeyer and Sigurd Weinreich "Paper presented at the PV conference in Nice". Here South EU considers Spain, Portugal, Greece and Italy.

By this estimation electricity produced by photovoltaics will already be cheaper than conventional electricity based on coal and gas as fuels sometime between 2010 and 2030. The cost differences between southern and northern Europe will imply that photovoltaics will be cost competitive earlier in southern countries.

Today grid connected PV solar panels are not competitive even considering the substantial fair market price on fossil based electricity in our scenario. PV's are only economically viable in areas far away from the grid for stand-alone applications. The major bottleneck hindering the introduction of photovoltaics today is the high production price for grid connected applications. The estimate of future competitive production prices are based on assumptions of a high level of research and development in more efficient solar cells and a substantial mass production leading to smaller production prices for solar panels due to economies of scale production. The assumptions behind the low production costs in 2050 are an increase in the efficiency of a factor 1.8 and a production cost decrease of factor 8.

Another possible solution which might make solar panels cheaper is to combine solar module technology and roof sealing techniques to reduce costs for traditional roof materials.

Even if these measures to overcome the problem of high prices on electricity produced by photovoltaics succeed there are other obstacles to the implementation of those. One is the recent monopolized regional energy supply structure where utilities produce electricity mostly in centralized plants. This organisational obstacle will not be considered in the scenario. Another obstacle which is important for our scenario though is that photovoltaics is an intermittent source which only produces power when the sun is shining.

The major questions to the price estimates for photovoltaics are:

Are the assumptions on future efficiency and production costs realistic, and are the assumptions behind the massive growth in production of solar modules consistent with our assumptions of a future fair market? A normal fair market assumption will be to consider that only the stand-alone applications which are now cost effective far away from the grid will have a market. The big question is if the major breakthrough of the technology will appear if the market is as small as today or if major public investments will have to be made to make the price go down. The later would not really be in line with our assumptions about a non-subsidized energy system in the fair market scenario.

Solar thermal low temperature heat.
Alexis estimates the 1990 price for solar thermal low temperature heat to be 70 mECU per kWh for southern European countries and 300 mECU for northern European countries. In the future the price is estimated to decrease by 25-50% in the medium term and up to a factor 3.5 in the long term. The price for both options is assumed to be cost competitive to electricity produced by gas around 2010.

[Insert more data from Alexis Andrew if we get them; also look at Bents paper for IPCC]

As solar thermal low temperature heat is much cheaper today than photovoltaic grid connected systems they will probably be implemented earlier and our assumption will be, that the installation of solar heat collectors will only stop when the demand for low temperature heat in the buildings has been covered. After this point people will install photovoltaics on the rest of their suitable roof and facade space when that technology becomes cost competitive to other electricity producing technologies.

Solar electricity produced on large centralized solar installations in southern Europe or northern Africa.
According to calculations and assumptions made by Sigurd Weinreich from ZEW exports of solar electricity produced on large centralized solar plants in southern Europe or northern Africa will be economically viable in the future and therefore an option in the fair market scenario.

[add material on biomass, expected from Wuppertal, and remarks on biomass and hydrogen imports from outside EU15]

SELECTED CONVERSION TECHNOLOGIES

Biogas

Bent Sørensen

Simple, labour-intensive biogas plants have been in fairly widespread use for several decades in countries like India and China (Sørensen, 1979; Jensen and Sørensen 1884). The technology has shown great promises for the development of rural areas, but has also gone though a number of difficulties, chiefly connected to organisational aspects. One key requirement is to ensure local expertise in operation and maintenance, and to make the users feel a responsibility for all the chores associated with collecting biomass and feeding and maintaining the plant.

In industrial countries, there has been a different line of development, aiming at large, industrial biogas plants operating with minimum attendance. During the last decade, a number of experiences have been accumulating, and the associated level of technology has greatly matured. The most common application is of the type illustrated in Figure 19. Typical inputs per plant are around several hundred tons of manure and industrial waste per day, and the biogas production runs up to several million cubic metres of gas per year. Figure 20 shows the biogas production per unit of biomass for 9 pilot plants in Denmark.

The latest biogas technology aims specifically at treating source-separated household waste (Danish Energy Agency, 1992). In contrast to the manure and industrial waste plants, which use a single, mixed digester, the new household waste plant at Elsinore, Denmark, uses a multistage-process with a number of side processes, such as fibre separation. When experience has been gathered, this would open the way to a global market for treatment of source-separated household waste.

The gas produced in the large installations is presently used in gas engines for combined power and heat production, or in pure boilers for district heating. Experiments with other uses are in progress, including use of compressed gas as fuel in vehicles (Stewart and McLeod, 1980; Danish Energy Agency, 1992).

Energy balance

The 1992 average production of the 10 large Danish biogas plants was 35.1 m3 biogas (64% methane) per m3 biomass, or 806 MJ/m3 (Tafdrup, 1993; note the large variation exhibited in Figure 20). In-plant energy use amounted to 90 MJ/m3 distributed on 28 MJ electricity and 50 MJ heat, all produced by the biogas plant itself. Fuel used in transporting manure to the plant totalled 35 MJ, and the fertilizer value of the returned residue is estimated at 30 MJ. Thus the net outside energy requirement is 5 MJ for a production of 716 MJ, or 0.7%, corresponding to an energy payback time of 3 days. If the in-plant biogas use is added, the energy consumption in the process is 13%. To this should be added the energy for construction of the plant, which has not been estimated. However, the economic break-even of the best plants indicate that also the energy balance is acceptable.

Direct cost

The pilot plant series constitutes a learning curve, and although 25-50% government subsidy has been given, the best of the 10 Danish plants, the layout of which is shown in Figure 19, is now roughly breaking even (Danish Energy Agency, 1992). This plant has a turn-over of 3.4 million m3 of biogas per year, sold at 1.1 Mecu. Operating costs (plant, and manure transportation) were 0.5 Mecu and capital costs 0.4 Mecu, but would have been 0.6 Mecu without the government subsidy.

Greenhouse gas emissions

Using as in the energy balance section above the average of 10 Danish plants as an example, the avoided CO2 emission from having the combined power and heat production use biomass instead of coal as a fuel is 68 kg per m3 of biomass converted. To this comes emissions from transportation of biomass, estimated at 3 kg, and avoided emissions from producing fertilizer replaced by biogas residue, estimated at 3 kg. Reduced methane emissions, relative to the case of spreading manure directly on the fields, is of the order of 61 kg CO2 equivalent (Tafdrup, 1993). As regards nitrous oxide, there is a possible gain by avoiding denitrification in the soil, but high uncertainty has made an actual estimate fortuitous at the present. The overall CO2 reduction obtained by summing up the estimates given here is then 129 kg for each m3 of biomass converted to biogas.

Other environmental effects

Compared with the current mix of coal, oil or natural gas plants, biogas plants have a 2-3 times lower SO2 emission but a correspondingly higher NOx emission. Higher ammonia content in the digested residue calls for greater care in using fertilizer from biogas plants, in order to avoid loss of ammonia. This is also true as regards avoiding loss of nutrients from fertilizer to waterways. Compared to spreading manure not refined by the biogas production process, there is a marked gain in fertilizer quality and a much better defined composition, which will contribute to assist correct dosage and avoid losses to the environment. The dissemination of biogas plants removes the need for landfills, which is seen as an environmental improvement. Odour is moved from the fields (where manure and slurry would otherwise be spread) to the biogas plant, where it can be controlled by suitable measures (filters etc.) (Tafdrup, 1993).

Global potential

It is difficult to estimate the total potential for biogas production, because it depends on the structure of the entire agricultural system. Household wastes could furnish some 2-3% of current energy use, whereas crop residues from existing agricultural activities (straw plus manure) could provide maybe 15%. With altered practices, involving growth of energy crops on land in rotation and introduction of harvesting methods better suited for recovering non-food parts of current crops, over 25% of current energy use could be produced in the form of biogas (Sørensen, 1994). This would involve a discussion of the most suitable mix of bioenergy options, considering liquid and gaseous fuel production as well as the environmentally less attractive direct combustion alternative.

Figure 19. Layout of biogas plant at Lintrup, Denmark. Capacity 300t biomass per day. (Danish Energy Agency, 1992)

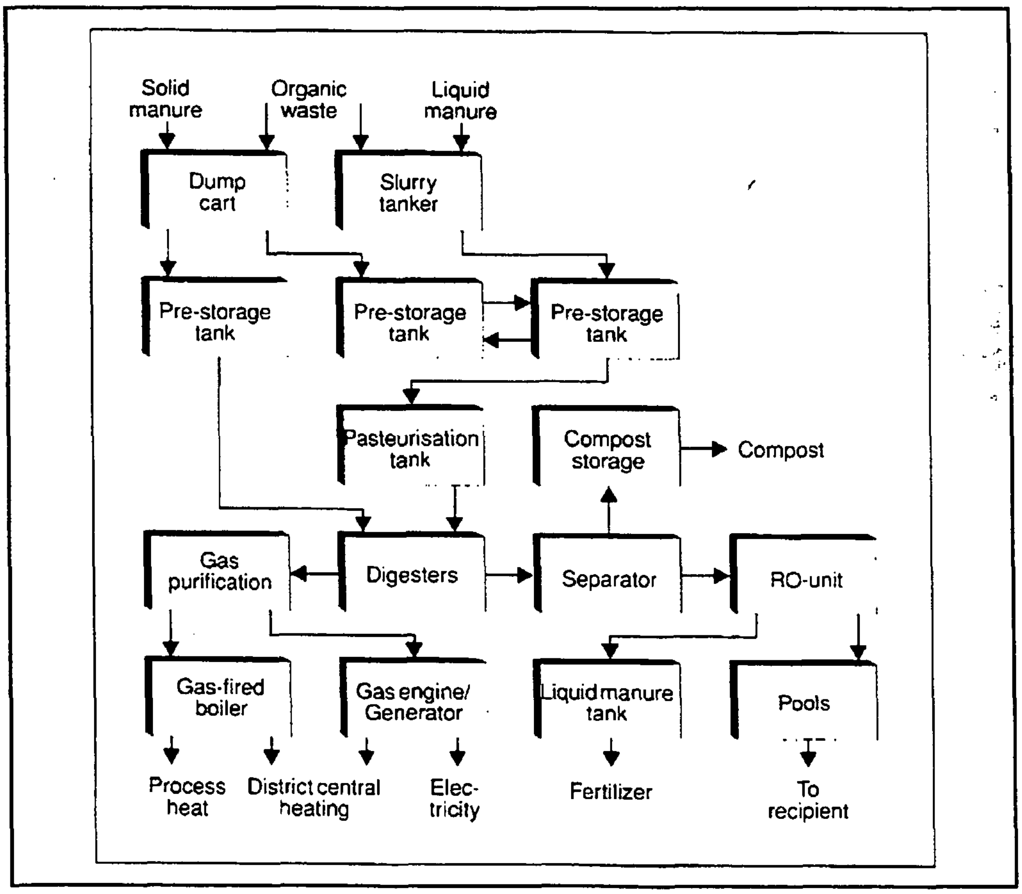
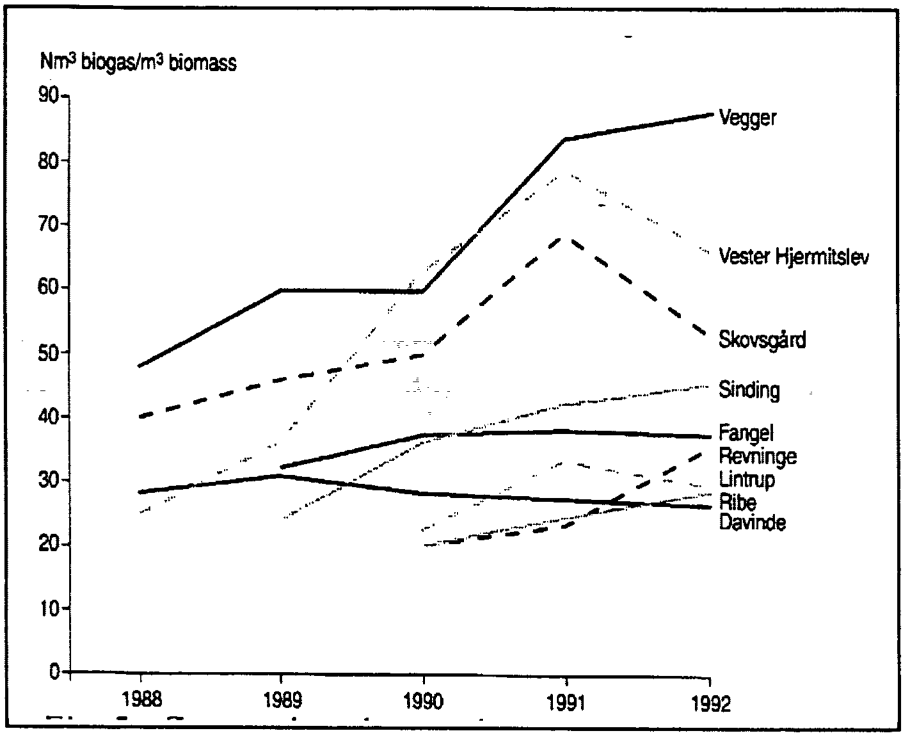


Figure 20.
Biogas production per m^3 of biomass for nine Danish centralized biogas plants, as function of operating experience (Danish Energy Agency, 1992)



Combined Heat and Power and Cogeneration and Heat Pumps

Bernd Kuemmel

The expression Combined Heat and Power (CHP) shall in this text exclusively mean the use of the excess heat from utilities' power plants in district heating (DH) systems. In steam power plants normally water is heated and transformed into steam, which is fed into a turbine, where it expands and drives the turbine. In order to cool the steam down again and to use it as feed water, heat exchangers transfer part of the heat that is left to another circuit, the one of DH.

The use of DH necessitates a system of pipes to transfer the heat energy to the consumers. This has been done for example in the greater Copenhagen area which is the World's biggest DH domain. But efficient CHP or DH schemes do not necessarily require large scale technology. They are workable and economical at sizes down to several households or larger single users in small industry, agriculture or the service sectors (DEA, 1993).

While CHP normally is provided by public utilities it is also possible to have power generation as a byproduct of the demand for process heat in various industries. This is called *cogeneration* in this text.

The total efficiency of CHP and industrial cogeneration, taking into account both the generated power and heat ralative to the energy content of the fuel, is much higher than generating the power or providing for heat seperately and typically reaches or surpasses 90 per cent. The electrical output itself can be higher than for new steam turbine power stations where at present it is maximally about 47 per cent. Generally speaking the heat for space heating purposes comes at a very low extra primary energy input compared to individual heating systems, this is beneficial for a national scale analysis.

Lower temperature heat (between 30 and 100 degrees Centigrade) can in principle be provided by cascading it from a higher temperature process to the lower temperature one (Sørensen, 1992) A backpressure DH system is such a case. But there also exists a means to transform lower temperature heat to higher temperature heat. The so-called heat pumps (HPs) do exactly this. In principle a HP works like a turned around refrigerator, with the outside being cooled down and the heat transfered to the inside of the building shell.

Heat pumps are constructed according to a compressor evaporator principle with a motor driven compressor. Compression warms a working fluid, it transfers heat to the heating circuit, the working fluid then expands over a valve, becomes cooler than the surroundings and thereby extracts heat from them. Another possibility is an absorption heat pump where two fluids evaporate and condensate in two different circuits and the phase changes either take up or release heat energy. Both types can work the other way round to be used for chilling, eg when a demand for cold exists during summer.

A variety of technologies is available for CHP or cogeneration. Combined Heat and Power (CHP) in older established DH systems is usually done as a means to exploit the excess heat of traditional steam power stations. In combination with Gasturbines (GT) or Gasengines (GE), mostly for newly established systems the efficiency of the cycle increases enormously. And the combination with fuel cells seems to be a very romising approach that will be realised in the near future.

Historical Overview:
Combined Heat and Power

Combined heat and power (CHP) has seen its earliest days in Denmark and some other places at the end of the last century. It was originally designed to diminish fuel demand in space heating. In the beginning the waste heat from electrical steam power plants was used in a district heating sytem. Later on waste incineration plants were included, too. There is also a tradition for this technology in Finland and a few other European places. The Danish DH system in the greater Copenhagen area is the most widespread in the world and there has been collected a vast knowledge.

After the first oil crisis in 1973 further steps were taken to increase the market share of DH in Denmark. This originated from the wish to reduce the dependance on imported oil. As a result the primary energy consumption for space heating drop by about 50 per cent between 1973 and 1993 in Denmark. But also other countries pursued such plans.

New technologies like better insulation of the forward and return pipes in the Danish DH systems made it possible to reduce the heat loss to the surroundings. This enabled extention of the area that can be served by existing plants. Alltogether in Denmark the investment in the extention of the DH system of G 1.3 1990-ECU has created a fuel saving worth about G 4.3 1990-ECU over a 30 year period (Sørensen, 1989).

DH has also been widespred in several Eastern and Middle European states, such as in the former DDR, as a means to increase the efficiency of the economies. Now the interest in it gets more widespread in Western Europe, too. The following table (Sørensen, 1994) illustrates the extent that CHP has in the DH market in various European countries:

TABLE 45

Country	Percentage of CHP in DH
France	13
Sweden	18
Austria	50
Denmark	62
Finland	71
Germany	73
Italy	79
Netherlands	91

Apparently in Sweden and France there has not been made much use of the combination of heat and power generation that CHP offers. In the other countries DH has been established together with the creation of new or by utilising existing power capacity.

Industrial Cogeneration

Opposite to CHP industrial cogeneration has not been very popular in Europe. According to OECD (1992) in 1990 it only provided 9 per cent of the total electrical energy production in the EU12. Economies of scale, the diminishing price differential between electricity and oil or gas, and unbenevolent or hostile regulations have decreased its attractivity to industry (Gainey, 1988).

Many utilities have been opposing the inclusion of smaller capacities like windturbines, smaller hydroelectric or biomass plants. In many instances those smaller capacities nearly exclusively are provided by independent producers and not by the established utilities. While renewable power sources generally work intermittingly the stability of the power supply itself has not been a major problem due to the typically small capacities.

There are countries where cogeneration always has been allowed, or where it at least had not been prevented by regulations. Several regions in Austria have explicitly allowed smaller hydroelectric plants (less than 5 *Megawatts* (MW)) the right to feed into the net. Also price politics have been structured by the political powers (Driscoll, 1990). This is also due to the fact that such small hydroelectric plants normally will work as a ground load base and not intermittently. Therefore they might substitute more expensive larger base load power stations.

In several countries the utilities' unilateral right to schedule electricity delivery contracts has only recently been questioned or changed, like in the USA following a new law, the PURPA (the Public

Utility Regulatory Policy Act), as a reaction to the oil price rise after the 1972 creation of the Organization of Petroleum Exporting Countries (OPEC). Such changes in the legislation enabled smaller suppliers to connect to the net. This is economical to the smaller capacities, because the PURPA requires the utilities to pay a fair price for third party generated electricity, and made cogeneration increasingly advantegeous. The market share of such installations rose till the mid 1980s where energy prices again levelled off in absolute prices (Gainey, 1988).

In the US there is a clear potential for an increasing market share of cogenerated power. When a Californian utility ran an auction in 1982 to buy autogenerated power they were offered several times the desired capacity (Lovins, 1990). Private investors offered 21 GW generating capacity of which 13 GW were already under construction. Those numbers were equivalent to 57 resp. 35 % of the peak generating capacity of California at that time.

Combined Heat and Power

Excess heat has been a waste product of traditional steam turbine power stations since the dawn of this technology. When this heat is fed into district heating (DH) systems this means using waste heat as a new heat source and reducing overall fuel costs. nd in summer, when heat demand is low but refrigeration demand high, absorption cooling systems can be used to produce chilled water for space and process cooling purposes.

The total efficiency of CHP is higher than for seperate systems where space heating is provided for individually. The marginal primary energy demand for the heat generation is smaller than for individual heating systems. But the heat has to be transported to the consumers by a vast network of DH pipes. The capital needed and the mischiefs inflicted due to the establishment of such a system deters wide spread installation of DH systems in existing, older towns. In newer building areas DH installations can be planned from scratch and will normally be as easily to construct as telecommunications or sewage systems.

In the mean time the advent of advanced gas turbine (GT) technology offers new benefits for utilities. First there has been a trend for more electricity which can be provided for easily and at a high efficiency with GTs. Second the space heating demand will very probably stagnate in many areas as insulation enables the heating of a larger floor area with the same energy demand. The GT technology takes care of both aspects. For smaller heat demands like in villages or for serving a small number of customers, utilities would prefer gas and dual fuel engines in cogeneration schemes that are applicable at smaller scales.

The small physical size of aeroderivative GTs resulting from their development for the airplane industry enables their preassemblance at the factory. This reduces costs in the field, ie at the installation site opposite to other existing power station technology (Williams and Larson, 1989) and leads to shorter planning and construction times which cuts costs. Such GTs, however, can only be used with fuels that only contain minor amounts of pollutants.

The nominal size of GTs has risen, so that nowadays an electrical capacity of above 200 MW is possible (ABB, 1993). In some places in Asia conglomerate systems are being built that comprise a total capacity of 2500 MW (DEA 1995). While the reliance on clean fuels restricts their application somewhat, this in fact minimizes mantainance costs which otherwise have been mentioned as a disadvantage with the older, heavy duty GTs that utilities used only for peak load. Those industrial GTs were fuelled with heavy oil and not mantained in the same way as aeroderivative GTs are today, which explained the higher mantainance costs.

But gas turbines are not always the best choice. The size of GTs is restricted by the power spectrum that the producers decide to make. They can not be tuned to the specific power and heat demands that might arise. So while aeroderivative GTs might be a good choice for utilities that generally demand larger capacities, they are not necessarily the first choice for providing smaller demands. Their advantage is the high exhaust temperature which enables steam production, but engine based systems of the rankine type might sometimes be more attractive, when power demand is not so high but electricity generation the prima facie.

The advantage of the gas engine over the GT in terms of electricity production can be seen in the following table (IPCC, 1994) that gives the power/heat output for a fuel energy input of 100 % for several technologies. Normally a power station will have an efficiency of 0.35 for creating electricity and a boiler of 0.94 for creating warm water. The normalised energy input for the seperate technologies is given in the second column with the savings for CHP in the third:

TABLE 46

Type of technology	Power to Heat ratio	Normalised energy input	CHP savings
Small biomass-fueled CHP	22/56	63/60	-18 %
Small GT CHP	30/55	86/59	-31 %
Medium-size Gas engine CHP	39/46	111/49	-38 %

Thus, introducing CHP instead of seperate power and heat generation leads to primary energy savings that in these examples range from 18 to 38 per cent. This leads to a reduction of the energy related CO_2 emissions, too. A new gas fired GT CHP station substituting a conventional coal fired power generation and individual gas fired warm water boilers would lead to a saving of about 1 million tons of CO_2 for each TWh of electricity (UK-DOE, 1992).

These examples indicate that reductions in fuel demand do not lead to a loss of life quality as the services, power and heat, still get provided, and at a much better economy than for the traditional approach that has been succesful only because economy of scale and diverse regulations have made alternatives unattractive.

It has to be taken into account that DH necessarily relies on the availability of a distribution net for the heat energy. In many instances such a net has to be built up. But not only this construction also, connecting the customers takes time unless use of DH is made obligatory. Apart from the technical difficulties that have to be solved the question of reliability and people's attitudes regarding a more centralised heat provision have to be considered. More consensus oriented populations like the Scandinavians might have less difficulties realising the advantage of larger scale DH instead of individual heating than the people in other member states of the European Union will face.

Industrial Cogeneration

In this text the generation of process heat for industrial processes together with electrical power is called *cogeneration.* The term autogeneration found in other texts is essentially the same. We shall also talk of cogeneration when we consider small scale systems in local communities.

Heat Demand in Industry

Process heat is used in many processes in various industries to speeden up chemical reactions. Normally only process heat is generated at a production site while electricity is bought from utilities. Thereby the advantage of coproducing heat with power in not exploited. Only at bigger production sites has cogeneration, the generation of steam or hot water together with power generation, existed for some time. This has historical reasons, as described above economy of scale has made autogeneration uneconomical until recently.

Despite the economical benefits site managers of industrial plants often have not realized that cogeneration in fact either can increase the revenue base or reduce production costs. And the size of the used technology needs not be large scale throughout. Smaller, industrial gas turbines and gas and diesel, or dual fuel engines have made cogeneration possible also at smaller scales, ie down to several kilowatts (Gainey, 1988). Eventual extra heat can be provided by reheating or boilers (Beckersandforth, 1991).

In the case of industries with high electricity demand that do not have the possibility to feed excess heat into a DH net cogeneration normally will be restricted to the substitution of the heat demand only. An economy analysis will then show how the most efficient and economical system should be constructed.

If not the whole process heat can be used in the industrial production the problem arises of how to cool the water vapour before recycling it in the boiler and turbine. This problem can be solved easily if the excess heat after the industrial process is fed into a DH system. Thereby excess heat becomes a marketable product. This minimizes the need for cooling installations at the site.

Excess heat can also be cascaded into other industrial processes. These do not necessarily have to be on the same premisses but could be on a site of another company nearby. This form of "cascading" (Sørensen, 1995) is another means to optimise the overall energy flow of an economy. Such a solution of course depends on the ability of different companies to communicate and the willingness to find an economical solution that is beneficial to all partners.

From an economical point of view the possibilities to increase cogeneration capacity are only restricted when drastic changes in the production capacity or the kind of industrial processes have to be expected in the nearer future. Then the contracts with utilities or other customers might be too rigid so that the overall economy suffers.

Short term variations in the heat demand can easily be overcome by heat capacitors (Williams and Larson, 1990). In that way the industrial cogeneration is more independent of the consumer demands when it is done in collaboration with a DH scheme, where there are distinct daily and seasonal variations of the heat demand.

Vacation periods, mantainance and restructuring of production lines can pose a problem when industrial cogeneration is coupled to a DH system. Even in the summer period there is a certain heat demand for hot water that has to be fulfiled (Drexler, 1991). During such periods backup systems are necessary. DH and cascading, thus, means somewhat restricted flexibility of the industrial production but on the other hand industrial processes require a steady power and heat supply, so the stability of industrially cogenerated heat in DH systems might not pose bigger problems after all.

When looking at the possibility to substitute pure heat generation (steam or warm water) for industrial processes with cogeneration the power-to-heat output ratio will play an important role. It illustrates the ratio between generated power and usable heat energy. For high heat demand and low power demand the ratio should be small and vice versa. This is illustrated in the followng table (Beckervordersandforth, 1991):

TABLE 47

Type of Technology	Power to Heat Ratio
Steamturbine DH	0,24-0,28
Gasturbine DH	0,50-0,70
Gasengine DH	0,60-0,85
Gasturbine CC-DH	0,72-1,00
Gasturbine with Steam Injection	0,50-1,10
Gasturbine with Cheng cycle	0.85-1.20

By selecting the right technology the demands of most users can be fulfilled. This customarization will take into account that the heat and power ratio is different not only in different industries but can even vary with different producers of the same branch, or that time dependent variations at the same production site occur (DEA, 1991). The possibility to work at part load has also be investigated, when a larger part of the energy demand occurs not at full load.

Technologies

Apart from simple a utilization of excess heat from a traditional steam power station in a DH system a variety of new technologies has seen the light in the last years and more are being developed. Here we shall present some of the technologies that can be used.

Combined Cycles

Opposite to a simple steam turbine in the *Combined Cycle* (CC) heat and power generation processes are combined by the use of gas turbine and steam turbine driven generators (Albisu, 1990). The second generator is driven by the steam generated by a *heat recovery steam generator* (HRSG), thus utilising the exhaust fumes of the gas turbine. Different combinations are possible to design a complete heat and power system that suits the demands of industry, services and utilities (Williams and Larson, 1989).

Introducing a turbine after having used the heat energy of the steam as process heat is called a bottoming unit or system, while the opposite of first using the fuel's energy to produce electricity is called a topping unit or system (Albisu, 1990). Topping systems are more versatile as low or medium temperature (100 - 500 degrees C) is sufficient for most industrial processes and for DH.

The power output of a GT can be increased by refeeding parts of the steam or exhaust gases. This is called steam injection generation, STIG. Steam injection into the inlet of a gas turbine boosts power by up to 50 % (Gainey, 1988), at the same time it reduces NO_x emissions. This is welcomed following new air quality programmes and regulations (Williams and Larson, 1989). A similar method is the Cheng cycle that also brings about a power boost by steam injection. As it is patented the supply for that technology is highly centralised.

There are still many other modifications of the cycles both high tech and low tech and some new ones like the Kalina or Rankine type that have the capacity to increase the generating efficiency and, thus, reduce the busbar costs of coal or gas fired CC systems (Williams and Larson, 1989).

An example of a very efficient way of engineering to boost a gas engine's performance is a combination of two gas turbines in series (ABB, 1993a). This increased the power efficiency from 41 to 46 per cent at a power boost of 100 MW from 500 WM. The gas turbine GT 26 in combination with reheating provides an electrical efficiency of 58.5 % compared to the heat input of the fuel. There has been realised a 53 % efficiency for a CC system and more improvements are expected (Flavin and Lenssen, 1994).

And there are other low technology cycle modifications that open efficiency gains. Examples are: reheaters, intercoolers, regeneration, evaporative regeneration or steam reforming of fuels (Williams and Larson, 1989).

Post combustion exploites the oxygen content of the fuse gases after the GT and helps to tailor steam production to the demand in the system with HRSG (Albisu, 1990).

Intermediate steam extraction makes available the process heat at various conditions and allow a more flexible power and heat generation. Thereby it is easier to vary the generation of process heat and electricity and optimise it according to the production needs (Albisu, 1990).

Gas Turbines

The gas turbines known as peak load units with the utilities were heavy-duty designed industrial gas turbines. This technology has been used since the beginning of the century, amongst others in ships. Such GTs normally feed on heavy oil. They typically have low compression ratios (8-16) which makes turbine exhaust gases up to 590 C hot. Therefore it is relatively easy to produce steam in a HRSG for CC systems. They are being manufactured with electrical capacities of typically 100 to 200 MW.

The industrail GTs bad reputation as being unreliable grew from their use in peak load power plants. where they were not serviced in the same way that the new aeroderivative technology are.

The new aeroderivative GTs are mantained like airplane engines. They are lightweight and compact rendering high compression ratios (18-30), but they demand clean fuels. Their cooler exhaust gases limit their use in smaller sites for process steam generation purposes (Williams and Larson, 1990). Capacities range from about 30 to around several hundreds MW where they have a high electrical efficiency in CC systems. With the ongoing development in both the power sector and the airoplane industry even bigger sizes can be expected in the future (DEA, 1990).

While aeroderivative gas turbines have received much attention in the last years one of the disadvantages of this technology is the total performance factor. For a given flue gas temperature it is lower than for the gas motor, a competing technology. This can be explained by the lambda factor and a lower proportion of fuel to inlet air. Therefore gas engines will be primarily chosen for processes where apart from power only hot water and not steam is needed. This is different from gas turbines, where the electrical efficiency can be greatly improved by HRSG and CC systems (Richartz and Kotzur, 1991).

Explosion Motors

Experience has been vast with Diesel motors, too. They have even been shown to work with a powdered coal and water slurry (Gyftopopoulos, 1990). Gas engines and ignition motors can also be fired with biomass fuels in gas or liquid form for cogeneration at smaller scales. This enables smaller communities to start their own power production and DH system.

An example of this approach are the so called Locus units that have been installed in some places in Denmark since 1983. They can provide 100 till 200 inhabitants of a village with heat and power. Depending on the individual demands between 50 and 100 per cent of the demand can be supplied with one LOCUS unit alone (Meyer and Nørgård, 1987). A more detailed description of combining the LOCUS system with more widespread wind power utilization can be found in Illum (1986).

For another example the Elsbett engine (a modified Diesel motor) runs on vegetable oil. While its market is clearly of minor importance in Europe today, this type of technology might be a very attractive choice in developing countries. But a vegetable oil fuelled gas engine driving a smaller cogeneration station could be viable in the not so near future in Europe, too, especially as water pollution by leaked mineral oil is prevented. When fuelled normally, ie with Diesel oil, this engine has a very favourable power economy compared to normal Diesel engines.

Also the Thermoselect method could be used to produce heat or fuel for power generation purposes. This is also a means to treat solid waste. Such systems have been tested in Northern Italy recently and the power generation is estimated to be about 450 kWh per metric ton waste. The advantage of the Thermoselect method or another development, the method of soldering burning (Schwelbrennverfahren (?), is a marked reduction of the amount of difficult to handle noxious wastes. Only 7 till 14 kg of such difficult to handle ashes arise per ton waste compared to 20 till 40 with normal waste incinceration plants (SZ, 1995c).

Fuel Cells

A relatively new technology, though in principle known for more than a hundred years, are fuel cells. Combining effectiveness of electricity production with the advantage to be able to store electrical energy in the form of chemical energy they offer a complete new way to design a power base. From the point of view of cogeneration it is notable that they come without moving parts and so shortcut an important contributor to ineffectiveness: mechanical movements.

Several types of fuel cells are currently being investigated: *AFC* (Alkaline Fuel Cell), *PAFC* (Phosphoric Acid Fuel Cell), *MCFC* (Molten Carbonate Fuel Cell), *SOFC* (Solid Oxide Fuel Cell) or *SPEFC* (Solid Polymer Electrolyte Fuel Cell), *SPFC* (Solid Protonexchange Fuel Cell), *DMFC* (Direct Methanol Fuel Cell), (IPCC, 1994; Zegers and van de Voort, 1991 in Stimming etal., 1992). This technology is currently in the development stage with installed capacities of some kilowatts to several Megawatts. The industrial limit the upper size of the electrical capacities is expected to be around some hundreds of megawatts per system with conversion efficiencies of 55-70 per cent for power generation.

Heat Pumps

With the rising building standards in Europe the quality of insulation becomes better and tighter building shells reduce the heat loss due to draught. As a result of this trend the heat demand of new buildings and retrofitted smaller ones is reduced. Individual heating systems can be kept smaller than before. This increases the chances for heat pumps. They are an excellent alternative to resistance heating for low temperature space heating purpose.

Heat pumps have been popular in several members of the EU, especially in Austria and Sweden. Even in countries where their popularity were not as marked they have been widely spread. In Germany more than 300000 systems have been working and Sweden boasts of having more than than 100000, at a population that is only a ninth of the German one (Laue, 1992; Berntsson, 1989).

An immediate advantage of heat pumps is the possibility to run them in warming mode in the winter time and in cooling mode during summer. This kind of airconditioning is widespread in North America where heat pumps are found much more often than in Europe. The kinds that are used there are air based systems where both the heat source is ambient air and air is used to transfer the heat into the building in the winter time.

It is necessary to have a heat source of sufficiently high temperature in the winter time. In places with long and cold winters the air temperature might be too low. When the temperature difference between ambient and room air is too high the performance and economy of an airbased heat pump system suffers. This is especially the case in climates with winters with extended and severe frost periods. It is then necessary to use another heat source with a temperature that does not become that low. Ground water or the ground can in principle be used. They both have the annual mean air temperature throughout the year. There are even layers in the ground where due to the heat dissipation laws the temperature curve is opposite to the one of the air, ie where it is warmest in the winter time and coldest in during the summer.

Ground based heat pumps use a working fluid that is pumped through pipes which means a capital demand for that installation. Ground water based systems necessitate two wells, one to pump up the ground water and another one to refeed it to the ground water stream. This imposes the need to apply for a water exploitation permit and might therefore not be possible near a drinking water production well. Both technologies open for a hydronic heating system for space heating purposes.

In summer the demand for space cooling can be realised by an absorption cooling system, where heat gets provided from the generation process. Even though absorption cooling needs much heat it makes sense in the summer when the demand for space heating is reduced and cooling demand arises. Then distribution systems for chilling water could be established (Wienecke, 1991).

The Economic Side

Energy Efficiency

According to Gainey (1988) the immediate savings in primary energy input for CHP are at least 17 per cent wheras Albisu (1990) mentions at least 21 % compared to the conventional, seperate heat and power production. CHP and cogeneration, thus, brings about an immediate national economic advantage. Historically larger thermal power plants, due to economics of scale, have replaced auto- and cogeneration capacities, even though the total energy utilisation of pure power stations until quite recently has been less (Gainey, 1988).

Profitablity

Where cogeneration is technically feasible in most cases it also will be profitable. As industrial cogeneration systems normally will be installed on the premises of already existing industrial sites the planning and implementation times are much shorter than is normally the case for the utilities' larger stand alone plants, where the planning horisons typically are about five to ten years. Cogeneration systems on the other hand can be operational within some months or at most two years (Richartz and Kotzur, 1991). Therefore cogeneration opens up for a rapid and substantial reduction of the primary energy input of the economy.

While there generally is a cost advantage of large scale technologies, Burkel (1992) has stressed that the economy of smaller scale cogeneration can be improved by a lean design (see also the epilogue). Regarding the smallest size of gas engine cogeneration systems there is a downward trend which opens up for new markets (DEA, 1990). Despite their specific price disadvantage the profitability of smaller cogeneration systems has been proven in the praxis for several performance and capacity ranges (ICIE, 1992)

Economical Considerations

Industry has rather easy access to investment capital, and cogeneration offers an extention of the revenue base, as power can be either sold or the demand for it reduced. When the price of the purchased power is sufficiently high, this means a reduced pay back time of the investment. Arguing for an extention of a financing scheme to take industrial cogeneration power capacity into consideration is then easy.

The variety of the power to heat ratios and the size of the systems that can be realized makes it possible to design a cogeneration system to meet any site's demands. There are, at least from a technical point of view, almost no size restrictions (Burkel, 1991). Smaller systems down to some kW electrical capacity can be made economical by a low technological standard and so cogeneration will be a choice for smaller industries or in the manufacturing sector (Beckersandforth, 1991). On the other hand financing difficulties with extremely large systems can impose restrictions in that direction.

Economical aspects will normally restrict the maximum economical size of a system to less than 100 per cent of the site's energy demand, especially with regards power consumption (DEA, 1991). But local differences may mean that this rule of thumb might not apply at every site and through the whole of Europe. For example in Denmark utilities charge a higher price for natural gas that is used in cogeneration than for process heat alone.

Choice of Technology

For intermittent use combinations of several gas engines or turbines give the most efficient performance also at partial capacity load. Aeroderivative gas turbines perform unefficient at lower loads (Richartz and Kotzur, 1991), so a proper design is vital for securing the economy of a site.

One disadvantage of the industrial gas engine is its high specific price, ie the purchase expense compared to the generating capacity. Gas engines are labour intensive to make. But there are ongoing developments that might lead to lower prices in the future. Already the market offers a large array of sizes and capacities especially in Japan (Fujino, 1991). Harder competition with the advent of cogeneration down to smaller scales could lead to price drops in the near future, despite the fact that the fuse gases need to be catalytically converted to fulfil the legislation on exhaust air quality.

Larger scale aeroderivative GTs on the other hand are quite cheap, and the construction cost of a GT CC system is lower than for a conventional steam plant. Williams and Larson (1989) cite a 200 MW plant with a GT and a CC efficiency of 45 % at 520 $US/kW compared to the 760 $US/kW that a conventional natural gas-fired power station with only 36 % efficiency would cost, a saving of 32 per cent.

Aeroderivative GTs could give back utilities the advantage of large scale competitiveness by scale of economics advantage. On the other hand a vast demand for this technology in the future might lead to rising prices so that the competitiveness of the systems may go down (DEA, 1995).

Tailoring a System

By combining different technologies the demands of most users can be fulfilled. This customarisation will take into account that the heat and power ratio is different not only in different industries but can even vary at the different producers of the same branch (DEA, 1991). In this respect it is important to remember that while the primary energy intensity of the European economies has been decreasing the electricity intensity has been increasing. This puts emphasis on processes that have high power to heat ratios. CC processes and gas engines are therefore the state of the art.

Due to its performance factor the gas or Diesel motor will give more electrical power output per unit of primary energy than a simple cycle GT. This also means that with gas motors the CO_2-reduction compared to the generated electricity will be up to twice that for gas turbines. This disadvantage with GTs can not easily be removed, and it is especially urgent at the smaller scales (<1 MW), where HRSG can not be used economically in a combined cycle system. This is often the case in smaller district heating (DH) systems.

Demand Pattern Analysis

In the planning phase of cogeneration systems it is obligatory to investigate thoroughly the actual demand and consumption. A change in the process design could increase the efficiency of the total system. A demand for steam might only be a historical relict instead of a real necessity (Richartz and Kotzur, 1991). When the analysis shows that such relicts can be removed without harm this will increase efficiency in itself, especially as lower temperatures of the heat supply system reduce the losses.

When the temperature of the forward water in the DH system can be lowered this automatically increases the efficiency of the power generation process due to basic thermodynamic laws. Increased insulation of the connected buildings enables one to lower the forward temperature. This minimizes the heat loss due to conduction from the pipe surface to the surroundings. Typical savings in Danish CHP systems are 0.85 per cent primary energy per Kelvin lowering of the supply and return temperature (DEA, 1993).

In CHP-DH holding the temperature of the supply water constant and reacting on differences in the heat demand by changing the flow of water through the system is more efficient than changing the supply temperature. The increased power demand of the pumps is negligible compared to the gain in the thermodynamic efficiency of the whole system (DEA, 1993), but there are opposing views on that topic.

Competitiveness

The economic attractivity of DH depends very much on the price of the heat medium that they replace. For example in Germany DH would not be competitive in several places. According to Grothkamp and Ständer (1992) the price for a thermal kWh from DH was higher than the one produced decentrally on natural gas boilers, 40 mECU vs 28 mECU (8.5 DPf vs 6 DPf). This is the case especially in Western Germany where natural gas distribution is widespread. The costs of a new DH system with connecting pipes will normally be imposed on the price of the delivered heat so that DH might not be attractive for the customers and therefore not profitable. In the five new German federal states the situation is different as large existing DH systems are already in operation there.

Heat energy generally is cheap. Utilities will therefore generally desire high power to heat ratios both to secure decent revenues and to minimise loses during the summer period. Also heat prices have to be chosen so low that DH will be attractive, to make introduction of DH easier and attractive to the customers. If the prices for heat energy are too low, the power prices will have to bear a larger share of the maintainance costs of the complete system. So the heat price might not necessarily have to be high, although such a strategy might be unfeasible in a deregulated power market with falling power prices in a liberated energy market. Where DH systems have been existing for a long time the original investments have been written off, so that profitability is ensured. Nørgård (1989) therefore mentions a heat price of 15 mECU/kWh$_{th}$ for Denmark.

With the increasing demand for space cooling especially in Southern Europe the use of absorption coolers for chilled water production might offer a good alternative to the commonly used compressor based air conditioning systems. While the latter are easy to assemble they rely on work fluids either with a high ozon destruction potential or on substitutes which do not necessarily have the same performance figures. However, mixtures of R32 and R134a or R32 and R152a seem to be energetically advantageous to the normally used R11 and R11 (Laue, 1992). Scale considerations might justify the use of absorption cooling systems in connection with DH systems in the summer period with the difference to the winter time that the cogeneration site would then provide for space cooling and not heating.

Busbar Costs Overview

Williams and Larson (1989) give some values on the unit and busbar costs of electricity for several types of power plants. Those show that gas turbines now have a competitive edge over the conventional coal fired steam plants as these figures for the USA might illustrate:

Table 48. Capacity costs and busbar costs of produced electricity of different cogeneration technologies

Type	Unit cost (ECU/kW)	busbar costs (mECU/kWh)
NG ISTIG	300	18
NG ACC	385	19
NG STIG	300	20
Coal IGCC-ISTIG	760	25
NG Steam	560	26
Coal Steam	1000	33
Nuclear Light	2200	42

(NG: Natural Gas, STIG: Steam injection, ISTIG: Intercooler Steam Injection, IGCC: Gasified Coal with hot gas clean up).

The levelized busbar cost of a kWh_{el} in Europe would be as low as 18 mECU at a gas price of 1.6 ECU/m^3 (Williams and Larson, 1989). For Sweden busbar costs of 24 $mECU/kWh_{el}$ have been mentioned for CHP systems and for industrial cogeneration 23 $mECU/kWh_{el}$ (Bodlund etal., 1989). Results in the LTI study indicate typical production costs of 30 to 40 $mECU/kWh_{el}$ including fuel costs and normal expenses for maintenance and operation.

Considering not least the national economic advantages that cogeneration and CHP offers it is amazing that they only stand for a minority of the energy that is converted in Europe today. The historical reasons have been described before. Even though in some places in Europe cogeneration has started to take a larger share more possibitilities still exist. A list of the technical-economical potential for pure CHP or industrial cogeneration is given here:

Table 49.

Region considered	Electrical capacity	CHP or cogeneration	Source
Bavaria	600 MW	CHP	Geis (1992)
Denmark	415 MW	cog	DEA (1991)
Belgium	1200 MW	CHP	Vebruggen and Vanlommel (1987)
Eire	460 MW	cog	NBST (1983)
France	20000 MW	cog	Petitjean & Radanne (1987)
Germany	85 TWh	CHP	EPROM (1988)
Germany	15 TWh	cog	Burkel (1992)
Nederlande	3200 MW	cog	Bezinningsgroep (1988)
Finland	38 TWh	CHP	Hausen & Petäjä (1988)
UK	30000 MW	CHP,cog	UK-DEO (1990)
UK	45000 MW	CHP,cog	UK-DEO (1990) (2005 Potential)
UK	60000 MW	CHP,cog	UK-DEO (1990) (2020 Potential)

As can be seen there is an economical potential in several regions in Europe, but the technical potential of course is much higher than those numbers indicate. The technical potential, though, will change much less with time, while the economical considerations change with the changing price levels and price differentials of different energy forms.

Historical Development of CHP and Cogeneration

Many utilities have been opposing smaller capacities by independent producers like windturbines, smaller hydroelectric or biomass plants (Driscoll, 1990). The problem is often not the stability of the power supply per se, it is more a question of influence. Industrial processes rely on stability far more than power plants do. The capacity factor of cogeneration facilities typically is 94.8 % compared to the general availability of the utilities' larger plants from typically 75-80 % down to 55-60 % for large nuclear plants (Hamrin, 1990).

Far from endangering the stability of power supply there are beneficial impacts that cogeneration has on the stability of the supply (Hamrin, 1990). In extreme situations the utilities' power stations might be taken off the net whereas this does not happen in industrial plants that even can increase power generation beyond the contractual capacity.

The flexibility of the current power net in Europe is sufficient to exclude wide spread power surges from the interruption of a single cogeneration capacity. What is more pressing is when the excess heat of the industrial process is used in DH. Then it is necessary to have backup systems for maintainance and vacation periods to provide for the warming needs of the customers.

There are, though, currently a few upper technical bounds on the amount of power that combined heat and power plants and autogenerators can provide. Utilities let power plants perform so that they can in- or decrease their power production by up to 2.5 per cent within 5 seconds and 5 per cent within 30 seconds (Grothkamp and Ständer, 1992). So cogeneration capacity that might be more intermittent due to different reasons can only replace the utilities' basic load power stations' capacity up to a certain degree. These are normally the most economical plants and so competition is hardest in that market segment. However with the advent of demand site management and more competition the flexibility of utilities necessarily will have to increase in the near future. This will make inclusion of smaller capacities easier rather than more difficult.

Examples of Realized Cogeneration Projects

Several expamples of well functioning and profitable installations can be found in the literature. Here we shall only cite one. Coll and Ros (1990) describe the economical benefits of a natural gas turbine with a 9.34 MW generater and a HRSG and afterburner in a polymerisation and spinning site in Spain. Apart from the process heat demand air conditioning is performed by chilled water production in an absorption cooling plant. The cogenerated electricity will only save part of the site's total power demand, which generally will be the case. At the prices considered in their study a combined specific saving 41 per cent will be created with regards the produced goods. The estimated payback time of the cogeneration installation is 3.2 years.

Transmission Technologies, intermittent generation and decentralization

Bent Sørensen

Electricity transmission technologies

Transmission of power over distances exceeding some 700 km is currently less expensive for DC cables (overhead or underwater) than for AC cables. Average Ohmic losses amount to about 4% per 1000 km, while losses associated with DC/AC conversion are 0.6-0.8% each way. The cost of DC transmission lines adds of the order of 0.01 ecu/kWh per 1000 km, with today's technology and depreciation schemes (IPCC, 1996). In the future, superconducting transmission lines may be contemplated for long-distance transmission, but the cost is currently unknown.

Handling intermittent power generation

Dealing with intermittent energy sources can be accomplished by a number of measures, some of which involves the end user, while others rest with the operator of supply and distribution.

User side:

Demand can be managed with intermittent energy sources in mind. This can be done based on knowledge of current and anticipated availability of power, information that may be transmitted through the power lines, or any other information channels (text-television, radio or telephone lines). The point is that the user gets a signal telling about the running availability and cost of power, so that use of electricity can be planned accordingly.

A typical user would divide his demands into a) priority demands that must be satisfied immediately, b) demands that do not suffer from being displaced a few hours (these could include clothes-washing, dish-washing, etc.) or even up to a day (compressor of freezer not being opened), and c) long-term displacable demands (such as agricultural drip irrigation) (Sørensen, 1991; 1992).

This kind of demand management can be fully automatised, by using intelligent appliances and other equipment corresponding directly to the signals received through the grid, according to pre-programmed preference selections.

Operator side:
Application of transmission planning, including transfer of electricity between different time-zones, can cope with some of the diurnal variations in solar input. The management of interconnected grids could be, but is not currently, optimized to allow maximum inputs from variable power sources. Some management of this type is, however, already done in order to make best use of base-load power plants (like renewable energy generators, these are capital intensive).

Another technique in widespread use is to operate special types of fuel-based power generators when intermittent power sources cannot meet demand. Such power generators must be easy to regulate, and because they are used only occasionally, they are preferably characterized by low capital cost (but high fuel cost). Currently, gas turbines and diesel sets are the preferred technologies for such peak power plants, but as new techniques for easy regulation of other power plants has become available, they may all serve this purpose (Kaye et al., 1993).

In case hydro power plants are available, they allow prompt regulation and can back up intermittent renewable energy generators.

Back-up systems based on fuels only diminish and do not eliminate the need for fuel conversion and the potentially associated hazards. Extended grid systems as they are found e.g. in Europe allows about 30% penetration of intermittent sources without special storage (Sørensen, 1987), as further discussed below. An energy supply system largely or completely based on renewable energy would require energy storage facilities of both short-term and long-term capacity:

Storage
Storage is essential for stand-alone systems but may also be required for utility systems, depending on the characteristics of the remainder of the system, including possible mismatch problems between production and demand.

Energy storage technologies that have been considered include (Sørensen, 1984):

Mechanical storage
Pumped hydro, compressed air, flywheels. All of these are developed and in practical use, although only a few compressed air and flywheel installations operate today. Flywheels are for very short-term storage (seconds, minutes), compressed air typically for diurnal storage, whereas pumped hydro embraces diurnal to seasonal, depending on the type of elevated reservoir available.

Electrochemical storage

Lead-acid batteries, alkaline batteries, high-temperature batteries. All of these are developed and in practical use, although at the present stage, only lead-acid batteries have found widespread acceptance for electric utility applications. Applications are typically for diurnal to at most a week or two worth of storage.

Fuel backup
Fossil fuels and biofuels, hydrogen. Fossil backup are in widespread use, while biofuel and hydrogen storage are at an experimental stage. Diurnal to seasonal storage is possible. Decentralized fuel cell technologies are expected to play an important role in future systems (Sørensen, 1983).

Thermal & other storage
Heat capacity (e.g. of rock material, aquifers or the fluid used in solar thermal electricity generators), phase change energy, superconductivity and photochemical energy storage. Experiments are performed with all these storage forms, which could be envisaged for diurnal to seasonal storage.

System dimensions and cost.

The levels of intermittent generation of power, e.g. from wind turbines or photovoltaic cells, that can be accepted in a supply system, strongly depends on the nature of the system and on the measures included to manage time variations in load. Typical percentages of wind or solar shares in systems without storage, and with a reference demand coverage of 100%, are 10% for small, isolated systems, about 25% for national systems with the option of regulating the rest of the production, and around 50% for large, international systems with reservoir-based hydro and time-zone variations of loads (Sørensen, 1981).

Short-term storage will ease regulation and possibly improve power quality, but only intermediate and long-term storage will allow large systems to have shares of variable renewable energy sources significantly exceed 50% (Jensen and Sørensen, 1984).

The cost is usually divided into a power- and an energy-related figure. The power-related cost (related to the speed at which the store can be filled or emptied) is lowest for lead-acid batteries (about 200 ECU/kW), and rising over advanced batteries, flywheels, pumped hydro, superconducting magnetic to compressed air storage (800 ECU/kW with possible price decreases as the technology is further developed). For the energy-related figure (i.e. capital cost for a store capable of holding a given amount of energy), pumped hydro leads at some 7 to 40 ECU/kWh, followed by compressed air at about 50 ECU/kWh, lead-acid batteries at 100-200 ECU/kWh (advanced batteries expected to halve these figures) to flywheels and superconducting storage at 300-800 ECU/kWh.

Roundtrip efficiencies are from 65-70% (lead-acid batteries, pumped hydro and compressed air) to 95% (superconducting storage) (Jensen and Sørensen, 1984).

Several of the storage facilities have important environmental problems, that needs to be taken care of.

End-use technologies

We have drawn on the technology descriptions made in the LTI project and the IPCC working group II. Some of these have been made by the Roskilde group (e.g. wave, tidal, CPH, biogas and transmission). Below is one example of a study made for the LTI project.

Possible Efficiency Advances in Households and the Service Sectors

Bernd Kuemmel

Electrical appliances are not always designed to minimise the consumption of energy. Designers and manufactorers often lack the awareness of the rather simple changes in design or technology that could increase efficiency at low or even no extra price at all.

Results of various work groups have shown drastic efficiency gains possible already with current materials and engineering practices. Advanced design practices would lead to higher efficiency. In many places this is a prerequisite for workable products. In order to reach lower physical dimensions of the installations miniturisation necessarily leads to lower power consumption.

Rather moderate investments in efficiency often result in large economic returns. The saved energy in many cases comes about at lower actual and social costs than having to provide surplus energy by traditional means. A striking example can be found in Geller (1991) where efficiency measures in Brazil have been shown to create a leverage of 40 in saved energy costs.

In a study by Bodlund etal. (1992) it is proven that there is no simple connection between efficiency and the retail price of several eletrical appliances (Figure 1, see Appendix). The opposite is often stated as a critical argument that more efficient appliances should be more expensive than the average ones.

By various design changes Guldbrandsen and Nørgård (1986) could produce a prototype of a refrigerator using only 44 % of the electricity that the best model on the Danish market did (Figure 2). Changes were made in the cabinet, mostly by using thicker insulation foam, a more efficient and properly sized compressor and increased heat capacities of condensors and evaporators.

Guldbrandsen and Nørgård (1986) claimed that the theoretical design limit of a 200 liter refrigerator was only 13 kWh/yr compared to the 185 kWh/yr of the best sold model on the Danish market in 1986; in other words such a refrigerator would only consume a fourteenth (1/14) of what the best model on the Danish market needed at that time.

The extra price for producing this very efficient refrigerator, due to thicker insulation, a more efficient compressor, higher cabinet and larger evaporators, would be only ECU 23.5 ($US 25) in 1986 prices. It would then only use 82 kWh/yr as compared to the best marketed in Denmark (185 kWh/yr) at that time. An extra ECU 4.7 (US$ 5) are due to the slightly higher space demand for the efficient model. The financial payback period for this appliance would be about 2.5 years. The extra energy of the production would be saved already after 9 months.

Efficiency tests and their results

A little description of the way the efficiency of fridges and freezers is determined in Denmark: The relevant appliance is situated in a test room with an air temperature of constant 25 degrees C. The refrigerator is fixed at an inner temperature of + 5 C, for a freezer - 18 C is chosen. The electricity consumption is then measured while the doors are kept closed during the experiment.

The data received during such an experiment are astonishingly real. That could be proved during a field test in which several households were using the best available efficiency instead of their average stock (Nørgård and Gydesen 1994).

In a report in 1989 Nørgård resumes former results showing how much efficience could be increased for larger typical household energy comsumers like washing machines, dish washing machines, clothes driers and ovens in households. He also pinpointed different cooking and washing habits as a further source of efficiency gains.

In general Nørgård etal. (1983) claim the uttermost theoretical limit for electrical intensity to be only a fiftieth (1/50!) of today's. As one example even flourescent light bulbs only convert about 15 % of the electrical energy into light (Nørgård 1986). They are of course more effective than incandescent bulbs, but technological advances are still possible.

The often stated criticism that it is necessary to use completely new technologies for reaching further efficiency gains is not valid according to Nørgård (1989). His results only take into consideration known technology.

Utilising the most efficient appliances on the market compared to the average stock makes it possible to reduce the electricity consumption of various services by a factor of 3.1. When electrical energy for low temperature heating purposes is substituted by other energy forms then the electricity consumption could be reduced by a factor of 4 (Nørgård etal. 1983).

In a field test in 1992 there were immediate savings of 47 % in the electricity consumption for the participating households (Nørgård and Gydesen 1994). They were achieved by exchanging the existing appliances with the best available on the market and only minor changes in personal behaviour.

Historical overview

The progress towards a stock of electrical appliances with low electricity consumption stems from the various energy and oil "crises" since 1973. This progress is slowed by the customers' lack of reliable information and their other prioritarisations.

Assuming progress continues undisturbed in the next years the efficiency gains of electrical appliances will lead to energy savings of 30 % in the year 2000 and 40 % in the year 2010. This will come about as a result of the normal substitution of old equipment and imposes no extra costs per se (Nørgård etal. 1983).

If the efficiency advancement is not speeded by legal or other measures then the marginal costs for cutting energy related emissions are negligible. But even under a more intense course this would only mean the equivalent of ECU (?) 40 $US per citizen and year, according to Schneider (1990).

Naturally the life span of appliances influences the speed of the substitution process. It can depend on choices made by the producer and is influenced by market reactions and consumer preferances. Shorter life times make more rapid efficiency gains possible for the overall stock, while longer life spans reduce the energy demand of the production process.

Only a life cycle analysis can describe the benefits and costs of both strategies (Sørensen and Nielsen, privat communication, 1995). During the time horison of this scenario the total stock will reach an efficiency that is the same as the one for the advanced efficiency technology today.

And using advanced efficiency appliances with heat substitution would mean that an average Danish Household only would have to use 490 kWh a year instead of the 2350 kWh that the energy services consume now. The best available technology on the market would still use 1030 kWh (Figure 3). These values are valid for 1988 (Nørgård and Gydesen, 1994).

Psychological Catches

In an investigation by the Danish consulting engineers' union (F.R.I. 1994) a description is given of the barriers that hinder energy efficiency in industry and service sectors:

Engineers are intuitive in their thinking and often do not use systematic methods to investigate alternatives. This is based in their *reluctance to accept knowledge and systematic procedures*. They tend to *overestimate their own experience*.

As a consequence of the stated engineers cannot break the barriers that make efficiency possible and they underestimate the savings potential of design changes and changed technology. Another important factor is the minor role that energy prices play in most businesses. Typically energy costs only make up 1 to 3 per cent of the total costs in Danish industry. This minimises the economical incentive for companies to investigate savings potentials (DEA, 1991).

When investigating the chances for further efficiency gains the following catch becomes important: some energy needs for certain services now are rather negligible compared to the total energy use. For example in normal houses in Denmark or Germany heating up fresh air is of minor importance now.

For a low energy house the amount necessary to heat up fresh air will be about the same as today. This is caused by health considerations that put a strain on the reduction of the air flow. The relative importance for heating the fresh air increases therefore (DMG 1992) in low energy houses. In other words the inhabitants' life styles will have a much higher influence on the distribution of the energy demand necessary for heating up fresh air than now.

Nørgård's (1991) argument supports this. From a vexed point of view it makes sense to move from a small flat to a large one when insulation, insolation and design specifications are comparable. Due to the larger specific surface area of the smaller house energy consumption in Watts per square metre is higher than for the large house. Even though the specific consumption then decreases the absolute demand for energy increases.

Efficiency vs Service Niveau

Efficiency gains by themselves do not necessarily lead to an absolute decrease in the energy consumption of an economy. The total consumption increases when the stock of new appliances grows faster than the realised saving's potential made by efficiency. Considering that efficiency gains have become valid practice in new design schemes new demands have to be created that by the technology and size themselves would lead to higher energy consumption.

But the trend is going away from large installations to smallers ones. This is connected to the intensifying global business cycles, too. The invention of the laptop and a possible docking to a stationary workplace as a replacement for the immobile PC is a good example for this. Here the miniturisation imposes technical changes that automatically lead to less power consumtion.

A critical point to be made is the introduction and penetration of the data- and telecommunication technology as a means to transfer business and private information. The leisure aspect of the information highway and the possible choice of a varitude of offers is not investigated properly yet. High definition TV (HDTV) is another area where massive market penetration will have huge consequences for the electrical energy demand in the future. In that area profound efficiency gains are possible (Sørensen 1991) (figure 4).

HDTV, independent of whether an analogue or digital approach is chosen, has the potential to thwart any approach to a low electrical energy intensity economy. It is to be hoped that the introduction of liquid crystal diodes (LCD) screens has the potential to reduce energy demand by this new technology despite the inherent necessary increase from the larger screen size.

One of the advancements in this area have just been realised at the Heinrich-Hertz-Institut in Berlin, where a phenomenon known as electroluminescence is exploited. The problem with this process, the lack of blue elements, has been solved which opens the possibility to create larger screens that might be valuable not only for HDTV (SZ 1995d).

Also virtual reality applications could lead to an absolute increase in energy demand when wide spread distribution will be reached without the necessary efficiency precautions. Here the same as for HDTV applies. Even though new technologies could minimise the risks of a rise of the absolute energy demand in the information sector.

Normal memory elements like the ones that keep the working program in a PC are dynamical which means that the information has to be refreshed regularly. Switching off the power means that the data and the program are lost. Therefore a computer has to read in the programs from the hard disk at new start. This needs energy.

One of the new techniques that can reduce the electricity consumption of computers in the startup phase are ferroelectric memory elements that keep the information also when the machine is not connected to the net (SZ 1995e). Therefore shutting down the computer will not necessitate a reloading of the program. Ferroelectric memory elements also could minimise the use of the hard disk and its energy demand.

Technical Options for Efficiency Gains

The following list is an investigation of the efficiency potential in three sectors: households, commercial service and private service sectors. The efficiency of the following technologies could be increased by the mentioned techniques:

Airconditioning:

pumps, vents, in- and outlets, ducts, design of airflow by modelling (BLAST, DOE2, etc; Feustel etal. 1994), natural ventilation, utilisation of large building masses

Space heating:

insulating windows, passive solar heat use, solar walls (aerogel), better insulation (walls, windows, roofs, floors, doors), utilisation of large building masses

Space heating systems:

variable speed pumps, utilisation of gravity/convenction, pipedesign, tensides for less friction, day-night cycling, thermostate ventiles, seperation from hot water preperation when possible, personal behaviour, better demand steering, water instead of steam based DH

Space Cooling:

better insulation (walls, windows, roofs, floors, doors), vegetational cooling (ivy,vine; ambients; shading), architectural shading, low-e glazing, natural ventilation, utilisation of large building masses, earth cooling tubes, District Cooling

Space Cooling systems:

variable pumps, pipedesign, tensides for less friction, day-night cycling, personal behaviour, district cooling instead of individual units, natural ventilation, utilisation of large building masses, better demand steering

Warm water (15-65 C):

solar heaters, individual meeters, water saving installations, personal behaviour, point of use heating instead of storage tanks

Hot water (65-100 C):

solar heaters, electric keddels instead of stoves, insulation, point of use heating instead of storage tanks

Cold water:

individual meeters, water saving installations, personal behaviour

Cooling water:

absorption techniques, District Cooling

Lighting:

CFL bulbs instead of incandescent, electronic ballasts, day-night cycling, sensor steering, better use of daylight, smart (holographic, Figure 5) windows, better lamp shades, personal behaviour

PC and other office equipment:

ventilators, LCD-screens, low voltage PV power sources, integration of elctronic parts, standby cycling ("Siesta, Suenho, Coma"), ferroelectric memory elements

Laser printers, copy- and faxmachines:

low temperature tonerdrum, improved standbycycling, substitution with inkjet printers

Coffeemachines:

thermocans instead of glasscans, automatic dekalking

Electronics:

miniturisation, better standbycycling

Washing mashines:

seperete warm water inlet, low temperature tensides, higher spinning rates, water level sensors, jet system, ultrosonic methods, heat insulation

Dishwashers:

warm water inlet, low temperature tensides, water level sensors, ultrosonic methods, heat insulation

Motorised movements:

motors, friction losses, design, adjustable speed drives, low magnetic metals

Flyweels:

reduced friction bearings (magnetic bearings, high pressure bearings)

Batteries:

PV-cell loading, 2nd generation LiFe

Fuel Cells:

Different technologies, filters for synthetic gases to keep out impurities

Space Heating:

Considering that the use of electricity for low temperature heat is thermodynamically unsound (Gyftopopoulos, 1990), its substitution with other heat sources is essential.

Households

Demand Analysis

Households have certain needs to fulfil to be able to function as recreative units and to regenerate the members for various works that are done outside the household. Some basic assumptions are made on the necessary services that shall be provided in the member states:

Physical surroundings,
Food preperation,
Personel hygiene,
Social intercourse and
Leisure activities.

An overview of the typical demands that fulfil these services has been given in Nørgård 1991, where the following table originates from:

Lighting: 1000 lm, corresponding to 6 incandescent lamps of each 60 W burning 6 hours a day.
Refrigeration: 200 litre refrigerator volume at 5 C and 100 litre freezing unit (,18 C)
Washing: 200 laundry washings per year, each 4 kg dry laundry, in an automatic electric washing machine and a non-electric heat source
Electronics: TV, HiFi, Radio, PC and other minor use of electronics at the same level as today.
Ventilation: Fresh air demand in heigh rise buildings and different forms of space cooling
Other uses: High efficiency electric equipment provided that they do not rely on electric heating elements

As Nørgård and collaborators have been concentrating on the electricity consumption this table does not contain the demand for hot water or space heating. At such low temperatures the demand should not be provided by electricity as this normally would be thermodynamically unsound.

Efficiency Potentials

For the most energy demanding activities of households the following explains some of the potentials for energy efficiency more in detail.

Physical Surroundings

A major part of the energy consumption of households today is used to provide the proper physical surroundings for the inhabitants, ie heating and cooling of the space humans stay in. This factor is very much dependent on the ways buildings are built, the climate of the location and the cultural differences in peoples' needs.

To change the energy demands of buildings takes a long time as the building stock is very longlasting. Klose (1992) cites the German Globus of 1987 with the following age distribution of flats:

Tabel 50 Age Distribution of German building stock in 1987

built in year	Part in %
.. - 1900	10
1901 - 1918	8
1919 - 1948	12
1949 - 1957	15
1958 - 1968	24
1969 - 1978	20
1979 and later	11

Normally houses are expected to last for about 100 years at least this is the normal design period of buildings accepted in the public, only in specific areas the depreciation times are shorter. In the City of London architects now are forced to design structures to last for 30 or even only 20 years, as the investment periods have become so short.

In Germany 36 % of the total primary energy consumption in buildings is due to the heating of buildings and stands for more than 70 % of the residential energy demand (IEA 1991 and DMG 1993). This is equivalent to about 30 % of the German CO_2 emissions.

The reduction of the heat demand of buildings and dwellings is, thus, an important factor of the energy demand reductions that can be reached. The long life time of buildings and the low turnover 1-3 % (IEA 1991) of the building stock could make it difficult to reach ambitious reduction targets.

Nevertheless in Denmark the reduction of the space heating demand has been a vital part of the construction regulations since 1975, when the first building regulation (DBS 1975) came into power. Since then there has been a constant process of improvements with announcements of new stricter rules every three years or so.

The efforts made in Denmark have shown results. DH now covers more than half of all Danish households. Residential primary energy consumption in Denmark fell due to the stricter building regulations and the extension of the DH system after 1973 (DEA 1993) by 45 per cent.

In Germany the saving potential for room heating can be set to 70-90 % (Spangenberg 1994). The upper value of 90 % may be achieved for existing houses built under less strict building regulations whereas the value of 80 % seems reasonable for newer buildings. A European value could be about the same. Climatical differences play some role but also the price of energy for space heating.

The energy demand of new low-energy buildings gets decreased to typically 40 kWh/yr/m2 by the use of new building conducts that have legal status (DMG 1992). This is equivalent to the so called "Scandinavian standard" which has been accomplished in that countries long ago. In Germany a new regulation will reduce the heat demand of new buildings by 30 % compared to the older regulations (DMG 1993).

In part the new regulations also have influence on the retrofitting of existing older houses. In the former GDR, the five new länder (Neufünfland), in Eastern Germany many residential complexes were built as so called "plate-buildings". Such houses normally were very ineffecient regarding the heating demand. Values of 200 till 400 kWh per square metre were common.

An example of the retrofitting capacity is given in SZ (1995b) where the energy balance has been improved by over 60 per cent, so that the energy demand per square metre now is only 50 till 80 kWh. This was reached by massive insulation of the walls with up to 32 centimetres of Styropor and Rockwool together with energy protective glacing. The resultant costs were ECU (?) (DEM 1600) per square metre.

Zero Energy Houses

Even in places like Germany the *Zero-Energy House* is feasible. Such buildings could be constructed with existing technologies costing about 3500 DEM/m² (1400 ECU/m²) (SZ, 1995a). Literally the expression Zero-Energy House does in fact not mean that such houses do not need any energy from exteriour sources whatsoever, but that heating energy exclusively is provided by spill heat or passive heat gains. New buildings can be easily constructed in that way by better insulation, while the improvement of existing buildings might take some time.

Klose (1992) mentions extra costs of 34 ECU (80 DEM) per square metre for low energy houses. Because of mass production lower values should be expected. The extra price for such houses will generally lie in the range of between 2.2 and 4 per cent.

The energy demand for space heating depends on the socalled degree days, the definition of which varies from country to country. This list illustrates the average annual number of degree days and the basis temperature to define it:

Tabel 51. Country based degree days

Country	no. degree days	basis (degree C)	source
Spain	1000	15.0	B&S (1987)
Eire	2400	15.5	B&S (1987)

Building Materials, Health Effects and Efficiency Gains

Regarding the environmental and health effects of abundant insulation and reduced air flow in buildings there has been such an investigation under the EXTERNE programme. A report by Hohmeyer etal. can be expected in due time. It will also shed light on the external costs of energy effectivisation in the building sector.

The shell tightness of buildings should be sufficient. At a pressure difference to the outside of 50 Pa the inside air should be exchanged not more than three times. Higher exchange rates will render insulation measurements mostly worthless (Klose 1992).

A Life cycle analysis that takes into consideration energy consumption, the use of raw materials and investment capital has to be performed for the materials, that get used in the building sector, is another important factor. Wood from tropical rain forrests or PVC might be examples of materials that not necessarily perform well in that respect.

When the building shells are made more impermeable and drought is reduced this minimises the air exchange of the inside air. Under this circumstances the outgassing of solvents poses a larger problem to air quality. The choice of the materials that are being used in the building sector and their outgasing qualitities will become much more critical in the future.

The reduced air quality as a result of increased rigity of the building shell can to a certain degree be overcome by active ventilation. In this technology heat exchangers to recover the heat from the exhaust fumes to warm the incoming air are indispensible. The increased inroom comfort comes by without straining the energy consumtion of the space heating system.

A recent innovation by the Forschungszentrum Karlsruhe is a heat exchanger of a size of only one ccm the capacity of which is sufficient to transfer the heating demand of one house (SZ 1995).

Heat Pumps

There have been a variety of space heating systems in use in the different European Union member states. Generally central heating in Europe is based on water to carry the heat energy to the radiators. But air based HVAC systems are becoming more important. When electrical energy used for space heating purposes its substitution with other heat sources is beneficial.

An alternative to electric heating systems are for example heat pumps (HP). They can provide low quality space heat more economical than normal electrical heating systems. In Sweden more than 100,000 are installed and working (Berntsson 1989), mostly as a substitute for liquified heating systems in single family dwellings (SFD) or on the basis of a liquified central heating in either multi family dwellings (MFD) or in larger dwelling complexes.

In Austria and Switzerland HPs have a significant market share. In Switzerland the use of electric panels has been forbidden as the primary heat source and so in 1991 every fourth new built house was equipped with a HP. In the same year in Austria more than 21,000 HPs were installed for room heating purposes (EBB 1994).

While it is not sound to use fossil fuel produced electricity in space heating directly, it may make sense to use hydroelectric power in electrical HPs for heating purposes. As long as this does not block for more efficient electricity use in other places, such an approach will minimise the electricity consumption for space heating.

As the seasonal performance factor (SPF) has to be reasonably low to admit the use of HPs from an economical point of view (Berntsson 1989) this excludes the use of HPs for more than base load. When outside air temperatures approach the water freezing point HPs cannot work properly any longer. The absorbant, water, will then freeze.

A way to overcome this is to tap ground water, or heat stored in the earth of the ground itself or even from stone bases from higher depths. Thereby the input medium will be of a higher temperature for most of Europe, as generally both the ground and the ground water adopt the mean climatic air temperature.

Considering the discussion of the ozondescructivity of freons Laue (1992) indicated that in compressor HPs R22 can be substituted leading to a consequent energy saving with R152a or the following mixtures R32/R134a or R32/R152a. Pure R134a and R32 instead would lead to an energetical disadvantage.

Solar Heating

Solar heating systems are widespread in Greece (B&S 1987) but otherwise do not provide much to the space heating in Europe. There have been some demonstration projects in various places in the European Union but generally the market share of this energy form has been little. Lately marketing campaigns have been started to increase the acceptance of solar heating systems (Herrmann 1993).

Space Cooling Demand rising

While the demand for space heating has received considerable attention in the last years this has not been the case for space cooling. Air conditioning of residential buildings is illegal in Denmark and the demand has so far been minimal in Central Europe and Scandinavia. Should the trend to extreme warm summers continue in the future the space cooling demand can be expected to rise in that area.

Apart from architectural design as in important factor when considering the demand for space cooling there are also some technical approaches that are being investigated. Smart windows that filter out part of the spectrum could be used to direct heat radiation into a building in winter and prevent this in summer. An investigation of whether such a technology was economical is not available.

Lighting

In most places in the residential area lighting is still provided by incandescent lamps. The substitution with compact fluorescent lamps can reduce the intensity for lighting down to a fifth (1/5). This values is assumed to be possible by advanced efficiency by Nørgård and Viegand (1994) for every form for lighting whereas they only consider the lowest averaged intensity to be a third (1/3).

A very important point when considering lighting is the use of more efficient lamps, ie shades and reflectors that increase the actual amount of light emitted by the light source. There are fittings on the market that only emit 20 % of the light produced by the bulb. Out of such a construct only about 1 % (20 % of 5 %) of the electrical energy will come out as light energy.

The substitution of magnetic with electronic ballasts increases efficiency by almost 10 % (Mills and Piette, 1994).

Daylighting

Ways to increase the amount of daylight for lighting purposes are described in Granqvist (1989). A promising approach, apart from the obvious architectural changes, is the use of holographic windows that so to speak change the sun light's path to lead more of it into an area that is far away from the window.

Food Preparation

The preparation of food needs energy and raw materials. Low (<100 C) and high (>100 C) temperature process heat is needed for cooking, frying and baking. It currently is provided via electricity, gas, biomass or coal. Water is a basic ingredient as a mediator of heat, or to clean the used appliances or prepare the foodstock.

In Europe pots and pans on stoves are often needed in the cooking and frying process but in the Pacific regions pots are used with an integrated electric heating element attached to the pot or pan that can easily be removed for the cleansing process.

A way to speeden up the boiling process is to use pressurised cookers by shorten the cooking time and, thus, the energy demand. This pots, however, require some skillfulness to be operated appropriately. By their construction they prevent the user from keeping eyecontact with the processed food, which might defer some people from using them. There are also still rumors of these cookers exploding. Some of the first models indeed did not contain propper security elements as ventiles to release overpressure to avoid structural damage.

According to Nørgård and Viegand (1994) the best technology in electrical cookers now only uses 57 % of the average stock while 40 % is conceivable by advanced efficiency.

Another possibility that has been proposed are micro wave ovens that reduce the heat demand for cooking and baking in two ways: first no extra water has to be heated as normally is the case when cooking in pots, second not even the pot has to be heated as the microwaves only heat up fabric containing water molecules, ie the food itself.

Baking and grilling processes need high temperature heat. Nørgård and Pedersen (1988) have proposed the combination of a smaller and a larger oven to minimise losses from heating up superfluous space as is the case with today's ovens. The larger cavity only needs to be warmed when large portions are prepared.

With a combination of a large and small oven reductions of 50 % of the energy demand should be accessible (CCE 1986). Fast reacting temperature controllers will also be a necessary means in that respect.

Combinations of microwave ovens with normal ovens or ventilation ovens increase the variability of food preperation in the kitchen and might be another way to reduce energy demand.

Apart from producing it, keeping food fresh needs energy, too. The penetration of refrigerators, combined with freezers or in combination with seperate freezing units keeps food fresh by cooling it to a temperature that minimises the destruction by bacterial activity.

The size of refrigerators is decisive for the electricity consumption in the same way as the insulation and the efficiency of the motors, compressors and absorbers that perform the actual cooling process.

In Nørgård and Viegand (1994) it is assumed that the energy intensity of refrigerators can be reduced to 64 % by using the best technology on the market today. Advanced efficiency will mean a reduction to 30 % from today's values. This is still far from the theoretical technical optimum (Guldbrandsen and Nørgård 1986).

Energy is also needed for the washing up of dishes. Apparently not much progress has yet been made in the development of detergents that work at lower temperatures so hot water is still used for this process. Ultrasonic methods can be used, unless, when humans get influenced negatively, of course.

There are possibilities to change the water inlet to provide for a seperate warm water source. Washing the dishes by hand can be energy wasting when it is done under running water, otherwise machine wash uses more energy than hand wash.

Personnel hygiene

Water and detergents are the main ingredient of the culture of personal hygiene prevalent in Europe. Warm water makes up 15-20 % of the heat budget of a typical family. It is provided by using electrical or chemical energy in boilers or by exchange from a district net. A minority of places solar water warmers are used. They are very common in Southern Europe, especially in Greece, and have gotten more spread in other parts of Europe in the beginning of the 1980s but have lost momentum in the 1990s.

Water is also used to lead the resumes of the digestion process through the sewers to the cleansing utilities. The amount of water used for this purpose can be diminshed by new water toilets and new designs of the canalisation. A typical reduction would be in the area of 30 % compared to the installed standards.

The reduced water needs in more efficient armatures mean also reduced heat loss from warming of spill water when it stays inside the cisterns or pipes. This reduces the basic heat demand of buildings. A value of about 1 % of today's values might be conceivable. This values of course rises in low energy houses where heat loss due to waste water becomes important.

Part of personel hygiene is to have access to fresh washed clothes. This can be a very energy consuming process and there has been progress in the manufacturing of washing and drying machines that are more energy efficient. The best new washing machines now use 40 % less energy than the average installed models (Nørgård and Viegand 1994).

Advanced efficiency will reduce the consumption to only 30 %. The investigated methods include ultrasonic vibrations to shake off adherent dust. Seperate warm water inlets are easier to provide.

The warm water demands for other washing and cleansing processes that are of personel interest: teeth, face, body, etc depend to a high degree on differences personal habits and preferences.

Education is a necessary and efficient way to reduce this extra consumption. Educational programmes have been started in several countries to increase awareness of this problem.

Cultural and leisure activities

The amount of electrical energy that gets used for this aspect has used to be of minor importance. This might change when efficiency leads to changes of this patterns. Leisure activities are taking place mostly outside the households and so has to be described in the analysis of the efficiency gains that are possible in the service sector.

The advent of leisure electronics like the use of PCs and consoles for various forms of games has the potential to influence the total energy consumption in a growth direction far from the efficiency gains that have been made in the other areas.

But new technologies like the LCD based computer and TV screens can amend this trend. Sørensen (1991) has described this for the service sector but his considerations are valid for the households as well.

Economies of Efficiency Measures in Households

Definitions

The following expressions are used later on and are defined here:

- AVG, average technology on the market
- AST, average stock efficiency
- BAT, best available technology on the market
- EAT, and advanced efficiency technology is either marketable soon or on the way to leave the drawing boards.

Efficiency cheaper than produced Electricity

It is often claimed that the saving of electrical energy were not cost competitive to the produced power. Data by Nørgård (1989), Nørgård and Viegand (1983), IWU (1989) and some other sources reveal that in several instances saving electricity is cheaper than the price of providing more of it.

The first row in Tabel 52 indicates whether the price of electricity or heat or the price of saving a kWh of electricity is considered. The next row indicates the price of the unit while the third row describes the technology or appliance investigated. The potential given in the fourth row indicates the savings of the best model compared to the average sold model for Nørgård's data. For IWU's data this row containes the difference between the average stock and the best model on the market. The last row has only statistical interest:

Tabel 52. Costs of saving one kWh with existing and expected technologies.

Unit considered	Cost of a saved kWh	Investigated technology	savings potential in kW/yr	Investigator	Total Cost-potential
el	30			Nørgård 1989	
heat	15			Nørgård 1989	
saved el	16	LER 200	180	Nørgård 1989	2880
saved el	33	EAT fridge	220	Nørgård 1989	7260
saved el	13	BAT freezer	220	Nørgård 1989	2860
saved el	45	EAT freezer	300	Nørgård 1989	13500
saved el	15	BAT comb F/R	250	Nørgård 1989	3750
saved el	39	EAT comb R/F	600	Nørgård 1989	23400
saved el	0	BAT wash mach	60	Nørgård 1989	0
saved el	33	EAT wash mach	200	Nørgård 1989	6600
saved el	16	BAT dish w	50	Nørgård 1989	800
saved el	26	EAT dish w/ seperate heat	195	Nørgård 1989	5070
saved el	0	BAT tumbledry	90	Nørgård 1989	0
saved el	33	EAT tumbledry w/ HP	260	Nørgård 1989	8580
saved el	44	EAT tumbledry/heat Xchange	340	Nørgård 1989	14960

saved el	19	BAT heat distrib (20Wpump)	200	Nørgård 1989	3800
saved el	30	EAT heat distrib	250	Nørgård 1989	7500
saved el	0	BAT ventilation	125	Nørgård 1989	0
saved el	24	EAT ventilation	325	Nørgård 1989	7800
saved el	0	AST>BAT Dishw	63	IWU 1989	0
saved el	0	AST>BAT wash m	54	IWU 1989	0
saved el	31	AST>BAT Tumble-dry	32	IWU 1989	992
saved el	41	AST>BAT Fridge	49	IWU 1989	2009
saved el	0	AST>BAT comb R/F	68	IWU 1989	0
saved el	24	AST>BAT Freezer	134	IWU 1989	3216
saved el	27	av. cost of saved kWh	4265	BEK,others	114977
saved el	10	AST>BAT		N&V 1994	
saved el	40	BAT>EAT		N&V 1994	
saved el	4	BAT market (ex light)	1100	Nørgård 1989	
saved el	19	EAT (ex light)	700	Nørgård 1989	
saved el	10	BAT+EAT	1800	BEK, Nørgård 1989	

(The line for the LER 200 would read: one LER 200 saves 180 kWh yearly compared to the average model on the Danish market at a cost of 16 mECU per saved kWh. The yearly savings potential of this appliance would be 2880 mECU.)
For Nørgård (1989) saved el means at costs relative to AVG on the market.
For IWU (1989) saved el is relative to stock efficiency, AST.
N&V = Nørgård and Viegand 1994
The costs of saved energy take into consideration a discount rate of 5-7 per cent.
In IWU 1989 the savings potential is not a result from comparing the best technology with the market average but with the average stock!

On average a saved kWh costs 27 mECU which is less than the typical production price for a kWh! This value only considers the residential sector and do not take care of the use and penetration of the different appliances. This simple calculation would assume that penetration was 100 % which is not the case. A value of 10 mECU is given in Nørgård (1989) for substituting the existing Danish stock with the best available technology on the Danish market, while it would cost 40 mECU to apply advanced efficient technology.

These average costs do not include lighting. The substitution of the average stock with BAT will in every sector contribute with a negative cost. This reduces the total average cost of saving a kWh, but it might lead the public to accept more efficient technologies only at negative costs. On the other hand, even though lighting effiicicency is highly cost efficient, its potential has by far been exploited in the last years.

Cost Savings Relationships

A comparison of the cost efficiency of different efficiency measures of typical household appliances is given in Figure 21. The societal price of a saved kilowatthour that arises from eventual extra costs in the production process is compared to the purchase price that typical

Danish consumers pay. Both prices are exclusive of the value added tax (VAT) but the electricity price contains various energy and environmental fees and taxes that may give an idea of the lower value of the externality of fossil fuel generated power. Whenever changes in technology make a saved kilowatthour cheaper than a generated one, society as a whole is saving financial capital that can be used for other purposes.

It can be seen that using the best efficient technologies instead of the average sold ones on the market, or even choosing more advanced technologies, is highly cost effective, if the substitution rate follows the per se substitution of old and worn out technology. This figure will not change much if the social production costs calculated for this figure are increased by the mechants margins. The unconditional profitability is, however, not necessarily the case for substitutions taken place before the end of the appliances' technical life times, as then the capital costs become prohibitively high.

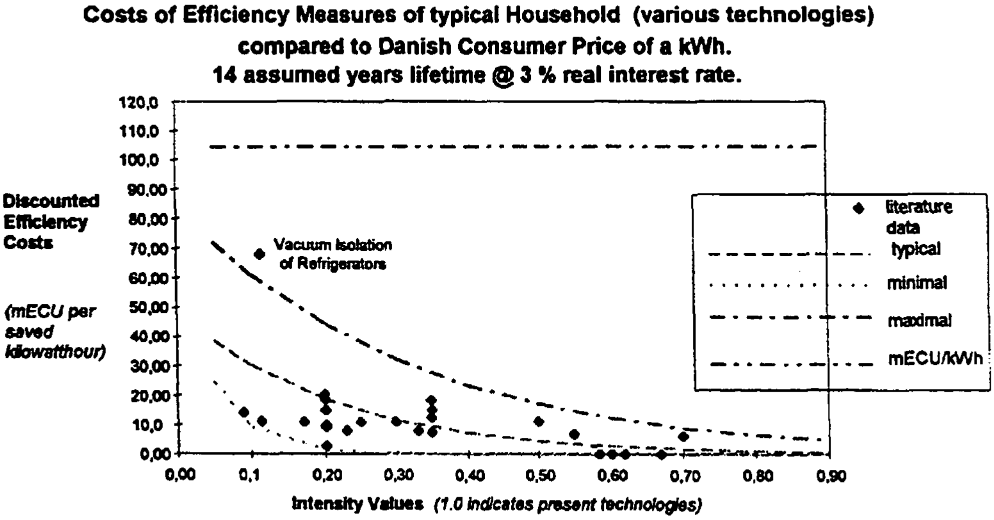


Figure 21: Cost Efficiency Response Curve of different technologies. A real interest rate of 3 per cent is assumed and an average life time of 14 years for electrical appliances used in households and service sectors. Compared to the Danish Consumer Prices (reduced for VAT) all efficiency measures pay off, even the mostly expensive vacuum insulation of refrigerators.

Using Nørgård's (1989) values of the cost of a kWh to be 30 mECU on average all of the substitutions were economical. This mixed assumption does not necessarily apply in reality. Especially it does not take into consideration that costs of choosing more efficient technology that are higher than the price of the saved electricity in practice only will be realised if they are legally imposed. Thereby for parts of the substitution the political considerations may outweigh the mixed economical benefits. On the other hand legislation will lead to a selective pressure in the businesses to find cost effective solutions to minimise eventual losses.

In terms of payback time, when choosing BAT instead of AVG, most of these appliances lie in the range of 1 till 3 years. After the payback time there are no further costs for the owner of an appliance and the energy savings are realised fully. The payback time of replacements is longer when they are made not due to necessity like the breakdown of old appliance, moving to a new flat, etc (Sørensen 1991).

Service Sectors Savings potential

Nørgård and Viegand (1994) have considered the savings potential for all the sectors of interest in this study. Dividing into the various forms of energy use the potentials are as follows, the plain values apply to Denmark with intervals given for a group of European countries:

Tabel 53: Electricity savings potential

	Intensity values in %, 100=AVG 1986			
	BAT DK	EAT DK	BAT EU	EAT EU
pumping	57	44	76-49	51-40
ventilation	58	41	65-30	48-15
refrigeration	64	30	65-63	30-29
motors	81	66	90-56	71-40
lighting	61	33	90-62	50-30
electronic	65	20	100-50	20
space cooling	50	25	50	25
lo heat	58	28	60-50	30-20
hi heat	83	72	90-55	80-40
misc	81	65	90-75	75-60

Private and Public Service Sector

Definition

We define here the private service sector as a provider of all such services that are feasible for private companies to provide, either by already being provided by private suppliers or possible by privatisation. In that respect for Europe only public administration, public health care, the execution of passed law, jurisdiction, and defence are actually supposed to be public sector jobs.

In this context also the following jobs shall be considered private: restauration, leisure and sports activities, electronic leisure providers, etc. But we have to admit that in some areas public service providers are being created in areas that originally belong to the private sector of the economy. Subsidised dancing schools are such an example.

In light of the many compalling aspects of private and public service we here only treat the public service sector in length as this one has been the one most investigated in Europe.

Public Sector Savings Potentials

A Danish study performed by Pedersen etal (1988) investigated the savings potential in the public sector. It can be seen that the efficiency gains are about the same in several areas independent of the investigated sector. This of course is due to the used technologies that do not differ a lot. So for the same sectors the intensity matrix looks like this:

Tabel 54: Service Sector Efficiency Gains in different Technologies compared to todays Average Electricity Demand

Technology	BAT	EAT
lighting	49%	37%
ventilation	54%	39%
pumping	49%	40%
div. heating	76%	58%
electronics	70%	38%
cooling	60%	29%
div electricity	84%	74%
other motors	87%	71%

Apparently the highest reduction potential is in the educational sector. Altogether electricity consumption could be reduced by 43 per cent if the existing technology was substituted with the best on the market. Waiting for advanced efficiency would increase the savings potential to 57 per cent. While these values are lower than Nørgård's it shall not be forgotten that the public service sector typically has a different consumption pattern than households have. For Denmark data can be found that describe the distribution of the electricity demand in the various sub groups of the public service sector. Unless specific data is found for other countries this relativ savings potential can be a reasonable first guess for the rest of Europe.

Tabel 55 Annual Electricity Consumption and Savings Potential in Denmark

			Consumption GWh/yr	Intensity (1988=100)		
	AVG	BAT	EAT		BAT	EAT
tot.pub.sector	3317	1875	1418	PVN 1988	57%	43%
school/inst.	660	288	195	PVN 1988	44%	30%
Homes/hosp.	560	383	268	PVN 1988	68%	48%
adm/div	1218	701	535	PVN 1988	58%	44%
utilities	879	503	420	PVN 1988	57%	48%

The Use of Standards

Despite the fact that there are very effient appliances on the market the efficiency often byuers do not take this parameter into consideration. Therefore the penetration of the stock with high efficient appliances takes a longer time than when eg standards were set to ensure a more rapid penetration.

In Europe there have been such plans. In a paper from the Nordic Coucil (1992) a description is given of a Dutch plan that would have reduced the number of certain appliances that could be marketed to a third. There have also been equivalent plans in the Nordic countries.

The Danish engineer union (F.R.I. 1994) claimed that the lack of standards made the choice of energy efficient technology difficult, as the time schedule for business investments often is very tight and therefore energy efficiency cannot be taken care of. Nevertheless increased awareness of energy consumption will speeden up the efficiency gains in the future.

Electricity Savings with New Technology

The development of new technologies make it possible to reduce the electrical energy demand of the public and private service sector even further. A few are listed below but such a list will never be exhaustive:

- Reduced pumping demand in waste water handling due to local infiltration of rain water instead of leading it into sewage systems
- Drinking water desalinisation by wind power (SZ 1995c) or solar powered techniques
- Solar powered parking lot dispensers, solar powered intelligent timetable lighting (SZ 1995d)
- LED based trafic lights (SZ 1995e)

Figure 22. *Lack of Correlation between Price and Energy Consumption for Refrigerators and Freezers in Sweden (Bodlund et al., 1989).* Bodlund's analysis is also valid for other countries in Europe. Please remark the "wrong" correlation of electricity consumption and price for freezers and combined F/R. The more you pay for the more every litre would cost you in electricity.

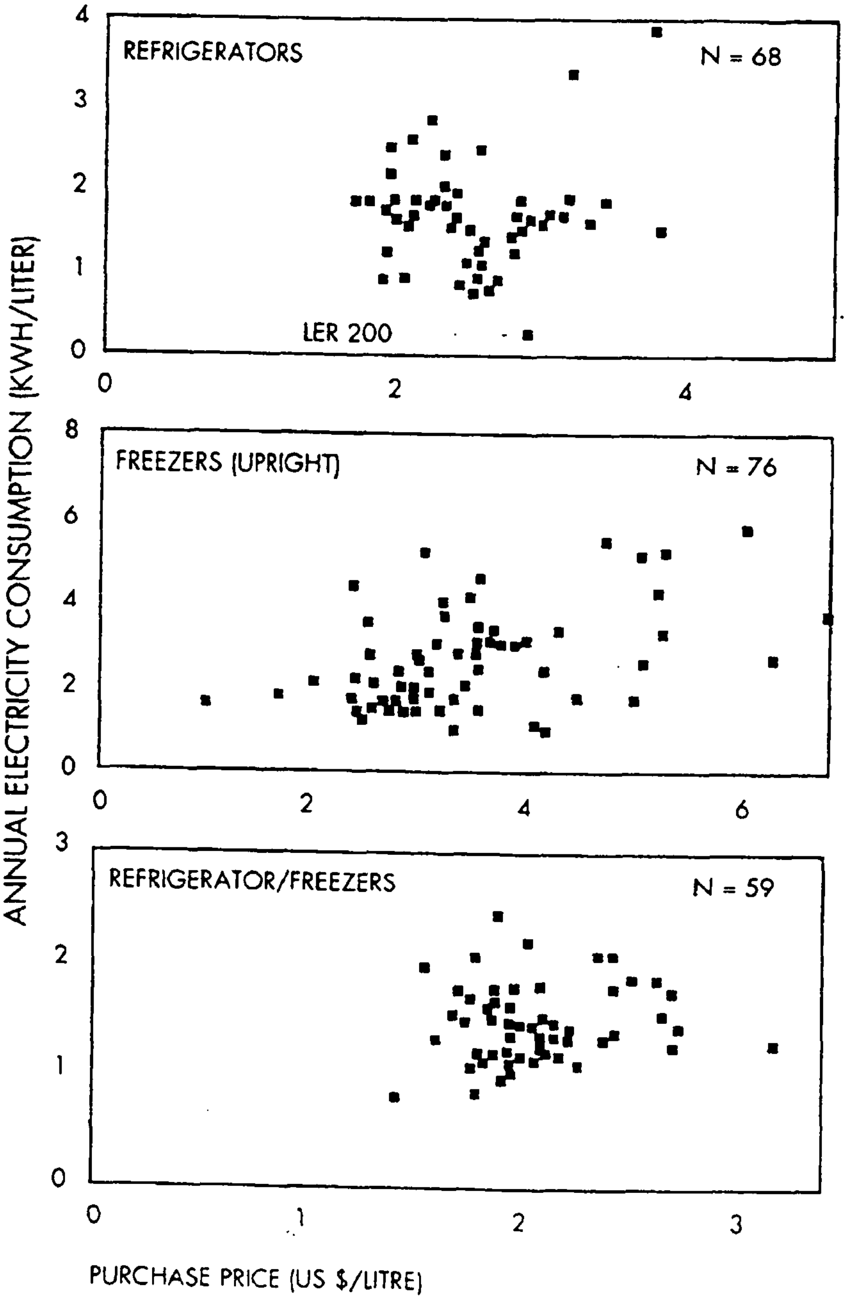


Figure 23. Nørgård's Prototype refrigerator from 1986 was overhaled by reality when a producer marketed the same design in 1988 (In the figure marked as "Best Available 1988". So fast can producers, thus, change design and approach efficiency targets (Nørgård, 1989).

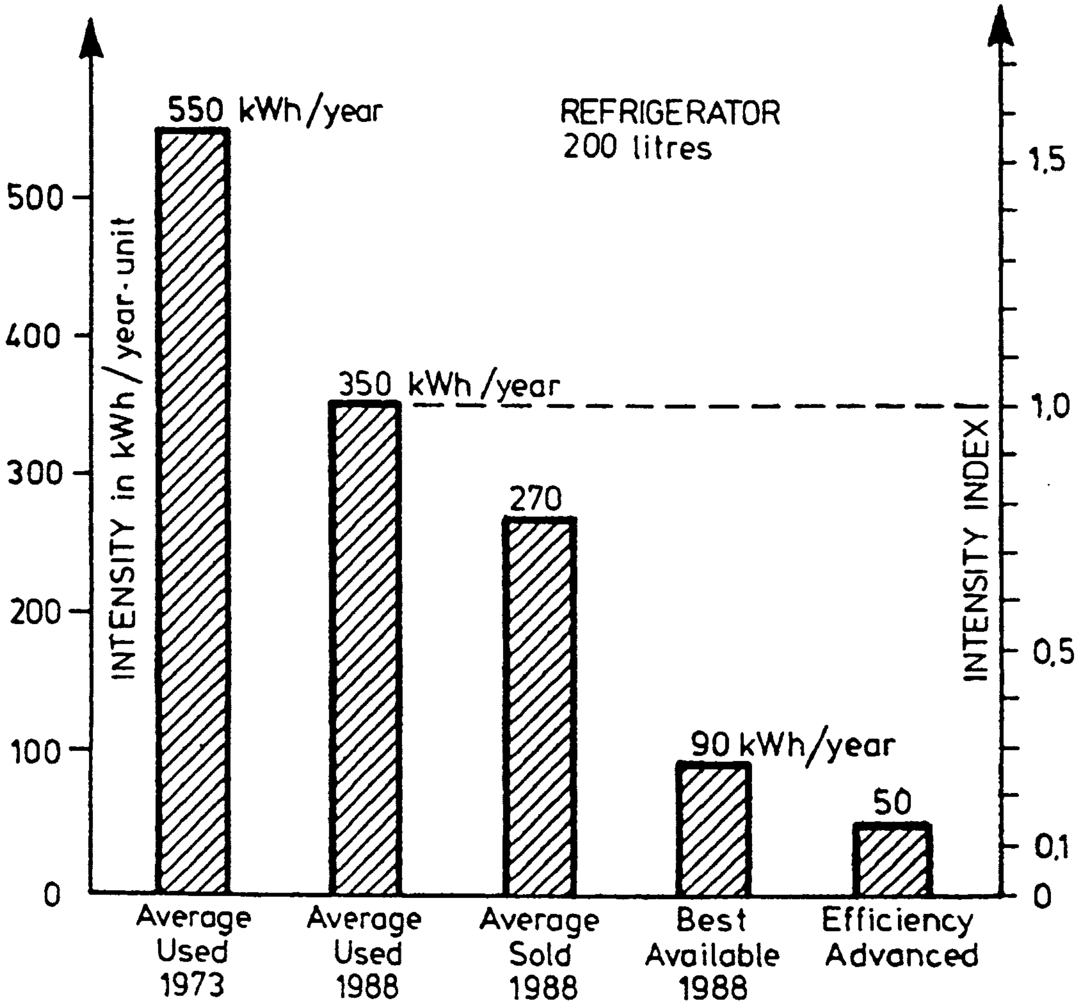


Figure 24. Substituting the average stock with more efficient appliances can reduce electricity consumption by more than a half. Advanced efficiency with heat substitution would reduce the demand to less than a fourth of today's (based on Nørgård, 1989).

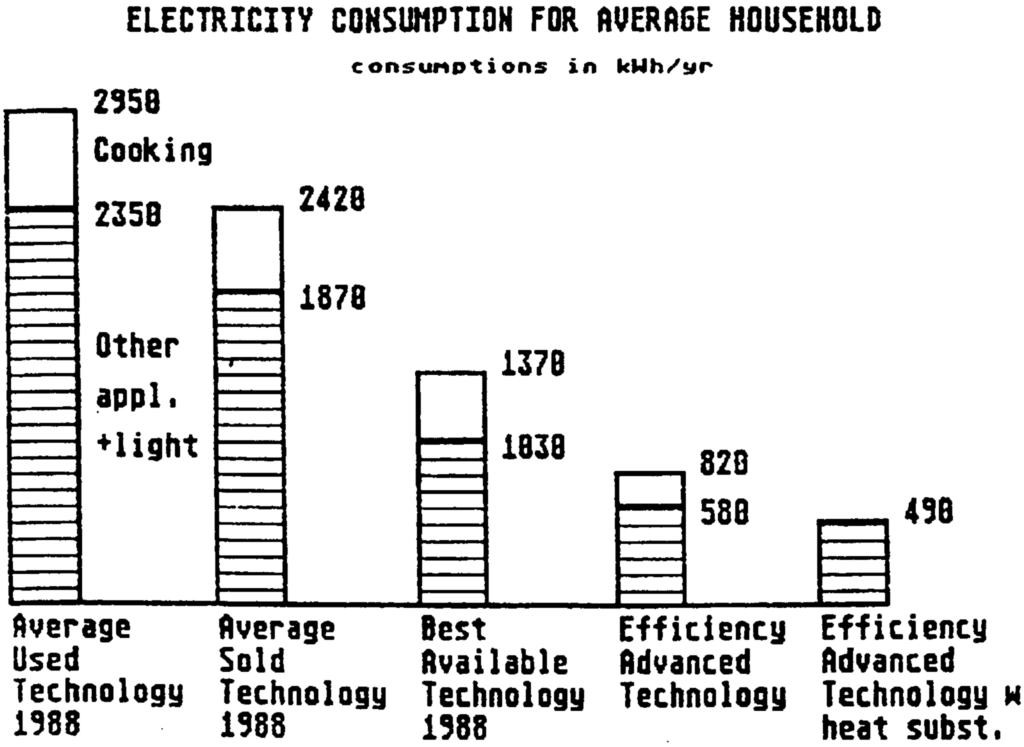


Figure 25. For information technology chosing the most efficient design does enable one to save three quarters of the electricity consumption. And you do not even have to wait for advanced efficiency technology (the 1988 and 1995 numbers refer to USA and assume a 25% increase in office staff. "Saturation" is taken to mean 0.87 computers per office worker, and "new office" includes peripherals such as scanners, CD-ROMs and printers. The "best efficiency" column refers to the best available technology in 1991 (Norford et al., 1989; Sørensen, 1992).

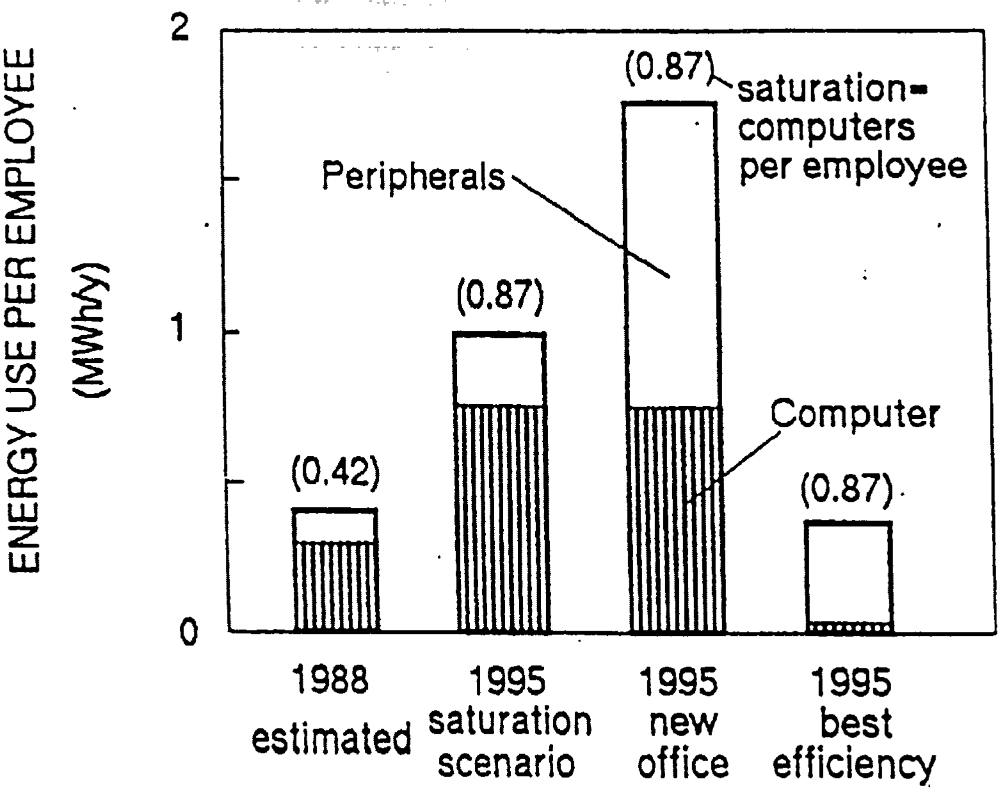
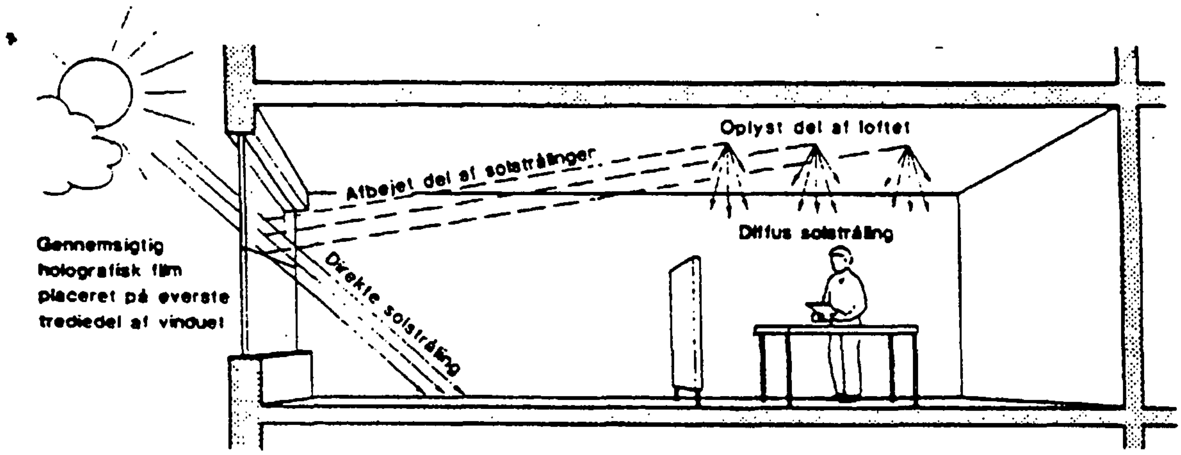


Figure 26. Holographic Windows can lead sun light deep into a room and change the way we perceive the demand for artificial lighting (Jensen, 1988; Crone & Koch, 1988).



Energy demand review and scenario assumptions

[no pages 122-124]

1990 energy demand in Europe
Hélène Connor-Lajambe

1. Data Collection

1.1. Sectoral versus end-use data.

In an end-use analysis, we are interested in knowing how energy systems contribute to providing services to society: shelter, food, light, economic, social and ludic activities for instance. Official statistical data, however, do not follow this classification and are only available for activities organised on a sectoral basis. In order to allow comparison, we will have to keep this sectoral segregation in our analysis.

1.2. Final energy versus end-use energy.

Offical data provide statistics for final energy demand, which do not show the amount of energy that is finally useful to render the service required, what we call the end-use energy. This end-use energy is the amount of energy that would have actually been necessary, had "the best technology known at present"[1] been used[2]. End-use figures are not easily constructed as they go into consideration of actual needs and of energy productivity which have been somewhat underplayed so far in energy analysis and research.

1.3 Uneven accuracy of data.

Programs of the European Commission, like SAVE and PACE, have started in the last three years studying the individual energy efficiency of various electric appliances. We have therefore precise numbers validated by the various national energy agencies contributing to such EC studies for these appliances and next to nothing for other equipments. Studies from non-European countries can help, but their findings are not necessarily replicable. The issues raised by these first in-depth studies are nevertheless throwing light on the energy efficiency issues which have to be considered for other appliances.

1.4. Choice of the reference data sources.

For coherence sake, we have tried using only Eurostats statistics for final energy demand in particular. In 1990, however, the European Union was still constituted by twelve countries : Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxemburg, the Netherlands, Portugal, Spain and the United Kingdom. In 1990, therefore, Eurostat only covered these countries, where our work had to include the new adherents to the Union : Austria, Finland and Sweden. The inclusion of Norway would also have made sense for purpose of energy trade, but was declined in this project. For the newcomers in the European Union, we therefore had recourse to statistics provided by the International Energy Agency (IEA), whose data are sometimes stratified differently and are generally less precise that Eurostat's, showing billions of energy units where we needed thousands or at least millions.

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[1] Bent Sørensen, The Use of Life-Cycle Analysis to Address Energy Cycle Externality Problems, IAEA Workshop on Comprehensive Climate-Benign Energy Planning, Beijing, 4-7 October 1994, p. 6.

[2] A middle-of-the-way option would be to choose as end-use technology the best available on the market at the time.

Table 56 shows the total energy delivered to the four main sectors of the fifteen European economies in 1990 in gigawatthours, using IEA statistics. These IEA statistics show the domestic and commercial sectors together under "Other sectors". They can sometime differ from the Eurostat statistics used in other parts of this study due to differences in aggregation of data.

National statistics and studies were also used to provide information not included in international organisations' data[3].

1.5. Conversion.

In order to make it easier to assess our proximity to the goal of the one-kilowatt society, it was agreed to work in kilowatthours (kWh) rather than in tons of oil equivalent (toe). The IEA rate of conversion was used: 1 million of toe (Mtoe) = 11630 gigawatthours (Gwh).

2. Description of European energy demand.

2.1. Demographic pull and economic status.

In 1990, the fifteen European countries represented a vast population of over 365 million people, dispersed in approximately 130 million households having generally a low occupancy rate and a high standard of living. See Table 57.

Energy needs were high and met mostly by fossil fuels. Even if the share of coal had somewhat changed in the recent past, dependence on oil remained high and seemed likely to stay that way until the transportation issue would have been tackled seriously. This demographic pull looked likely to diminish as the level of population tended to increase slowly in most European countries. Simultaneously the lowering rate of occupancy of dwellings could stabilise somewhat if continuing high rates of unemployment lead mature children to live with their parents or to share apartments.

We see on the Eurostat chart shown on Figure 27 that, in the twelve countries of the 1990 European Union, less than 40% of the primary energy, shown under "Gross inland consumption", actually reached households appliances or factory equipment. Out of this delivered energy, called "useful energy" on the chart, only part of it represents end-use energy and provides real services. It is therefore obvious that the European level of amenability may increase, but, thanks to smarter energy use, it should not require increased energy flows in the economy.

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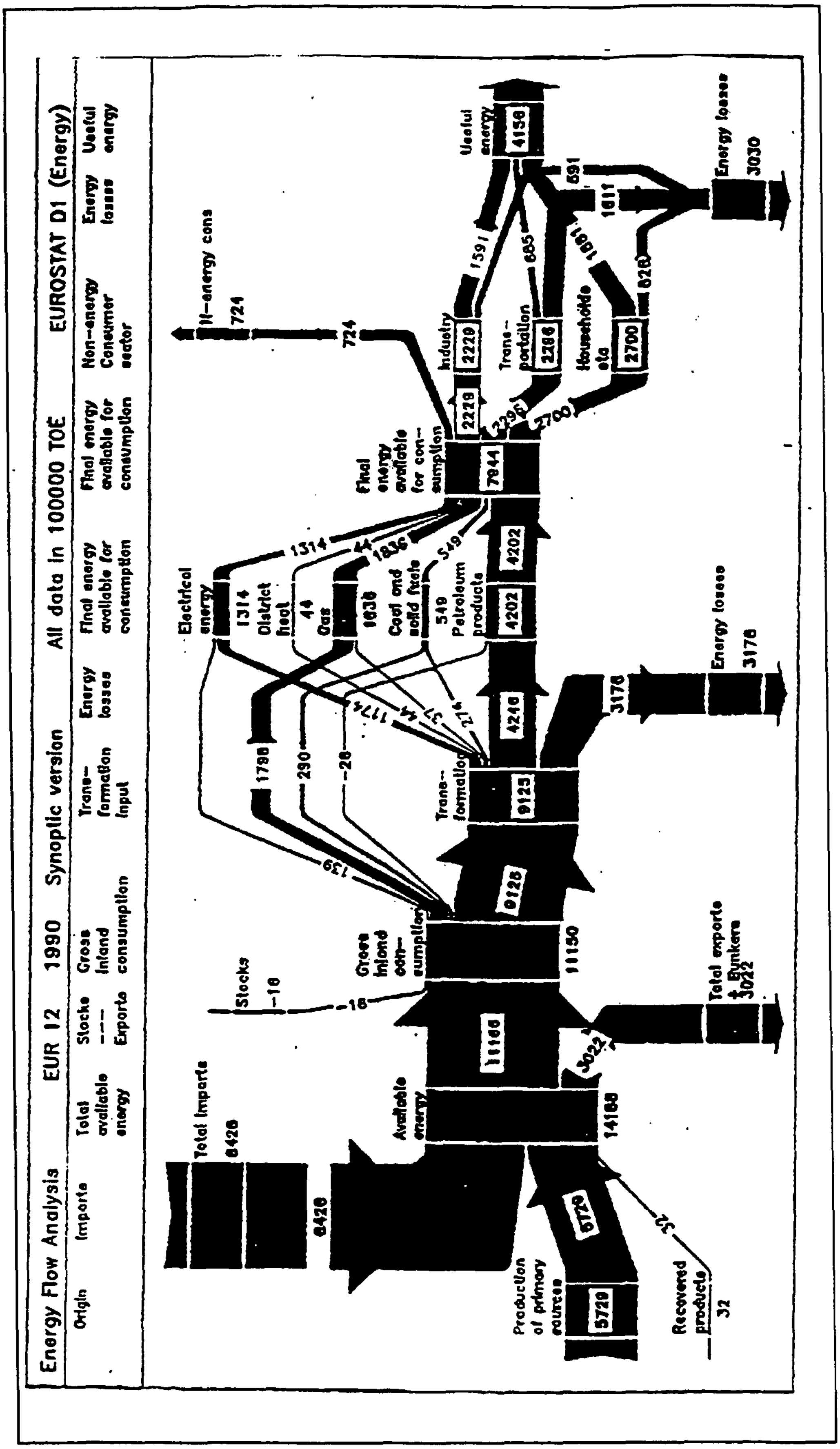
[3] Communication from Kirsten Halsnæs and Poul-Erik Grohnheit, Risø National Laboratory, Systems Analysis Department, on *Draft Tutorial for Energy Supply Modelling.*

FIGURE 27
(from Euro
stat for 1990)



2.2. The residential sector.

Domestic energy needs are for the confort of the home, the alimentation, upkeep and entertainment of the people living within the household[4]. These are provided via energy of various quality : low degrees of heat for air and water heating, higher level of temperature heat for cooking, electricity for lighting and activating appliances, not to forget ventilation or climatisation.

2.2.1. Data collection and methodology.

The ideal end-use study would need a full inventory and description of all the dwellings, appliances and habits of all the inhabitants, themselves categorised by age, sex, marital status, birthplace, possessions, career and life expectancy, if not more. This very detailed "bottom-up" analysis being clearly unmanageable within this study, we have chosen to start from existing national statistics available, to analyse them and then to work our way down to the level of the individual needs in a "top-down" approach.

Data on total delivered energy (Table 58 and 59) are taken from *IEA Energy Balances of OECD Countries* and global electricity use comes from the *IEA Energy Statistics of OECD Countries* for 1990-1991.

Official statistics provide fairly global figures of "final" or delivered energy. Using studies and inquiries made by consultants and universities, as well as by energy efficiency agencies sometimes working together within the N'Group[5], it was possible to obtain a breakdown by uses, as seen on Table 58 for the main domestic uses. This disagregration into cooking needs, water and air heating was arrived at using work completed or still being done for the German[6], British[7] and French[8] governments. The category of electricity doesn't distinguish between the different needs fulfilled, of which only some are specifically electric and using electric devices not yet substitutable: lights, fridges, freezers, washing machines, dryers, dishwashers, radio-TV and video equiment.

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[4] The welfare and enjoyment of the homedweller are not measurable amounts. But the useful energy needed for a well-fulfilled service can be quantified, it is the end-use energy.

[5] The N'G is the Group of European energy agencies which comes together to study European energy needs in particular for the DG XVII, the General Directorate for Energy in Bruxelles.

[6] *The Development of the Energy Sector of the Federal Republic of Germany up to the Year 2010,* Study for the Federal Ministry of Economics, by Prognos, European Center for Applied Economic Research, Basel, October 1989.

[7] Written communication from ETSU, June 8th, 1995, referring to sources like the *Digest of UK Energy Statistics* (DUKES), and to work done by the firm ENERDATA.

[8] *Tableaux des consommations d'Energie en France*, issued by the Observatoire de l'Energie, DG-EMP, Edition 1993.

The proportion of electricity and of appliance use shown on Table 59 was computed using the above-mentioned studies plus one made in Denmark for the European Environment Bureau[9], two at the University of Utrecht in the Netherlands[10] and one at the University of Oxford[11]. These national studies are not all showing 1990 data, but they nevertheless could give us the approximate proportion of electricity used by the different equipements in some countries: Denmark (1986), France (1990), Germany (1986), Netherlands (199?) and the United Kingdom (1982).

For the other European countries, we devised a default ratio mentioned at the bottom of Table 60. This procedure gave us a fair evaluation of what each country used in 1990 for the different functions performed by electricity. What each individual or each household used on average can therefore be computed. These are still "top-down" measures of energy quantities, even if they sometimes were arrived at with an aggregation of "bottom-up" measures.

But these quantitites still reflect the amount of energy used, not the amount of energy actually needed. We therefore still need to apply a ratio of efficiency -or inefficiency- to these numbers to obtain the real amount of end-use energy. This ratio representing what was in 1990 the gap between the efficiency of the equipment used and the efficiency of the "best known" equipment can be taken in particular from the work done by Jørgen S. Nørgård[12] and from the documentation in support of the EU directives on refrigeration[13], wet appliances[14] i.e. washing machines, driers and dishwashers, and lighting[15].

On Table 60, we summarise some of the findings of these studies and include the ratio of improved productivity that they suggest. Only Nørgård's studies, however, display a ratio of

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[9] *Low Electricity Europe - Sustainable Options*, by J. S. Nørgård and J. Viegand for the European Environment Bureau, 1994.

[10] *Icarus -3. The Potential of Energy Efficiency Improvement in the Netherlands up to 2000 and 2015,* by J.G. de Beer, M.T. van Wees, E. Worrell and Kornelis Blok, 94013, Utrecht University, October 1994. Preliminary draft of *Efficient Electricity Use in the European Union*, by the Utrecht University.

[11] *DECADE* , Domestic Equipment and Carbone Dioxide Emissions, First Year Report 1994, University of Oxford, Environmental Change Unit, p.33.

[12] Jørgen Nørgård, "Low Electricity Appliances - Options for the Future", in *Electricity Efficient End-Use and New Generation Technologies and their Planning Implications*, by Th. Johansson, B. Bodlund and R. Williams, Lund University Press, April 1989. *Environmental Design of Appliances*, Proceedings from the Energy Efficiency Symposium, Hong Kong, March 1991.

[13] Commission of the European Communities, *Study on Energy Efficiency Standards for Domestic Refrigeration Appliances*, Group for Efficient Appliances, ADEME, DEA and Novem, March 1993.

[14] Group for Efficient Appliances, *Washing Machines, Driers and Dishwashers*, Final Report of the E^{n}R Working Group, June 1995.

[15] INESTENE, *Analyse des Potentiels d'Economie d'Electricite dans l'Eclairage*, Final Report, July 1995. The analysis was done for France using the model MURE-Electricity which replicates with precision the electricity sector peculiarities and could be used for the other countries.

proven advanced efficiency technologies which is close to our definition of "end-use". Using these ratios, we deduct what would have been the 1990 electricity use had residential appliances embodied the best technology known at the time. Table 60 shows that the amount of end-use electricity needed was about 40% of the actual amount of electricity used. Exergetic needs would be much lower still as examplified in Sørensen[16]

The IEA figures for delivered electricity include specific electricity used by electric appliances as well as electricity used for cooking and for heating. We have included these last two categories of end uses in Table 60 to which we apply an end-use efficiency coefficient of 0.25. We assumed that a factor four reduction could have represented the best proven technology in 1990 after studying the difference between Danish[17] energy use and end-use. See Table 61.

We add electric cooking of Table 60 and non-electric cooking to have the total amount of energy used for cooking. We then do the same for air and water heating of the two origins.

It is now possible to convert the amounts of energy of each end use, from gigawatthours per nation into watts per person under strict assumptions[18]. See Table 61.

2.3. The Service Sector

This composite sector is also called Tertiary Sector and includes activities as diverse as banking establishments, schools, hospitals, hotels, restaurants, sports facilities, army barracks, bus depots and a host of offices and stores having very different characteristics. The tertiary sector has taken an increased importance with the de-industrialisation of most European countries. It is evaluated that two out of three jobs are now in the service sector and three quarters of all investments are made in that sector.

2.3.1. Data Collection and Methodology

Total final use come from *IEA Energy Balances of OECD Countries* and electricity use from *IEA Energy Statistics of OECD Countries* for 1990-1991. (Table 62). Tertiary and residential statistics are often lumped together in international organisations documents. Sometimes also with agriculture. In this study, agriculture is studied alongside the Industry Sector.

For the disagregation into various uses, the same statistical sources were used as for the domestic sector, plus reports from Electricité de France[19] and a new series of detailed sectoral guides

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[16] Bent Sørensen, "Creative Energy Planning. A simple guide to people and their governments on how to design energy futures", Lecture Notes, 1983.

[17] Bent Sørensen, Life-Cycle Analysis of the Total Danish Energy System, February 1995, Roskilde University, p. 26 of the Danish part and pp. 15-16 of the paper for the Beijing Workshop.

[18] These watts of capacity are assumed to produce without interruption, for instance.

[19] Electricité de France, *Le tertiaire francais*, Direction du Développement et de la Stratégie Commerciale, January 1995.

from ADEME (Agence de l'Environnement et de la Maitrise de l'Energie) and AICVF (Association des Ingénieurs en Climatique, Ventilation et Froid) on hotels and restaurants[20], schools[21], health institutions[22], offices[23].

The EDF paper gives electricity and energy use in kilowatthours per square meter for most of the tertiary sector (see Table 63). These unit final energy measurements could be replicable to other European countries, if we have the squarage of the various subsectors of the service industry in each country.

Office equipment is using a growing amount of electricity as new devices appear in the office. It is estimated at 3% of total commercial energy consumption in 1990, not counting the necessary cooling energy needed to offset the waste heat generated. This use may increase fivefold during the next decade[24].

Global actual energy consommations for Europe are shown on Table 62. Efficiency intensity ratios obtained from bottom-up analysis of this sector, mostly those from Nørgård's studies, are applied to give us 1990 end-use measurements on Table 64. We assume that in 1990 best available technology in lighting would have used 35% of the actual energy used then, electricity 47%, for water heating and cooking 57% and for air heating 47%. Thus end-use energy required would have been only 48% of the energy actually used.

2.4. The Industry Sector

The Agriculture Sector statistics are shown alongside the data for the Industry Sector. Both sectors are productive sectors, contributing goods -durable or consumable- and equipment for human sustainance. Even if the Industry Sector has relatively diminished, compared to the other sectors, it remains the one that requires the most sophisticated and expensive energy-using equipment. In 1990, it can be safely assumed that a fair number of energy-saving measures have already been implemented.

2.4.1. Data Collection and Methodology

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[20] ADEME (Agence de l'Environnement et de la Maitrise de l'Energie) and AICVF (Association des Ingénieurs en Climatique, Ventilation et Froid), *Hôtels-Restaurants; Programmer, concevoir, gérer les bâtiments á hautes performances énergétiques,* 1993.

[21] ADEME/AICVF, *Enseignement. Programmer, concevoir, gérer les bâtiments à hautes performances énergétiques*, 1993.

[22] ibid.

[23] ibid.

[24] American Council for an Energy-Efficient Economy, *Guide to Energy-Efficient Office Equipment*, 1993.

The final energy demand (converted from Mtoe) is taken from Eurostat ten sub-sectors classification for the twelve 1990 EC countries (Table 65). It does not include the energy sector (which is however included in IEA "Industry" statistics) and this is fine for our work since the energy sector does not represent final demand.

The statistics for Austria, Finland and Sweden come from the 1990 IEA Balances which counts 13 sub-sectors. Therefore, for these three countries, "Wood and Wood Products" was amalgamated into "Construction", and "Building Materials" includes "Non-Metallic Minerals" as well as "Machinery" and "Transport Equipment". The energy sector consumption has been taken to be "Distribution Losses" plus "Electricity Plants" (to avoid duplication).

Electricity use was taken from the IEA 1990 Statistics (Table 66). By substracting the amount of electricity from total energy we obtained the amount of process heat used for the remaining power needs and for heating purposes (Table 67).

Percentages of electricity once calculated, the split among the various temperatures of process heat was made (Table 68). This step required consultation of the documents mentioned above for the residential and tertiary sectors, a communication with the International Project for Soft Energy Paths, and more specifically finding hindsights in technical documents and on-going research[25]. Nobody seems to have yet disagregated energy use by quality as needed, i.e. into specific electricity, mobile or stationary power and heat of different temperatures. Analysts in every country are still investigating what energy is really used for and we had to carry out our own deductions.

To obtain the end-use energy, we applied efficiency ratios also deducted from some of the same technical documents. The only somewhat clear indications of efficiency came from documents on electricity, from the University of Utrecht, from Electricité de France[26] and from the European Environmental Bureau.[27]

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[25] - *Analyse van de Warmtevoorziening, Programmeringsstudie voor het SYRENE onderzoeksprogramma,* by Ad van Wijk, Wim Gilijamse and Ernst Worrell, Utrecht, 1992, N¡ 92046.

- *Industriële Proceswarmte in Relatie Tot Het Temperatuurniveau,* by A.H. Boot and F.G.H. van Wees, June 1982, Energie Studie Centrum ESC-21.

- Graph 6.2-4 from *Lehrstuhl für Energiewirtschaft und Kraftwerkstechnik,* Technical University of Munich, 1994.

- *Heat and Electricity Consumption of Large Industrial Energy Users in the Netherlands,* by K. Blok and E. Worrell, in Heat Recovery Systems & CHP, Vol. 12, N¡ 5, 1992.

- Draft of *The Energy Intensity of the Economies of OECD Member States Measured by Production of Energy Intensive Commodities and Consumption of Energy in Industry Sectors,* by W. O. Sugg, III and J.R. Spradley, Jr., March 1995.

[26] *L'Electricité dans l'industrie : un vecteur d'amélioration de l'efficacité energetique et de compétitivité economique,* by Pascal Gibielle, Electricité de France, UNIPEDE Congress 22-24 May 1995, Paris, and private communication, 12. September 1995.

[27] *Low Electricity Europe - Sustainable Options,* J.S. Nørgård and J. Viegand, p.33.

Given the financial incentive that the industrialists logically have to save on their manufacturing and other processes, we assumed that they were producing goods using some of the most advanced technologies. Therefore, the gap between the technology used and the best technically proven technology should not be too wide. For industrial electricity, a saving of 15% was assumed, and for thermal uses of 30%.

In the agricultural sector, electricity could have been reduced by 45% and thermal uses by 40%. See Tables 69. for the figures of end-use electricity, Table 70. for those of process heat, Table 71. for the new total of energy demand according to our end-use definition and Table 72 for the new repartition by quality in the whole sectors.

Electricity represent now 33% - instead of 28% - of the overall energy needs as more savings could be made on thermal uses. Therefore, in 1990, using the best known technology would have been 26,5% more efficient, thus saving 758 924 GWh.

2.5. The Transport Sector

2.5.1. Data Collection and Methodology

Eurostat 1990 data in Mtoe are used for the 1990 twelve EC countries. Austria, Finland and Sweden are taken from OECD Environmental Data, 1993. These figures are shown on Table 73.

Road transport is by far the most utilised. We give here a breakdown showing the traffic of each category of vehicle (Table 74) and the number of vehicles in use in each category (Table 75). The respective parts of passengers and goods in road traffic are shown in Table 76.

The efficiency of transport measured in passenger-kilometers by kilo-equivalent of oil (p-km/k-ep) or in tonne of goods-kilometers per p-km/kep vary greatly with type of vehicles and length of trips, urban or interurban traffic. See Table 77.

Without taking into acccount possible substitution between modes or categories of vehicles, we assume an arbitrary best proven technology that could have been globally 30% more efficient in rail, air and water transport, and 35% more efficient in road traffic. Electric railways are assumed to have been 15% less efficient that best proven technology. These assumptions are reflected in Table 78.

3. Conclusions

Table 79 shows the per capita delivered energy in 1990 in each of the different sectors. Luxemburg exhibits a big discrepancy, especially in industry and transport. Finland and Sweden are otherwise the largest energy users. Portugal, Spain and Greece are the ones requiring the less, in almost every sector except for agriculture.

A distribution by quality of delivered energy (Table 80) shows that the biggest user is the transport sector requiring almost one-third of total energy. Once we translate this distribution into end-use energy (Tables 81 and 82), this proportion grows to almost two-fifth as the best proven technology assumed is not yet efficient enough to reverse the increasing requirements for mobility.

Table 56. Total delivered energy by sector (GWh/y)

	INDUSTRY	TRANSPORT	Other Sectors	TOTAL (GWh)	ENERGY Sector	NON-Energy Use
AUSTRIA	72571	64430	103740	240741	16282	12095
BELGIUM	160145	91644	134327	386116	36390	26656
DENMARK	31401	53265	77223	161890	3838	8257
FINLAND	115370	50707	87109	253185	17445	7792
FRANCE	515093	498229	610691	1624013	51172	85481
GERMANY	1024603	698265	1125784	2848652	213259	128139
GREECE	46404	69199	53614	169217	6362	12118
IRELAND	24888	23609	39309	87807	7292	1907
ITALY	499741	399374	444731	1343847	115021	85364
LUXEMBOURG	20236	11979	6862	39077	233	361
NETHERLANDS	237950	122929	226901	587780	106391	62907
PORTUGAL	68036	44427	30471	142933	24272	7653
SPAIN	260628	265513	143282	669423	67989	54940
SWEDEN	151190	86295	133396	370881	7327	20353
Un. KINGDOM	478575	540446	650815	1669835	112567	149992
TOTAL /Sector	3706830	3020311	3868254	10595395	785839	664015
Proportion	35%	29%	37%	100%		
Source: IEA						

Table 57: Population and housing data

	POPULATION	HOUSEHOLDS	OCCUPAN	CY
1990	'000	'000	RATE	
AUSTRIA	7712	2937		2.6
BELGIUM	9956	3980		2.5
DENMARK	5140	2229		2.3
FINLAND	4986	2266		2.2
FRANCE	56440	21535		2.6
GERMANY*	79484	34827		2.3
GREECE	10067	3247		3.1
IRELAND	3503	999		3.3
ITALY	57663	20594		2.8
LUXEMBOURG	378	145		2.6
NETHERLANDS	14943	5955		2.4
PORTUGAL	10354	3235		3.2
SPAIN	38959	11806		3.4
SWEDEN	8559	4076		2.1
United KINGDOM	57395	22400		2.5
TOTAL	365539	140231		2.6
* East Germany not included			Average:	2,7
Sources	World Bank	Eurostat	Eurostat	

Table 58: 1990 delivered energy in the residential sector in GWh

E 15 /GWh	Electricity	Non-Elec.Cooking	Water Heating	Non-elec.Heating	TOTAL GWh
AUSTRIA	11220.0	5112.3	14017.6	52106.7	82456.7
BELGIUM	18414.0	5883.8	16133.1	54469.8	94900.8
DENMARK	9102.0	2941.9	8066.6	27339.9	47450.4
FINLAND	14599.0	3598.1	9865.7	29970.9	58033.7
FRANCE	96908.0	15473.9	42428.6	94769.3	249579.8
GERMANY	137054.0	42463.2	116431.4	388942.1	684890.7
GREECE	9074.0	2026.2	5555.7	16024.5	32680.3
IRELAND	4572.0	1499.8	4112.4	14006.2	24190.4
ITALY	52730.0	22100.5	60598.1	221030.9	356459.5
LUXEMBOURG	650.0	266.8	731.5	2654.8	4303.1
NETHERLANDS	16500.0	6958.2	19079.0	69692.3	112229.5
PORTUGAL	5920.0	1124.9	3084.3	8013.7	18142.8
SPAIN	30210.0	5170.0	14175.8	33831.3	83387.1
SWEDEN	38095.0	4953.7	13582.7	23266.7	79898.1
United KINGDOM	93793.0	26938.8	73864.5	239900.5	434496.8
TOTAL	538841.0	146512.2	401726.9	1276019.6	2363099.7
Average %	0.2	0.1	0.2	0.5	1.0
Sources	IEA	Prop. of Total	Prop. of Total	Residual	IEA

Table 59: 1990 delivered electricity in the residential sector in GWh

E 15 /GWh	LIGHTING	FRIDGES	FREEZERS	LAUNDRY	DRYERS	DISHWSH.	M.MEDIA	HEATING	COOKING	OTHERS	TOTAL
AUSTRIA	1458.6	1346.4	897.6	785.4	224.4	224.4	448.8	3029.4	1795.2	1234.2	11220.0
BELGIUM	2393.8	2209.7	1473.1	1289.0	368.3	368.3	736.6	4971.8	2946.2	2025.5	18414.0
DENMARK	1281.0	958.0	850.0	734.0	170.0	264.0	245.0	2234.0	1538.0	829.0	9102.0
FINLAND	1897.9	1751.9	1167.9	1021.9	292.0	292.0	584.0	3941.7	2335.8	1605.9	14599.0
FRANCE	8100.0	13100.0	6200.0	5700.0	800.0	2400.0	2100.0	26165.2	15505.3	10659.9	96908.0
GERMANY	10925.0	20111.0	9435.0	7200.0	1986.0	3228.0	5711.0	44940.0	24084.0	9435.0	137054.0
GREECE	1179.6	1088.9	725.9	635.2	181.5	181.5	363.0	2450.0	1451.8	998.1	9074.0
IRELAND	594.4	548.6	365.8	320.0	91.4	91.4	182.9	1234.4	731.5	502.9	4572.0
ITALY	6854.9	6327.6	4218.4	3691.1	1054.6	1054.6	2109.2	14237.1	8436.8	5800.3	52730.0
LUXEMBOURG	84.5	78.0	52.0	45.5	13.0	13.0	26.0	175.5	104.0	71.5	650.0
NETHERLANDS	4176.0	2037.0	1528.0	917.0	331.0	255.0	611.0	2292.0	586.0	3769.0	16500.0
PORTUGAL	769.6	710.4	473.6	414.4	118.4	118.4	236.8	1598.4	947.2	651.2	5920.0
SPAIN	3927.3	3625.2	2416.8	2114.7	604.2	604.2	1208.4	8156.7	4833.6	3323.1	30210.0
SWEDEN	4952.4	4571.4	3047.6	2666.7	761.9	761.9	1523.8	10285.7	6095.2	4190.5	38095.0
Un. KINGDOM	9247.0	12220.0	6605.0	3963.0	2312.0	661.0	6275.0	30714.0	13871.0	7926.0	93793.0
TOTAL	57841.9	70684.1	39456.7	31497.9	9308.7	10517.7	22361.4	156425.8	85261.7	53022.1	538841.0
Default %	13.0	12.0	8.0	7.0	2.0	2.0	4.0	33.0	15.0	8.0	100.0

Table 60: End-use electricity needed in the residential sector in 1990

	EU	AUT	BE	DK	FIN	FR	GE	GR	EI	IT	LU	NL	P	SP	SW	UK
WASHING MACHINES																
Av.Spe.Elec.Use kWh/kg	.43	.41	.38	.40	.44	.46	.42		.36	.43		.41	.46		.41	
Techn.Proven SEU	.17															
Average Saving in %	60.0															
Nørgard Advanced Eff.*				.30												
1990 Actual Use in GWh	31498.0	785.0	1289.0	734.0	1022.0	5700.0	7200.0	635.0	320.0	3691.0	46.0	917.0	414.0	2115.0	2667.0	3963.0
1990 End-use El.needed	9449.4	235.5	386.7	220.2	306.6	1710.0	2160.0	190.5	96.0	1107.3	13.8	275.1	124.2	634.5	800.1	1188.9
1990 Ownership %	90.0															
Frequency of Use/wk	4.6															
DRIERS																
Av.Spe.Elec.Use kWh/kg	.69	.68		.69	.69	.63	.71		.73			.73			.76	
Techn.Proven SEU	.48															
Average Saving in %	30.0															
Nørgard Advanced Eff.*				.35												
1990 Actual Use in kWh	9307.0	224.0	368.0	170.0	292.0	800.0	1986.0	181.0	91.0	1055.0	13.0	331.0	118.0	604.0	762.0	2312.0
1990 End-use El.needed	3257.5	78.4	128.8	59.5	102.2	280.0	695.1	63.4	31.9	369.3	4.6	115.9	41.3	211.4	266.7	809.2
1990 Ownership %	20.0															
Frequency of Use/wk	2.9															
DISHWASHERS																
Av.Spe.Elec.Use kWh/kg	.136	.129	.155	.127		.142	.132		.144	.137		.127			.143	.154
Techn.Proven SEU	.076															
Average Saving in %	44.0															
Nørgard Advanced Eff.*				0.3												
1990 Actual Use in kWh	10516.0	224.0	368.0	264.0	292.0	2400.0	3228.0	181.0	91.0	1055.0	13.0	255.0	118.0	604.0	762.0	661.0
1990 End-use El.needed	3470.3	73.9	121.4	87.1	96.4	792.0	1065.2	59.7	30.0	348.2	4.3	84.2	38.9	199.3	251.5	218.1
1990 Ownership %	26.0															
Frequency of Use/wk	4.3															
LIGHTING																
1990 Actual Use in GWh	57842.0	1459.0	2394.0	1281.0	1898.0	8100.0	10925.0	1180.0	594.0	6855.0	84.0	4176.0	770.0	3927.0	4952.0	9247.0
Nørgard Advanced Eff.				.20												
INESTENE 2005 EFF.Scen.						.72										
Appl. End-use Eff.Ratio*	.50															
1990 End-use El.needed	28921.0	729.5	1197.0	640.5	949.0	4050.0	5462.5	590.0	297.0	3427.5	42.0	2088.0	385.0	1963.5	2476.0	4623.5
FRIDGES																
1990 Actual Use in GWh	70684.0	1346.0	2210.0	958.0	1752.0	13100.0	20111.0	1089.0	549.0	6328.0	78.0	2037.0	710.0	3625.0	4571.0	12220.0
Nørgard Advanced Eff.				.14												
R2 EU Fridge	.54															
Appl. End-use Eff.Ratio*	.30															
1990 End-use El.needed	21205.2	403.8	663.0	287.4	525.6	3930.0	6033.3	326.7	164.7	1898.4	23.4	611.1	213.0	1087.5	1371.3	3666.0
FREEZERS																
1990 Actual Use in GWh	39458.0	898.0	1473.0	850.0	1168.0	6200.0	9435.0	726.0	366.0	4218.0	52.0	1528.0	474.0	2417.0	3048.0	6605.0
Nørgard Advanced Eff.				.20												
F1 EU Freezer	.52															
Appl. End-use Eff.Ratio*	.35															
1990 End-use El.needed	13810.3	314.3	515.6	297.5	408.8	2170.0	3302.3	254.1	128.1	1476.3	18.2	534.8	165.9	846.0	1066.8	2311.8
M-MEDIA																
1990 Actual Use in GWh	22362.0	449.0	737.0	245.0	584.0	2100.0	5711.0	363.0	183.0	2109.0	26.0	611.0	237.0	1208.0	1524.0	6275.0
Nørgard Miscel. Eff.				.50												
Appl. End-use Eff.Ratio*	.50															
1990 End-use El.needed	11181.0	224.5	368.5	122.5	292.0	1050.0	2855.5	181.5	91.5	1054.5	13.0	305.5	118.5	604.0	762.0	3137.5
HEATING																
1990 Actual Use in GWh	156426.0	3029.0	4972.0	2234.0	3942.0	26165.0	44940.0	2450.0	1234.0	14237.0	176.0	2292.0	1598.0	8157.0	10286.0	30714.0
Nørgard Advanced Eff.												.55				
Appl. End-use Eff.Ratio*	.50															
1990 End-use El.needed	78213.0	1514.5	2486.0	1117.0	1971.0	13082.5	22470.0	1225.0	617.0	7118.5	88.0	1146.0	799.0	4078.5	5143.0	15357.0
COOKING																
1990 Actual Use in GWh	85262.0	1795.0	2946.0	1538.0	2336.0	15505.0	24084.0	1452.0	732.0	8437.0	104.0	586.0	947.0	4834.0	6095.0	13871.0
Nørgard Advanced Eff.				.40												
Appl. End-use Eff.Ratio*	.40															
1990 End-use El.needed	34104.8	718.0	1178.4	615.2	934.4	6202.0	9633.6	580.8	292.8	3374.8	41.6	234.4	378.8	1933.6	2438.0	5548.4
OTHERS																
1990 Actual Use in GWh	53022.0	1234.0	2026.0	829.0	1606.0	10660.0	9435.0	998.0	503.0	5800.0	72.0	3769.0	651.0	3323.0	4190.0	7926.0
Nørgard Average Eff.*				.26												
1990 End-use El.needed	13785.7	320.8	526.8	215.5	417.6	2771.6	2453.1	259.5	130.8	1508.0	18.7	979.9	169.3	864.0	1089.4	2060.8
END-USE SPEC. ELEC.	105080.4	2380.8	3907.8	1930.3	3098.1	16753.6	24027.0	1925.4	970.0	11189.4	138.0	4994.4	1256.1	6410.2	8083.8	18015.7
(w/o Heat.&Cooking)																
TOT. END-USE ELEC.	217398.2	4613.3	7572.2	3662.5	6003.5	36038.1	56130.6	3731.2	1879.8	21682.7	267.6	6374.8	2433.9	12422.3	15664.8	38921.1

Table 61: 1990 end-use energy in the residential sector in watts per capita

	EU	AUT	BE	DK	FIN	FR	GE	GR	EI	IT	LU	NL	P	SP	SW	UK
POPULATION '000	365539.0	7712.0	9956.0	5140.0	4986.0	56440.0	79484.0	10067.0	3503.0	57663.0	378.0	14943.0	10354.0	38959.0	8559.0	57395.0
END-USE SPEC. ELEC.GWh	105080.4	2380.8	3907.8	1930.3	3098.1	16753.6	24027.0	1925.4	970.0	11189.4	138.0	4994.4	1256.1	6410.2	8083.8	18015.7
E-U SP.ELEC. in MW	11995.5	271.8	446.1	220.3	353.7	1912.5	2742.8	219.8	110.7	1277.3	15.7	570.1	143.4	731.8	922.8	2056.6
E-U Elec. in W/cap.	32.8	35.2	44.8	42.9	70.9	33.9	34.5	21.8	31.6	22.2	41.7	38.2	13.8	18.8	107.8	35.8
Non-Electric Water Heat	401728.0	14018.0	16133.0	8067.0	9866.0	42429.0	116431.0	5556.0	4112.0	60598.0	732.0	19079.0	3084.0	14176.0	13583.0	73864.0
Non-Electric Heating	1276020.0	52107.0	54470.0	27340.0	29971.0	94769.0	388942.0	16024.0	14006.0	221031.0	2655.0	69692.0	8014.0	33831.0	23267.0	239901.0
Total Non-Electric Heat	1677748.0	66125.0	70603.0	35407.0	39837.0	137198.0	505373.0	21580.0	18118.0	281629.0	3387.0	88771.0	11098.0	48007.0	36850.0	313765.0
Heat End-use Eff. Ratio*	.25															
End-use Non-Elec.Heat	419437.0	16531.3	17650.8	8851.8	9959.3	34299.5	126343.3	5395.0	4529.5	70407.3	846.8	22192.8	2774.5	12001.8	9212.5	78441.3
END-USE HEAT in GWh	497650.0	18045.8	20136.8	9968.8	11930.3	47382.0	148813.3	6620.0	5146.5	77525.8	934.8	23338.8	3573.5	16080.3	14355.5	93798.3
E-U HEAT in MW	56809.4	2060.0	2298.7	1138.0	1361.9	5408.9	16987.8	755.7	587.5	8850.0	106.7	2664.2	407.9	1835.6	1638.8	10707.6
E-U Heat in W/cap.	155.4	267.1	230.9	221.4	273.1	95.8	213.7	75.1	167.7	153.5	282.3	178.3	39.4	47.1	191.5	186.6
Non-Electric Cooking	146512.0	5112.0	5884.0	2942.0	3598.0	15474.0	42463.0	2026.0	1500.0	22100.0	267.0	6958.0	1125.0	5170.0	4954.0	26939.0
Heat End-use Eff. Ratio*	.25															
End-use Non-El. Cooking	36628.0	1278.0	1471.0	735.5	899.5	3868.5	10615.8	506.5	375.0	5525.0	66.8	1739.5	281.3	1292.5	1238.5	6734.8
END-USE COOKING GWh	70732.8	1996.0	2649.4	1350.7	1833.9	10070.5	20249.4	1087.3	667.8	8899.8	108.4	1973.9	660.1	3226.1	3676.5	12283.2
E-U COOKING in MW	8074.5	227.9	302.4	154.2	209.3	1149.6	2311.6	124.1	76.2	1016.0	12.4	225.3	75.3	368.3	419.7	1402.2
E-U Cooking W/cap.	22.1	29.5	30.4	30.0	42.0	20.4	29.1	12.3	21.8	17.6	32.7	15.1	7.3	9.5	49.0	24.4
TOTAL END-USE in GWh	673463.2	22422.5	26693.9	13249.7	16862.3	74206.1	193089.6	9632.7	6784.3	97615.0	1181.1	30307.1	5489.7	25716.5	26115.8	124097.1
TOT. END-USE W/cap.	210.3	331.9	306.1	294.3	386.1	150.1	277.3	109.2	221.1	193.2	356.7	231.5	60.5	75.4	348.3	246.8

Table 62: Total energy delivered in the tertiary sector (1990)					
E 15 /GWh	Lighting	Electricity	Water Heat.&Cooking	Heating	TOTAL GWh
AUSTRIA		9769.0			9769.2
BELGIUM	1686.4	7798.0	4384.5	19858.1	33727.0
DENMARK	552.4	7875.0	1436.3	1184.8	11048.5
FINLAND		10351.0			10350.7
FRANCE	16130.8	79037.0	41940.1	185508.3	322616.2
GERMANY	16991.4	80655.0	44177.7	198004.5	339828.6
GREECE	412.9	5605.0	1073.4	1166.0	8257.3
IRELAND	418.7	2795.0	1088.6	4071.4	8373.6
ITALY	2581.9	40011.0	6712.8	2331.5	51637.2
LUXEMBOURG	116.3	725.0	302.4	1182.3	2326.0
NETHERLANDS		20662.0		39.4	20701.4
PORTUGAL	348.9	4829.0	907.1	893.0	6978.0
SPAIN	1994.5	25103.0	5185.8	7607.5	39890.9
SWEDEN	2320.2	24361.0	6032.5	13690.0	46403.7
United KINGDOM	7042.0	62084.0	18309.1	53404.2	140839.3
TOTAL	50596.3	381660.0	131550.4	488941.0	1052747.6
Average %	5.0	36.3	13.0	45.7	100.0
Source: IEA					

Table 63: 1990 unit energy use per year in the french tertiary sector

	TOURISM	OFFICES	HEALTH	SCHOOLS	COMMUN.HOU.	COMMERCE	LEISURE/SP.	TRANSP.BLDG	TOTAL
Area Mill.m2	43.7	130.9	78.9	137.5	43.9	170.9	32.8	19.2	666.
Light kWh/m2	27.0	40.0	25.0	10.0	19.0	19.0	19.0	19.0	
Heat kWh/m2	196.0	165.0	185.0	140.0	174.0	174.0	273.0	273.0	
Proportions :									
Air Condit.	0.5	0.6	0.7	0.8					
Hot Water	0.1	0.1	0.1	0.1					
Cooking	0.3	0.0	0.1	0.0					
Lighting	0.1	0.1	0.1	0.1					
Others	0.1	0.2	0.1	0.0					

Table 64: 1990 end-use energy in the tertiary sector in GWh

END-USE	Lighting	Electricity	Water&Coc	Heating	TOTAL GWh
AUSTRIA		4591.4			4591.4
BELGIUM	590.2	3665.1	2499.2	9333.3	16087.8
DENMARK	193.3	3701.3	818.7	556.8	5270.1
FINLAND		4865.0			4865.0
FRANCE	5645.8	37147.4	23905.9	87188.9	153887.9
GERMANY	5947.0	37907.9	25181.3	93062.1	162098.2
GREECE	144.5	2634.4	611.9	548.0	3938.7
IRELAND	146.5	1313.7	620.5	1913.5	3994.2
ITALY	903.7	18805.2	3826.3	1095.8	24630.9
LUXEMBOURG	40.7	340.8	172.4	555.7	1109.5
NETHERLANDS		9711.1		18.5	9729.7
PORTUGAL	122.1	2269.6	517.1	419.7	3328.5
SPAIN	698.1	11798.4	2955.9	3575.5	19028.0
SWEDEN	812.1	11449.7	3438.5	6434.3	22134.6
United KINGDOM	2464.7	29179.5	10436.2	25100.0	67180.3
TOTAL	17708.7	179380.2	74983.7	229802.3	501874.9
New Proportion	0.0	0.4	0.1	0.5	1.0
% of Prev.Tot.	2.4	17.0	7.4	21.5	48.3

Table 65: 1990 total delivered energy in agriculture, industry and the energy sectors (in GWh)

TOTAL Delivered	AGRIC.	Ir-Steel	NF-Met.	Chemical	BldgMat	Mining	Food-Drug	Textiles	P & P	Constr.	Oth.Ind.	TOTAL	Energy Sector	Non-energyuse
AUSTRIA	1395.6	20119.9	2326.0	35122.6	11630.0	1046.7	4070.5	2093.4	2209.7	2791.2	348.9	83154.5	22911.1	16282
BELGIUM	5640.6	55789.1	4058.9	25295.3	12118.5	453.6	8676.0	3163.4	4291.5	6256.9	10990.4	136733.9	26655.96	36390.27
DENMARK	6908.2	2081.8	0.0	3628.6	7292.0	325.6	7873.5	895.5	2046.9	3186.6	2919.1	37157.9	8257.3	3837.9
FINLAND	9885.5	10350.7	1860.8	10001.8	11281.1	1163.0	4652.0	581.5	42682.1	6280.2	15584.2	114322.9	51637.2	18491.7
FRANCE	33878.2	80607.5	20410.7	63081.1	51986.1	6745.4	46601.4	10699.6	27237.5	44333.6	48578.5	434159.5	104390.88	148794.22
GERMANY	24202.0	159645.0	30238.0	91702.6	58208.2	7885.1	36250.7	13362.9	25958.2	42309.9	25586.0	515348.6	128139.34	213259.31
GREECE	11327.6	3396.0	5373.1	3058.7	14735.2	1023.4	3791.4	2523.7	1570.1	569.9	6105.8	53474.7	12118.46	6361.61
IRELAND	2384.2	918.8	2337.6	2954.0	953.7	221.0	4175.2	569.9	255.9	1430.5	3884.4	20085.0	1907.32	7292.01
ITALY	33424.6	84131.4	9676.2	84712.9	84712.9	1616.6	24388.1	22969.3	21224.8	38634.9	44577.8	450069.4	85364.2	115032.33
LUXEMBOURG	139.6	15153.9	0.0	988.6	372.2	23.3	104.7	221.0	0.0	360.5	1872.4	19236.0	360.53	232.6
NETHERLANDS	38646.5	22515.7	6291.8	64604.7	10874.1	360.5	18747.6	1674.7	7710.7	9455.2	4163.5	185044.9	62906.67	106391.24
PORTUGAL	5303.3	3070.3	988.6	4826.5	11618.4	476.8	3651.8	5535.9	3977.5	1639.8	4756.7	45845.5	7652.54	24271.81
SPAIN	19515.1	43984.7	11490.4	33936.3	36890.4	3105.2	18910.4	10815.9	13386.1	14281.6	7571.1	213887.3	54940.12	67988.98
SWEDEN	6280.2	17677.6	3372.7	8141.0	15235.3	3372.7	5698.7	814.1	60127.1	10583.3	7908.4	139211.1	145026.1	7326.9
Un. KINGDOM	13781.6	75699.7	14363.1	81096.0	41298.1	3256.4	41670.3	12060.3	22632.0	56475.3	56580.0	418912.6	149992.11	112566.77
TOTAL	212712.7	595142.0	112787.7	513150.5	369206.0	31075.4	229262.2	87981.0	235309.8	238589.5	241427.2	2653931.1	862259.83	884519.65
Proportion %		22.4	4.2	19.3	13.9	1.2	8.6	3.3	8.9	9.0	9.1	100.0		

Source: Eurostat and IEA

Table 66: 1990 electricity use in agriculture, industry and the energy sector (in GWh)

Electricity delivered	AGRICULT.	Ir-Steel	NF-Met.	Chemical	BldgMat	Mining	Food-Drug	Textiles	P & P	Constr.	Oth.Ind.	TOTAL INDUSTRY	Energy Sect.
AUSTRIA	1320	1962	2149	3149	3992	470	1130	692	3630	821	177	18172	6974
BELGIUM		5136	2106	9875	5053	333	2793	1694	2117	699	717	30523	9138
DENMARK	2883	713		1726	2160		2257	268	680	633	293	8730	3528
FINLAND	1000	1858	1472	3655	2645	590	1300	285	18430	1615	668	32518	6077
FRANCE	2106	11643	10539	26791	28013	3663	13797	4241	9385	6024	560	114666	72805
GERMANY	7223	27365	19858	62496	37771	6453	12053	7105	16948	4159	22271	216479	95514
GREECE	1558	1002	3315	1381	2355	282	710	1072	505	112	1375	12109	7242
IRELAND		237	426	579	909	101	1256	228	111	138	500	4485	2647
ITALY	4228	19409	6160	25975	29258	1265	7498	9773	7123	3817	561	110839	37462
LUXEMBOURG	82	1190		561	364	21	58	218			205	2617	1182
NETHERLANDS	1847	2268	5287	11633	5081	113	4643	517	2904	676	105	33237	7555
PORTUGAL	266	655	86	2330	2941	165	1197	2290	1367	756	432	12219	4993
SPAIN	3538	9534	8138	10320	14323	1673	5773	3824	3979	2212	3503	63279	25522
SWEDEN	1462	4760	2736	6487	8839	2246	2814	418	20471	3053	2452	53876	24472
United KINGDOM	3844	9071	6714	18193	28410		10940	3032	7977	1279	15026	100642	56512
TOTAL	31357	96803	68986	185151	172114	17375	68219	35657	95627	25994	48845	814391	361623
TOTAL ENERGY	212713	595142	112788	513150	369206	31075	229262	87981	235310	238589	241427	2866644	862260
% Electricity	15	16	61	36	47	56	30	41	41	11	20	28	42

Table 67: 1990 heat delivered in agriculture, industry and the energy sector

HEAT Del.	AGRICULT.	Ir-Steel	NF-Met.	Chemical	BldgMat	Mining	Food-Drug	Textiles	P & P	Constr.	Oth.Ind.	TOT. INDUSTRY
AUSTRIA	75.6	18157.9	177.0	31973.6	7638.0	576.7	2940.5	1401.4	189.7	1970.2	171.9	65272.5
BELGIUM	5640.6	50653.1	1952.9	15420.3	7065.5	120.6	5883.0	1469.4	2174.5	5557.9	10273.4	106210.9
DENMARK	4025.2	1368.8		1902.6	5132.0	325.6	5616.5	627.5	1366.9	2553.6	2626.1	25544.9
FINLAND	8885.5	8492.7	388.8	6346.8	8636.1	573.0	3352.0	296.5	24252.1	4665.2	14916.2	80804.9
FRANCE	31772.2	68964.5	9871.7	36290.1	23973.1	3082.4	32804.4	6458.6	17852.5	38309.6	48018.5	317397.5
GERMANY	16979.0	132280.0	10380.0	29206.6	20437.2	1432.1	24197.7	6257.9	9010.2	38150.9	3315.0	291646.6
GREECE	9769.6	2394.0	2058.1	1677.7	12380.2	741.4	3081.4	1451.7	1065.1	457.9	4730.8	39807.7
IRELAND	2384.2	681.8	1911.6	2375.0	44.7	120.0	2919.2	341.9	144.9	1292.5	3384.4	15600.0
ITALY	29196.6	64722.4	3516.2	58737.9	55454.9	351.6	16890.1	13196.3	14101.8	34817.9	44016.8	335002.4
LUXEMBOURG	57.6	13963.9		427.6	8.2	2.3	46.7	3.0		360.5	1667.4	16537.0
NETHERLANDS	36799.5	20247.7	1004.8	52971.7	5793.1	247.5	14104.6	1157.7	4806.7	8779.2	4058.5	149970.9
PORTUGAL	5037.3	2415.3	902.6	2496.5	8677.4	311.8	2454.8	3245.9	2610.5	883.8	4324.7	33360.5
SPAIN	15977.1	34450.7	3352.4	23616.3	22567.4	1432.2	13137.4	6991.9	9407.1	12069.6	4068.1	147070.3
SWEDEN	4818.2	12917.6	636.7	1654.0	6396.3	1126.7	2884.7	396.1	39656.1	7530.3	5456.4	83473.1
United KINGDOM	9937.6	66628.7	7649.1	62903.0	12888.1	3256.4	30730.3	9028.3	14655.0	55196.3	41554.0	314426.6
TOTAL	181355.7	498339.0	43801.7	327999.5	197092.0	13700.4	161043.2	52324.0	141292.8	212595.5	192582.2	2022125.8

Table 68: 1990 repartition of delivered energy by energy quality in agriculture and industry

%	AGRICULT.	Ir-Steel	NF-Met.	Chemical	BldgMat	Mining	Food-Drug	Textiles	P & P	Constr.	Oth.Ind.		
POWER (Elect.)	15	16	61	36	47	56	30	40	40	11	20		
HEAT>1200°C		60		5	10	24				20			
HEAT 200-1200°		24	39	34	33	20				9	5		
HEAT <200°C	85			25	10		70	60	60	60	75		
TOTAL	100	100	100	100	100	100	100	100	100	100	100		
E-15 /GWh	AGRICULT.	Ir-Steel	NF-Met.	Chemical	BldgMat	Mining	Food-Drug	Textiles	P & P	Constr.	Oth.Ind.	TOTAL	SHARE
POWER (ELECT.)	31357.0	95222.7	68800.5	184734.2	173526.8	17402.2	68778.7	35192.4	94123.9	26244.8	48285.0	812311.2	0.31
HEAT>1200°C		357085.2		25657.5	36920.6	7458.1				47717.9		474839.3	0.18
HEAT 200-1200°		142834.1	43987.2	174471.2	121838.0	6215.1				21473.1	12071.4	522889.9	0.20
HEAT <200°C	181356.0			128287.6	36920.6		160483.5	52788.6	141185.9	143153.7	181070.4	843890.2	0.32
TOTAL	212713.0	595142.0	112787.7	513150.5	369206.0	31075.4	229262.2	87981.0	235309.8	238589.5	241427.2	2653931.1	

Table 69: 1990 end-use electricity in the agriculture and industry sectors (in GWh)

Electricity end-use	AGRICULT.	Iron-steel	NF-metal	Chemical	Bldg.mat.	Mining	Food-Drug	Textiles	Paper,pulp	Constr.	Oth.Ind.	TOTAL IND.
AUSTRIA	726.0	1667.7	1826.7	2676.7	3393.2	399.5	960.5	588.2	3085.5	697.9	150.5	15446.2
BELGIUM		4365.6	1790.1	8393.8	4295.1	283.1	2374.1	1439.9	1799.5	594.2	609.5	25944.6
DENMARK	1585.7	606.1		1467.1	1836.0		1918.5	227.8	578.0	538.1	249.1	7420.5
FINLAND	550.0	1579.3	1251.2	3106.8	2248.3	501.5	1105.0	242.3	15665.5	1372.8	567.8	27640.3
FRANCE	1158.3	9896.6	8958.2	22772.4	23811.1	3113.6	11727.5	3604.9	7977.3	5120.4	476.0	97466.1
GERMANY	3972.7	23260.3	16879.3	53121.6	32105.4	5485.1	10245.1	6039.3	14405.8	3535.2	18930.4	184007.2
GREECE	856.9	851.7	2817.8	1173.9	2001.8	239.7	603.5	911.2	429.3	95.2	1168.8	10292.7
IRELAND	0.0	201.5	362.1	492.2	772.7	85.9	1067.6	193.8	94.4	117.3	425.0	3812.3
ITALY	2325.4	16497.7	5236.0	22078.8	24869.3	1075.3	6373.3	8307.1	6054.6	3244.5	476.9	94213.2
LUXEMBOURG	45.1	1011.5		476.9	309.4	17.9	49.3	185.3			174.3	2224.5
NETHERLANDS	1015.9	1927.8	4494.0	9888.1	4318.9	96.1	3946.6	439.5	2468.4	574.6	89.3	28251.5
PORTUGAL	146.3	556.8	73.1	1980.5	2499.9	140.3	1017.5	1946.5	1162.0	642.6	367.2	10386.2
SPAIN	1945.9	8103.9	6917.3	8772.0	12174.6	1422.1	4907.1	3250.4	3382.2	1880.2	2977.6	53787.2
SWEDEN	804.1	4046.0	2325.6	5514.0	7513.2	1909.1	2391.9	355.3	17400.4	2595.1	2084.2	45794.6
United KINGDOM	2114.2	7710.4	5706.9	15464.1	24148.5		9299.0	2577.2	6780.5	1087.2	12772.1	85545.7
TOTAL	17246.4	82282.6	58638.1	157378.4	146296.9	14768.8	57986.2	30308.5	81283.0	22094.9	41518.3	692232.4

Table 70. 1990 End-use process heat in agriculture, industry and energy sector, GWh/y

Heat end-use	AGRICULT.	Iron-steel	NF-metals	Chemical	BldgMat	Mining	Food-Drug	Textiles	Paper,pulp	Constr.	Oth.Ind.	TOTAL IND.
AUSTRIA	45.4	12710.5	123.9	22381.5	5346.6	403.7	2058.4	981.0	132.8	1379.1	120.3	45637.8
BELGIUM	3384.3	35457.2	1367.0	10794.2	4945.8	84.4	4118.1	1028.6	1522.1	3890.6	7191.3	70399.3
DENMARK	2415.1	958.1		1331.8	3592.4	227.9	3931.6	439.3	956.8	1787.5	1838.3	15063.7
FINLAND	5331.3	5944.9	272.2	4442.8	6045.3	401.1	2346.4	207.6	16976.5	3265.6	10441.3	50343.6
FRANCE	19063.3	48275.2	6910.2	25403.1	16781.2	2157.7	22963.1	4521.0	12496.7	26816.7	33613.0	199937.7
GERMANY	10187.4	92596.0	7266.0	20444.6	14306.0	1002.5	16938.4	4380.5	6307.1	26705.7	2320.5	192267.3
GREECE	5861.8	1675.8	1440.6	1174.4	8666.1	519.0	2157.0	1016.2	745.5	320.5	3311.5	21026.7
IRELAND	1430.5	477.2	1338.1	1662.5	31.3	84.0	2043.4	239.3	101.4	904.7	2369.1	9251.1
ITALY	17518.0	45305.7	2461.3	41116.5	38818.4	246.1	11823.1	9237.4	9871.2	24372.5	30811.8	214064.0
LUXEMBOURG	34.5	9774.7		299.3	5.7	1.6	32.7	2.1		252.4	1167.2	11535.6
NETHERLANDS	22079.7	14173.4	703.4	37080.2	4055.1	173.3	9873.2	810.4	3364.7	6145.4	2841.0	79220.0
PORTUGAL	3022.4	1690.7	631.8	1747.5	6074.2	218.3	1718.4	2272.1	1827.3	618.7	3027.3	19826.2
SPAIN	9586.3	24115.5	2346.7	16531.4	15797.2	1002.5	9196.2	4894.3	6585.0	8448.7	2847.7	91765.2
SWEDEN	2890.9	9042.3	445.7	1157.8	4477.4	788.7	2019.3	277.3	27759.3	5271.2	3819.5	55058.4
United KINGDOM	5962.5	46640.1	5354.3	44032.1	9021.7	2279.5	21511.2	6319.8	10258.5	38637.4	29087.8	213142.3
TOTAL	108813.4	348837.3	30661.2	229599.6	137964.4	9590.3	112730.2	36626.8	98905.0	148816.8	134807.5	1288539.1

Table 71. Total energy end-use in agriculture and industry (GWh/y)

TOTAL*	AGRICULT.	Iron-steel	NF-Met.	Chemical	BldgMat	Mining	Food-Drug	Textiles	Paper&P	Constr.	Oth.Ind.	TOTAL IND.
AUSTRIA	771.4	14378.2	1950.6	25058.2	8739.8	803.2	3018.9	1569.2	3218.3	2077.0	270.8	61084.0
BELGIUM	3384.3	39822.8	3157.1	19187.9	9240.9	367.4	6492.1	2468.5	3321.6	4484.7	7800.8	96343.8
DENMARK	4000.8	1564.2		2798.9	5428.4	227.9	5850.0	667.1	1534.8	2325.6	2087.3	22484.2
FINLAND	5881.3	7524.2	1523.4	7549.5	8293.5	902.6	3451.4	449.8	32642.0	4638.4	11009.1	77983.9
FRANCE	20221.6	58171.7	15868.3	48175.4	40592.2	5271.2	34690.5	8125.9	20474.0	31937.1	34089.0	297403.8
GERMANY	14160.1	115856.3	24145.3	73566.2	46411.4	6487.5	27183.4	10419.8	20712.9	30240.8	21250.9	376274.4
GREECE	6718.7	2527.5	4258.4	2348.2	10667.9	758.7	2760.5	1927.4	1174.8	415.7	4480.3	31319.3
IRELAND	1430.5	678.7	1700.2	2154.7	803.9	169.8	3111.0	433.1	195.8	1022.0	2794.1	13063.4
ITALY	19843.4	61803.3	7697.3	63195.3	63687.7	1321.3	18196.4	17544.4	15925.8	27617.0	31288.6	308277.2
LUXEMBOURG	79.6	10786.2		776.1	315.1	19.4	82.0	187.4		252.4	1341.5	13760.1
NETHERLANDS	23095.5	16101.2	5197.3	46968.2	8374.0	269.3	13819.7	1249.9	5833.1	6720.0	2930.2	107471.5
PORTUGAL	3168.7	2247.5	704.9	3728.0	8574.0	358.5	2735.8	4218.6	2989.3	1261.3	3394.5	30212.4
SPAIN	11532.2	32219.4	9264.0	25303.4	27971.7	2424.6	14103.2	8144.7	9967.1	10328.9	5825.2	145552.4
SWEDEN	3695.0	13088.3	2771.3	6671.8	11990.6	2697.8	4411.2	632.6	45159.6	7866.3	5903.7	100853.0
United KINGDOM	8076.7	54350.4	11061.2	59496.1	33170.2	2279.5	30810.2	8897.0	17038.9	39724.5	41859.9	298688.0
TOTAL	126059.8	431119.8	89299.3	386978.0	284261.3	24359.0	170716.4	66935.2	180187.9	170911.7	176325.8	1980771.4

Table 72: 1990 repartition of end-use energy by energy quality in agriculture and industry

%	AGRICULT.	Iron-steel	NF-metals	Chemical	BldgMat	Mining	Food-Drug	Textiles	Paper,pulp	Constr.	Oth.Ind.	TOTAL	
Electric Power	14	19	66	41	51	61	34	45	45	13	24	33	
HEAT>1200°C		57		3	6	22				19		15	
HEAT 200-1200°		24	34	32	33	17				8	2	18	
HEAT <200°C	86			24	10		66	55	55	60	74	29	
TOTAL	100	100	100	100	100	100	100	100	100	100	100	94	
EU-15 (GWh/y)	AGRICULT.	Iron-steel	NF-metals	Chemical	BldgMat	Mining	Food-Drug	Textiles	Paper,pulp	Constr.	Oth.Ind.	TOTAL IND.	%
Electric Power	17246	82283	58638	157378	146297	14769	57986	30308	81283	22095	41518	692232	35
HEAT>1200°C		245738		11609	17056	5359				32473		312236	16
HEAT 200-1200°		103099	30661	125116	92483	4231				13673	3527	372789	19
HEAT <200°C	108411			92875	28426		112730	36627	98905	102671	131281	603838	30
TOTAL	126060	431120	89299	386978	284261	24359	170716	66935	180188	170912	176326	1981094	
Proportion (%)		22	5	20	14	1	9	3	9	9	9		

Table 73: 1990 delivered energy to the transport sector in GWh					
E 15 /GWh	ROAD	RAIL	AIR	WATERWAYS	TOTAL
AUSTRIA	56521.80	3837.90	4070.50		64430.20
BELGIUM	74932.09	2058.51	11106.65	1500.27	89597.52
DENMARK	37216.00	1360.71	8141.00	5594.03	52311.74
FINLAND	43147.30	1163.00	5582.40	814.10	50706.80
FRANCE	420668.73	13362.87	45008.10	8338.71	487378.41
GERMANY	514464.68	17165.88	61266.84	7419.94	600317.34
GREECE	45391.89	883.88	14793.36	6570.95	67640.08
IRELAND	18003.24	534.98	4419.40	58.15	23015.77
ITALY	353458.96	7908.40	21910.92	4524.07	387802.35
LUXEMBOURG	10118.10	58.15	1523.53		11699.78
NETHERLANDS	93493.57	1267.67	18759.19	6466.28	119986.71
PORTUGAL	35192.38	965.29	6768.66	500.09	43426.42
SPAIN	205583.51	6163.90	28702.84	19247.65	259697.90
SWEDEN	72454.90	2907.50	9187.70	1744.50	86294.60
United KINGDOM	422308.56	13002.34	78700.21	12920.93	526932.04
TOTAL	2402955.71	72640.98	319941.30	75699.67	2871237.66
Proportion	0.84	0.03	0.11	0.03	
Source: Eurostat anbd OECD					

Table 74: 1990 traffic volume in million vehicle kilometres					
	CARS	BUSES	TRUCKS	Two-WHEELERS	TOTAL
AUSTRIA (1987)	41900.00	547.00	7065.00		49512.00
BELGIUM (1989)	49445.00		7259.00		56704.00
DENMARK	29900.00	500.00	6300.00		36700.00
FINLAND	33430.00	680.00	5640.00		39750.00
FRANCE	314000.00	4000.00	104.00	16500.00	334604.00
GERMANY (Fed.Rep)	401600.00	3600.00	40800.00	7500.00	453500.00
GREECE (1988)	9392.00	483.00	3390.00		13265.00
IRELAND	19271.00	257.00	4677.00	241.00	24446.00
ITALY (1988)	244963.00	4579.00	44668.00	37590.00	331800.00
LUXEMBOURG (1989)	2901.00	47.00	336.00		3284.00
NETHERLANDS	76960.00	590.00	12590.00	2440.00	92580.00
PORTUGAL (1988)		95.00	3070.00		3165.00
SPAIN (1988)	69559.00	1458.00	21800.00	1917.00	94734.00
SWEDEN (1988)	53000.00		6000.00		59000.00
United KINGDOM	329700.00	4300.00	285000.00	6200.00	625200.00
TOTAL	1676021.00	21136.00	448699.00	72388.00	2218244.00
Proportion	0.76	0.01	0.20	0.03	
Source: Int. Road Fed., World Road Statistics 1986-1990					

Table 75: 1990 vehicles in use

	PRIVATE CARS	BUSES	TRUCKS	VANS	TOTAL
AUSTRIA	2991390.00	9402.00	252504.00		3253296.00
BELGIUM	3833294.00	15525.00	150704.00	235673.00	4235196.00
DENMARK (1988)	1654128.00	8093.00	234212.00		1896433.00
FINLAND	1926326.00	9287.00	54269.00	207226.00	2197108.00
FRANCE	23550000.00	70000.00	370000.00	4300000.00	28290000.00
GERMANY (Fed.Rep)	30695082.00	70258.00	1408952.00		32174292.00
GREECE (1988)	1507952.00	19077.00	688894.00		2215923.00
IRELAND	796408.00	5352.00	143166.00		944926.00
ITALY (1988)	25290250.00	75820.00	2115072.00	1107842.00	28588984.00
LUXEMBOURG (1989)	183404.00	734.00	4948.00	6327.00	195413.00
NETHERLANDS	5509000.00	12100.00	115700.00	418000.00	6054800.00
PORTUGAL	1605000.00	11000.00	109000.00	473000.00	2198000.00
SPAIN	12010717.00	45963.00	2339250.00		14395930.00
SWEDEN (1989)	3578042.00	14530.00	294901.00		3887473.00
United KINGDOM	19742000.00	114000.00	501000.00	2246000.00	22603000.00
TOTAL	134872993.00	481141.00	8782572.00	8994068.00	153130774.00

Table 76: 1990 passenger and goods transport

in millions	Passenger-kilomete	Tonne-kilometers
AUSTRIA		
BELGIUM	106.00	34.00
DENMARK	46.00	14.00
FINLAND		
FRANCE	549.00	174.00
GERMANY (Fed.Rep)	641.00	286.00
GREECE (1988)	49.00	20.00
IRELAND	22.00	5.00
ITALY (1988)	562.00	236.00
LUXEMBOURG (1989)		
NETHERLANDS	161.00	31.00
PORTUGAL (1988)	59.00	13.00
SPAIN (1988)	289.00	163.00
SWEDEN (1988)		
United KINGDOM	549.00	205.00
TOTAL	3033.00	1181.00

source: International road federation world road statistics 1986-1990

Table 77: 1990 urban and interurban transport efficiency

P-km/kep	PASSENGERS		t-km/kep	GOODS	
	URBAN	INTERURBAN		URBAN	INTERURBAN
Private car	16.20	33.50	Pick-up <3t	2.40	16.10
Commuter bus	37.80	54.60			
City bus	41.60				
Commuter train	47.60		Full-up train		128.20
Underground	51.60		Single wagon		52.10
RER train	53.10		Combined train		100.00
TER		41.60			
Trains		56.80			
TGV HighSpeedTrain		82.60			
Airplane		19.50			

Source: Ministère de l'environment, France, Pour une politique soutenable des transports, p13.

Table 78: End use estimate for transport sector 1990

E 15 /GWh	ROAD	RAIL	AIR	WATERWAYS	TOTAL	Electricity	OIL
AUSTRIA	42391.35	2686.53	2849.35		47927.23	2255.05	45672.18
BELGIUM	56199.07	1440.96	7774.66	1050.19	66464.87	1061.65	65403.22
DENMARK	27912.00	952.50	5698.70	3915.82	38479.02	179.35	38299.67
FINLAND	32360.48	814.10	3907.68	569.87	37652.13	361.25	37290.88
FRANCE	315501.55	9354.01	31505.67	5837.10	362198.32	7548.00	354650.32
GERMANY	385848.51	12016.12	42886.79	5193.96	445945.37	11617.80	434327.57
GREECE	34043.92	618.72	10355.35	4599.67	49617.65	106.25	49511.40
IRELAND	13502.43	374.49	3093.58	40.71	17011.20	13.60	16997.60
ITALY	265094.22	5535.88	15337.64	3166.85	289134.59	5334.60	283799.99
LUXEMBOURG	7588.58	40.71	1066.47		8695.75	45.05	8650.70
NETHERLANDS	70120.18	887.37	13131.43	4526.40	88665.38	1082.05	87583.33
PORTUGAL	26394.29	675.70	4738.06	350.06	32158.11	263.50	31894.61
SPAIN	154187.63	4314.73	20091.99	13473.36	192067.71	3118.65	188949.06
SWEDEN	54341.18	2035.25	6431.39	1221.15	64028.97	2102.90	61926.07
United KINGDOM	316731.42	9101.64	55090.15	9044.65	389967.86	4490.55	385477.31
TOTAL	1802216.78	50848.69	223958.91	52989.77	2130014.15	39580.25	2090433.90
Proportion	0.85	0.02	0.11	0.02		0.02	0.98

Source: IEA and OECD

Table 79: 1990 per capita delivered energy in the European Union (MWh/y/capita)

	AUT	BE	DK	FIN	FR	GE	GR	EI	IT	LUX	NL	P	SP	SW	UK	TOTAL
Population ('000)	7712	9948	5130	4962	56556	79113	10046	3641	57576	378	14891	10337	38925	8566	57297	365078
Residential, GWh	82457	94901	47450	58034	249580	684891	32680	24190	356460	4303	112230	18143	83387	79898	434497	2363101
MWh/cap	10.7	9.5	9.2	11.7	4.4	8.7	3.3	6.6	6.2	11.4	7.5	1.8	2.1	9.3	7.6	6.5
Service, GWh	9769	33727	11048	10351	322616	339829	8257	8374	51637	2326	20701	6978	39891	46404	140839	1052748
MWh/cap	1.3	3.4	2.2	2.1	5.7	4.3	0.8	2.3	0.9	6.2	1.4	0.7	1.0	5.4	2.5	2.9
Industrial, GWh	83154	136734	37158	114323	434160	515349	53475	20085	450069	19236	185045	45845	213887	139211	418913	2653931
MWh/cap	10.8	13.7	7.2	23.0	7.7	6.5	5.3	5.5	7.8	50.9	12.4	4.4	5.5	16.3	7.3	7.3
Agriculture, GWh	1396	5641	6908	9886	33878	24202	11328	2384	33425	140	38646	5303	19515	6280	13782	212713
MWh/cap	0.2	0.6	1.3	2.0	0.6	0.3	1.1	0.7	0.6	0.4	2.6	0.5	0.5	0.7	0.2	0.6
Transport, GWh	64430	89598	52312	50707	487378	600317	67640	23016	387802	11700	119987	43426	259698	86295	526932	2871238
MWh/cap	8.4	9.0	10.2	10.2	8.6	7.6	6.7	6.3	6.7	31.0	8.1	4.2	6.7	10.1	9.2	7.9
TOTAL, GWh	241206	360601	154876	243301	1527612	2164588	173380	78049	1279393	37705	476609	119695	616378	358088	1534963	9153731
MWh/cap	31.3	36.2	30.2	49.0	27.0	27.4	17.3	21.4	22.2	99.7	32.0	11.6	15.8	41.8	26.8	25.1

Table 80: 1990 distribution of delivered energy by quality

E-15 /GWh	RESIDENTIAL	TERTIARY	TRANSPORT	AGRICULTURE	INDUSTRY	TOTAL	Share (%)
POWER (Electricity)	538741	432256	46565	31357	814391	1863310	20
HEAT >1200°C					474839	474839	5
HEAT 200-1200°C					522890	522890	6
HEAT 20-200°C	146512	131550		181356	843890	1303308	14
HEAT <20°C	1677847	488941				2166788	24
MOBILITY (non-El.)			2824673			2824673	31
TOTAL	2363100	1052747	2871238	212713	2656010	9155808	100
PROPORTION %	26	11	31	2	29	100	

Table 81: 1990 distribution of end-use energy between sectors

EU-15 (GWh/y)	RESIDENTIAL	TERTIARY	TRANSPORT	AGRICULTURE	INDUSTRY	TOTAL	Share (%)
ELECTRICITY	105080	197089	39580	17246	692232	1051227	19
HEAT >1200°C					312236	312236	6
HEAT 200-1200°C					372810	372810	7
HEAT 20-200°C	70733	74984		108813	603493	858023	16
HEAT <20°C	497650	229802				727452	13
MOBILITY (non-El.)			2090434			2090434	39
TOTAL	673463	501875	2130014	126059	1980771	5412182	100
PROPORTION %	12	9	39	2	37	100	

Table 82: Estimated 1990 per capita end-use energy.

	AUT	BE	DK	FIN	FR	GE	GR	EI	IT	LUX	NL	P	SP	SW	UK	TOTAL
POP'000	7712	9956	5130	4962	56556	79113	10046	3641	57576	378	14891	10337	38925	8566	57297	365086
RESID.GWh	22423	26694	13250	16862	74206	193090	9633	6784	97615	1181	30307	5490	25716	26116	124097	673463
MWh/cap	2.9	2.7	2.6	3.4	1.3	2.4	1.0	1.9	1.7	3.1	2.0	0.5	0.7	3.0	2.2	1.8
SERVICE.GWh	4591	16088	5270	4865	153888	162098	3939	3994	24631	1110	9730	3329	19028	22135	67180	501875
MWh/cap	0.6	1.6	1.0	1.0	2.7	2.0	0.4	1.1	0.4	2.9	0.7	0.3	0.5	2.6	1.2	1.4
INDUS. GWh	61084	96344	22484	77984	297404	376274	31319	13063	308277	13760	107471	30212	145552	100853	298688	1980771
MWh/cap	7.9	9.7	4.4	15.7	5.3	4.8	3.1	3.6	5.4	36.4	7.2	2.9	3.7	11.8	5.2	5.4
AGRIC. GWh	776	3384	4001	5881	20222	14160	6719	1430	19843	80	23096	3169	11532	3695	8077	126060
MWh/cap	0.1	0.3	0.8	1.2	0.4	0.2	0.7	0.4	0.3	0.2	1.6	0.3	0.3	0.4	0.1	0.3
TRANSP. GWh	47927	66465	38479	37652	362198	445945	49618	17011	289135	8696	88665	32158	192068	64029	389968	2130014
MWh/cap	6.2	6.7	7.5	7.6	6.4	5.6	4.9	4.7	5.0	23.0	6.0	3.1	4.9	7.5	6.8	5.8
TOTAL GWh	136801	208975	83484	143244	907918	1191567	101228	42282	739501	24827	259269	74358	393896	216828	888010	5412183
MWh/cap	17.7	21.0	16.3	28.9	16.1	15.1	10.1	11.6	12.8	65.7	17.4	7.2	10.1	25.3	15.5	14.8

A Trial Bottom-Up Analysis of the EU-15 Households' Electricity Consumption

Bernd Kuemmel

When we want to know how the electricity demand for certain services, such as refrigeration of food, will evolve in the future, one important factor is the technology level. In this section we have estimated the energy demand reduction potential with regards to todays service levels in households. This establishment of the end-use energy efficiency can tell us how much the energy consumption in todays households would be, had todays most efficient or an even more advanced technology with much better efficiency been used.

An accepted way to come up with such answers is to perform a top-down analysis that uses factors gained from experience. They are themselves highly dependent on the savings potentials one sees with the technologies. Here we shall present a bottom-up analysis of households' electricity consumption patterns in the European Union and an estimate of the energy demand with most efficient technology.

Introduction

Several previous studies have gained insight into the possibility of reducing households' energy demand by improving the energy efficiency of various appliances. Typical examples are the works of Nørgård (1989) who has investigated the elecricity savings potential in the various sectors.

In the "Low Electricity Europe" Study that rather should be called a "High Efficiency Europe" study, Nørgård and Viegand (1994) estimated that a pronounced efficiency strategy would result in vast savings in the electricity consumption in several European countries[28]. Regarding households they made plausible how the introduction of more efficient technologies leads to vast reduction potentials in the electricity demand and that the total potential depends very much on development of the service levels within a community.

In this short paper we present results of a short investigation on the efficiency potential in the 15 por tiempo member states of the European Union[29] (EU-15). We utilize several earlier studies to gain insight into the way the electricity consumption patternscan change. As a large part of the work is based on data that Nørgård and Viegand (1994) have collected, and that we kindly had the opportunity to work with, we shall mention them here and thank them very much for their kind support.

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[28] AT, BE, CH, DE, ES, FI, FR, IT, NL, NO, SE, UK

[29] These are (with their international two character codes in brackets): Austria (AT), Belgium (BE), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU), the Netherlands (NL), Portugal (PO), Sweden (SE) and the United Kingdom (UK).

Background

It is not common to find more detailed data on households electricity consumption in statistics. Such information normally does not make its way into the statistical year books of the statistical offices of the member states neither are they readily available in eg Eurostat publications. One noteworthy exception from this rule is a 1993 publication of the Eurostat office (ES, 1993). It contains more specific data for ten of the EU-15 member states.

When we mean households' electricity consumption patterns we think of an aggregate of the total electricity demand into at least the following four groups

- cooking,
- space heating,
- hot water,
- appliances.

Cooking includes baking, too. Regards the use of microwaves there is a slight chance that the official statistics will include this technology in the appliances-post, even though it belongs into the cooking department. Space heating contains all forms of electricity powered heating systems, normal resistancy heating and heat pumps, too. The same is true for hot water generation.

The post appliances consists of several technologies like: lighting, TV- and radio-sets, other electronic devices, refrigerators and freezers, food processors, electric shavers and hair driers, and of course: clothes driers, dish washers and washing machines. (Unfortunately some countries' data exclude the warm water preperation in the last two technologies and include it in the warm water generation post. This can normally be assessed by a data comparison.)

The present day situation

How much energy the different technologies use per year is described here. Using washing machines as an example ask a representative number of people about what kind of washing machine they have, how often they use it, at what temperature and which programmes (cycles) that they use. This data has to be combined with the knowledge, or at a least qualified guess, of each of the washing machines' energy demand for each washing cycle. The result will be a good estimate of the national or utility concession area distribution of the electricity consumption. One example is a field test performed by Nørgård (1989) with 200 participating households in Denmark.

While the approach described just above immediately sounds authoritive we have to beware of its shortcomings. One is that it might be difficult to reach a representative part of the population. Another that there in fact does not exist a proper data base for each kind of appliance that is used. So the aggregate will contain elements of insecurity. On the other hand the only thing that is certain to a reasonably high degree is the number of kilowatthours the utilites sell to the customers. This fixes the margins that buttom up analyses may not either under- or overestimate.

With regards the appliances' electricity demand there are both cultural and technological differences. Some people traditionally wash clothes in cold water, Even when such differences do not perturb the statistics, technological differences may. It has been argued that the manufacturors and grossists in some countries have a laissez faire attitude, partly helped by the populations ignorance of differences in energy demands, that leads to unnecessarily high electricity consumption with the customers (Herring, 1994).

Data analysis

In this study we had explicit data for many member states of the EU-15 members. The data comprised the specific electricity consumption of the fourteen most used technologies[30] and a post called miscalleneous. We had complete data on the penetration rate and specific elecricity consumption for each of the technologies from Nørgård and Viegand (1994) for DE, DK, FR, IT, NL, SE and UK. From a Eurostat report (ES, 1993) we gained the penetration data for another four countries (BE, GR, IE, PO) for most technologies. With a few exceptions we had complete data for all members of the EU-15.

We used data from countries from which we had more complete data for other countries that we considered had similar technological and penetration levels, but where we lacked data. Spain is one example where we used data from Portugal and Italy for to create a more complete database, the reason is that the other two countries are southern european with supposedly similar lifestyles and technology level. Austria is another one where lacking specific data we used data from Denmark. We do not claim to have produced excellent data with this method. Apparently there are discrepancies between Eurostat's and the IEA data. With regards Germany our data originally only included the old federal states, and the penetration rates are probably lower in the five new ones.

Results

When we use the data on penetration rate and specific consumption for the fifteen technologies we gain electricity demand data that are similar with the data given by IEA (figure 28). Our calculations both under- and overestimates Eurostat's data.

However the distribution of the households' electricity demand in the four categories cooking, space heating, warm water and appliances is not replicated so well. Figure 29 compares the split into the four groups for Belgium, Denmark, Greece,Italy, the Netherlands and the United Kingdom. We see that the while the total figures for households electricity consumption are nearly correct the consumption patterns are not.

This could be caused by the simplifications that we applied. First the keys that we have used with regards the specific energy demand or the penetration rate of the technologies might be wrong. This distorts the picture but it is interesting to see that the total energy demand in the different countries still is reached. An interesting conclusion would be: as it is difficult to esta-

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[30] The technologies are: refrigerators, freezers, combined refrigerator-freezers, washing machines, clothes driers, dishwashers, lighting, electronics (mostly TV), cooking, space heating, ventilation, space cooling, warm water and miscalleneous.

blish the energy patterns of households electricity consumption the official data might bear marks of the simplifications that were used by the statistical offices of the member countries.

Scenario description

If we consider that the official data on the penetration rates for the technologies are correct they allow us to calculate what the usage of the best available technology on the European markets today would have meant for the household electricity demand and energy charges. This approach is justified by the conversion trend that has started in the EU.

The specific consumption of most appliances is assumed to be the same in each of the three regions that Europe was divided into: Southern Europe (ES, GR, IT, PO), Western Europe (AT, BE, DE, FR, IE, LU, NL, UK) and Northern Europe (DK, FI, SE). But there are some exceptions:

In Southern Europe the demand for space heating is much lower than in the other two regions. On the other hand the demand for space cooling arises. For both technologies current data for the specific consumption in Italy has been used.

Due to the warmer climate in Souther Europe the specific electricity consumption of refrigerators and combined freezer/refrigerators is assumed to be increased by 20 per cent and that of freezers by 10 per cent compared to the rest of Europe[31].

We have assumed the electricity consumption of electrical cookers to be 25 % higher in the Southern than the other regions of Europe for cultural reasons[32].

The demand for space heating given by the Nørgård data for Denmark is taken for Northern Europe while for Western Europe it is assumed that the heat demand will be less by 20 %.

The electricity demand for space heating in the Netherlands will not change in the future from todays value of 25 kWh/yr and household.

The electricity demand for lighting is 10 % lower in Southern Europe due to longer daylight.

For space heating the results of better insulation nearly halve the specific elecricity consumption compared to present values[33]. Our figures for space heating are conservative as we do not assume electrical resistance heating to be substituted by other forms of low quality

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[31] Interview with Jørgen Nørgård, october 25, 1995.

[32] Personal communication with Bent Sørense, october 25, 1995.

[33] As also explained in Nørgård and Viegand (1994).

energy, like solar collectors. For the best efficient technology we do include heat pumps in areas with mild winters though. A similar development is assumed to take place with the hot water preparation.

Discussion

If we assume that todays average technology was substituted with the most efficient on the market today this would mean energy savings in the EU-15 households of 45 %. The substitution of todays technology with the more efficient one that is currently in the research and development phase would result in about a third of the total households' electricty consumption. This does not imply changes in the life styles of the people.

This short analysis supports the notion that a reduction by a factor three is possible in the household electricity demand. A factor of four is often mentioned in discussions on energy systems. Our analysis principially does not conflict with this. Further savings in electricity consumption can be gained by substituting electricity with other energy sources. For example electrical heating coils in washing machines and dish washers can be abolished when warm water is provided via cental heating systems. Neither have we substituted electrical resistance space heating with heat pumps or biomass fired central heating systems.

In the longer run (2010) todays best available technology will become the average stock in European households[34]. Technology much more efficient than the best on the market today, but not yet marketed, will be the standard in 2030 and 2050. This assumption is reasonable as we already have seen a tendency towards more efficient technologies (Nørgård, 1989) although energy prices have not changed much in real prices.

It is fair to assume an average life time of about 15 years for most of the technologies. Therefore the total stock used in the households today will be refreshed by the year 2010. So the best known technology of today will very likely be the standard equipment of European households at that time. Even more efficient technology on the drawing boards or in the reasearch laboratories today means that all the services fulfiled today will be so in 2050 at a quarter of todays electricity demand.

The service level in several member states of the EU definitely will rise to reach a more even distribution of life styles and possibilities in the EU-15. Chances are that energy efficient appliances will gain from this development. It is driven by the wish of the people to improve the lot of all Europeans. Energy efficiency is a part of the peoples' attitudes on energy consumption as well as on material well-being. Both can not be separated.

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[34] There has been observed a downward trend in the specific electricity consumption of household appliances since the early 1970s. The levels reached today are still far from the technologically feasible (Nørgård, 1989), so that further efficiency gains can be expected in the future.

Figure 28. Comparison of total household electricity consumption data from our bottom up analysis with Eurostat data.

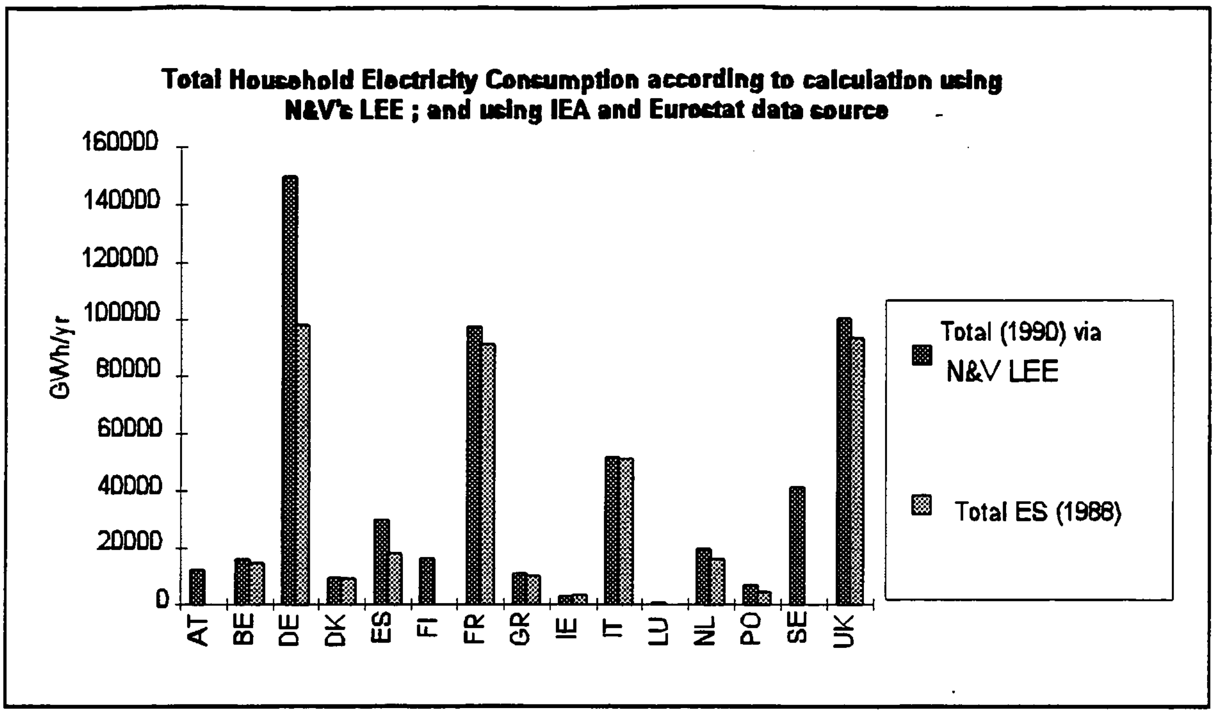
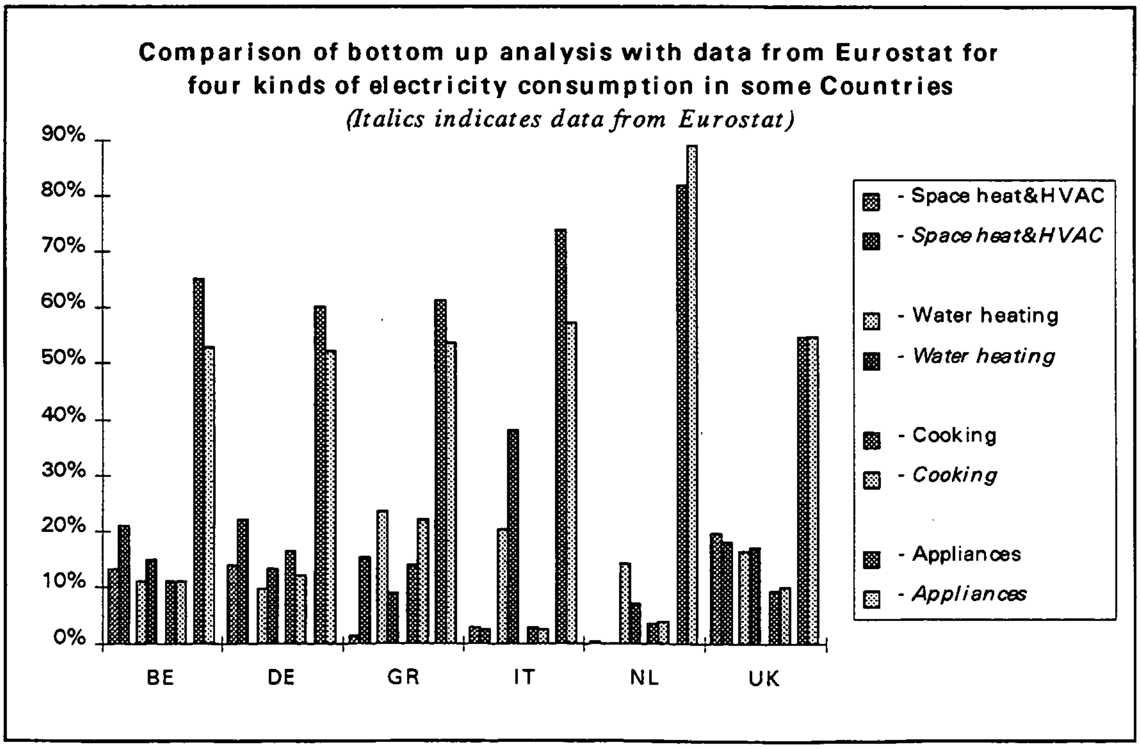


Figure 29. Comparison of the household electricity consumption data for the four groupings from our bottom up analysis with Eurostat data.



Fair market scenario demand

Stefan Krüger Nielsen

Household sector.

Possible future electricity savings in the household sector.

Our assumptions about the potential future electricity savings in households due to implementation of energy efficient electrical appliances are based on Jørgen Nørgaards estimates in the report "Low Electricity Europe"[1]. Nørgaard's estimates are rather conservative in the sense that he has only estimated the efficiency gains that will be possible today or in the near future. He operates with three categories of technology: Average technology used, best technology sold on the market today and advanced efficiency technology which is close to commercialization today, but still only exist as prototypes in the laboratories. In the long term much higher efficiency gains can be applied to the electric appliances, so we obviously choose a quite conservative approach as we assume that the intensity index possible already in 2010 will not be improved further in our scenario for 2050. In the household sector we assume that the recent stock of appliances will be fully substituted by advanced efficiency electric appliances within 2010, after this point we do not expect further efficiency gains.

Table 83: Intensity indexes for household appliances [Intensity of existing stock in 1987=1].

Type of appliances etc.	2000	2010	2020	2050
Refrigerator	0,25	0,14	0,14	0,14
Freezer	0,35	0,2	0,2	0,2
Comb. ref./freezer	0,55	0,2	0,2	0,2
Washing machine	0,6	0,3	0,3	0,3
Dishwasher	0,62	0,33	0,33	0,33
Clothes drier	0,67	0,35	0,35	0,35
Electric cooker	0,57	0,4	0,4	0,4
Heat distribution	0,25	0,13	0,13	0,13
Ventilation	0,55	0,15	0,15	0,15
Lighting	0,35	0,2	0,2	0,2
Electronic	0,5	0,25	0,25	0,25
Space heating	0,5	0,25	0,25	0,25
Electric hot water	0,5	0,35	0,35	0,35
Miscellaneous	0,7	0,5	0,5	0,5

The intensity indexes in 2000 can be reached assuming that all existing appliances are substituted by the most efficient technologies sold on the market in 1987. The intensity indexes for 2010, 2020 and 2050 can be reached if all existing appliances are substituted by advanced efficiency appliances.
Source: Jørgen Nørgaard "Low Electricity Europe", European Environmental Bureau, 1994.

As seen in the figure below all the investments in low electricity appliances needed to reach the intensity indexes shown in table 83 are relatively low and cost competitive to the recent danish consumer price on electricity, i.e. the cost of saving one kilowatt hour electricity is lower than the price of buying one for all the efficiency measures included in this study. However at a certain point the price of attaining a higher efficiency will rise steeply if further efficiency gains should be reached with the technology known at present. Still it is very likely that even more efficient appliances can be constructed at lower costs in the future as new technologies and production methods emerge.

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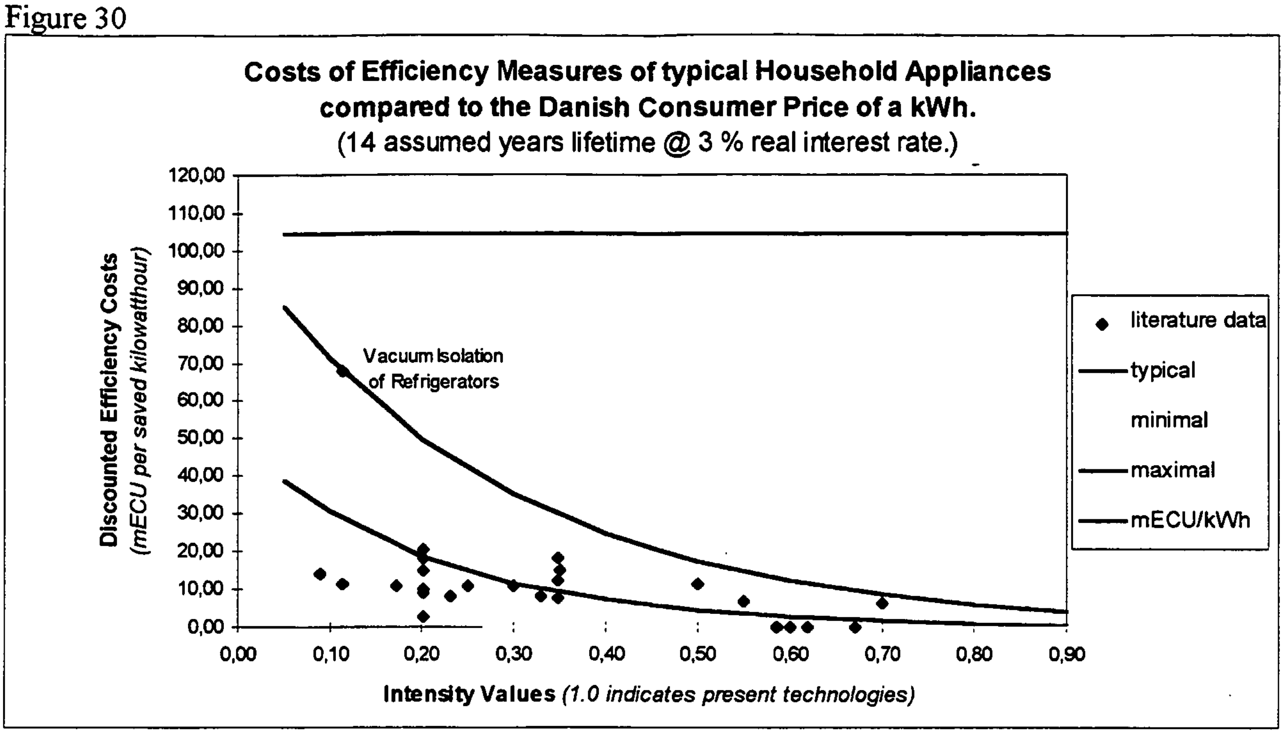
[1] Nørgaard, Jørgen, "Low Electricity Europe", European Environmental Bureau, 1994.

Figure 30



Source: Bernd Kuemmel, "Work paper for the 'Long Term Integration project" 'Possible efficiency advancements in households and public and private service sectors", Institute II, Roskilde University, Denmark, 1995.

Future demand for services from electric appliances, electric heaters and electric boilers and cookers in households.

The demand for electricity is assumed to be smaller in the future as each appliance becomes more efficient. However, we expect that appliances which we already know today will have a higher penetration rate in the future, i.e. a higher percentage of households will have and use each appliance. Besides this we expect that many new domestic appliances will be invented in the future and that many households will use these. Finally, we expect the demand for energy services from electric appliances to grow due to an anticipated growth in the total amount of households in EU in the future. The use of appliances is assumed to grow proportionally with the growth in the total number of households even though this might not be quite true as fewer people live in each household. Some of the reasons for the decreasing number of persons per household is, according to Eurostat, that less children are born, less grown up children live with their parents and more elderly people live in elderly- and nursery homes. It is significant that the southern countries (GR, S and P) and Ireland have the highest numbers of people per household. We assume that the growth in the total number of households will be evenly distributed among the countries. If the cultural differences seen today will change there might be the possibility that countries with a high amount of persons per household will actually move towards the life style in Scandinavia. However the opposite might also be true.

Table 84: Average size of households, 1st of january [persons per household].

	1980	1981	1982	1984	1985	1990	1991
Belgium		2,7					2,5
Denmark	2,5				2,4	2,3	2,2
Germany BRD	2,5				2,3	2,3	2,3
DDR	2,5					2,4	
Greece		3,1					3,1
Spain		3,5			3,5	3,4	3,3
Finland*						2,4	
France			2,7	2,7		2,6	2,6
Ireland	3,7				3,5	3,3	3,3
Italia		3			3	2,7	2,8
Luxembourg		2,8				2,7	2,6
Netherlands	2,8				2,6	2,4	2,4
Portugal	3,3				3,3	3,2	3,1
United Kingdom	2,7				2,6	2,5	2,5
Austria	2,7				2,7	2,6	2,5
Sweden	2,3				2,2	2,1	

Source: 'Statistics on housing in the European Community", Commission of the European Communities, 1993. *Statistical yearbook of Finland.

Table 85: Households, 1st of january [in thousands].

	1980	1981	1985	1986	1988	1990	1991	Growth 1981-91
Belgium		3608					3953	9,6%
Denmark		2030		2148		2229	2251	10,9%
Germany BRD		25100		26739		28175		10,2%
DDR		6510				6652		
Greece		2974		3234			3344	12,4%
Spain		10665		11354		11806	12040	12,9%
Finland*					1982	2009		
France	19044			20657		21535		13,1%
Ireland		911		976			1029	13,0%
Italia		18632		20118				
Luxembourg		128		134			145	13,3%
Netherlands		5006		5620		5955	6135	22,6%
Portugal		2924					3176	8,6%
United Kingdom		20700		21600		22400	22800	9,7%
Austria		2764		2826		2937	3013	9,0%
Sweden	3498		3670	3830				9,0%

Source: 'Statistics on housing in the European Community", Commission of the European Communities, 1993. *Statistical yearbook of Finland.

It is important that the future growth in services derived from electrical appliances does not eat up the savings which has been accomplished by using more efficient appliances. We assume, that the total amount of energy services derived from electric appliances will be doubled in 2050 compared to 1990. There are areas which might exceed this drastically. One such area could be the future demand for space cooling in central and southern Europe. If the demand for space cooling grow by more than the considered 100% in our scenario we assume that it will be supplied by electricity derived from additional renewable sources which are not considered in our scenario, e.g. from additional sea based wind turbines or centralized solar power plants. However it will be preferable if houses are built with considerations for passive climatic heat gains in the future.

Low- and high temperature heat savings in households.

Our assumptions for the possible efficiency gains of different technologies for low- and high temperature heat end-uses are a bit more pragmatic as we have not got as detailed studies of all technologies as we have for electric appliances in Nørgaards study. We do not have accurate data describing the nature of building shells and their insolation and windows or the heat sources providing the services. What we have good data for is the availability of different heat sources and the repartition on all energy uses in households in 1988-89 in 11 of the 15 EU countries[2].

We assume that an overall intensity index of 0,25 can be reached for non-electric water heating, non-electric space heating and non-electric cooking, i.e. a 75% reduction in the energy consumption per service unit for these end-uses compared to 1990.

One example that can justify that such substantial savings can be obtained is the development in the Danish domestic sector since the oil crisis in 1973. The Danish government has done a lot to support energy conservation in buildings. Focus has primarily been aimed at improving insolation in existing and new houses and by shifting the heat sources. The resulting efficiency gains has reduced the demand for space heating per square meter in buildings by 50%[3] and the energy demand for water heating by 50%[4] in ten years between 1973 and 1983. In the years since then the improvements has not been as drastic, but one major goal of the danish energy plan '2000" is to achieve a further reduction of 50% in the demand for low temperature heating in buildings before 2000, compared to 1992[5]. This example shows that government actions and restrictive building regulations can actually induce substantial energy savings. Sørensen[6] estimates that the investments for halving the residential heat use in Denmark was recovered within a period of ten years on average. However future investments might have longer capital pay back times.

A similar development took place in Sweden in the period between 1970 and 1990. The average energy demand in the swedish domestic sector fell from 183 kWh/m^2 to 102 kWh/m^2 on average as a result of retrofitting of old houses, demolition of old buildings and construction of new more energy efficient buildings. Christiansson et.al[7] estimate that in the near future it will be possible to construct energy efficient Swedish single family houses which only use 25kWh/m^2 without increasing the life cycle cost of the buildings.

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[2] Eurostat "Energy consumption in households", 1993. Unfortunately this report only have data for the EU12 excluding Luxembourg.

[3] Christophersen, Erik: 'Energirigtige bygninger - besparelser eller mere kvalitet", in 'Vejen frem for dansk byggeri", SBI-rapport nr. 219, Statens Byggeforskningsinstitut, 1992.

[4] Løppenthin, Brita: "Energi år 2040 - en bæredygtig fremtid", rapporten resumerer en konference tilrettelagt af statens byggeforskningsinstitut i juni 1989, Energistyrelsens forskningsudvalg for energianvendelse i bygninger.

[5] Energistyrelsen: "Energiforbrug i bygninger - baggrundsrapport nr.1 til ENERGI 2000", 1990.

[6] Sørensen, Bent, "Energy and greenhouse strategies in Scandinavia", Invited paper for workshop on "Energy and the greenhouse effect", Sydney, 1990.

[7] Christiansson, Lena et.al., "End-use energy efficiency and analysis" in "Expanding environmental perspectives - lessons of the past prospects for the future", Department of Environmental and Energy Systems Studies, Lund University Press, 1994.

In Germany the Enquette Kommission presents different estimates of the possible efficiency gains in the specific low temperature heating demand in buildings. In 1990 the average demand for space heating was 162 kWh per m^2 in Germany. According to a scenario made by IWO there was already then a technical potential to reduce this demand to 50 kWh per m^2 on average[8]. As can be seen in the table below Feist has estimated the costs of different efficiency measures in german buildings in 1993-1994.

Table 86

Type of building	Yearly heat use [kWh/m^2 /year]	Heat savings compared to 1984 standard [%]	Price of each saved kWh [1990mECU]
Average	162		
1984 standard for new buildings	130		
1995 standard for new buildings	90-100	27	18,1
Low energy house	40-70	58	38,2-70,2*
Passive house	10	92	149,8
Zero-energy house	0	100	1567,1

*=38,2mECU for 70kWh/m^2 /year and 70,2 mECU for 40kWh/m^2 /year.
Source: Enquette commission "Schutz der Erdatmosphäre"des Deutschen Bundestag, "Mehr zukunft für die Erde - Nachhaltige Energiepolitik für dauerhaften Klimaschutz", Economica Verlag, 1995, (page 400).

The cost per saved kWh in passive houses is estimated to 149,8mECU/kWh (1994) due to extra investments per m^2 compared to 1984 standard house. This price is actually lower than the cost of delivered energy from fossil fuels in our scenario. Yet, zero energy houses seem to be too expensive to be implemented in large scale in our scenario but up to a 92% reduction of energy demand per square meter compared to the standard in 1984 in new buildings in Germany might be cost competitive compared to the fair market consumer price of delivered heat in our market scenario.

Provided that the price of delivered energy includes all externalities which will make energy expensive there will be a good intensive for constructers to build houses with more respect to energy efficiency. The higher pricing will of course also affect that people will have further economic intensives to buy houses which are more efficient or for retrofitting existing energy intensive houses. This development should be further supported by government intensives like research and development in building energy efficiency and of course by strengthening the recent energy performance standards for buildings.

In the future it will be necessary to make legislation and norms for the energy use and indoor climatic conditions of buildings already at the phase when the buildings are projected. The planners will have to consider the total mix of possible solutions for optimization of the energy economy in new buildings besides better heating insolation: Highly insolated windows, solar architecture, smart windows, better use of daylight, efficient appliances, ventilation with heat exchangers, thermal storage, passive solutions which do not aquire energy, place the house right according to climatic conditions (wind, sun...), use the right materials, build houses with small surface compared to its indoor size, build houses with longer lifetimes, etc...when planning new houses. As for the old

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[8] Enquette commission "Schutz der Erdatmosphäre" des Deutschen Bundestag, "Mehr zukunft für die Erde - Nachhaltige Energiepolitik für dauerhaften Klimaschutz", Economica Verlag, 1995, (page 369).

houses of which the majority probably still exist in 2050 it will be necessary to retrofit them, i.e. put in better insolation, low emission windows and to shift to efficient heat sources such as heat pumps and low temperature district heating.

Future demand for space heating, water heating and cooking in the domestic sector.
There are some major factors influencing the demand for energy in houses: The total amount of buildings and the specific energy demand of those buildings and the amount and energy efficiency of energy producing and consuming appliances used in the building. Our aim is to estimate which level of energy services that could be demanded by the consumers in the far future, and how this demand will be fulfilled, e.g. which type of energy that will be needed and from which source it will be derived.

The first major problem is to assess how many buildings that will be necessary to fulfill peoples needs in 2050. In the domestic sector we assume that there will be more dwellings in the future, partly due to a small growth in the population and partly because we expect some of the developments that we have seen in the past to continue in the future. The major factor influencing the number of buildings necessary in the domestic sector will be the distribution of people in the buildings. First of all we expect that a presumably higher share of elderly people in the population will affect the distribution as we expect that these people will live in separate households like it is the case in Denmark today. Secondly we expect that more people will choose to live alone. These are tendencies which we have seen in the last couple of years in EU[9]. This will probably lead to a higher amount of dwellings being needed in the future. Besides this the size of the households will also have influence on the amount of energy service per capita for space heating purposes.

We assume that the demand for the energy services space heating, water heating and cooking will grow by 30% due to the tendencies mentioned above.

Energy pay-back: It would be worthwhile to think about wether the energy efficiency measures will be eaten up by the energy used for constructing new houses. Will the changes induced by the trends we see in todays society affect that a lot of energy is used for construction and retrofitting in the future, and how fast this will be paid back by a lower energy consumption in the buildings? Can we estimate a general energy pay-back time for buildings? Will this make us able to predict whether it will be sensible to construct or retrofit buildings before it would be done anyway? I have found some data for Denmark and Finland which gives one estimate about this issue:

On average energy use in Danish buildings in 1995 is 160kWh/m^2 per year[10]. The total energy use in the Finnish construction sector amounts to 500kWh per m^2, including both the energy used at the place of construction and the amount of energy used for the production of building materials[11]. This indicates that for northern countries there is a relatively short energy pay back time as the energy intensity per m^2 is higher than in warmer climates. However, the energy pay back time will be considerably longer when considering low energy houses. As the use of energy in the total life time

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[9] See table 84+85.

[10] "Energi og arkitektur - en eksempelsamling af nyere byggerier", SBI-rapport 242, Statens byggeforskningsinstitut, 1995.

[11] "Bygningers totalenergiforbrug og miljøbelastning", konference i Kbh. den 11. september 1990, SBI - meddelelse 85, Statens Byggeforskningsinstitut, 1991.

of the house will be smaller the energy used in the construction phase will amount to a bigger share. There is of course a very high uncertainty to this kind of calculations, as the proportion of energy used for both construction and heating can change over time. The important parameters are the specific energy use for construction and heating per square meter and the specific lifetime of the building. Several Danish sources estimate that the average energy pay back time for Danish buildings has been around 10 years since he mid-sixties as the specific energy use for construction and room heating has decreased at the same rate since then[12]

Another interesting fact concerning the Danish building sector is that at the beginning of the century 90% of the investments for construction was the cost of building materials and construction. In 1970 this share was only 22%. Today 40% of the cost is due to technical installations (tele, el, water, etc..) and approximately 40% is spent on the interior design. Furthermore the technical installations and the interior design will probably be changed several times within the life time of the building shell[13]. As the cost of the building shell is rather small compared to the other parts of todays buildings it seems reasonable to assume that higher building shell costs due to use of more energy efficient materials will only have marginal influence on the life cycle costs of all building parts.

Service sector.

As our data for the end-use in the service sector are not as detailed as those concerning the household sector we have not been able to estimate the possible efficiency gains as precisely as in the domestic sector.

[Generally heat demand ought to be lower in service than in households as there are mostly only people in the daytime. Maybe investigate further]

We have not been able to establish any knowledge on the nature of different end-uses. The IEA statistics only give data for electricity and total energy delivered. Because of this lack of knowledge we have only been able to make an overall estimate of the efficiency gains in the service sector. We assume that an index of 0.25 will be realistic as the energy services needed in the service sector are assumed to be quite similar to those in the domestic sector.

This means that we assume the same efficiency improvements for electrical appliances and low- and high temperature heat as in households.

We assume that the service sector will grow considerably in the future as the information society emerges, therefore a doubling of the energy service demand for low- and high temperature space heating is assumed in this category. However a tribbling of the demand for energy services delivered by electric appliances is assumed.

Industry sector.

[to be based on the ISI report]

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[12] Pedersen, Dan O., "Byggeriets energiforbrug og emission af SO2 og CO2", i "Miljøpåvirkninger fra byggeri", Statens Byggforskningsinstitut, 1992.

[13] "Miljøpåvirkninger fra byggeri", SBI-meddelelse 93, 1992.

Until now I have used the same efficiency potentials and activity assumptions as Bent used in the preliminary scenario. Efficiency: Factor 4 for low temperature heat, factor 2 for high temperature heat and factor 4 for electricity. 30% increase in demand.

Transport sector.

The transport sector has increased energy use while other sectors have stabilized energy use. If this trend continues in the future the transport sector's share of the total energy consumption and CO^2 emissions derived from the use of energy might very well become larger than the other sector's shares. Therefore the transportation sector is probably the most important in the CO^2 discussion.

Table 87: Increase in CO^2 emissions in OECD Europe

	Mobile sources		Energy transformation		Industry		Others		Total	
	[mio. t]	[%]	[mio. t]	[%]	[mio. t]	[%]	[mio. t]	[%]	[mio. t]	[%]
1971	575,8	17	1015,6	30	945,8	28	796,3	24	3333,5	100
1991	936,7	26	1231,4	34	687,8	19	733,5	20	3589,4	100

Source: "Transport Policy and Sustainability - The State of the Art", keynote paper, motor fuels action group: Energy 2000, Geneva, march 1994.

The development in transport of persons and freight in Europe in the last 20 years.

The total amount of transport in the EU12 has been growing in the last twenty years, both considering the transport of persons and goods. The statistics for the amount of transport in EU12 between 1970 and 1990 can be found in the European Commissions "White Paper" from 1992[14].

As seen in figure 31 the total amount of internal transport in the EU12 has increased in the period 1970 to 1990. The volume of freight has grown by more than 50% (measured in tonne-kilometres) while the transport of persons has grown by more than 90% (measured in passenger kilometres). This development has pimarily appeared due to growth in road transport. The transport of goods by road has grown compared to transport on rail and ship and the share of persons transported by private cars has grown compared to rail and buses. The amount of passenger kilometers in air transport has grown by a factor 4 in the same period.

Figure 31: Development in freight and passenger transport in EU12 measured in tonne-km and passenger-km (internal transport within EU12).

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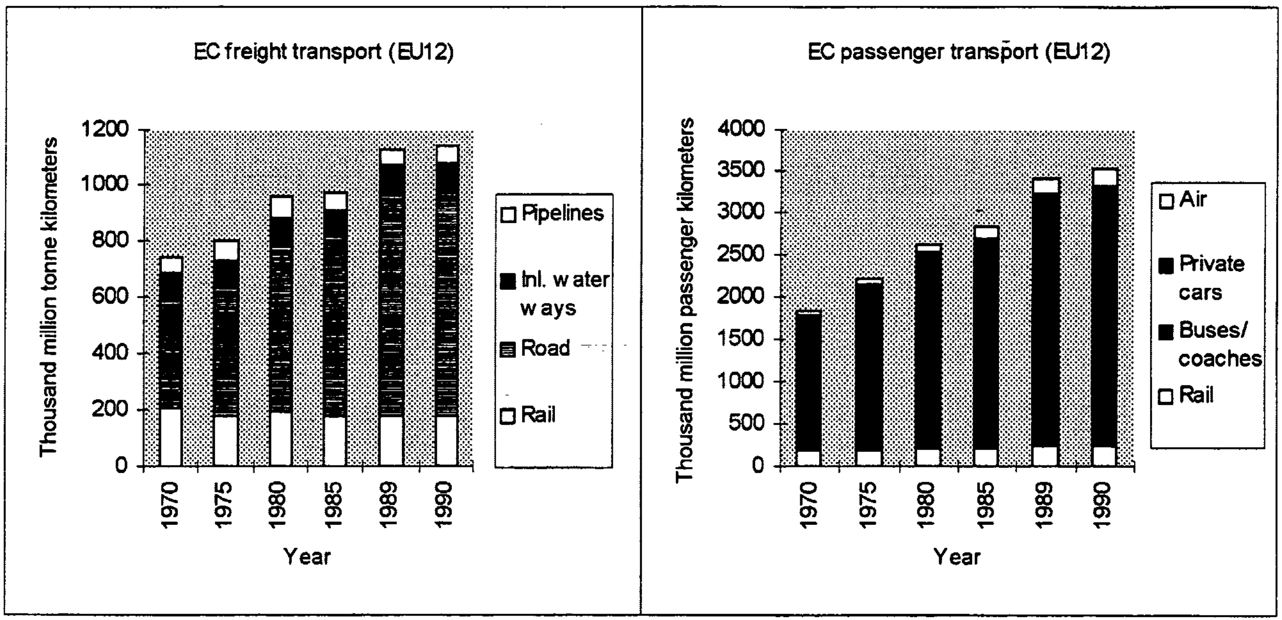
[14] The European Commissions white paper on transport: "Den fælles transportpolitiks fremtidige udvikling - en omfattende fællesskabsstrategi for "bæredygtig mobilitet"", KOM(92)494 endelig udgave, Kommissionen for de europæiske fællesskaber. Meddelelse fra kommissionen, KOM(92)494, Bruxelles, 1992.



Source: "EC white paper on transportation", KOM-(92)494, 1992.

Not only the amount of transport in terms of transport kilometers has grown since 1970. The total energy consumption for air and road transport has doubled in the same period while the total amount of energy used for rail transport was 18% smaller in 1990 than in 1970. All together the growth in transportation has doubled the sector's energy use in 20 years. Aviation and road transport dominated transport energy use in the period 1970-1990 and their share has grown. Railways final energy use has declined mainly because of fuel switching from coal to diesel and electricity, but if fuel used for power generation is included, rail energy use has also grown. Both marine and inland waterways energy use have been fairly steady since 1970.

Table 88:Transport energy use in OECD Europe [mtoe] and indexes [1970=100].

	1970	1975	1980	1985	1990	1991
Air	15,1	19,22	22,45	24,4	31,29	30,58
Air index	100	127	149	162	207	203
Road	108,34	135,24	166,4	180,27	231,89	236,32
Road index	100	125	154	166	214	218
Rail coal	2,65	0,9	0,31	0,16	0,05	0,05
Rail oil	4,46	3,94	3,48	3,01	3,18	3,29
Rail el	2,56	2,78	3,23	3,51	4,33	4,57
Total rail	9,67	7,62	7,02	6,68	7,56	7,91
Total rail index	100	79	73	69	78	82
Inland waterways	7,72	9,7	9,05	7,32	8,07	8,33
Inland waterways index	100	126	117	95	105	108
Total transport	146,8	178,3	212,5	226,9	288,9	293,8
Total transport index	100	121	145	155	197	200
Marine bunkers	36,35	34,58	30,25	27,52	34,87	34,72
Marine bunkers index	100	95	83	76	96	96

Source: Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO_2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

The breakdown of energy use within subsectors of these main transport categories is not very well known in European countries. For bottom-up analysis of energy use in the transport sector it would be worthwhile to examine the distribution of the overall uses of energy into different fuels used by different categories of modes to get a more precise picture of the distribution of the energy use. For example it would be of interest to know how much of the fuel for road transport that is used for lorries, buses and private cars or the division of air transport on freight and passenger transport. Furthermore it would be interesting to know to which purposes of transport activities the energy use is related. For example the division between work related or leisure related activities of different kinds of passenger transportation or division of air energy use on domestic and international flights. Most governments have no reliable record of such breakdowns. However, Lee Schipper has gathered some data on these issues from a few European countries which give a hint to the present situation in Europe. Some of these results are presented later in this text.

In 1990 70% of all internal freight and 88% of all internal persons transport in EU12 was transported by road. In 1970 these shares were 50% and 87% respectively[15]. This tells us that the most important parameter to regulate in the future if the growth in energy use for transportation should be stalled is road transport. 15% of the internal freight transport by road in the EU12 in 1990 was transported less than 50 kilometres, 25% was transported 50-150 kilometres, 40% was transported 150-500 kilometres and 20% was transported more than 500 kilometres[16]. Especially for the long distance trips there might be some potential to move some of these freights from road to ship or rail.

Official prognoses for the expected future development in transport services.

The growth in the total volume of transport seems to have been following the GDP growth in the last 20 years. Generally the demand for transport for both goods and passengers seem to grow parallel to the economic GDP-growth. The mean economic growth in the EU has been around 2,6% since 1970 and the mean growth in transport has been around 2,3% for goods and 3,1% for persons in the same period[17].

This general picture is expected to continue in the following years. If the economic GDP growth continues, the European Commission expect that the overall growth in the demand for transport services will follow the GDP growth. For the transport of goods the Commission expects the growth to be even higher due to anticipated smaller and higher amounts of loads of goods in the future[18].

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[15] The European Commissions white paper on transport: "Den fælles transportpolitiks fremtidige udvikling - en omfattende fællesskabsstrategi for "bæredygtig mobilitet"", KOM(92)494 endelig udgave, Kommissionen for de europæiske fællesskaber. Meddelelse fra kommissionen, KOM(92)494, Bruxelles, 1992.

[16] Transportrådet: "EF's transportpolitik - en oversigt", juni 1993.

[17] The European Commissions white paper on transport: "Den fælles transportpolitiks fremtidige udvikling - en omfattende fællesskabsstrategi for "bæredygtig mobilitet"", KOM(92)494 endelig udgave, Kommissionen for de europæiske fællesskaber.

[18] The European Commissions white paper on transport: "Den fælles transportpolitiks fremtidige udvikling - en omfattende fællesskabsstrategi for "bæredygtig mobilitet"", KOM(92)494 endelig udgave, Kommissionen for de europæiske fællesskaber.

The expected increase in economic activity as well inside of the EU12 and in relation to the rest of the world is likely to boost transport demand. In a business as usual scenario especially the road transport in EU12 will continue to grow significantly. In a projection cited in the Commissions green paper[19] the expected growth in road transport is 42% between 1990 and 2010, whereas rail transport is expected to grow by 33%. The stock of private cars is expected to grow by 45% from 115 million in 1987 to 167 million by 2010, leading to a growth in car ownership from 381 to 503 per 1000 inhabitants in the same period. Air transport is expected to rise by 74% between 1990 and 2010.

EU's transport policy.

As a response to the growing capacity problems on the trans European transport networks and the growing concern in the population about growing environmental damages due to the growth in transport the European Commission has published several reports[20] presenting proposals on how to reach "sustainable mobility". One of the most important messages in these reports is that even with the use of better standards for emissions, new environmentally friendly technologies and alternative energy fuels it is not expected that it will be possible to reduce the energy use or the environmental damages caused by transport due to the anticipated future growth in the volume of transport. Therefore the Commission points out the necessity to use other measures to reduce the energy use and environmental damages due to transport.

One of the most important measures to reach sustainable mobility is the introduction of taxes which ought to secure that the transport users pay the full costs which are related to the transport services: "*The realization of all these objectives implies that as a general rule all transport users should pay the full costs, internal and external, of the transport services that they consume, even if these costs are in some cases paid by society to assist those in need. In particular, internalization of external costs should be a major element of a transport policy integrating the protection of the environment.*"[21]

Unfortunately there are some major interests conflicting with the constraints to reduce the amount of transport. The term "sustainable mobility" used as the major goal of the Commissions transport policy includes both the above mentioned goals for a reduction of the energy use and environmental damages due to transport and also the constraints to achieve a high degree of mobility to ensure the full realization of the internal market and the continuation of economic growth in the EU countries.

When it comes to the concrete realization of the conflicting goals namely the constraints to achieve a higher degree of mobility on a future extended trans national European infrastructural system and at the same time reduce the use of energy and the environmental damages it seems that many different measures will have to come into play in the future transport policy in Europe. Therefore the Commission advocates that other measures than the technical (shift in energy fuels, more effective vehicles, and so on..) and the fiscal (the introduction of taxation of transport which represents the full costs of transport services) measures should be introduced, e.g. a reduction of the demand for

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[19] The European Commissions green paper on transport, "The impact of transport on the environment - a community strategy for "sustainable mobility"", COM(92)46 final, Brussels, 1992.

[20] See for instance the Commissions green paper: "The impact of transport on the environment - a community strategy for "sustainable mobility"" or the Commissions white paper: "Den fælles transportpolitiks fremtidige udvikling".

[21] This is qouted in "EF's transportpolitik - en oversigt", Transportrådet, rapport nr. 93.02, 1993.

transport, especially in cities, and a shift in the balance of transport modes favouring public over private transport.

Despite the built-in conflict between environmental concerns and the concern for economic growth and high mobility it seems obvious that the European Commission wants to establish a future transport policy which puts emphasis on environment and alternatives to private ear transport. This policy seems to incorporate taxes on environment, infrastructure and other external costs of transport which should in principle be paid by the users of the transport services.

However it is clear that this future policy is yet far from realization. The battle goes on with proposals for minimum taxes on mineral oils, direct and indirect user payments on infrastructure and minimum taxes on vehicles.

A low energy intensity and low polluting transport sector.

Even though the level of transport of goods and persons (measured in tonne and passenger kilometres) will end up at a much higher level in 2050 compared to 1990 we expect that the use of energy and the environmental loads per service unit will decrease as a whole range of measures is used to create a new transport policy in EU15.

If the EU15 countries are to reach a low energy intensity transport development in the future it will be necessary to use several different measures. The realization of fair pricing of transport might not in itself be enough to reach a "sustainable transport development". The following measures are just examples. Supplementing measures will probably be necessary:

* standards for the energy intensity and environmental loads of motor vehicles, motorcycles, airplanes, ships and trains.

* development of environmentally friendly fuels, such as biofuels, electricity or hydrogen.

* governmental regulation to secure lower speed limits on highways.

* optimal use of the different transport modes, including a coordination between different modes and high occupancy rates and optimization of the amount of products in the transport modes.

* shift to less energy intensive transport modes, e.g. shift from private to public transport systems and from air to ship and so on...

* fiscal and economic instruments should be used to ensure that all external social costs are included in the price of transport to promote environmentally friendly and low energy intensive transport modes.

* investments in infrastructure projects favouring public transport.

* a reduction of the amount of private cars in cities by either strict regulation[22], parking fees or paying a high price to enter a city.

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[22] E.g. to forbid cars in the city.

* structural changes in society like for instance people working more at home and living closer to the place they work, shops being built near to peoples homes and people essentially driving less.

The social costs of transport.

In our fair market scenario the development in transport should mainly be driven by the introduction of full cost pricing on transport. It is therefore necessary that we find estimates of the actual social costs of different transport modes.

In Denmark the social costs of road transport have been estimated by Arbejderbevægelsens Erhvervsråd. They calculated the social costs of road transport, including health effects of NO^x, SO^2, CO, ozone and particles, the greenhouse effect and other costs like noise, accidents, infrastructure, smell, dirt and queues. The authors propose that the gasoline consumer price ought to be doubled and the diesel consumer price almost trippled in Denmark to cover all social costs. Their estimates of the external costs of different effects are listed in the table below.

[some change with efficiency assumed, some to be scaled:]

Table 89: Social costs of energy use in transport in Denmark in 1992.

	Total costs [million 1990ECU]	Gasoline [1990ECU/liter]	Diesel [1990ECU/liter]
Health including:	999	0,314	0,288
SO2	38	0,006	0,019
NOx	794	0,256	0,154
CO	0	0,000	0,000
Particles	64	0,006	0,032
Ozone	102	0,045	0,083
Greenhouse effect (CO2)	218	0,038	0,058
Smell	41	0,000	0,019
Dirt	41	0,000	0,019
Noise	179	0,032	0,045
Accidents	640	0,070	0,070
Queues	346	0,307	0,307
Road use	884	0,192	0,192
Total	3329	0,954	0,999

Source: Arbejdernes erhvervsråd "Grøn vækst", 1995.

Another Danish study from 1993 estimated the external costs of transport in cars and lorries in Denmark and compared their estimates to two earlier studies of external costs in Denmark and Sweden. As can be seen in the matrixes below the studies are not quite comparable due to differences in the choice of external effects evaluated and difference in the locations studied and other methodological differences. Nevertheless these figures might give a hint of the range of the external costs of road transport in Scandinavia which might actually be accepted and applied to the cost of gasoline in the fair market scenario.

Table 90: Private cars: Comparison of three different studies on the external costs of transport in private cars in Denmark and Sweden [1990 ECU/km].

	Sweden 1987 [1990 ECU]	T&E Denmark1992/3 [1990 ECU]	DMU Denmark 1991 [1990 ECU]
Infrastructure constant			2,149
Infrastructure variable	0,410		
Queus, time			
Accidents	1,505	1,537	1,897
Air, nature	0,821	2,561	1,391
Air locally			2,655
Air, climate	0,821	0,768	
Noise		0,256	1,644
Barrier effect			0,885
Total	3,557	5,122	7,966

Source: Transportrådet, "Transportsektorens eksterne effekter", 1993.

Table 91: Lorries: Comparison of three different studies on the external costs of transport by lorries in Denmark and Sweden [1990ECU/km].

	Sweden 1987 [1990ECU]	T&E Denmark 1992/3 [1990ECU]	DMU Denmark 1991 [1990ECU]
Infrastructure constant		4,226	5,310
Infrastructure variable	6,430		
Queus, time			
Accidents	2,052	3,201	4,552
Air, nature	3,830	8,068	4,046
Air locally			7,966
Air, climate	4,104	4,994	
Noise		0,896	9,483
Barrier effect			4,805
Total	16,416	17,160	28,196

Source: Transportrådet, "Transportsektorens eksterne effekter", Danmarks Miljøundersøgelser, 1993.

Another study has tried to estimate the external costs of passenger transport for trains, airplanes and private cars in eight of the countries dealt with in this report[23]. In general Kågeson estimates that the unpaid costs of transport in Europe amount to something like 2,5% of GDP on average. The necessary fuel tax suggested by Kågeson is seen in the table below. For all countries at least a doubling of the fuel tax is needed according to Kågeson to make the fuel prices reflect the social costs of transport.

Table 92: Necessary fuel tax compared to existing fuel taxes in 1992 [1993 ECU].

	Necessary fuel tax 1993	Petrol tax 1992	Diesel tax 1992
AT	0,96	0,24	0,22
DK	0,81	0,30	0,24
FR	1,05	0,41	0,24
IT	0,94	0,55	0,41
NL	0,76	0,44	0,21
ES	0,74	0,39	0,29
SE	0,70	0,42	0,28
UK	0,71	0,33	0,32

Source: Kågeson, Per, "Getting the prices right - a european scheme for making transport pay its true costs, T&E European Federation for Transport and Environment, 1993.

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[23] Kågeson, Per, "Getting the prices right - a european scheme for making transport pay its true costs, T&E European Federation for Transport and Environment, 1993.

One example of the more detailed results of Kågeson's study is shown in the matrix below. It is interesting that the external costs per passenger kilometer by car are around seven times higher than for train and more than twice as high as airplane per passenger kilometer. For goods transport it is interesting that trains and ships have considerably lower external costs than lorries. A similar picture is given for other European countries in Kågeson's study.

Table 93: Estimated external costs of passenger transport in Denmark 1993 (1993ECU per thousand tonne and passenger kilometres).

	Pass. Car	Pass. Train	Pass. Air	Tonne Lorry	Tonne train	Tonne ro-ro
Air pollution	14,6	0,9	7,3	5,6	0,6	6,0
CO2	4,5	2,2	9,2	3,5	2,9	0,6
Noise	1,3	0,3	1,7	0,6	0,3	0,0
Accidents	8,5	0,9	0,3	2,2	0,9	0,1
Total	28,9	4,3	18,5	11,9	4,7	6,7

Source: Per Kågeson, "Getting the prices right:" A European scheme for making transport pay its true costs",Stockholm: European Federation for Transport and Environment, 1993.

None of the above mentioned studies account for all external costs of transport and they are all site specific using somewhat different methodologies for the estimation of social costs of transport in Europe. We can maybe use these estimates to choose a level of social costs which might be applied to the consumer prices in our market scenario. At least for road transport I think that a doubling of the present consumer price level in Denmark would be a fair estimate for the fair price level in all European countries.

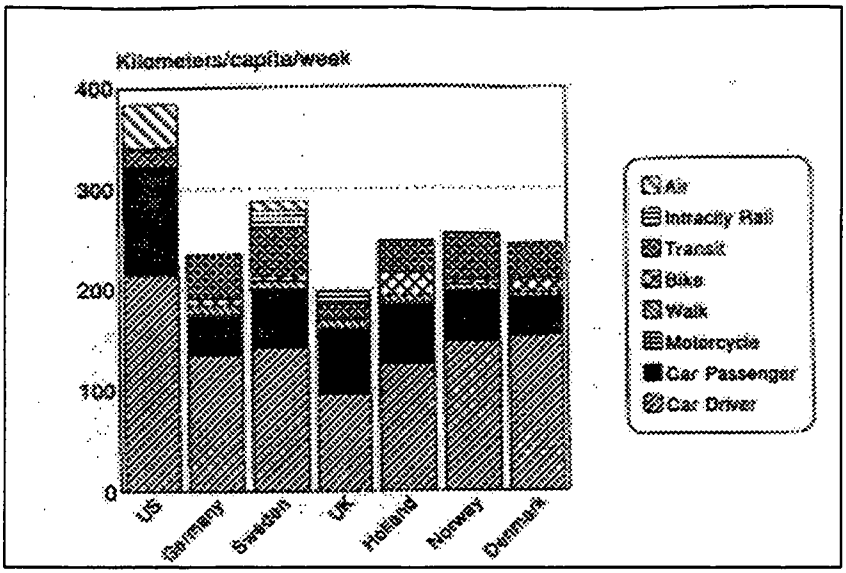
The important question for us must be whether the inclusion of all social costs of transport will be enough to stall the growth in transport in the future. Personally I think that it will be necessary to use a whole range of measures to reach a more sustainable transport development. This argument is supported by the presumably low demand-price elasticities on transport fuels.

[Add here something about different surveys on the demand/price elasticities of transport fuels]

Division of persons transport on modes and purposes.

Lee Schipper has gathered statistical data for Germany, Sweden, Denmark, UK and the Netherlands to describe which proportions of the passenger kilometers travelled in Europe that relates to different modes of transport. In these countries each person travelled between 200 and 250 kilometers per week on average. As seen in the figure below the split on different types of modes was quite different from country to country. However in general more than 75% of all passenger transport were in cars either as driver or as passenger in european countries.

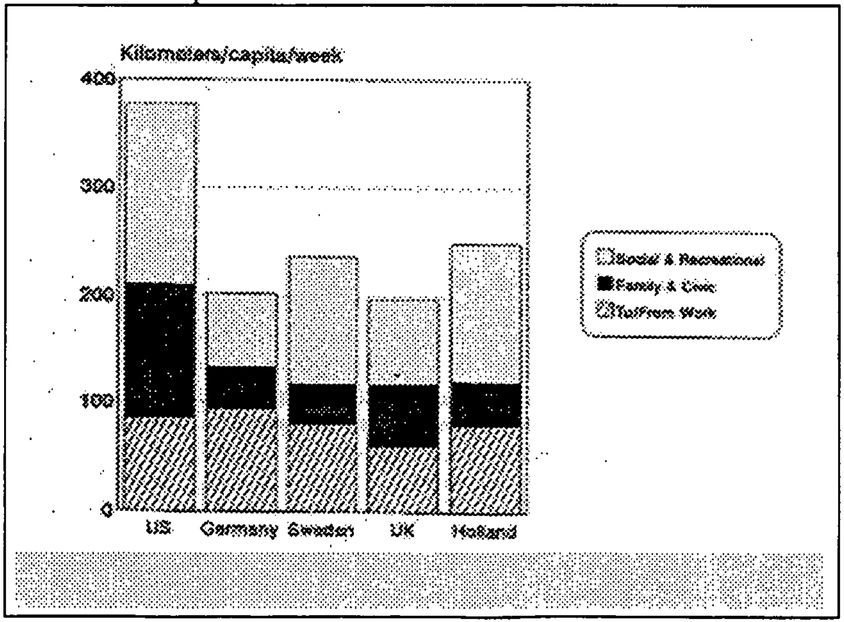
Figure 32: Kilometers travelled per capita per week in seven OECD countries, by mode of transport.



Source: Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995.

Schipper has also gathered data for the split on different purposes of all trips in passenger transport in Germany, Sweden, UK and Holland. As seen in the figure below there are large differences in the patterns of persons travel for different purposes between these countries. Between 30-50% of all persons travel in the four European countries is for work, 15-25% is for family activities including civic purposes, shopping and education and about 30-50% is for free time activities, including vacations. The later two has been growing relative to work related activities in the last years.

Figure 33: Distance travelled per capita per week in five OECD countries, by purpose of trip. All modes of transport included.

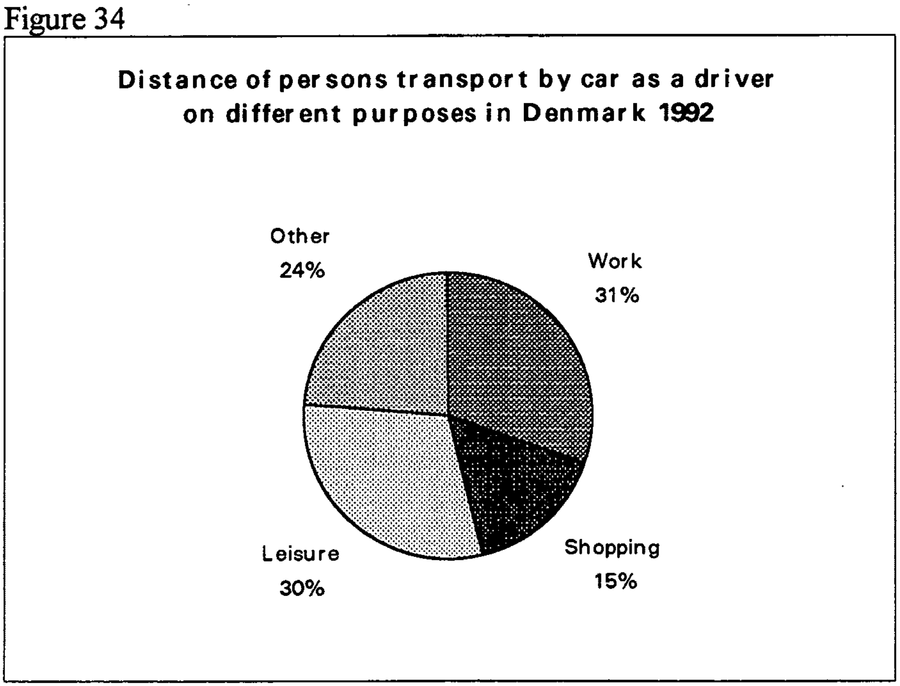


Source: Lee Schipper, "Determinants of automobile use and energy consumption in OECD countries", Annual Review on Energy and Environment 1995, 20:325-86.

The data for the purposes of persons transport on different modes in Denmark has been estimated in a survey made by the Danish statistical office. In 1992-1994 72% of the persons transport on normal week days and 79% in the weekends were spent in private cars either as a driver or a passenger. In Denmark approximately 35% of the persons transport by car on normal week days was due to work or education related travel while 28% was for spare time activities and 19% for shopping. In weekends 65% of the persons transport by car was spent on spare time activities. Still 19% was related to shopping as many people go shopping at saturdays while most shops are closed on sundays. Generally people travel a little longer in the weekends than the rest of the week.

As seen in the figure below 31% of the persons transport by car as a driver was related to work 30% for leisure, 15% for shopping and 24% for other purposes.

Figure 34



Source: "Transportstatistik '95", Danmarks statistik, 1995.

Altoghether work related activities covered 39% of all persons transport by all modes on normal week days and only 6% in weekends. 15% of all persons transport on all modes was related to shopping, all seven days a week. Spare time activities caused 25% of the persons transport on all modes in week days and 67% in weekends[24]. In Denmark spare time activities and shoppings shares of total transport kilometers are growing.

In Germany a recent study has estimated the share of persons travel related to all activities by modes. The overall results of this study can be seen in the figure below.

Figure 35: Shares of the persons transport which relates to holidays, leisure time, shopping and work and education in Germany in 1992.

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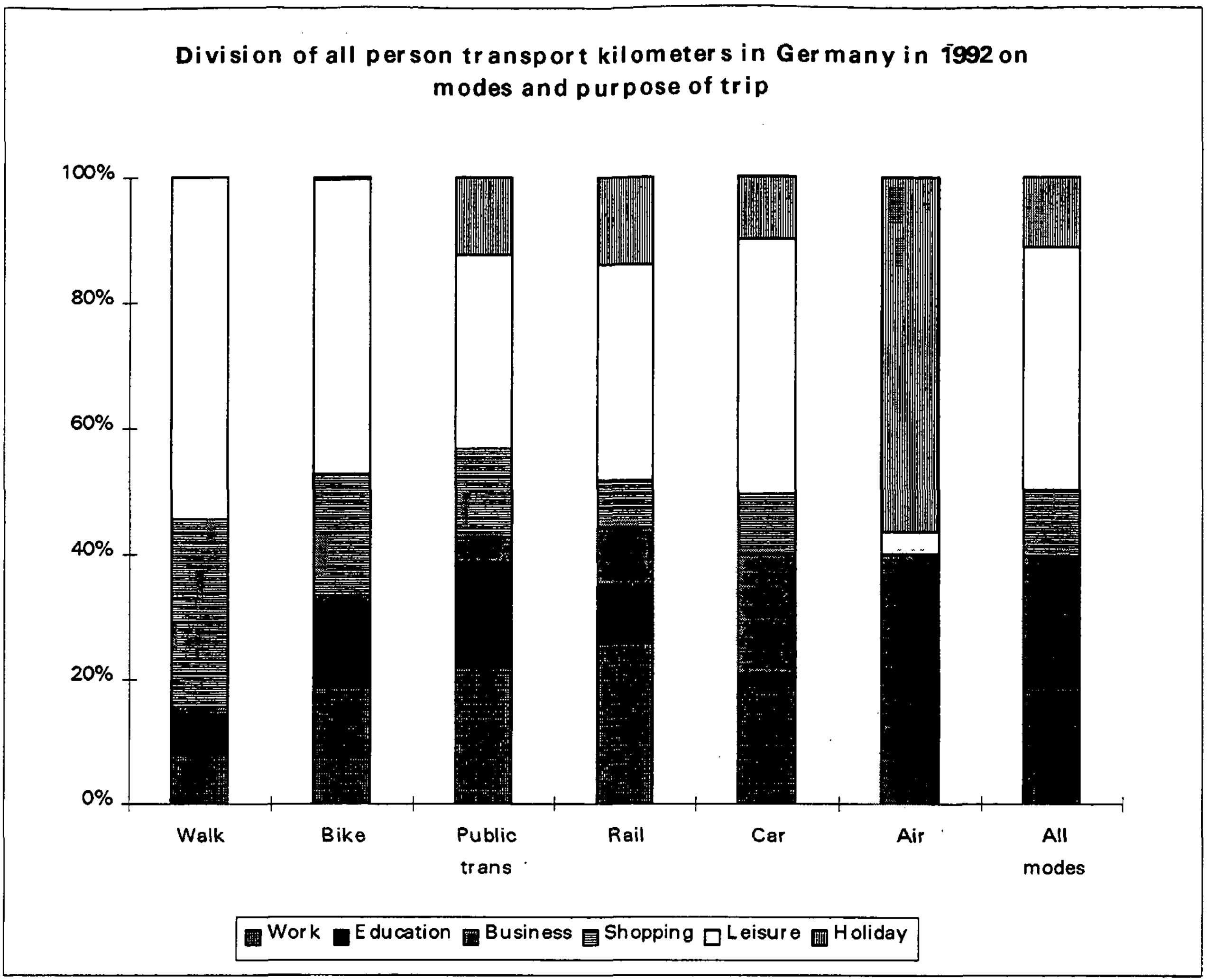
[24] Transportstatistik 95, The Danish Statistical Office, 1995.



Source: "DIW Wochenbericht 22/94", Deutsches Institut für Wirtschaftforschung, 1994.

According to this DIW study approximately 9% of all passenger traffic in Germany in 1992 were related to holidays, 40% were related to leisure activities, 11% were related to shopping and the residual 40% were related to work and education with 19% for work, 4% for education and 17% for business travel.

According to Michaelis half of Europe's passenger air traffic is international. Around 90% of goods air transport is international[25].

[As I have not been able to collect this kind of data for each country we will have to use a quite pragmatic method when estimating the division of energy use on different modes and purposes. Our first idea of specifying how much leisure and shopping and work related travel will grow is not possible as we do not know the amount today for all countries. Another problem is that we do not know which kind of transport mode that is used for each kind of transport service, for instance the distribution of people travelling by plane or train or car

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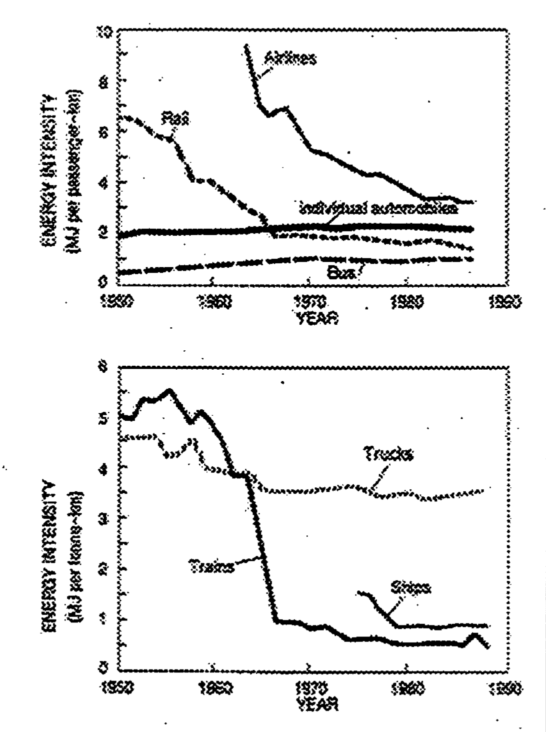
[25] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO_2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

when going on holiday.....and so on! Only for Germany we have some data! Maybe we will have to assume that the division in the other countries is similar to Germany! The division betwwen goods and persons transport should be found in energy units!]

Historical development in the energy intensity of different transportation modes.

Between 1950 and 1970 the specific energy intensity of persons and goods transport by rail per passenger and tonne kilometer was improved drastically. The same was the case with air passenger transport. However, since the early 70'ies the energy intensity of transport modes for persons and goods transport has not improved much except for aircrafts.

Figure 36: Development of average freight transportation energy intensity in the UK.



Source: Sørensen, Bent, "Et mørkegrønt scenarie" in "Fremtidens vedvarende energisystem", Teknologinævnet, 1994, (Based upon UK DoE, 1987; UK DoT 1987; Martin and Schock 1989).

In fact it seems that the overall intensity of all transport has increased a bit, at least in eight selected European countries studied by Lee Schipper.

Table 94: Energy intensity of different travel modes [MJ/passenger km].

	USA	USA	JAP	JAP	EU-4	EU-4	NO-4	NO-4
	1973	1992	1973	1992	1973	1991	1973	1992
Energy intensity	3,08	2,55	1,41	1,72	1,51	1,53	1,55	1,67
Car	3,07	2,62	2,79	2,67	1,72	1,68	1,69	1,79
Bus	0,79	0,88	0,54	0,66	0,58	0,74	0,82	0,88
Rail	1,81	2,1	0,34	0,42	0,58	0,48	0,89	0,83
Air	4,92	2,61	3,49	2,25	4,73	2,96	2,78	3,36

NO4= DK, FI, NO, SE
EU4= FR, UK, IT, W-DE

Source: Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995.

Specific energy consumption of different modes of passenger transportation.

The specific energy consumption per passenger kilometer differs with the specific energy consumption of the transport mode and the occupancy rate. One example of the specific energy consumption of different modes at different occupancy rates is given in the European Commissions "Green paper on transportation".

Table 95: Primary energy consumption for different transport modes in MJ primary energy/passenger/km.

	Occupancy rate			
	25%	50%	75%	100%
Gasoline car				
<1,4	2,61	1,31	0,87	0,62
1,4-2,0	2,98	1,49	0,99	0,75
>2,0	4,65	2,33	1,55	1,16
Diesel car				
<1,4	2,26	1,13	0,75	0,57
1,4-2,0	2,76	1,38	0,92	0,69
>2,0	3,65	1,83	1,22	0,91
Railways				
Intercity	1,14	0,57	0,38	0,29
Super sprinter	1,31	0,66	0,44	0,33
Suburban electrical line	1,05	0,59	0,35	0,26
High speed train 300 km/h (type Bruxelles-Paris)	2,86	1,43	0,96	0,72
High speed train 300 km/h (type London-Paris)	2,5	1,25	0,83	0,62
Bus/car				
Doubledecker	0,7	0,35	0,23	0,17
Bus	1,17	0,58	0,39	0,29
Minibus	1,42	0,71	0,47	0,35
Express car	0,95	0,5	0,33	0,25
Air				
Boeing 727	5,78	2,89	1,94	1,45
"Soft transport"				
Cykling				0,06
Walking				0,16

Source: The EC greenpaper on transport.

As can be seen in table 88 energy efficiency varies with modes. At the present technological situation substantial energy savings could be reached by changing mode or by improving occupancy rates of all modes.

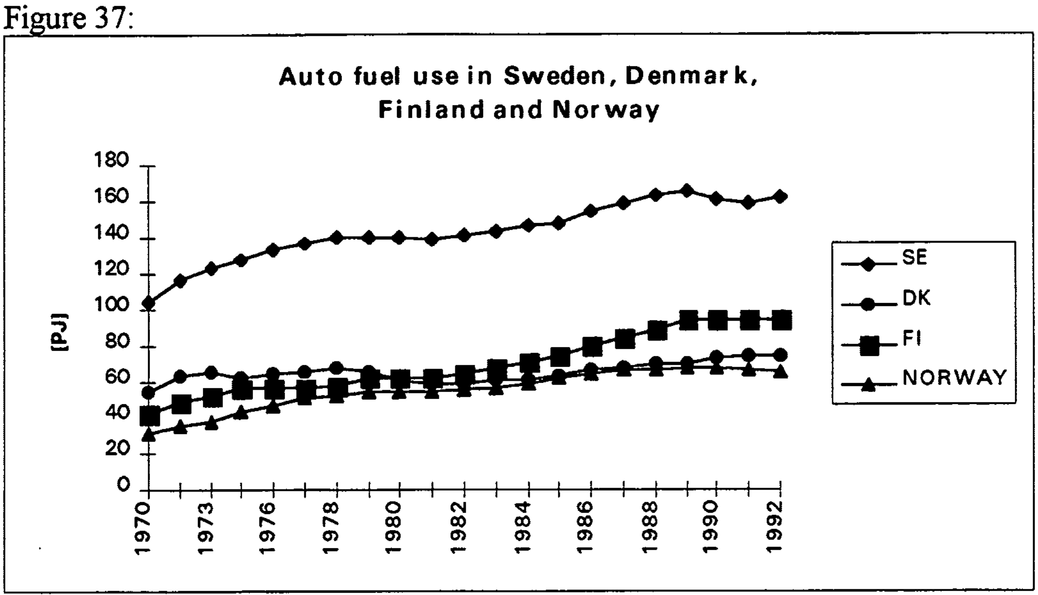
However the differences in specific energy consumption per passenger kilometer can change as the energy efficiency of different modes of transport are improved. Therefore we have to consider the technological possibilities of improving the fuel economy of existing technologies In the future.

Possible future technological efficiency gains in transport.

Cars.

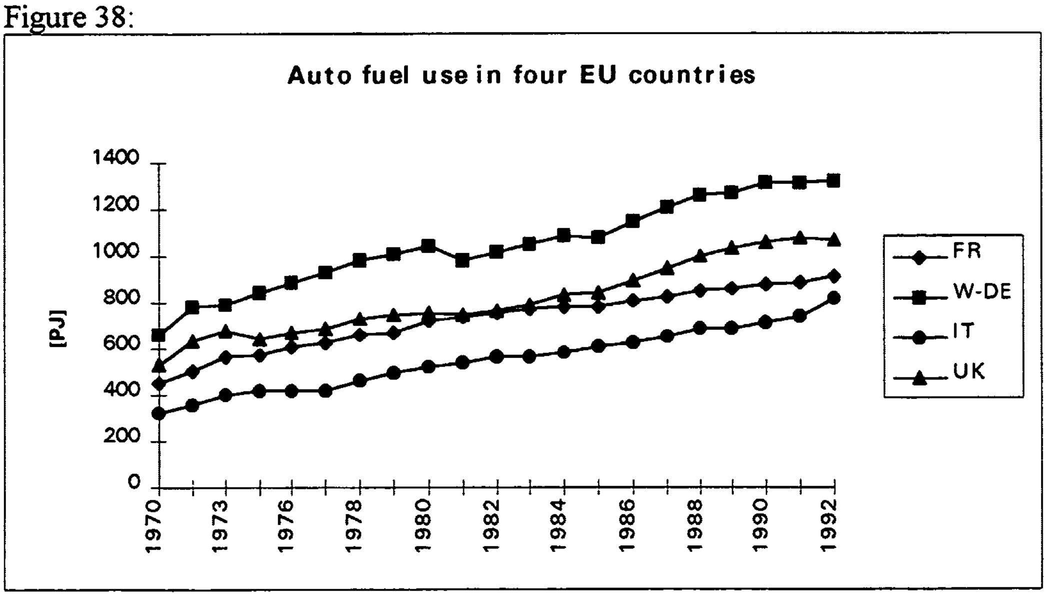
The use of fuel in cars has increased dramatically in the last twenty years in all European countries due to growth in the total amount of travel.

Figure 37:



Source: Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995.

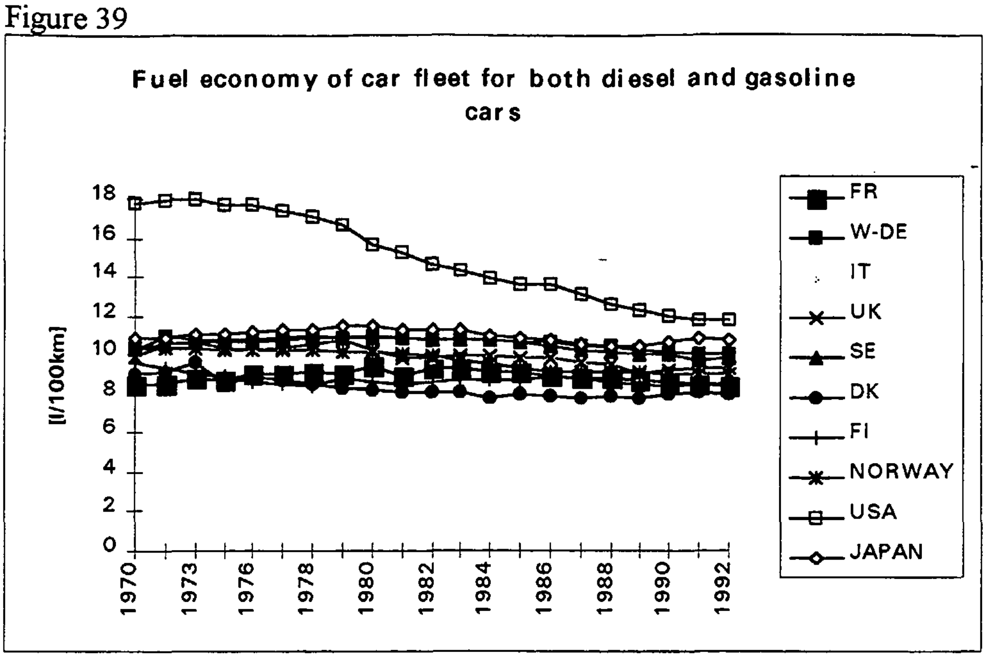
Figure 38:



Source: Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995.

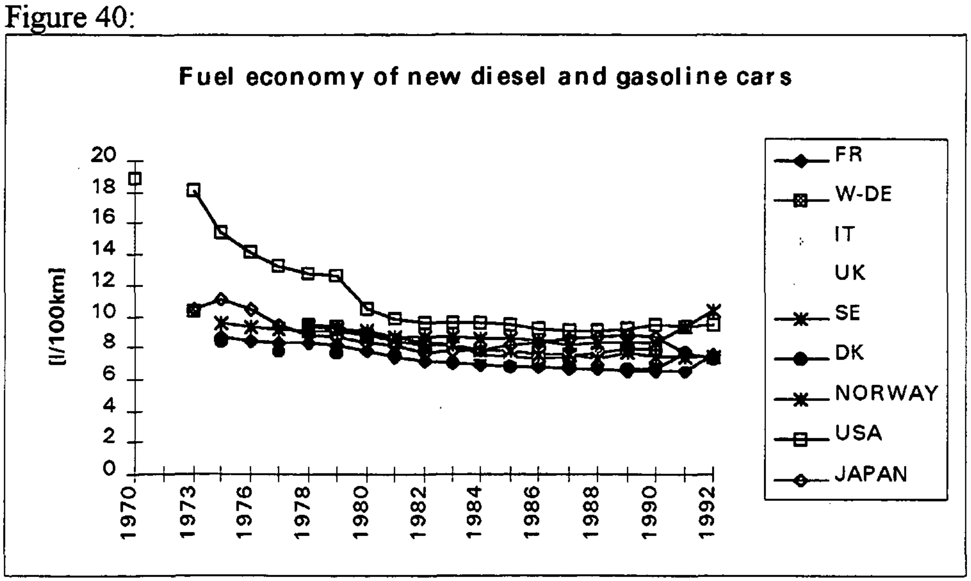
As the specific fuel consumption of automobiles tends to remain constant in all European countries there seems to be no concrete signs of a reduction in total energy use through a reduction in the specific energy intensity of cars.

Figure 39



Source: Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995.

Figure 40:



Source: Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995.

Several studies indicate that the actual energy use of new cars on the road is normally 15-25% higher than the estimates based on results from official fuel economy tests[26].

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[26] Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995, Vibe-Petersen, Johs, "Nye bilers energiforbrug og sikkerhed", Instituttet for samfundsudvikling og planlægning, AUC, 1991, Michaelis, Laurie, "The transport sector in OECD Europe", in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

The stagnating trend in fuel efficiency has occurred despite the availability of new efficient fuel saving technologies. Todays prototype cars of many car manufacturers have fuel consumption of around 3 litres/100km. Prototype automobiles with fuel economies in the range of 2-4 litres/100 km have demonstrated that it is technologically possible to approximately double the average fuel economy of automobiles without sacrificing interior space and preserving adequate performance[27]. There is a consensus that in Europe the maximum potential for improving fuel consumption in cars is around 40%-50% by the year 2010[28].

Ultralight passenger cars with hybrid-electric drives could achieve less than 1,6 litres/100 km with demonstrated technologies such as switched reluctance motors, conventional buffer batteries and compact petrol engines[29]. If we assume that the standard car of the future will be a light car using the above mentioned technologies substantial efficiency can be reached. In the long term it seems reasonable to assume that even with conventional technologies it will be possible to construct automobiles which use less than one fourth of the energy used in the average cars of 1990 in OECD Europe. We assume that the average car will use 75% less energy in 2050 than was the case in 1990. However this development will probably only take place if the European Community takes action to promote energy efficient cars.

Buses.

Table 96: Status of bus design technologies (Adapted from ETSU 1994, Grübler et. al. 1993)

Parameter	1990 norm	Lowest energy use 1990	Feasible 2025-2050
Drag coefficient	0,65	0,4	0,3
Rolling resistance coefficient	0,01	0,007	0,005
Engine efficiency	17-20	22-25	25-30
Mass/seat [kg]	240	175	150
Energy requirement [MJ/seat-km]	0,4	0,25	0,16

Source: Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO_2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

As can be seen in the matrix above there exists potentials for improving the energy efficiency of buses. In the long term a 50% reduction of energy intensity seems feasible according to ETSU (1994) and Grübler et. al. (1993)[30].

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[27] Frank Von Hippel "Automotive fuel economy - the technical potential" in "Low consumption/low emission automobile - proceedings of an expert panel", OECD, 1990.

[28] See for instance OECD and IEA "Low consumption/low emission automobile - proceedings of an expert panel", 1990 or "Transport Policy and Sustainability - The State of the Art", keynote paper, motor fuels action group: Energy 2000, Geneva, march 1994 or T&E (European Federation for Transport and Environment), "Making fuel go further", by Per Kågeson, november 1992.

[29] "Transport Policy and Sustainability - The State of the Art", keynote paper, motor fuels action group: Energy 2000, Geneva, march 1994.

[30] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Lorries.

Michaelis presents some results of Lee Schipers work on energy intensity of road freght. As seen in the matrix below the average intensity of road freight seem to vary between countries. The differences can appear because of differences in technologies used, geographical differences, differences in the load factor of average freights in different countries, different speed and driving circumstances and probably also differences in the methodologies used by the researchers in each country which made the country specific estimates.

Table 97: Energy intensity of road freight

Source	Country	Energy intensity [MJ/tonne km]
Schipper et.al. 1993	FR	4,35
Schipper et.al. 1993	DE	2,51
Schipper et.al. 1993	IT	3,43
Schipper et.al. 1993	NO	4,32
Schipper et.al. 1993	SE	2,35
Schipper et.al. 1993	UK	3,81

Source: Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO^2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Michaelis state that there has been made no attempts to optimize the aerodynamic style of trucks, and estimates that air resistance could be reduced 40% leading to a 20% reduction in the specific energy use. Further optimization of engines seems to be unrealistic in the short to medium term. In the long term however some reductions might be possible.

The Enquette Commission estimate that the efficiency of the German fleet can become 10-20% more energy efficient before 2005. The best new lorries in 1992 can be up to 33% more energy efficient by 2005[31].

Rail.

Table 98: Primary energy intensity of rail freight

Source	Region	Type of rail freight	Energy intensity [MJ/tonne km]
Martin and Shock 1989	UK	Trainload	0,7
		Mixed	1,0
Rigaud 1989	FR	Containers	0,4
		Mixed	0,9

Source: Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Like it is the case for road freight energy intensity of rail freight varies with the technology in use, the geographical conditions in the area in question and the actual load factor. Estimates by Martin

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[31] Enquette-Kommission "Schutz der erdatmosphäre" des Deutschen Bundestages, "Mobilität und klima - wege zu einer klimaverträglichen Verkehrspolitik", Economica Verlag, 1994.

and Shock (1989) for UK and Rigaud (1989) for France indicate that the intensity is much lower for rail freight than it is the case for road freight (see table above). A first rough estimation when comparing the two tables above tells us that moving goods by rail is much more efficient than moving them on trucks. However the picture is not valid in all cases as these energy intensities vary with the actual operation load factors and the distance of the freight. However on longer distances rail seems to be the most energy efficient way of transporting goods on land. Further investigations will have to be made on the subject in each actual freight delivery.

Table 99: Scope for energy saving through train design

Type of mode	Weight reduction [%]	Rolling resistance reduction [%]	Drag reduction [%]	Overall tractive energy saving [%]
High speed train	50	20	25	25-50
Locomotive hauled	60	20	25	40-50
Suburban (10km between stops)	60	20	25	45-50
Urban train (2km between stops)	60	20	25	65
Container freight	50	50	10-20	25-30
Minerals freight	50	50	50	65

Source: Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO^2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

As can be seen in the table above Michaelis estimate that there is a technical potential to improve the energy intensity of different train models of around 25-65%.

The Enquette Commission also estimates that considerable reductions in energy intensity of trains will be possible. A reduction of the weight might lead to 50% reductions in energy use per kilometer. Besides this potential there are considerable potentials in regenerated breaking energy, new dieselmotors and the energy use for space heating and heat exchange inside the passenger trains.

All in all the future energy intensity of trains can become substantially lower than today and also lower than it is the case with future efficient freight trucks.

Ships.

In general ships use below 0,45 MJ per tonne kilometer which is considerably lower than todays intensity of freight by trains and trucks[32].

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[32] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Table 100. Long term potential fuel savings through improved ship technology (Martin and Michaelis, 1992, Tanja et. al., 1992)

Technology	Fuel saving [%]
Advanced engines	5-10
Wind assistance	10-20
Propellor design	5-16
Hull design	8-15
Reduced skin friction	0-14
Overall savings	25-50

Source: Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO^2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Michaelis estimates that two stroke ship engines have already efficiencies aproaching 50%, so only small efficiency gains around 5-10% is to expect through refinement of engine cooling and better exhaust energy recovery. Ship hull and propellor designs are also already close to the technological optimum. Wind assistance is installation of vertical axis wind turbines on ships which might save 10-20% of ship transport energy and improve ship stability. Altogether Michaeles estimates that the realistic potential of improving ships energy intensity is quite small compared to the other transport modes. For our scenario we assume that a 25% reduction of energy intensity of ships might be plausible in 2050.

Air.

Aircrafts end-use of energy per passenger-km has decreased dramatically since the mid-sixties[33]. World civic aviation fuel consumption rose 60% between 1976 and 1989 while the amount of passengers transported rose by 150%[34].This indicates substantial efficiency improvements in this period.

Bent Sørensen mentions, that Martin and Shock (1989) estimates a potential for a 30% improvement in energy efficiency over the next 20 years, by technical means such as improved aerodynamic efficiency and drag reduction, reducing weight of materials and improving engine efficiency. Besides the technical potential there is also a potential of reducing the waiting time in the air above airports and by trying to keep a higher occupancy rate[35].

As airplanes have relatively long lifetimes of 20 to 30 years and even more the required improvements in the fleet's average intensity index is probably going to happen relatively slow.

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[33] Schipper, Lee "Energy, environment and travel", in "Low consumption/low emission automobile - proceedings of an expert panel", OECD, 1990; Sørensen, Bent, "Et mørkegrønt scenarie" in "Fremtidens vedvarende energisystem", Teknologinævnet, 1994.

[34] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

[35] Sørensen, Bent, "Selected experiences on energy conservation and efficiency measures in other countries, that may be relevant to the Australian effort to reduce the greenhouse effect, COWI Consult, 1991.

However historical development has shown that the intensity improvements of aircrafts have been quite substantial with annual decreases in fleet intensity per passenger km of around 3,5% per annum[36]. One of the main reasons for this substantial improvement is the high degree of competition between airline companies and also fuel costs relatively large share of operating costs. In 1991 fuel costs were about 15% of total operating costs. Expected efficiency improvements in the near future are the use of new materials for aircrafts, turbofan engines and a high number of seats (600-800 seats). In the long term new engine concepts like the propfan, a propellor with specially designed curved blades allowing high speed operation, is expected to raise efficiency further[37]. Another technological development might be the use of advanced light weight heat exchangers, of a type not yet developed, to provide cooling and recuperate exhaust heat from the engine.[38] Furthermore the use of new fuel types like liquefied natural gas or hydrogen could in principle lower intensity as those fuels weigh less per unit of energy in the fuel[39].

The Enquette Commission estimates that there is a technical potential to reduce the energy intensity of airplanes by 71% in 2050. As can be seen in the figure below some of the expected technologies are probably not going to be developed in the short term, and some of them are even unspecified.

Table 101:

Year	Resistance	Weight	Potential fuel index after improving weight and resistance	Motor concept	SFC	EINO x	Total fuel index per passenger
1990	100	100	100	3. generation Turbofan with conventional combustion chamber	100	100	100
2005	77	92	71	Shaded propfan fat less combustion chamber	80	33	57
2020	62	90	56	Shaded propfan with ICR core, LPB combustion chamber	68	9	38
2050	55	90	50	Not defined	57	6	29

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[36] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994 and Sørensen, Bent, "Selected experiences on energy conservation and efficiency measures in other countries, that may be relevant to the australian effort to reduce the greenhouse effect, COWI Consult, 1991 and Schipper, Lee: "Determinants of automobile use and energy consumption in OECD countries", Annual review of energy and environment, 20:325-86, 1995.

[37] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994 and Enquette-Kommission "Schutz der Erdatmosphäre" des Deutschen Bundestages, "Mobilität und klima - wege zu einer klimaverträglichen Verkehrspolitik", Economica Verlag, 1994.

[38] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

[39] Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Source: "Mobilität und Klima", Enquette-Kommission "Schutz der Erdatmosphäre" des Deutschen Bundestages, Economica Verlag, 1994.

Estimation of realistic economic potential for energy efficiency improvements of modes.

When it comes to the realization of the technologically feasible improvements of the energy efficiency of different transport modes like indicated in the previous chapter there does not seem to be many signs in the development in the previous twenty years that these improvements will appear without strong governmental interaction. Michaelis has summarized her predictions of possible future effiencies of all modes in the table below. As can be seen the projected change to 2010-2020 for the economic potential indicates that the intensity is not going to drop by itself under the economic situation in 1995. However the introduction of a whole range of governmental measures including the inclusion of all external costs of transport into the pricing of transport fuels might have the potential of pushing the development in the right direction.

Table 103: Technical and economic potential for energy efficiency of different transport modes according to Michaelis.

Mode	Current intensity [MJ/pass-km or tonne-km]	2010-2020 Projected change (lower limit close to economic potential) [%]	2010-2020 Technical reduction potential at constant performance [%]	2010-2020 Technical reduction potential with reduced performance [%]	Technically possible reduction 2050? [%]
Cars	1,2-2,0	0 to 30	35 to 60	80	90
Buses	0,5-1,3	+10 to -10	40	60 to 70?	70 to 80?
Heavy trucks	0,6-1,0	-10 to -20	50	50 to 75?	80?
Passenger trains	0,9-2,8	+10 to -10	25 to 65	90	95?
Freight trains	0,4-1,0	+10 to -10	25 to 65	80 to 90	90 to 95?
Air travel	1,5-2,5	-20 to -30	40 to 60	70?	80?
Marine freight	0,1-0,4	+10 to -10	30 to 50	80 to 90	90?

Source: Michaelis, L., "The transport sector in OECD Europe" in "Energy technologies to reduce CO^2 emissions in Europe: Prospects, competition, synergy", Conference proceedings, Petten, the Netherlands, 11-12 april, IEA/OECD, 1994.

Projection of the future demand for transport services.

In our market scenario we assume that the amount of transport in the EU15 will continue to grow. The improvements in energy efficiency of the transport technologies and the possible shift to low intensity transport modes will therefore be the only favourable solutions on the way to a less energy intensive transport sector.

As we assume that the total amount of trade between the EU15 countries will continue to rise as the internal market is realized we assume that the internal freight transport level and the internal persons transport level related to work and education will grow by 30% compared to 1990. Leisure travel is assumed to grow significantly due to the trends seen today where people travel further away on holidays and make more long trips through the year. Therefore we assume a doubling of leisure travel activities, both domestic and international, in 2050 compared to 1990.

[I hope this depends on prices

Also discuss cost if intercontinental transport og goods (no taxes on fuels today)]

Example of Danish energy scenario

The scenarios selected for the present study have been influenced by recent scenarios found in the literature, as noted earlier. Among the normative scenarios, the following scenario for Denmark has played a role, whereas for the scenario aiming to describe a society where neither of the actor groups discussed before have gained absolute majority, we use a European scenario that we refer to as the "fair market scenario", because as discussed above it includes a correction of consumer prices to reflect external or social costs. After the two indicative sections below, the actual scenarios assumed for the study will be described **[not ready for this version].** The following excerpt is taken from Sørensen (1995).

Demand models

The bottom-up approach for determining energy demand (Sørensen, 1981b; 1984; 1988) is based on a model in which all basic needs are to be covered (food, shelter, human interaction), and furthermore a broad selection of secondary needs, that may be selected differently by different societies and by different individuals (activities, relations, possessions). The needs are then analyzed in terms of energy inputs, recognizing that in many cases the same

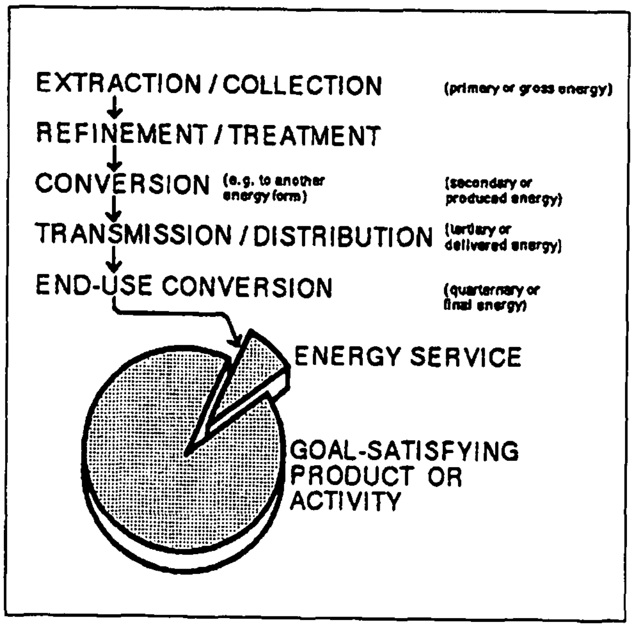


Figure 2. Energy conversion chain (Sørensen, 1988).

	1. Cooling & refrigeration	2. Space heating	3. Process heat under 100°C	4. Process heat 100-500°C	5. Process heat over 500°C	6. Stationary mechanical energy	7. Electric appliances	8. Transportation work	9. Food energy	TOTAL
A. Biologically acceptable surroundings	0-24	0-1500	0	0	0	0	0	0	0	*0-1524*
B. Food and water	14-24	0	15	2-6	0	0	0	0	120	*151-165*
C. Security	(0)	(0)	0	0	0	(0)	0	(0)	0	*(0)*
D. Health	0	0	80-150	20-40	0	0	(0)	(0)	0	*100-190*
E. Relations, leisure	(0)	(0)	0	0	0	0	10-60	25-133	0	*35-193*
F. Activities:										
Construction	0	0	0	0	0	30-60	0	7-15	0	*37-75*
Trade, service and distribution	1-8	0-600	0-12	0	0	6	10-20	30-70	0	*47-716*
Agriculture	0	0	2-12	0	0	3-6	0-2	3-6	0	*8-26*
Manufacturing industry	1-16	0-600	10-100	20-70	12-30	20-60	15-30	7-15	0	*85-921*
Raw Materials and energy industry	0	0	0-30	0-20	0-250	0-170	0-30	0-20	0	*0-520*
Education	0-2	0-160	0	0	0	0	1-2	0	0	*1-164*
Commuting	0	0	0	0	0	0	0	0-30	0	*0-30*
TOTAL	*16-74*	*0-2860*	*107-319*	*42-136*	*12-280*	*59-302*	*36-144*	*72-289*	*120*	*464-4524*

Figure 3. Scenario for the rate of end-use energy needed for satisfying goals in different societies at different goegraphical locations (W per cap) (Sørensen, 1984; 1988; 1994).

products and services can be produced in different ways, characterized by highly different inputs of materials and energy (Figure 2).

The outcome of this analysis is, that over a broad range of secondary needs selections, geographical locations (important for heating and cooling needs) and settlement types (from dense cities to dispersed living), the required average flow of energy inputs are in the range of a half to two kW per capita, except for extremely cold climates. This assumes using the best technology known at present. Fifty or a hundred years ago, the numbers would have been higher (if the same needs could have been delivered), and in the future, new technological breakthroughs may make the numbers lower. Particularly as regards the low-temperature heat use, a wealth of options are available, including heat pumps and heat cascading.

Figure 3 gives an overview of energy flows, graded by energy qualities and broad classes of activities. Note that the bottom-up approach implies that the desired human activities constitute the driving force, and that production of goods and services becomes a derived quantity, the size of which depends entirely on the specification of needs. The societies are not assumed to produce goods blindly, in the hope that a demand can be created, once the goods are brought to the market. Again this is a Scandinavian way of looking at the production process, very different from the primitive market picture prevail-

	1. Cooling & refrigeration	2. Space heating	3. Process heat under 100°C	4. Process heat 100-500°C	5. Process heat over 500°C	6. Stationary mechanical energy	7. Electric appliances	8. Transportation work	9. Food energy	TOTAL
A. Biologically acceptable surroundings	0	260	0	0	0	0	0	0	0	*260*
B. Food and water	18	0	3	6	0	0	0	0	120	*147*
C. Security	0	0	0	0	0	0	0	0	0	*0*
D. Health	0	0	100	24	0	0	0	0	0	*124*
E. Relations, leisure	0	0	0	0	0	0	54	36	0	*90*
F. Activities:										
Construction	0	0	0	0	0	60	0	15	0	*75*
Trade, service and distribution	6	120	12	0	0	6	18	48	0	*210*
Agriculture	0	0	12	0	0	6	2	6	0	*26*
Manufacturing industry	15	106	12	10	10	60	30	15	0	*258*
Raw Materials and energy industry	0	0	12	10	10	30	12	15	0	*89*
Education	0	26	0	0	0	0	2	0	0	*28*
Commuting	0	0	0	0	0	0	0	15	0	*15*
TOTAL	*39*	*512*	*151*	*50*	*20*	*162*	*118*	*150*	*120*	*1322*

Figure 4. Scenario for the rate of Danish energy use at the end-user in year 2030 (W per cap) (Sørensen et al., 1994.)

ing in e.g. Anglo-Saxon countries. However, different societies may place emphasis on different types of production (basic materials, consumer goods, agricultural products, knowledge-based services, and so on). This is what gives rise to the wide ranges of possible energy use in the activity sectors.

Figure 4 gives a specific example of the demand matrix of Figure 3, to be used for the energy supply model considered in the following chapter and pertaining to one particular scenario for Denmark attempting to realize some important traits of Danish preferences (Sørensen, 1994).

Among the energy demand models that could be considered, there would generally be growth and saturation models. By this is understood growth and saturation in services and production, which again may or may not lead to growth in energy demand, depending on the cost of energy systems as compared with other factors in the economy. Historically, short periods of growth have been followed by long periods of saturation on various levels, both for production and energy use (see Figure 5).

Present arguments for or against growth both refer to third world development: One side claims that economic growth will make the cake to share larger and everybody happier, while the other side says that growth will create stronger competition for scarce resources, and that will hurt the regions trying to develop. The actual development trends over the latest decades in some

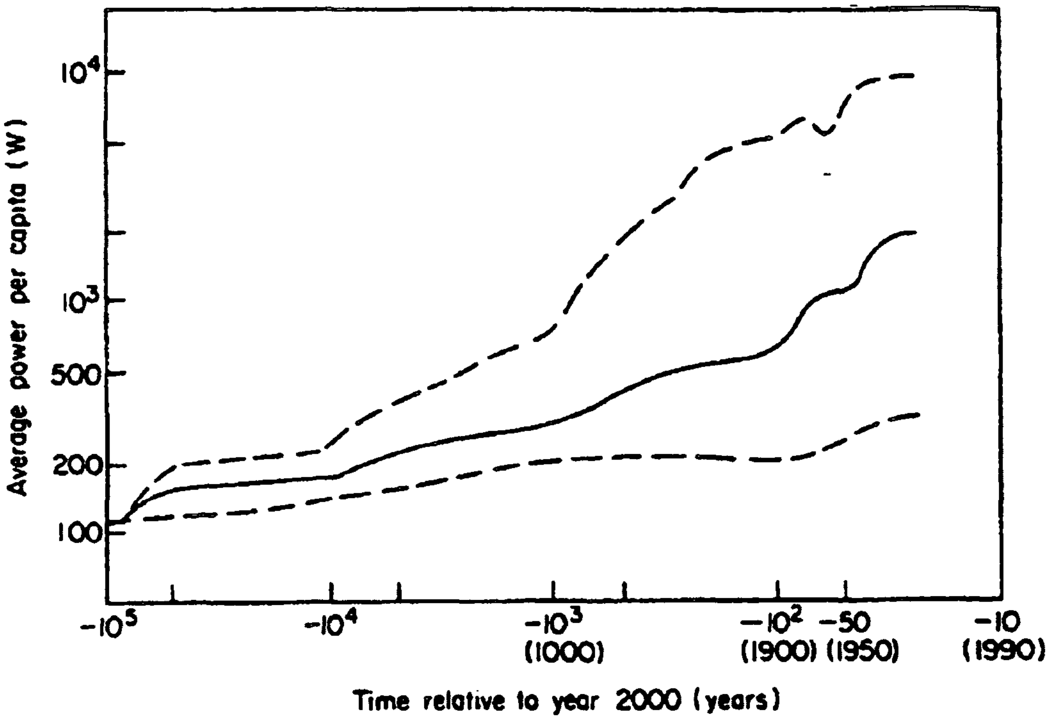


Figure 5. Sketch of the average rate of energy use by humans as function of time. The Solid line represents a global average, the dashed ones averages for the more and the less advanced regions at any given time (Sørensen, 1979).

areas support the second view, and it is not difficult to argue in general terms that global claims on the resource base do not seem to promote equity, but certainly help to creating hostility and cause warfare (problem of fundamentalist movements, oil wars).

It is important to stress, that one can have growth in the economic sense without the associated growth in resource usage: If the main growth is in intellectual activities and services, the physical growth can be zero or negative, while the economy may continue to flourish, remembering that economic indicators such as GNP only measure the level of *activity*. The scenario depicted in Figures 3 and 4 assumes a future society with increased emphasis on environmental sustainability, low and efficient resource usage and growth in those activities expected in an information-society (Porat, 1977; Valaskakis and Fitzpatrich-Martin, 1980).

Bottom-up construction of energy systems

Once the energy demand structure is given, the modeller's task is to construct a supply, conversion and delivery system capable of satisfying the demand of the end-users. The selection of the system depends on the technologies available, but also in some cases on preferences between different system layouts, of which one is not clearly superior to all the other ones. Typically, the life-cycle impacts of different types of system are so different that some groups in the society have clear preferences for one solution and feel that they would not like to live with some of the other solutions, while other groups in the society may feel just the opposite way.

In such cases, one could possibly give high priority to options involving a decentralization, that would allow different subgroups in a society to select different solutions, rather than going for centralized solutions bound to make some fraction of society unhappy. That this is possible hinges on the recent development of decentralized solutions without cost penalties, i.e. as technology has entered a stage, where the economy of scale is less important than it was some decades ago.

The technique for constructing the energy system may consist in tracing the system back from the end-user, but as it will become clear, this is not always possible, and some tracking back and forth between supply end demand may be required. At each end-user, one may first consider the options for local energy production, such as solar heat, solar cells, building-size fuel cells, and so on. When intermittent production is included, the question of load-matching and energy storage has to be considered. Some such storage may be located at the end-user. Current examples are batteries for portable equipment and heat stores for solar thermal collection systems. In a wider perspective, load management also has to be considered, such as postponement of non-urgent tasks, within time-limits accepted by the user and possibly reflected in her/his cost of energy.

On the supply side, there might be installations characterized by a large fraction of the cost tied up in equipment (e.g. wind turbines, photovoltaic panels), but for which the operating cost is very small. Such equipment should have priority, once it is part of the system, and if the energy generation is also intermittent, these installations should be dispatched before others that may be regulated. This means, that such priority equipment has to be considered up front, also in cases where it is not located near the user, and thus transmission and any further conversion to other energy forms should be determined at this stage. There may also be options for central storage in the system, that can take care of surplus production from priority sources. If not, any overflow must be exported or will be lost.

In principle, the modeller works backwards from the end-user through transmission and conversion equipment to the primary energy source inputs, but with the above-mentioned priority sources as fixed options. In some systems, the delivery paths in place (gas, electricity and heat transmission lines) determine which energy flows can be routed to particular groups of end-users,

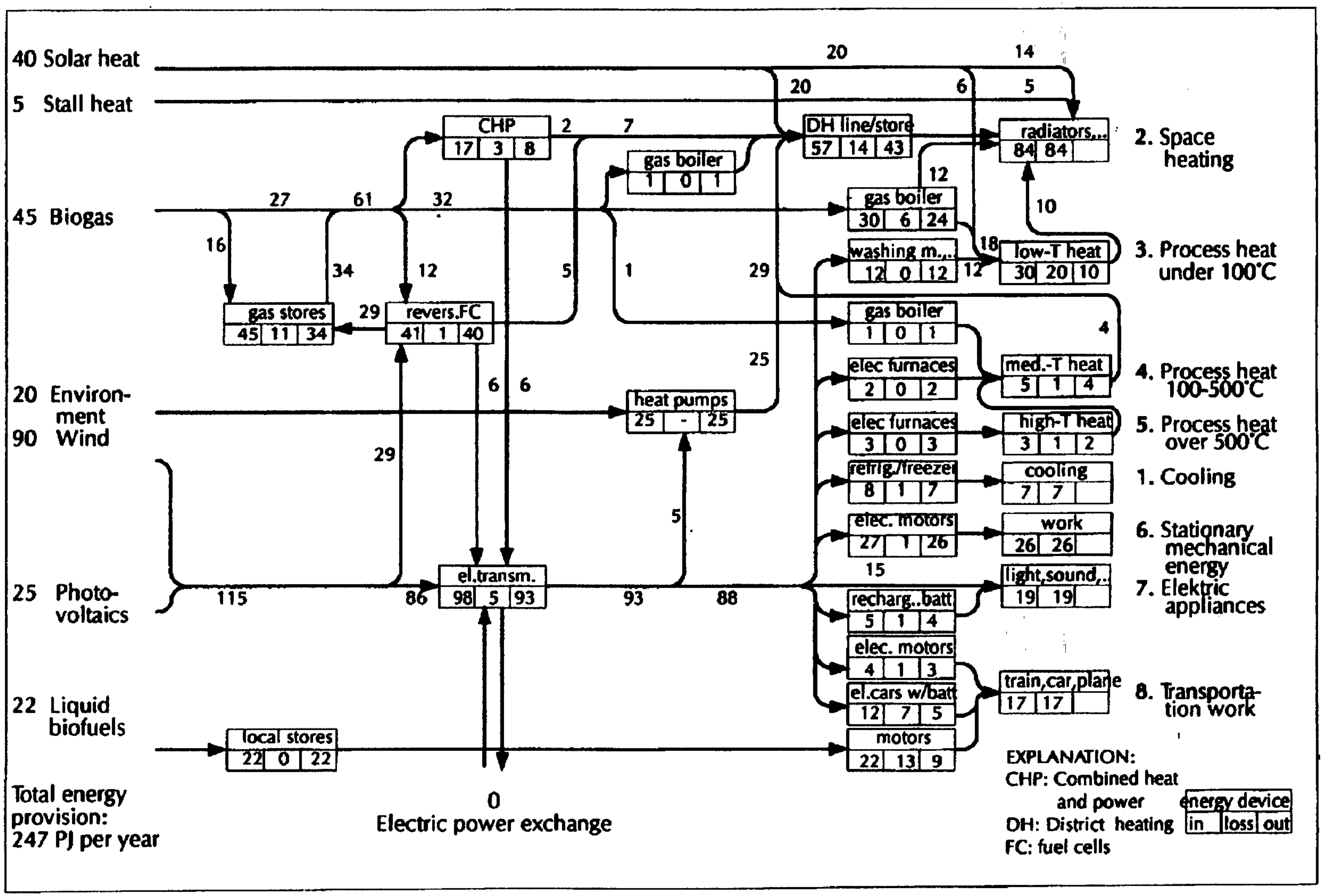


Fig 6. Scenario for a renewable energy based system for Denmark anno 2030 (units: PJ per year). (Sørensen et al., 1994)

but in many cases there would be more than one option for generating the various energy forms then demanded. This defines the dispatch problem, where a routine must be found for selecting the running order of generating equipment and feeding energy sources, that will be employed at any given moment.

This selection may be based on a ranking of the sources (e.g. in terms of generating costs), but often there is more than one solution satisfying any simple criteria. This is certainly the case, if the system comprises storage and import/export options in various places between supply and demand. One of the criteria to consider is security of supply, meaning that one minimizes the risk that, for example, stores are empty when they are unconditionally needed (especially relevant for systems with a high fraction of intermittent sources).

It is important to distinguish between systems modelling aiming at proposing an optimal system layout, i.e. which components to build, and modelling aimed at utilizing a given system optimally, by selecting the best dispatch pattern. These two aspects may be combined in a dynamic simulation of the system, where one tries to identify the signals, that should lead to decisions to add components to the system (or phase out components), with given lead times between decision and operability of the new components.

Figures 6–7 give an overview of a preliminary scenario for a future Danish energy system based upon renewable energy sources and the demand scenario of Figure 4 (Sørensen, 1994).

It assumes a wind contribution based on a number of 2 MW turbines similar to the present number of smaller machines, and that roughly a quarter of all buildings have solar thermal or photovoltaic collectors. The contribution from biomass include gas and liquid fuels, and is based on the already started transition in the Danish agricultural sector, where a smaller area will be used only for food production, yielding however the same export of refined products but a balance considered more healthy between animal and vegetable products for indigenous consumption. The biomass for energy purposes is partly derived from better utilization of current "waste", partly from dedicated energy crops. However, the total cultivated area is not expanded from its present value.

Figure 7 details the flows in the agricultural sector, while Figure 6 treats the rest of the system leading to the end-users. The scenario is preliminary, as the dynamic simulation of the supply-demand matching has not yet been performed, but only the overall balancing of flows. However, it gives an example of a system taking advantage of the current transmission network for electricity, gas and heat, and at the same time removing fossil fuel inputs and their greenhouse emissions over a 30 year period, with minimum requirement for long-term energy storage (although the system does comprise heat stores, gas stores in aquifers and salt domes, and a little electricity storage capacity in batteries and compressed gas stores).

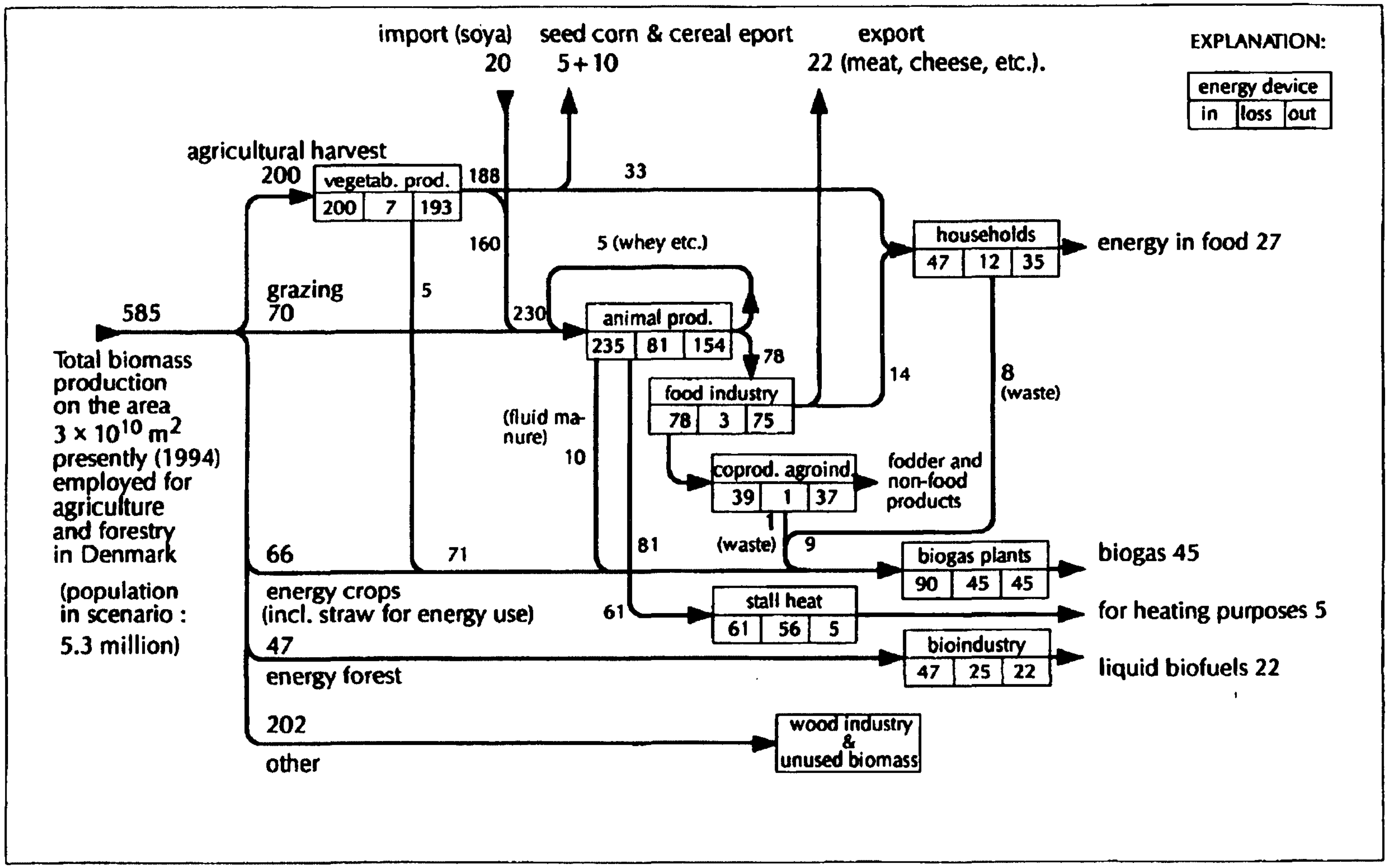


Fig. 7. Scenario for Danish biomass sector anno 2030 (indirect energy inputs through chemical fertilizers etc. are not included. Units: PJ per year.

It is assumed that the interconnection with the European power grid will take care of any further mismatch between electricity production and local demand. This involves some imports and exports, judged to be beneficial to both partners in the exchange. For example, the exchange with countries such as Norway possessing large seasonal hydro stores allows for taking care of day-to-day mismatch, while adding to the resilience of the Norwegian system towards coping with particular dry years, a function which today is taken care of by the Danish fossil fuel power stations (Sørensen, 1981).

In the transportation sector, the scenario for year 2030 assumes that only electric vehicles are allowed in cities, and that long-distance transport of goods and people will be based on biofuels.

Example of European energy scenario

Bent Sørensen, October 1995

INTRODUCTION

This section outlines the end-point of the fair market scenario, by treating the 15 present European Union as one region. Later the North-South differences will be modelled and the scenario will be made on a country basis.

The efficiency of end-use conversion equipment and task arrangement is based on the best known current technology, which is assumed to be in place by 2050, except for building shells, where only a part of the known potential is assumed realised. The reason is the long time required for replacement of buildings. Included is best technology for new buildings and retrofitting of most existing buildings. Basically, the efficiency improvements for all sectors are taken from the technology descriptions made within this project. It is clear that the effect of new break-through's may further improve the actual efficiency by 2050. The measures included are all cost effective relative to current energy prices.

As regards energy sources, the renewable energy sources used in the scenario have costs that according to the technology descriptions are below 50 mECU/kWh for solar and wind power, below 80 mECU/kWh for biomass technologies and below 90 mECU/kWh for solar thermal. Some of the technologies, such as wind, are already there, whereas other ones will reach this level only around 2050 (e.g. solar photovoltaic). These differences will play a role in tracing the trajectories from now until 2050. The 2050 renewable energy costs are all below the estimated cost of fossil fuels including externalities but excluding non-environmental taxes and subsidies. The present cost is around 40 mECU/kWh and the assumed externality costs around 150 mECU/kWh, with considerable spread between fuels and conversion products, and a large uncertainty particularly regarding greenhouse warming externalities.

In addition to the cost of renewable energy conversion systems, added costs are incurred due to the increased need for energy storage, as the fraction of fluctuating sources increases. The cheaper storability of biofuels is used to minimise the storage costs, so that the total system cost can be held below the level given by present cost plus externalities. It should be mentioned, that the renewable energy costs are only valid up to a certain level of usage. Above that, the problems of access to enough renewable energy will reflect itself in higher prices. Examples are use of photovoltaics above the level that can be accommodated on rooftops, and the use of bioenergy above the level that can be derived from integrated agriculture on land areas presently in use for farming. As it will become evident, we do not reach these ceilings in the present scenario, and thus avoid the problem of fossil fuels being cheaper than excess use of renewables, despite externality incorporation. This simplifies the scenario construction, as the consumer reactions on steeply rising prices (reduced demand or changed priorities) need not be calculated. However, a discussion of these issues will be included, cf. the previously distributed note on price elasticities.

On the demand side, our basic assumptions include an economic growth determined by market mechanisms, but where the qualitative content of the growth is influenced by emerging value systems. The assumption, which prompted us in the previously communicated social descriptions of the fair market scenario to use the alternative name "trend scenario", is that about a third of the growth is in material-intensive activities, and two thirds in non-material intensive areas, which are characterised by little need for energy-related activities. Instead of using exponential growth rates, that cover lack of knowledge regarding the underlying causes, we have tried to identify the likely growth in each subsector of the economy, using partly the market activities identified and partly the individual citizen's pattern of behaviour, as discussed in terms of currently identified trends and the actor model described in the previous papers on the scenario model.

The overall activity growth in the European Union countries was a factor 5.6 during the preceding 60 years, from an average GNP of 2200 1990-US$/cap. in 1930 to 12370 1990-US$/cap. in 1990. The growth has been uneven (depression, World War II, reconstruction period, unprecedented growth period 1956-1971, and a stabilizing period from 1973), but over the entire 60 years perhaps symptomatic of the technology progress achieved during this in the World history quite exceptional period. Most analysts assume, that the growth over the next 60 years will be lower, and that high growth rates will be seen predominantly in certain Asian regions, whereas Europe is more in a stabilising period. The IPCC Second Assessment (1995) estimates in its high-growth scenario, that the growth in Western Europe will reach a GNP of 45300 1990-US$/cap. by 2050, as contrasted to 69500 1990-US$/cap., if the growth factor equalled that seen in the period 1930-1990. We find a 2050 GNP level of 32000 US$/cap. for EU-15 more realistic, corresponding to a development between the IPCC low and high growth scenarios. It is still a growth in absolute terms twice as big as between 1930 and 1990 (20000 for the period 1990-2050 vs. 10000 1990-US$/cap. between 1930 and 1990).

Our assumption in the trend/fair market scenario of an emerging European "information society" with two thirds of the growth decoupled from energy and material's use implies in simplistic terms that the growth factor for demand of energy services should be one third of the GNP growth.. However, the relationship between energy and GNP is more complex and depends both on attitudes and on technology developments during the period considered. The ratio between energy and GNP growth 1930-1990 first declined from 1.5 to 1.0, then rose to 2.0 during the exceptional period and became negative after 1973. This is partly an effect of energy (and particularly oil) prices, but also technology requirements have played a role, by improving energy efficiency after 1975 in ways far exceeding a cost-driven transition (e.g. the problem of microelectronics fault rates depending on waste heat from microprocessors has caused heat losses to be reduced at a much faster rate than would have been expected on pure energy cost grounds). In short, we have assumed an overall increase in end-use energy of just under 50%, which in fact may be similar to the 1930-1990 growth in delivered energy service. For specific primary energy, the increase in the EU-15 countries between 1930 and 1990 was a factor 2.7 (from 1700 to 4633 W/cap.), which is under half of the growth in GNP during the same period. Our claim is that the change in delivered energy service may have been even lower (for example the improvement in service between bicycle transport and automobile transport is not always as big as the increase in energy use would suggest).

The specific assumptions on the fair marked scenario assumptions on energy demand and supply are discussed in the two following sections.

ENERGY DEMAND

The two adjacent Figures show an aggregate picture of the European (EU-15) energy system in 1990, and the similarly simplified fair market scenario picture for year 2050. As in most statistical sources, three sectors of final demand are indicated: Industry, transportation and households plus tertiary sectors (commerce, public,...), with delivered energy distributed on sources and on qualities, the latter derived from our paper on end-use written for this project. The Figure used here simplify this analysis by having fewer categories: Heat-1 (below 100°C) comprises space heating, hot water and process heat in this temperature regime. Heat-2 is cooking and process heat above 100°C, and "electricity etc." includes electric appliances, motors, light, computers, refrigeration, cooling and stationary mechanical energy. Person transport is divided into leisure travel and work-related travel (service, commuting, etc.), while freight transportation comprises both long-hauling of goods and local distribution.

For households, we assume the area per person to increase by 30%, due to smaller family size. This implies a 30% increase in both space heating and number of appliances, although in the latter case, the energy use should increase less. The activity increase in this sector is assumed primarily to be in electrical appliances (increased penetration of known appliances and multi-media devices, plus addition of novel ones). A doubling of energy service demand in this category is assumed. Note that the (fairly arbitrary) concept of using the best currently known technology is rendered meaningful by rigorously adhering to the same definition in 1990 and 2050. This means that the difference between the 1990 and 2050 numbers are precisely the difference in service rendered, and the 2050 scenario assumes that the best advanced technology of 1990 is used throughout, i.e. there is no longer a difference between "delivered energy" and the "service level" defined by the specific "best technology". Naturally, this does not mean that there will not be further efficiency improvements both before and after 2050. However, we do not know what they involve and therefore do not include them. The most likely situation in 2050 is that the energy efficiency will actually be better than we assume here, and the scenario thus easier to achieve.

In industry, our assumption that a third of the activity increase is energy related implies a 50% increase in energy demand. However, the Figure for 1990 indicates end-uses using the same efficiencies as for the household sector, which is known in the case of industry to be an overestimate. The reason is that industry in most European countries pay substantially less per unit of energy than the private citizen (due to tax rebates and subsidies). The overall scenario assumption of "fair prices" means that subsidies to the energy purchases of European industry have to be removed. Thus the increase in end-use energy for industry is taken as 30% rather than 50%, considered to match the activity growth assumption with the fair price requirement. If European countries still want to subsidize their industry, it would have to happen in ways other than over the energy bill.

For transportation, we have extrapolated the current trend of increased leisure travel (more than one long-distance journey vacation a year per capita) and assumed a doubling of leisure transport. Work-related person travel and freight transportation is increased by 30%, for the reasons given above for industry.

Regarding the 1990 Figure, it should be mentioned that there are still a few minor discrepancies in the data (IEA and Eurostat Statistics). Some of these are discussed in our notes on the 1990 end-use figures, distributed in parallel with this paper.

ENERGY SUPPLY SYSTEM

The 2050 supply system depicted in the adjacent Figure (and the special Figure detailing the biomass sector) is based on selecting a few conversion technologies considered of high potential for the conversion of energy derived from renewable sources. These are reversible fuel cells and heat pumps, plus simple gas and heat storage systems. In practice, several other technologies are available, that could do the same job at similar or slightly lower efficiency. Presumably, the final picture will be different for different European countries, and the choice of one particular set of technologies here is mainly for the purpose of simplicity in illustrating the system layout, and there would be several more or less equally attractive solutions available (meaning that our scenario is not standing or falling with the progress in e.g. fuel cell technology).

Reversible fuel cells are expected to become available over a very wide range of size, from power plant level over larger individual buildings to perhaps mobile applications (in case of low-temperature fuel cells). The reversibility is particularly relevant for a renewable energy system, because the will at times be an overproduction of electricity (from variable sources such as wind and photovoltaic panels). No detailed time simulation is made to ensure the supply-demand match, but it is assumed that only 40% of the wind and solar electric power may be used immediately. The rest goes through the fuel cell systems and is stored as gas in underground caverns and containers, for use with a displacement from hours to at most two weeks. This is consistent with estimates of the capacity factor of variable sources in large electricity supply systems (Sørensen, ...) and on the effect of storage on wind power (Sørensen, ...). The need for fuel storage is diminished by having also a considerable share of biofuels in the system. For these, the production may be chosen to follow variations in demand minus supply of variable renewables. Heat storage, that is required e.g. in connection with solar thermal systems, is in the present scenario diminished by shifting a large fraction of the heat load to heat pumps. In Southern Europe these would use ambient air as their low-temperature source, whereas in Northern climates, it is advantageous to use soil or waterways (when available). District heating systems are assumed to play a role primarily in cities of Northern Europe, the U.K., Benelux and Germany. Today, only Finland and Denmark have a large coverage.

With these choices, the energy supply turns out to be amenable without use of fossil fuels, except for non-fuel uses such as chemical feedstocks and lubricants. This is gratifying, partly for the reasons given above, and partly because the solution is then robust against some variations in demand. Especially for wind and solar electricity, the exploitable resources are considerably higher. In the case of wind, visual impacts have been used to reduce the resource estimate considerably. As the true externality cost of this visual intrusion is low (very low compared to that of currently accepted energy sources), and in the case of wind totally reversible, an increased demand could easily change the attitude. The same is true for photovoltaics, where non-agricultural land could be used for central photovoltaic plants, also with a reversible visual impact. The present scenario only uses suitably located rooftops and façades.

The areas suitable for solar installations have been estimated on the basis of this project's technology descriptions. In the case of wind, the WEC and IPCC estimates are used (see van Wijk, Coelingh and Turkenberg, 1993; Grubb and Meyer, 1993; Sørensen, 1995). Hydro utilization is kept at the 1990-level and the non-energy uses of oil and natural gas is around half of the 20% of 1990 uses that would correspond to IPCC recommendations (although in our case, no CO_2 is emitted).

Biomass sources play a special role, due to their versatility as storage media and as fuels for the transportation sector (half of which is assumed to run on electricity - electric vehicles and trains). From woody biomass (forest residues and energy plantations) methanol is produced, and another fraction of the vehicle fleet is operated on the basis of compressed gas. This may be compressed biogas (methane, as the CO_2 has to be removed before compression) or hydrogen. The methane comes from community-sized biogas plants being fed animal manure, straw and household waste, and the hydrogen comes from gasification of any biomass residue or crop. Fast rotation species would be grown on marginal land, whereas as large a fraction of the biomass needed for energy is to be derived from residues. An optimized integrated food and energy production will yield much more biomass for energy purposes than today's agriculture, that is based on artificial straw-shortening, due to residues previously being considered a nuisance. The efficiency of the best operating biogas plants today is about 50%, and the same efficiency is assumed for gasification (in actuality, it depends on how pure the hydrogen is required to be - between primary producer gas and pure hydrogen). Methanol plants are assumed to have an efficiency of 40%. Energy needed for these processes are derived from the processes themselves, but a residue is left over, which in the case of biogas is a fertilizer of particularly high value - far better than the material that were originally removed from the farm. But also the gasification residues contain all recyclable nutrients, and may be returned to the fields as it is, or in an improved physical state (e.g. granulized).

It is thus assumed, that the primary agricultural production is unaltered from 1990 to 2050, although the dietary balance between grain and vegetables versus meat may well change, as would the area allocation to rotation crops, permanent crops, meadows and energy crops.

[Detailed scenarios

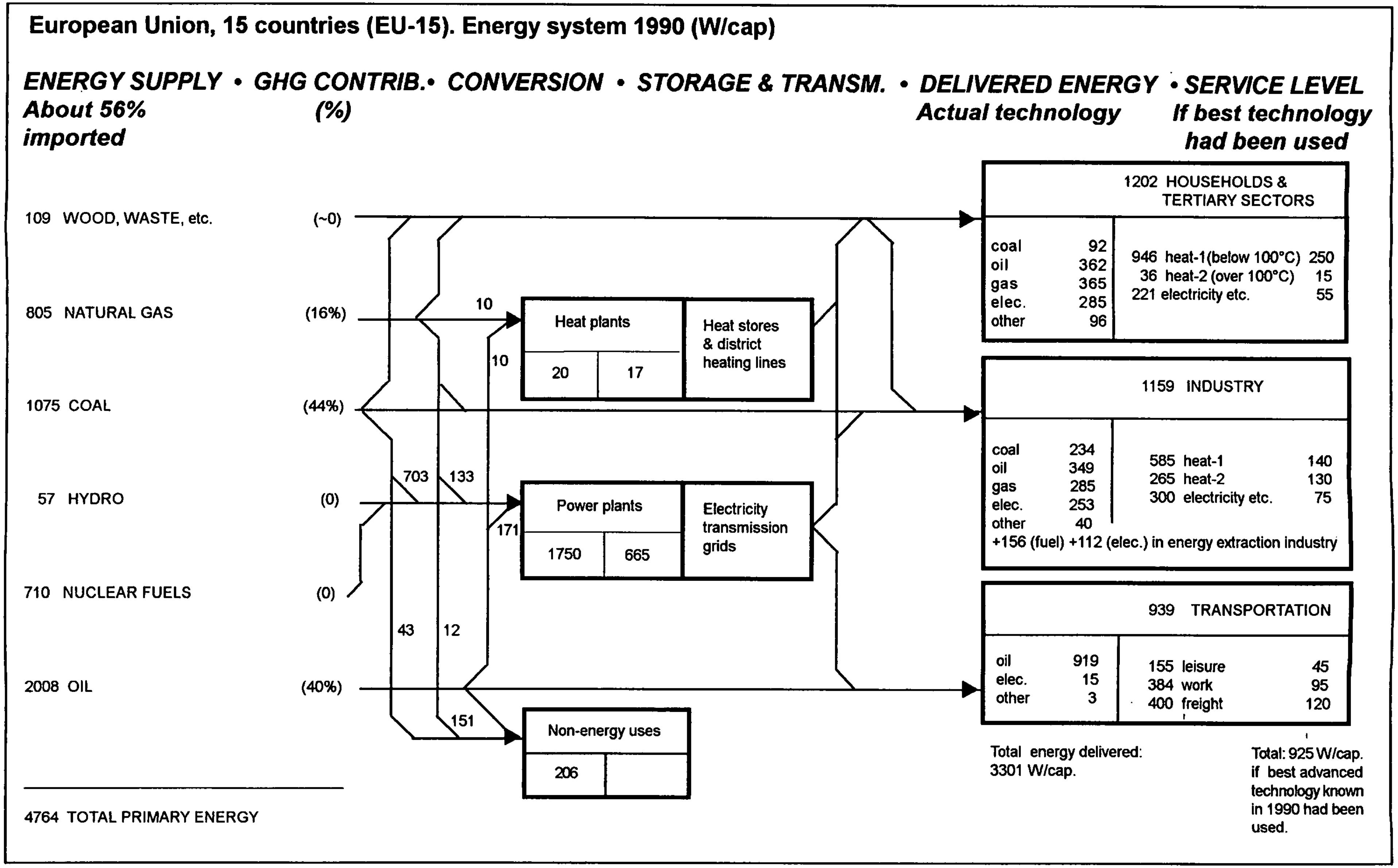
Fair market and sustainability scenario for Denmark to be described here.

Trajectories

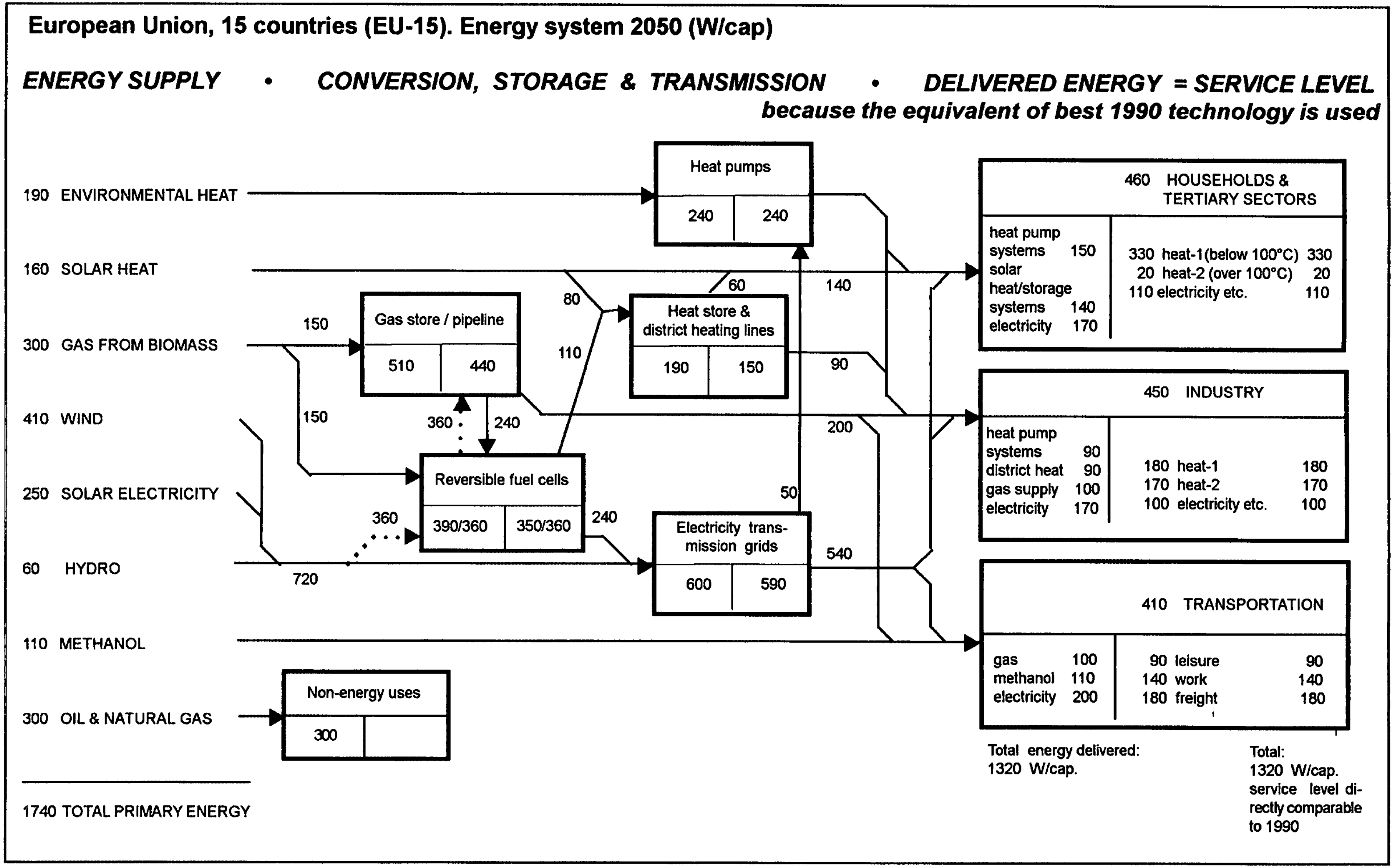
Here some midpoints (2000, 2010, 2030) will be described, in order to show the different pace of penetration for different technologies.

Consistency evaluation

The time-variability of some renewable energy sources makes it necessary to ascertain, that demand and supply can be matched at all times, due to sufficient storable fuels and energy storage systems built into the conversion setup.]



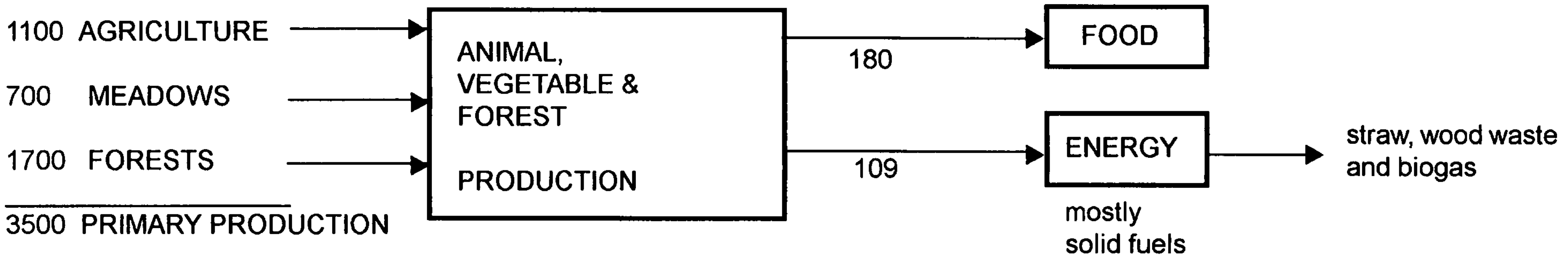
CURRENT EU-15 ENERGY SYSTEM (based on IEA and Eurostat data)



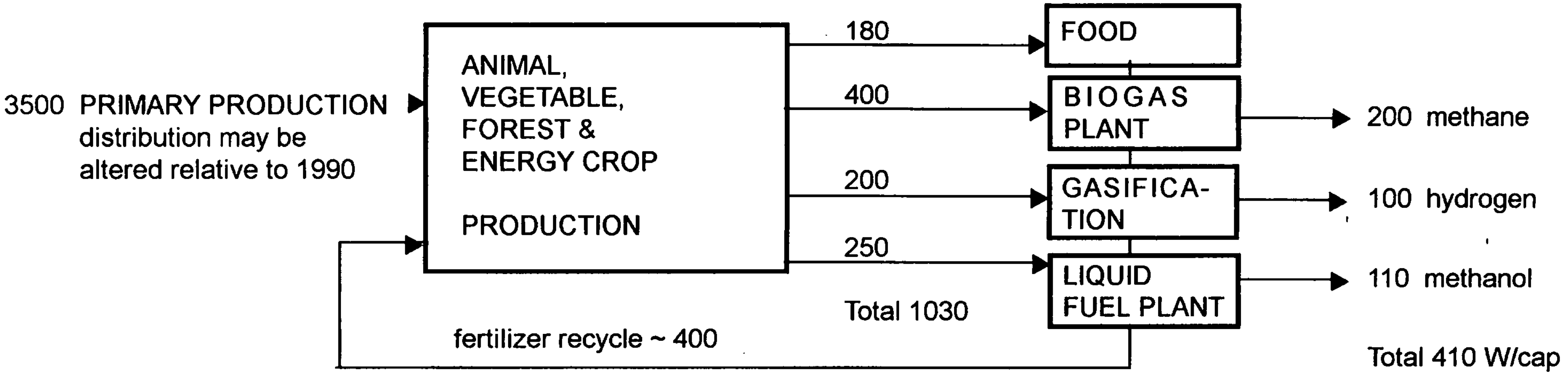
2050 EU-15 ENERGY SYSTEM, FAIR MARKET SCENARIO

European Union, 15 countries (EU-15). Biomass sub-system 1990 and 2050 (W/cap)

BIOMASS PRODUCTION • HARVEST • PRIMARY CONVERSION • ENERGY PRODUCTION FOR SUPPLY



CURRENT (1990) EU-15 BIOMASS SUB-SYSTEM



2050 EU-15 BIOMASS SUB-SYSTEM, FAIR MARKET SCENARIO

Life-cycle analysis

Bent Sørensen, June 1995
(based on contribution to ExternE project)
(Sørensen, 1995)

Overview

1. Why are LCA/externality studies made, what are the limitations?

The purpose of performing externality studies of energy systems is to assist decision-makers in the process of assessing different solutions in the energy field. While for a decision on erecting a site-specific energy installation, a dedicated study pertaining to the proposed technology situated at the given site will be relevant, many decisions relate to general energy policy and necessarily are generic, at least for a region or a nation. This means that cost and externality data should be of a fairly aggregated nature, and the site specific variations would rather be seen as a component in choosing one site rather than another one for a given installation. On the other hand, it is not possible to assess generic systems without having access to real data, and such data can only be procured from specific studies of specific technology at specific sites. Once a certain body of such data have been made available, one may generalize the data base to provide the needed aggregate data. In other words, it is not a question of one or the other approach, but some site specific studies such as the EC ExternE project (European Commission, 1995) are simply necessary in order to establish methodology and to construct the foundation for aggregate studies relevant to planning and policy decisions.

2. Impacts to include in specific studies

There are a number of impact categories to consider for inclusion (Sørensen, 1994). Externality studies typically include environmental impacts and some social impacts (e.g. those associated with occupational injuries and large accidents). Economic impacts are usually considered to be internalized, although this is not always true for impacts on national payment's balances and distribution of employment. Other impacts, related to supply security, resilience and policy, are rarely considered in externality studies, and are not included in the EC ExternE study mentioned above. Again the appropriateness of trying to distinguish between impacts internalized in prices and externalities depends on the purpose of the analysis. If for instance, the analysis is to be used as a basis for considering the magnitude of an energy tax, the distinction is important. On the other hand, in other cases, where the prices are already including taxation on both inputs and outputs, it may be very difficult to identify what is internalized and what not. This type of problem is clearly present in studies such as ExternE, where impacts on workers in coal mines may be said to be reflected in wages, and where some countries apply different taxes on fossil and renewable power.

Also in another way, the current studies may be said to be biased. Most of the impacts considered are seen from the point of view of human beings, a bias particularly difficult to avoid when monetising is attempted. The pollution affects ecosystems and their many inhabitants, but only impacts on human health are quantified in detail. Some non-human impacts have nevertheless been considered, such as loss of species and recreational value, but again the valuation is seen from the point of view of human society. Needless to say, the long-term effects of pollution on our planet are difficult to enumerate, and impossible to valuate.

As regards the social impacts and impacts on resilience, on infrastructure and on development goals, many arise from stages of the fuel cycles not considered in detail (e.g. distribution and end-use), or are indirect impacts considered in a life-cycle analysis, but not in a straight fuel cycle assessment. Occupational impacts are enumerated as far as they involve workdays lost, hospitalization or death, but less tangible impacts involving stress and poor work environment are difficult to assess and thus often left out. In general terms, this is the basic approach taken in the studies presented: Those impacts that are difficult to quantify or even identify are simply left out. Clearly there would be cases, where this introduces a bias in assessment, namely if two systems are compared, that have very different quantities of such qualitative impacts.

Whether a full LCA should be performed or a more restricted fuel cycle analysis, not including indirect pathways, depends on an estimate of which impacts may be important. No assessment will include all possible impacts, so an initial screening is usually made in order to identify the most important impacts for a given system. This is a very important step in the analysis, as errors of omission at this stage can of course be detrimental to the excercise.

3. Top-down or bottom-up approach?

Early estimates of externalities in the energy sector used top-down approaches, primarily out of necessity. One approach is to look at broad industry statistics on occupational health impacts, and to translate them to the energy sector either by evaluating impacts on the basis of economic activity (i.e. so many impacts per ecu spent in adding value, preferably taken from industry categories similar to those of the energy sector and its suppliers, if data from the energy industry itself are unavailable). An alternative is to relate impacts to materials used, so that impacts would be e.g. occupational deaths per unit of steel processed. Such approaches have been used from the earliest studies by e.g. Inhaber (1979), Sørensen (1981) to recent ones by Hohmeyer (1988) and Ottinger (1991).

The sometimes huge spread of values arrived at by top-down estimates for the same energy system indicates a problem with this approach. Clearly, specific studies can help in pin-pointing the correct order of magnitude of impacts, and a good data base of site and technology dependent facts is indispensable for a good top-down analysis. However, also the bottom-up approach has problems.

The bottom-up approach has a tendency to contemplate only a subset of impacts, because it focusses on areas where data are available and impact pathways can be established. There may be a lack of completeness, due to not considering synergistic effects, such as the common-mode failures known to be a feature of complex technologies, but often difficult to describe sufficiently accurately to allow an evaluation of impacts. The bottom-up approach can therefore be expected to always give an *under-estimate* of the impacts. Allegorically speaking, the bottom-up approach looks at the roots of the tree but may not have found them all. The top-down approach, on the other hand, takes a birds-eye view of the tree and may not disclose everything going on under the leaves or below ground. However, it is less likely to miss system-wide links, and in some cases may avoid errors by averaging over many pathways.

In practice, a mixture of top-down and bottom-up approaches is often used.

4. Site and technology specificity or generic approach.

Site-specificity makes impacts depend on factors such as geology and population distribution around the energy facility considered. Technology specificity is linked to the purpose of the study: For licensing a new power plant, the actual technology used should of course be considered. However, the results of such state-of-the-art technology is rarely indicative of the average technology in place. The U.K. coal fired power plant considered in the EC ExternE project has flue gas desulphurisation equipment not present on the majority of U.K. plants. For use of externality assessments in future energy planning, clearly the best technology should be considered, if that is the technology intended for installation.

Generic studies are of interest for assessing the existing energy system without embarking on enormous amounts of work, and may be of interest for planning purposes, where sites of future installations have not yet been decided, but where it is assumed, that site specific considerations will be made during implementation of a certain energy plan. Aggregating over time is less attractive, partly because the newest technology will normally be used for new energy facilities, and partly because impacts pertaining to different time periods may be difficult to compare. Not only the physical setting will change with time, but also the social setup and the values prevailing in societies. This is a complication common to all assessments of impacts of an energy system, because of the extended life time of the system, and in some cases the extension of impacts far beyond the life of the actual facilities associated with the system.

5. Marginal change or systemic transition

Studies such as the EC ExternE project (European Commission, 1995) make the assumption that the new systems considered are marginal additions to the existing system. This implies that in calculating the impacts of manufacturing e.g photovoltaic panels, the energy input comes from the current mix of power plants, typically coal-fired plants or nuclear ones. Evidently, this gives results very different from those emerging from a transition to a renewable energy based energy supply system, where the manufacturing impacts would come from solar, wind and biomass plants.

One workable alternative to the marginal assumption is to consider each system as autonomous, i.e. for the photovoltaic plant to assume that the energy for manufacture comes from similar photovoltaic plants. This makes the impact evaluation selfcontained, although it is no longer a representation of the actual situation. In some cases, however, the power for site-specific work mostly comes from nearby installations, rather than from the national average system. As renewable systems like wind turbines and solar plants are of small unit size, the gradual establishment of a sizeable capacity could be viewed as involving the use of energy from the previously installed plants of the same kind.

6. Qualitative versus quantitative estimates of impacts

There is no disagreement that one should try to quantify as much as possible in any impact assessment. However, the divergence comes in handling of those impacts that cannot be quantified (and later for those quantifiable impacts that prove to be hard to monetise). One standard approach is to ignore impacts that cannot be quantified. The EC ExternE approach tries instead to clearly mark the presence of such impacts, and adds the warning that numbers representing impacts cannot be summed up to a total, as some impacts are missing. As many authors (see e.g. Ottinger, 1991) have pointed out, the danger is that policy-makers will still ignore the warnings and use the numbers given as if they were totals. Hopefully this is an underestimation of the capacities of decision-makers, as their task is precisely to make decisions in areas, where only part of the consequences are known at any given time, and where most quantitative data are uncertain. If this was not the case, there would be no need for decision-makers, as the calculated total impact values would directly point to the best alternative.

7. To monetise or not to monetise.

There has been considerable discussion in the EC ExternE project group on the methods of monetising. Is willingness to pay (WTP) a fair representation of anything but a momentary consumer outlook? Is the art of policy-making not precisely to be able to look beyond todays chores? Clearly, the systems considered here have impacts reaching decades and in some cases centuries into the future, so a fair monetising should take into account changes in value systems, intergenerational equity, and so on. The trends observed today is for increasing concern over the state of the environment, implying increasing standards and hence increased valuation of even the same impacts, with time. Contingency evaluations should thus try to identify not just present attitudes, but trends in attitudes, and the extrapolated values should be employed in calculating the monetary value of impacts occurring over a period of time. None of this has been done in the current studies, which even replace unknown WTP's with artificial constructs such as the statistical value of life taken from insurance premiums.

Similar discussions take place in connection with the use of interest rates to discount future impacts. Although everybody agrees that the long-term interest rate to use for this type of evaluation should be lower than the short-term one, there is little agreement on how much smaller. The EC ExternE study uses 10%, 3% and 0% per year to illustrate the range. The 3% rate happens to be the average real interest rate over the last century, but if, as suggested above, the concern over the future of the planet is increasing, then not only should money be deposited today to take care of environmental clean-up according to current practices, but also to take care of future requirements that may be much stricter than the current ones. On the other hand, technology progress may decrease future costs of clean-up compared to present costs, so there are tendencies working in both direction. Probably ignoring depreciation completely is the most fair way to represent the present knowledge of future requirements.

8. How to present the results

Some thoughts have gone into representing the results of the EC ExternE study, resulting in summary tables with statements of uncertainty, of whether the impacts are local, regional or global, and whether they are short-term or long-term. In addition, there are as mentioned warnings against summing up to arrive at totals, due to unquantified impacts. Unfortunately, some of the impacts that might be largest are classified as too uncertain to include in the summary tables. This includes the impacts of global greenhouse warming, and the effects of large nuclear accidents, proliferation and nuclear waste impacts on future societies.

I have proposed an alternative approach (Sørensen, 1993), in which impact profiles are presented to decision-makers. This would allow impacts that are vaguely known to be small, medium or large, to be compared for different energy systems. The idea of the profiles is that each particular type of impact are evaluated in the same way for different systems. Thus, the magnitude of the profile is no more subjective than the monetised values, but they cannot be summed across different impact categories. Clearly those impacts that can be monetised should be so, but the advantage of the profile method is that the decision maker sees both the bar representing a monetised value, and besides it a bar describing a qualitative assessment. Thus the chance of overlooking important impacts is diminished.

One should remember that decision-making is basically a continuous process, involving planning, implementation and assessment in a cyclic fashion, with the assessment of actual experiences leading to adjustments of plans, or in some cases to entirely new planning.

9. What is LCA?

(taken from Environmental Encyclopedia, Sørensen, 1995)

An assessment of all direct and indirect impacts of a given technology, be it a product, a system or an entire sector in society, is called a life-cycle analysis (LCA). Not only are direct impacts from cradle to grave included, but also indirect effects from materials, energy and other inputs to the manufacturing process and subsequent handling - from building the production facilities, from transport of related goods and services, from use of the product, and finally from disposing of it, whether in the form of reuse, recycling or waste deposition.

The ideas behind LCA were developed during the 1970s, and went under different names. such as "total assessment", "including externalities", or "least cost planning". The first applications of LCA were in the energy field, including both individual energy technologies and entire energy supply systems. It was soon realized, that the procurement of all required data was a difficult problem. As a result, the emphasis went towards LCA applied to individual products, where the data handling seemed more manageable. However, it is still a very open-ended process, because manufacture of say a milk container requires both materials and energy, and to assess the impacts associated with the energy input anyway calls for an LCA of the energy supply system. Only as the gathering of relevant data has been ongoing for a considerable duration of time, has it become possible to perform credible LCA's.

The impacts to be included in an LCA may be grouped into categories:

1) Economic impacts such as impacts on owners economy and on national economy, including questions of foreign payments balance and employment.

2) Environmental impacts, e.g. land use, noise, visual impact, local pollution of soil, water, air and biota, regional and global pollution and other impacts on the Earth-atmosphere system, such as climatic change.

3) Social impacts, related to satisfaction of needs, impacts on health and work environment, risks, impact of large accidents, institutions required.

4) Security impacts, including both supply security and also safety against misuse, terror actions, etc.

5) Resilience, i.e. sensitivity to system failures, planning uncertainties and future changes in criteria for impact assessment.

6) Development impacts relate to the consistency of a product or a technology to the goals of a given society.

7) Political impacts include impacts of control requirements, and on openness to decentralization in both physical and decision-making terms.

It is clear that a list of this kind is open-ended, and that some impacts will never become quantifiable. This raises new problems of how to present and how to use an LCA, which would typically produce a list of impact estimations, some of which quantified and some not, and with the quantifiable impacts often given in quite different units (e.g. tons of sulphur dioxide, number of work accidents, capital cost of equipment).

One philosophy is to try to convert all impacts into monetary values, i.e. replace the sulphur dioxide amounts with either the cost of reducing the emissions to some low threshold value (avoidance cost) or alternatively an estimated cost of the impacts: hospitalization and workday salaries lost, replanting cost of dead forests, restauration of historic buildings damaged by acid rain. Accidental death would be replaced by the insurance cost of a human life, and so on (damage costs). Unavailability of numbers has led to the alternative philosophy of interviewing cross sections of affected population on the amount of money they would be willing to pay to avoid a specific impact or to monitor their actual investments (revealed preferences).

All of these methods are deficient, the first by not including a (political) weighing of different issues (e.g. weighing immediate impacts against impacts occurring in the future), the second by doing so on a wrong basis (influenced by peoples knowledge of the issues, by their accessible assets, etc.). The best alternative may be to present the entire impact profile to decision-makers, in the original units and with a time-sequence indicating when each impact is believed to occur, and then to invite a true political debate on the proper weighing of the different issues.

Major product LCA's performed include assessments of aluminum cans and of milk containers, while system LCA's have been mainly the analyses of energy supply systems based on fossil, nuclear of various renewable energy sources.

The difficulties encountered in using LCA in the political decision-making process have been partly offset by the advantages of bringing the many impacts often disregarded (as "externalities", meaning issues not included in the economic analysis) into the debate. It may be fair to say that LCA will hardly ever become a routine method of computerized assessment, but that it may continue to serve a useful purpose by focussing and sharpening the debate involved in any decision-making process, and hopefully help increase the quality of the basis information, upon which a final decision is taken, whether on starting to manufacture a given new product, or to arrange a sector of society (such as the energy sector) in one or another way.

10. Questions and limitations

This section discusses several critical issues in the construction of models for assessing the impacts of energy installations and systems. Some of these are connected to the process of data collection and use, where it is pointed out, that different methods have to be applied according to the purpose envisaged for a particular study (e.g. plant licensing, environmental assessment or energy planning). Further concerns are discussed, related to the common need to aggregate data and, in relation to the actual client or target group of the work, to present results in a sufficiently generic fashion. The report discusses aggregation over technologies, over sites, over time and over social settings. As regards the actual technique used for the impact calculations, the differences between externality calculations, extended risk analysis and life-cycle analysis is described. Finally, the issue of quantification is illustrated by two very difficult but also very important examples: global climate impacts and impacts of nuclear accidents.

11. Data acquisition

Any impact assessment will require the collection of primary data on the physical interplay between a given energy installation or system, and its environment. These would include emissions and other releases, noise levels, etc. Below follows first a discussion of the pathway approach employed for site and technology specific studies, and then a discussion of generic data appropriate for other types of investigation.

11.1 Pathway method

Given a concrete energy installation (power plant, mining operation, refinery, a piece of end-use equipment, etc.) at a given location, the impact analysis for the particular step in the energy conversion chain represented by the installation in focus can be made according to the pathway method, as illustrated in Figure 1. The method in principle applies to both normal operation of the installation and accident situations.

The initiating step in calculating impacts may be in the form of emissions (e.g. of chemical or radioactive substances) from the installation to the atmosphere, releases of similar substances to other environmental reservoirs, or emissions of noise. Other impacts could be from inputs to the fuel cycle step (water, energy, materials such as chalk for scrubbers). In a life-cycle analysis, the indirect impacts associated with the production of these inputs (typically at other sites, using other equipment) have to be enumerated, as well as the inputs to inputs, for as long as significant impacts are involved. As regards basic emission data, these are becoming routinely collected for power plants, whereas the data for other conversion steps are often more difficult to obtain. Of course, emission data e.g. from road vehicles are available in some form, but rarely distributed over driving modes and location as one would need in most assessment work.

Based on releases, the next step is to calculate the dispersal in the ecosphere, for example by using available atmospheric or aquatic dispersion models. In the case of radioactivity also decay and transformation has to be considered. For airborne pollutants, the concentration in the atmosphere is used to calculate deposition (using dry deposition models, deposition by precipitation scavenging or after adsorption or absorption of the pollutants by water droplets). As a result, the distribution of pollutants (possibly transformed from their original form, e.g. sulphur dioxide to sulphate aerosols) in air and on ground or in water bodies will result, normally given as function of time, because further physical processes may move the pollutants, down through the soil (eventually reaching ground water or aquifers) or again into the atmosphere (e.g. as dust).

Given the concentration of pollutants as function of place and time, the pathway may be further expanded to include an impact on human society, such as by human ingestion of the pollutant. Quite extended areas may have to be considered, both for fossil fuel power plant normal releases and for nuclear plant accidents (typically a distance from the energy installation of a thousand kilometers or more). Along with the negative impacts there is of course the positive impact derived from the energy delivered. In the end, these are the ones that will have to be weighed against each other. In some cases, the comparison is assisted by translating the dose-responses (primarily given as number of cancers, deaths, workdays lost, and so on) into monetary values. This should only be done if the additional uncertainty introduced by monetising is not so large, that the evaluation of the monetised impacts become arbitrary. In any case, some impacts are likely to remain, which cannot meaningfully be expressed in monetary terms.

11.2 Generic data

If the purpose of the assessment is to obtain generic energy technology evaluations (e.g. as inputs into planning and policy debates), one would try to avoid using data depending too strongly on the specific site selected for the installation. These could be important impacts depending on a specific location (involving e.g. special dispersal features, such as in a mountainous terrain) or a specific population distribution (presence of high-density settlements near to the energy installation studied). For policy uses, these special situations should normally be avoided, as the detailed plant siting phase can usually eliminate unsuited locations, if the planning area is sufficiently diverse.

Pure emission data are often dependent only on the physical characteristics of a given facility (power plant stack heights, quality of electrostatic filters, sulphate scrubbers, nitrogen oxide treatment facilities, and so on), and not on the site. However, the dispersion models are of course site dependent, but general concentration versus distance relations can usually be derived in model calculations avoiding any special features of sites. As regards the dose commitment, it will necessarily be depending on population distribution, while the dose-response relationship should not depend on this. As a result, a generic assessment can in many cases be performed, with only a few adjustable parameters left in the calculation, such as the population density distribution, which may be replaced with average densities for an extended region.

The approach outlined above will only serve as a template for assessing new energy systems, as the technology must be specified and usually would involve a comparison between state of the art, new technologies. If the impacts of the existing energy system in a given nation or region has to be evaluated, the diversity of the technologies in place must be included in the analysis, which would most likely have to proceed as a site and technology specific analysis for each piece of equipment.

In generic assessments, not only technology and population distribution has to be fixed, but also a number of features of the surrounding society will have to be assumed, in as much as they may influence the valuation of the calculated impacts (and in some cases also the physical evaluation, e.g. as regards society's preparedness for handling major accidents, which may influence the impact assessment in essential ways).

12. Aggregation issues

Because of the importance of aggregation issues, both for data definition and for calculation of impacts, this topic will in this section be dealt with in some detail. There are at least four dimensions of aggregation, that play a role in impact assessments:

* Aggregation over technologies
* Aggregation over sites
* Aggregation over time
* Aggregation over social settings

The most disaggregated studies done today are termed "bottom-up" studies of a specific technology located at a specific site. Since the impacts will continue over the life-time of the installation, and possibly longer (radioactive contamination), there is certainly an aggregation over time involved in stating the impacts in compact form. The better studies attempt to display impacts as function of time, e.g. as short, medium and long-term effects. However, even this approach may not catch important concerns, as it will typically aggregate over social settings, assuming them to be inert as function of time. This is of course never the case in reality, and in recent centuries, the development with time of societies have been very rapid, entailing also rapid changes in social perceptions of a given impact. For example, the importance presently accorded to environmental damage was absent just a few decades ago, and there are bound to be issues, that society over the next decades will be concerned about, but currently are just considered as marginal by wide sections of society.

The item of aggregation over social settings also has a precise meaning at a given instance. For example, the impacts of a nuclear accident with greatly depend on the response of the society. Will there be heroic firemen as in Chernobyl, who will sacrifice their own lives in order to diminish the consequences of the accident? Have the population been properly informed about what to do in case of an accident (going indoors, closing and opening windows at appropriate times, etc.), have there been drills of evacuation procedures? In Russia no, in Sweden yes. A study making assumptions on accident mitigation effects must be in accordance with the makeup of the society for which the analysis is being performed.

Aggregation over sites imply, that peculiarities in topography (leading perhaps to irregular dispersal of airborne pollutants) are not considered, and that variations in population density around the energy installation studied will be disregarded. This may be a sensible approach in a planning phase, where the actual location of the installation may not have been selected. It also gives more weight to the technologies themselves, making this approach suitable for generic planning choices between classes of technology (e.g. nuclear, fossil, renewable). Of course, once actual installations are to be built, new, site-specific analyses may be invoked in order to determine the best location.

As regards aggregation over technologies, this would in most cases not make sense. However, in the particular case, where the existing stock of e.g. power plants in a region is to be assessed, something like technology aggregation may play a role. For example, one might use average technology for the impact analysis, rather than performing multiple calculations for specific installations involving both the most advanced and the most outdated technology.

In a strict sense, aggregation is not allowed in any case, because the impacts that play a role never depends linearly or in simple ways on assumptions of technology, topography, population distribution, and so on. One should in principle treat all installations individually and make the desired averages on the basis of the actual data. This may sound obvious, but it is also inachievable, because only for some issues, the actual situations underlying the averages can be addressed. As regards the preferences and concerns of future societies, or the impacts of current releases in the future (such as climate impacts), one will always have to do some indirect analysis, involving aggregation and assumptions on future societies (using e.g. the scenario method).

One may conclude, that some aggregation is always required, but that the level of aggregation must depend on the purpose of the assessment. One may discern the following purposes for impact assessments currently performed:

* Licensing of particular installations
* Energy system assessment
* Energy planning and policy.

For licensing of a particular installation along a fuel chain or for a renewable energy system, clearly a site- and technology-specific analysis has to be taken into account, making use of actual data for physical pathways and populations at risk (as well as corresponding data for impacts on ecosystems, etc.). For the assessment of a particular energy system, the full chain from mining or extraction over refining, treatment plants and transportation to power plants, transmission and final use must be considered separately, as they would typically involve different locations. A complication in this respect is, that e.g. for a fuel-based system, it is highly probable, that over the lifetime of the installation, fuel would be purchased from different vendors, and the fuel would often come from many geographical areas with widely different extraction methods and impacts (e.g. Middle East versus North Sea oil or gas, German or Bolivian coal mines, open-pit coal extraction in Australia, and so on). Future prices and environmental regulations will determine the change in fuel mix over the lifetime of the installation, and any specific assumptions may turn out to be invalid.

For the planning type of assessment, it would in most industrialized nations be normal to consider only state-of-the-art technology, although even in some advanced countries, there is a reluctance to apply environmental cleaning options available (currently for particle, SO_2 and NO_x emission, in the future probable also for CO_2 sequestering or other removal of greenhouse gases). In developing countries, there is a tendency to ignore available but costly environmental impact mitigation options. In some cases, the level of sophistication selected for a given technology depends on the intended site (e.g. near to or away from population centers). Another issue is maintenance policies. The lifetime of a given installation depends sensitively on the willingness to spend money on maintenance, and the level of spending opted for is a matter to be considered in the planning decisions.

The following list enumerates some of the issues involved (Sørensen, 1993):

Technology and organization
- Type and scale of technology
- Age of technology
- Maintenance state and policy
- Matching technology with the level of skills available
- Management and control setup

Natural setting

- Topography, vegetation, location of waterways, ground water tables, etc.
- Climatic regime: temperature, solar radiation, wind conditions, currents (if applicable), cloud cover, precipitation patterns, air stability, atmospheric particle content.

Social setting

- Scale and diversity of society
- Development stage and goals
- Types of government, institutions and infrastructure

Human setting

- Values and attitudes, goals of individuals
- Level of participation, level of decentralization of decision-making

Impact assessments suitable for addressing these issues involve the construction of scenarios for future society, in order to have a reference frame for discussion social impacts. Because the scenario method is normative, it would in most cases be best to consider more than one scenario, spanning important positions in the social debate of the society in question.

Another issue is the emergence of new technologies, that may play a role over the planning period considered. Most scenarios of future societies do involve some assumption of new technologies coming into place, based on current research and development. However, the actual development is likely to involve new technologies, that were not anticipated at the time of making the assessment. It is possible to analyse scenarios for sensitivity to such new technologies, as well as to possible errors in other scenario assumptions. This makes it possible to distinguish between those future scenarios, that are resilient, i.e. do not become totally invalidated by changes in assumptions, as distinct from those, which depend strongly on the assumptions made. In the case of energy technologies, it is equally important to consider the uncertainty of demand assumptions and assumptions on supply technologies. The demand may vary according to social preferences, as well as due to the emergence of new end-use technologies, that may provide better services with less energy input. It is therefore essential, that the entire energy chain is looked at, down to not the energy delivered, but the non-energy service derived. No one demands energy, but we demand transportation, air conditioning, computing, entertainment and so on.

The discussion of aggregation issues clearly point to the dilemma of impact analyses: Those answers that would be most useful in the political context often are answers that can be given only with large uncertainty. This places the final responsibility in the hands of the political decision-maker, who has to weigh the impacts associated with different solutions, and in that process to take the uncertainties into account (e.g. chosing a more expensive solution because it has less uncertainty). But this is of course what decision-making is about!

13. Life-cycle analysis

13.1 History of life-cycle analysis

Life-cycle analysis (LCA) is a method, by which it is possible in principle to assess all direct and indirect impacts of a technology, whether a product, a system or an entire sector of society. LCA incorporates impacts over time, including impacts deriving from materials or facilities used to manufacture tools and equipment for the process under study, and it includes final disposal of equipment and materials, whether involving reuse, recycling or waste disposal.

Whereas product LCA is used by manufacturers and regulators to select the optimal one among different products serving the same purpose, energy system and energy policy LCA may be used to handle greenhouse emission issues in a way consistently embedding the global warming issue within other environmental and social issues. In case not just individual energy systems, but national and regional energy policies have to be assessed, the LCA must be based on an assumed transition to a scenario for future energy supply, transmission, conversion and use.

Product LCA has been promoted by organizations such as SETAC (Consoli, 1993) and several applications have appeared over recent years (e.g. Mekel and Huppes, 1990; Pommer et al., 1991; Johnson et al., 1994; DATV, 1995). Site and technology specific LCA of energy systems have been addressed in the ExternE project of the European Commission DGXII (for energy cycles where life-cycle impacts were deemed important, e,g, Eyre, 1995) and other recent projects (Petersen, 1991; Inabu et al, 1992; Kato et al, 1993; Meyer et al., 1994; Sørensen and Watt, 1993, Sørensen, 1994; Yasukawa et al. 1995; Sørensen, 1995a,b). Methodological issues have been addressed by Baumgartner, 1993; Sørensen, 1993; Engelenburg and Nieuwlaar, 1993) and energy system-wide considerations by Knöepfel, 1993; Sørensen, 1995c, the latter with emphasis on greenhouse gas emission impacts.

13.2. Description of the elements of a life-cycle analysis

The types of impacts that may be contemplated for assessment reflect to some extent the issues that at a given moment in time have been identified as important in a given society. It is therefore possible, that the list will be modified with time, and that some societies will add new concerns to the list. However, the following groups of impacts, a summary of which are listed in Table 7, constitute a fairly comprehensive list of impacts considered in most studies made to date (Sørensen, 1993):

*** Economic impacts such as impacts on owners economy and on national economy, including questions of foreign payments balance and employment.**

This group of impacts aim at the direct economy reflected in market prices and costs. All other impacts can be said to constitute indirect costs or externalities, the latter if they are not included in prices through e.g. environmental taxes. Economy is basically a way of allocating scarce resources. Applying economic assessment to an energy system, the different payment times of different expenses have to be taken into account, e.g. by discounting individual costs to present values. This again gives rise to different economic evaluations for an individual, an enterprise, a nation, and some imaginary global stake holder. One possible way of dealing with these issues is to apply different sets of interest rates for the above types of actors, and in some cases even a different interest rate for short-term costs and for long-term, inter-generational costs, for the same actor. Ingredients in these kinds of economic evaluation are the separate private economy and national economy accounts often made in the past. The national economy evaluation includes such factors as import fraction (balance of foreign payments), employment impact (i.e. distribution between labour and non-labour costs), and more subtle components such as regional economic impacts. Impact evaluations must pay particular attention to imports and exports, as many of the indirect impacts will often not be included in trade prices, or their presence or absence will be unknown.

*** Environmental impacts, e.g. land use, noise, visual impact, local pollution of soil, water, air and biota, regional and global pollution and other impacts on the Earth-atmosphere system, such as climatic change.**

Environmental impacts include a very wide range of impacts on the natural environment, including both atmosphere, hydrosphere, lithosphere and biosphere, but usually with the human society left out (but to be included under the heading social impacts below). Impacts may be classified as local, regional and global. At the resource extraction stage, in addition to the impacts associated with extraction, there is the impact of resource depletion. In many evaluations, the resource efficiency issue of energy use in resource extraction is treated in conjunction with energy use further along the energy conversion chain, including energy used to manufacture and operate production equipment. The resulting figure is often expressed as an energy pay-back time, which is reasonable because the sole purpose of the system is to produce energy, and thus it would be unacceptable if energy inputs exceeded outputs. In practise, the level of energy input over output that is acceptable depends on the overall cost, and should be adequately represented by the other impacts, which presumably would become large compared with the benefits, if energy inputs approached outputs. In other words, energy pay-back time is a secondary indicator, which should not itself be included in the assessment, when the primary indicators of positive and negative impacts are sufficiently well estimated. Also issues of the quality of the environment, as seen from an anthropogenic point of view, should be included here. They include noise, smell and visual impacts associated with the cycles in the energy activity. Other concerns could be the preservation of natural flora and fauna. It is normally necessary to distinguish between impacts on the natural ecosystems and those affecting human well-being or health. Although human societies are of course part of the natural ecosystem, it is convenient and often necessary to treat some impacts on human societies separately, which will be done in the following group. However, the situation is often, that a pollutant is first injected into the natural environment, and later finds its way to humans, e.g. by inhalation or through food and water. In such cases the evaluation of health impacts involves a number of calculation steps (dispersal, dose-response relation) that naturally have to be carried out in order.

*** Social impacts, related to satisfaction of needs, impacts on health and work environment, risks, impact of large accidents.**

Social impacts include the impacts from using the energy provided, which means the positive impacts derived from services and products arising from the energy use (usually with other inputs as well), and the negative impacts associated with the energy end-use conversion. Furthermore, social impacts derive from each step in the energy production, conversion and transmission chain. Examples are health impacts, work environment, job satisfaction, and risk, including the risk of large accidents. It is often useful to distinguish between occupational impacts and impacts to the general public. Many of these impacts involve transfer of pollutants first to the general environment and then to human society, where each transfer requires separate investigation as stated above. This is true both for releases during normal operation of the facilities in question, and for accidents. Clearly, the accident part is a basic risk problem that involves estimating probabilities of accidental events of increasing magnitude.

*** Security impacts, including both supply security and also safety against misuse, terror actions, etc.**

Security can be understood in different ways. One is supply security, and another the security of energy installations and materials, against theft, sabotage and hostage situations. Both are relevant in a life-cycle analysis of an energy system. Supply security is a very important issue, e.g. for energy systems depending on fuels unevenly spread over the planet. Indeed, some of the most threatening crises in energy supply have been related to supply security (1973/74 oil supply withdrawal, 1991 Golf War).

*** Resilience, i.e. sensitivity to system failures, planning uncertainties and future changes in criteria for impact assessment.**

Resilience is also a concept with two interpretations: One is the technical resilience, including fault resistance and parallelism, e.g. in providing more than one transmission route between important energy supply and use locations. Another is a more broadly defined resilience against planning errors (e.g. resulting from a misjudgment of resources, fuel price developments, or future demand development). A more tricky, self-referencing issue is resilience against errors in impact assessment, assuming that the impact assessment is used to make energy policy choices. All the resilience issues are connected to certain features of the system choice and layout, including modularity, unit size, and transmission strategy. The resilience questions may well be formulated in terms of risk.

*** Development impacts (e.g. consistency of a product or a technology with the goals of a given society).**

Energy systems may exert an influence on the direction of development, a society will take, or rather may be compatible with one development goal and not with another goal. These could be goals of decentralization, goals of concentration on knowledge business rather than heavy industry, etc. For so-called developing countries, clear goals usually include satisfying basic needs, furthering education, and raising standards. Goals of industrialized nations are often more difficult to identify.

*** Political impacts include e.g. impacts of control requirements, and on openness to decentralization in both physical and decision-making terms.**

There is a geopolitical dimension to the above issues: Development or political goals calling for import of fuels for energy may imply increased competition for scarce resources, an impact which may be evaluated in terms of increasing cost expectations, or in terms of increasing political unrest (more "energy wars"). The political issue also has a local component, pertaining to the freedom or lack of freedom of local societies to choose their own solutions, possibly different from the one selected by the neighbouring local areas.

13.3. Level of analysis

Using in the remainder of this section the energy sector as an example, the different levels of analysis will be discussed. Consider first a single energy conversion device, placed at an identified site and employing a specific technology. Inputs are the materials and labour used to construct the device, say a power plant, and the inputs needed for operation and maintenance, including fuels if any, and finally the inputs needed for decommissioning and disposal or reuse/recycling of the constituents of the installation. The primary output from the device would typically be energy of a given form (or a service if it is an end-use device), plus associated outputs in the form of residues, emissions and nonphysical emissions. These outputs may affect the environment as well as human societies in different ways, which the assessment proposes to describe in terms of costs and benefits, quantified or not quantified, monetised or not.

The next level of analysis will try to embrace the entire fuel chain, i.e. extraction of fuels, refinement, transport and conversion, as well as the back-end of the conversion chain (spent fuel reprocessing, e.g. for nuclear fuels or ashes and tar from fossil power plants), and plant decommissioning. Fuel chain analyses rarely consider indirect impacts from energy and materials used in construction of e.g. the power plant.

At the next level, the entire energy system of a given society is assessed, including transmission and end-use. In this case, the benefits can be taken as the final energy services, and indirect impacts everywhere in the system may be included. A possible exception is imports (say of fuels) or exports of energy, for which concrete analysis may not be possible. However, if this type of analysis aims at a full life-cycle treatment, then the origin of materials and equipment has to be traced back through society, which means that the ultimate analysis involves the entire (global) society.

This highest level of analysis includes all direct and indirect impacts, and therefore must include a model of society detailed enough to be able to trace impacts back to their origin, for materials and equipment. The simplest way of doing this would be through use of the input-out put tables available in most countries, but of course the tables must be expressed in terms of physical quantities and not just monetary terms, because e.g. the environmental impacts of materials imbedded in certain equipment used in the energy industry will depend on the kind of materials involved (metals, composites, etc.), rather than on their cost. Again, this kind of assessment is made difficult, if many imports and exports are involved. The matrix methods associated with input-output analysis are useful tools in this type of calculation, but in most cases, the indirect impacts need to be traced back only a few steps, so that simpler methods can be used to give results within the overall uncertainty level, which is most often dominated by direct impacts rather than indirect ones. Certain renewable energy systems are exceptions, for which there are no significant direct impacts and where the indirect ones are hence dominating.

Figure 48 shows the impact pathway for a particular step in an energy chain (schematically illustrated in Figure 49). The global energy conversion system is presented in a schematic form in Figure 50. The individual chains pertain to certain flows in the overall system, and the pathway method aims at identifying direct and indirect impacts incurred along the chain. It is clear, that for a particular fuel cycle, the main impacts may be localized in such a way, that a full life-cycle analysis is not required (e.g. for most fossil fuel systems, the main impacts are associated with the combustion of fuels), whereas in other cases (such as photovoltaics), no meaningful analysis can be made without involving the indirect impacts of a life-cycle analysis.

13.4. Pathway approach

The impacts pertaining to a given step in the chain of energy conversions or transport may be divided into those characterising normal operation, and those arising in case of accidents. In reality, the borderline between often occurring problems during routine operation, mishaps of varying degree of seriousness, and accidents of different size are fairly hazy and may be described in terms of declining probability for various magnitudes of problems. The pathways of impact development are to a considerable extent similar for routine and accidental situations, involving injuries and other local effects, e.g. connected with ingestion or inhalation of pollutants, and as regards public impacts the release and dispersal of substances causing nuisance where they reach inhabited areas, croplands or recreational areas. The analysis of these transfers involves identifying all important pathways from the responsible component of the energy system, to the final recipient of the impact, such as a person developing illness or death, possibly with delays of considerable lapses of time, in cases such as late cancers.

Figure 50 shows how the pathway approach can be used to assess the direct impacts from a particular fuel cycle step. However, if the indirect effects are to be included in a full life-cycle analysis, then also inputs into the selected energy conversion step must be considered, whether they are materials, equipment, energy, water or other types. In some cases there would be possible substitutions between human labour and machinery, linking the analysis to models of employment and reproductive activities. In order to find all the impacts, vital parts of the economic transactions of society have to be studied. For a given step in the energy conversion chain, one must consider all inputs to and outputs from a given device (i.e. a piece of conversion equipment, a transmission line or transport process, or an end-use device converting energy to a desired service or product). The relations between inputs and outputs of a given device may be highly non-linear, but in many cases given by a deterministic relationship. Exceptions are e.g. combined heat-and-power plants, where the same fuel input may be producing a range of different proportions of heat and electricity. This gives rise to an optimisation problem for the operator of the plant (who will have to consider fluctuating demands along with different dispatch options involving different costs). But for the actual mode of operation, the determination of inputs and outputs is of course unique. These are the numbers used in the impact assessment, which then has to trace where the inputs came from, and keep track of where the outputs are going. For each step, total impacts have to be determined, and in some cases the successive transfers may lead back to devices already considered. The way to deal with this problem is to set up all transfers between devices belonging to the energy system in a matrix. In what corresponds to an economic input-output model, the items associated with positive or negative impacts must be kept track of, such that all impacts belonging to the life-cycle will be covered.

Once this is done, the impact assessment itself involves integrations over time and space, or rather a determination of the distribution of impacts over time and space. The spatial part involves use of dispersal models or compartment transfer models (Sørensen, 1992), while the temporal part involves charting the presence of offensive agents (pollutants, global warming inducers, etc.) as function of time for each location, and further to determine the impacts (health impacts, global warming trends, and so on), with the associated additional time delays. This is conveniently done by considering the steps indicated in the pathway definition (cf. Figure 48). The result with be an impact profile in two dimensions, such as the ones emerging from the concrete examples in section 13.7 and briefly discussed in section 13.8.

13.5. Risk-related impacts and accident treatment

Of the impacts presented below in section 13.7, clearly the accident related figures are parts of a risk analysis. As regards the health impacts associated with dispersal of air pollutants followed by ingestion and an application of a dose-response function describing processes in the human body, that may lead to illness or death, one can as mentioned in section 9 view these as processes governed by stochastic events, and thus suitable for inclusion in a risk assessment in the broad sense.

Probabilistic treatment of accident risks needs a few accompanying words. The standard risk assessment used in the airplane industry consist in applying fault tree analysis or event tree analysis to trace accident probabilities forward from initiating events or backward from final outcomes. The idea is that each step in the evaluation is a known failure type associated with a concrete piece of equipment, and that the probability for failure of such a component should be known from experience. The combined probability is thus the sum of products of partial event probabilities for each step along a series of identified pathways. It is important to realise, that the purpose of this evaluation is to improve design, by pointing out the areas where improved design is likely to pay off. Necessarily, unanticipated event chains cannot be included. In areas such as airplane safety, one is aware that the total accident probability consists of one part made up by anticipated event trees, and one made up by unanticipated events. The purpose of the design efforts is clearly to make those accidents that can be predicted by the fault tree analysis (and thus may be said to constitute "built-in" weaknesses of design) small compared with the unanticipated accidents, for which no defense is possible, except to learn from actual experiences and hopefully move event chains including e.g. common mode failures from the "unanticipated" category into the "anticipated", where engineering design efforts may be addressed. This procedure has lead to declining airplane accident rates, while the ratio between unanticipated and anticipated events has stayed at approximately the value ten.

It should of course be said, that the term "probability" is here used in a loose manner, as there is no proof of a common, underlying statistical distribution (Sørensen, 1979), due to constant technological change, making the empirical data different from the outcome of a large number of identical experiments. This is equally true, if we go to the cases of oil spills or nuclear accidents, for which the empirical data is weak, due to the low frequency of catastrophic events (albeit compounded with potentially large consequences). Here the term "probability" is really out of place, and if used should be construed to mean just "an indicator of a possible frequency of events".

The observed number of large accidents is for nuclear core-melt accidents two (Three Mile Island and Chernobyl), and for large oil spills similar or smaller. The implied "probability" in the nuclear case is illustrated in Table 106. Counting two accidents over the accumulated power production to the end of 1994 one gets a 10^{-4} per TWh frequency, or a $5x10^{-5}$ per TWh frequency for an accident with severe external consequences. At the time of the Chernobyl accident, the estimate would have been 3-4 times higher, due to the much lower accumulated power production of reactors worldwide by 1986. For comparison, the built-in probability for an accident with Chernobyl-type consequences for a new, state-of-the-art light-water nuclear reactor is by the fault-tree analysis calculated to be about 1.25×10^{-6} per TWh (ST2-accident; see Dreicer et al., vol. 5 of European Commission, 1995). The factor 40 difference between the two numbers comes partly from the difference between a state-of-the-art reactor and the average stock, and partly from the difference between the probability of anticipated accidents and the actual frequency, including unanticipated events. The latter should as mentioned contribute about a factor 10 according to sound engineering practices, and the former would thus be a factor of four. It is reassuring that the present risk assessments based on theoretical and on empirical methods thus have magnitudes that are basically understood, including the origin of differences.

Table 106. Frequency of and damage from large nuclear accidents

Accumulated experience when Three Mile Island accident happened (1979)	3000 Twh
Accumulated experience when Charnobyl accident happened (1986)	5800 Twh
Accumulated experience to end of 1994	20000 Twh
Implied order of magnitude for frequency of core-melt accident	$1\text{x}10^{-4}$ Twh^{-1}
* Implied order of magnitude for accident with Chernobyl-type releases	$5\text{x}10^{-5}$ Twh^{-1}
Chernobyl:	
Dose commitment (UNSCEAR, 1993)	560000 man Sv
Induced cancers (SVL=2.6 Mecu, no discounting)	200 Gecu
Birth defects	20 Gecu
Emergency teams, clean-up teams, security teams	50 Mecu
Early radiation deaths (SVL=2.6 Mecu)	100 Mecu
Evacuation and relocation	100 Mecu
Food bans and restrictions	100 Mecu
Unplanned power purchases	1 Gecu
Capacity loss and reduced supply security	10 Gecu
Cost of encapsulation and clean-up (at plant and elsewhere)	170 Gecu
Increased decommissioning costs	100 Gecu
Impact on nuclear industry (reputation, reduced new orders)	100 Gecu
Monitoring, experts' and regulators' time	10 Mecu
Concerns in general public (psychosomatic impacts)	100 Mecu
Total estimate of Chernobyl accident costs	600 Gecu
Industry average accident cost using *	30 mecu/kWh

1 mecu = 0.125 US cents = 0.125 ¥

13.6. Monetising issues

The use of common units for as many impacts as possible is of course aimed at facilitating the job of a decision-maker wanting to make a comparison between different systems. However, it is important that this procedure does not further marginalize those impacts that cannot be quantified, or which seems to resist monetising efforts. The basic question is really, whether or not the further uncertainty introduced by monetising offsets the value of being able to use common units.

Monetising may be accomplished by expressing damage in monetary terms, or by substituting the cost of reducing the emissions to some low threshold value (avoidance cost). Damage costs may be obtained from health impacts by counting hospitalization and workday salaries lost, replanting cost of dead forests, restauration of historic buildings damaged by acid rain, and so on. Accidental death may e.g. be replaced by the insurance cost of a human life. Unavailability of data on monetising has led to the alternative philosophy of interviewing cross sections of affected population on the amount of money they would be willing to pay to avoid a specific impact or to monitor their actual investments (contingency evaluations such as hedonic pricing, revealed preferences, or willingness to pay). Such measures may change from day to day, depending on exposure to random bits of information (whether true or false), and also depend strongly on the income at the respondents' disposal, as well as competing expenses of perhaps more tangible nature. Should the statistical value of life (SVL) be reduced by the fraction of people actually taking out life insurance, or should it be allowed to take different values in societies of different affluence?

All of the methods introduced above are clearly deficient, the damage cost by not including a (political) weighing of different issues (e.g. weighing immediate impacts against impacts occurring in the future), the contingency evaluation by doing so on a wrong basis (influenced by people's knowledge of the issues, by their accessible assets, etc.). The best alternative may be to present the entire impact profile to decision-makers, in the original units and with a time-sequence indicating when each impact is believed to occur, and then to invite a true political debate on the proper weighing of the different issues.

A special role is played by problems of intergenerational equity, an issue that becomes relevant for many impacts from energy systems, due to delays between cause and effect, particularly in the case of nuclear energy. Several studies of monetised impacts use a discount rate to express the preference of having assets now rather than in the future. This preference is evident for individuals with a finite lifespan, but looking at national economies, the question arises, if assets left to future generations might not be exploited in a better way than present technology allows. The same may be true for liabilities, such as nuclear waste, that can be stored for later processing, whereas for air pollution the impacts are of course already committed at the time of ingestion. Most people would prefer a cancer occurring 20 years into the future to one now, but the question becomes more subtle if continuous suffering is involved. The intergenerational interest rate should basically be zero, placing the same value on the future as on the present. However, some would argue that we build up a stock of amenities for the future, which together with the technological progress enabling cheaper handling of deferred problems would point to a positive discount rate. On the other hand, knowledge regarding health and environmental impacts are likely to grow with time, making e.g. environmental standards likely to become more stringent in the future (continuing their development over the last couple of decades). Also new concerns are likely to emerge, all of which points to a negative discount rate. Because there is no way of telling precisely what the future societies will be concerned with, the most reasonable choice of an intergenereational discount rate in my view is zero.

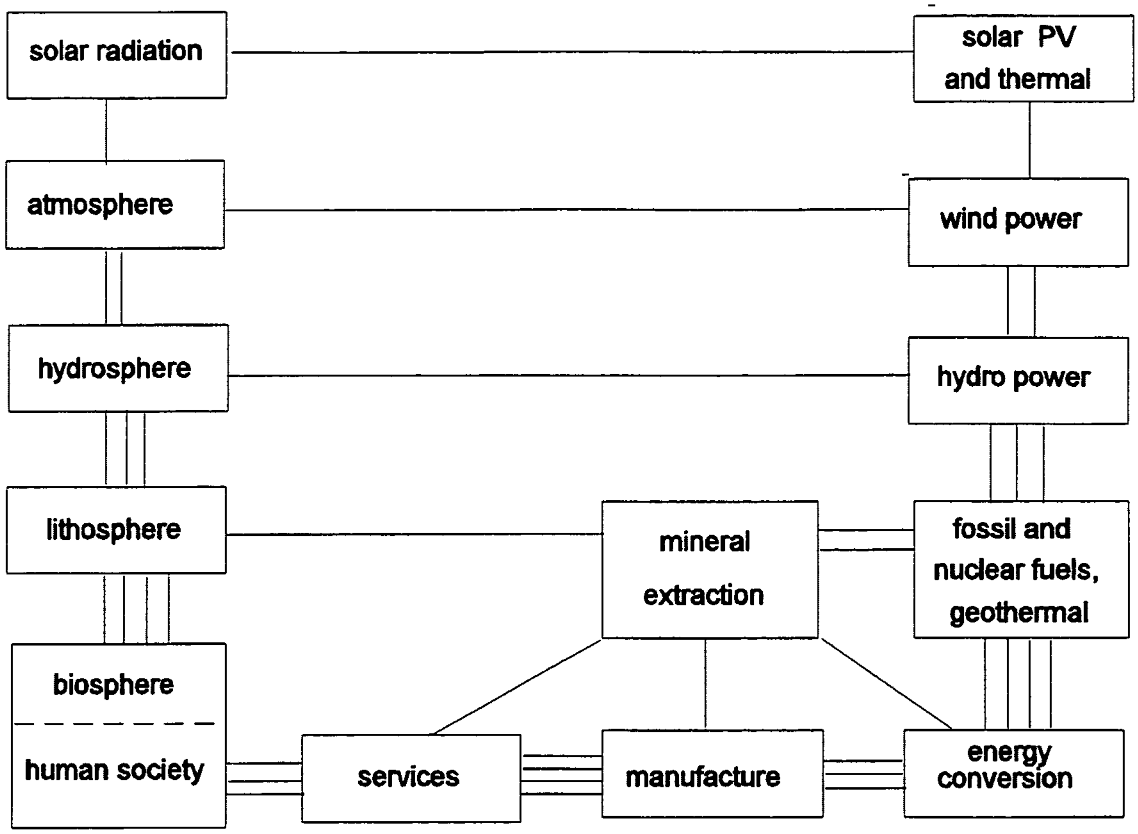


Figure 48. Overall structure of global energy system

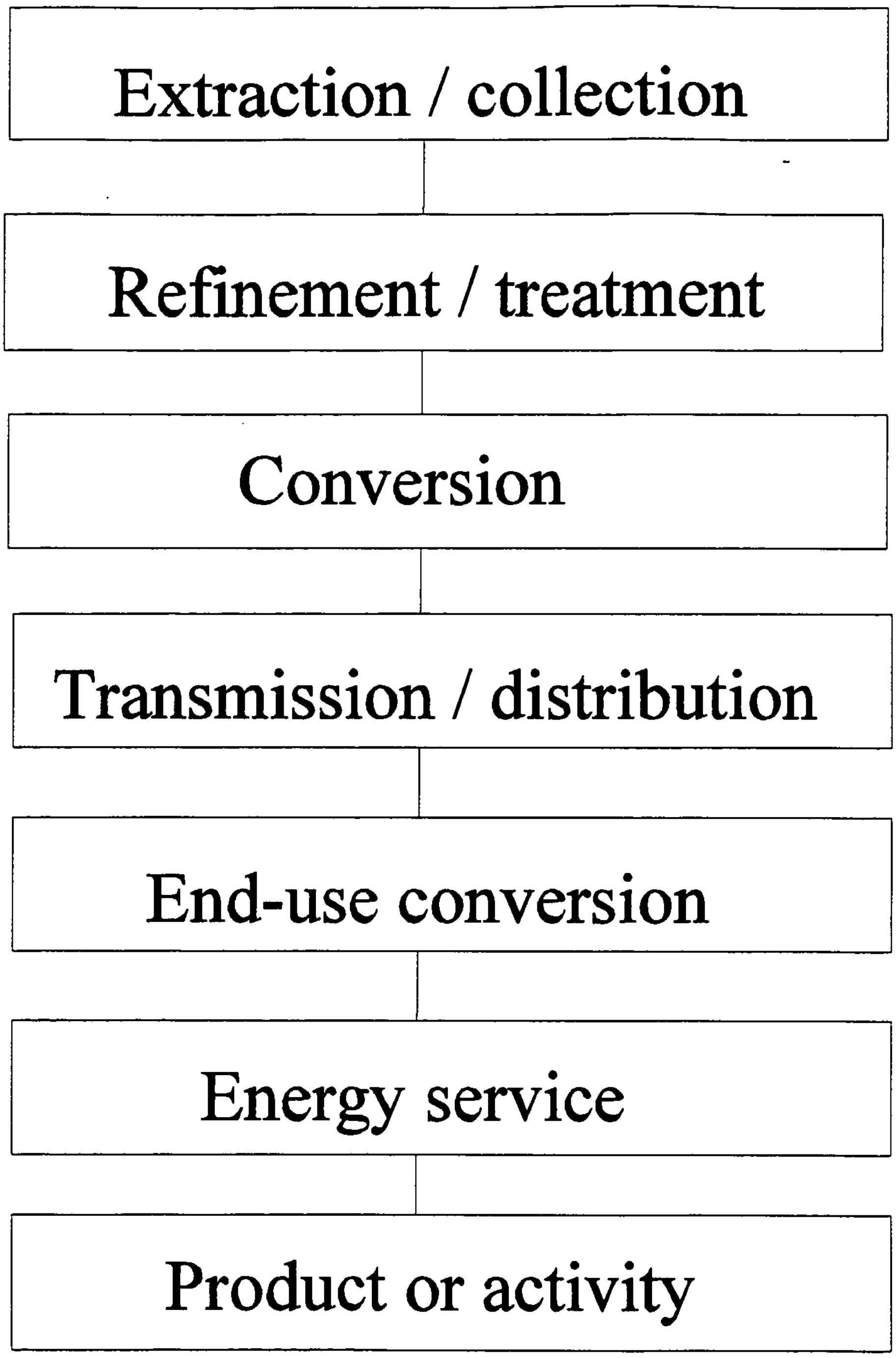
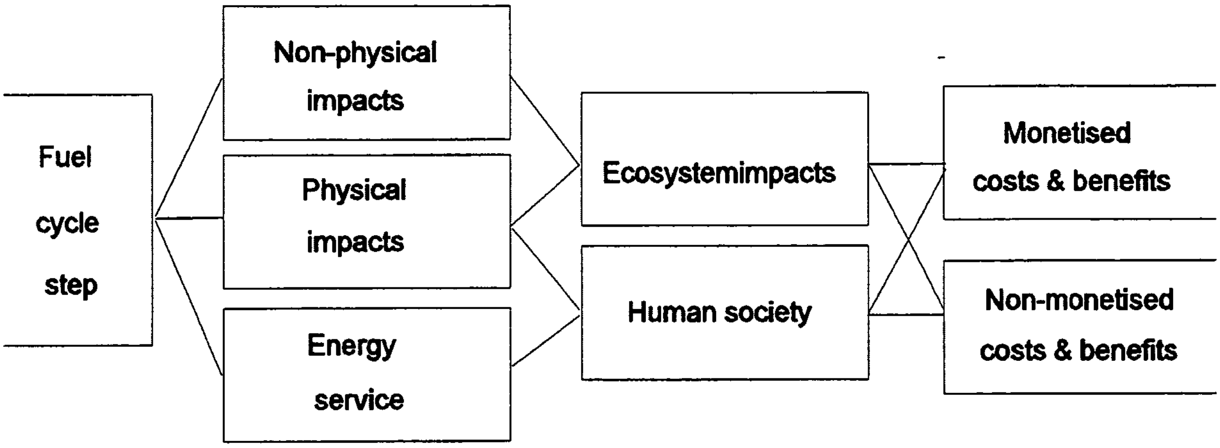


Figure 49. Energy conversion chain.



E.g.: emissions → dispersal → level/concentration → dose-response → valuation → cost

Figure 50. Pathways for evaluating impacts.

Global climatic change perspectives of a strategy based on the long term integration of renewables into the european energy system

Bernd Kuemmel, January 1996

The long term integration of renewables into the European energy system is motivated by the wish to reduce the very probable harmful effects of human induced climatic change. The idea to shift from fossil fuels to regenerative sources of energy is supported by amongst others the effects that the use of fossil fuels has on natural ecosystems and man made structures. It has been argued that the inclusion of externalities is necessary to reduce the consumption of fossils but that the price mechanism would prevent this as it would lead to a rapid disengagement from fossil fuels which therefore obliviates the necessity of having to impose externalities. Here we shall try to show that even imposing high valued externalities will neither dissolve its actual motivation nor its necessity.

If we look at the energy system of today it is based massively on fossil fuels, at least in the inustrialized countries. Fossils bring with them certain consequences. From the discussion of man made climatic and environmental change the definition of fossils' externality costs in principle is a straightforward matter.

Externalities arise in a society in groups external to the actual users of a commodity or service. Imagine people living nearby a factory that releases dust into the air. The people will have to wash their cares more often than were the factory not placed nearby. These costs, that the people have to bear, are external to the factory. The production process goes on as if no people were living in the neighbourhood and the costs that the people bear do not occur in the balance sheets of the company's annual reports.

External costs can be internalized when an entity, that is entitled to do so takes care of the external costs, and imposes them on the production process in the factory. This can be done by levies, taxes from public entities or by a private agreement between the cause of an externality, in this case the factory, and the impacted. Independent of how the actual regulation turns out to be, in a market economy imposing externalities will lead to the desire to reduce these external costs. This can be realized by changing production processes or various end of pipe technologies. The threat of stopping a process technology is another possibility, but if this is considered, the actual production would not be viable in the long term anyway.

In the case of the fossil based energy system externalities consist of environmental and structutural damages due to acid rain and the greenhouse effect, to mention the uttermost important ones. Noise from transporting the fuels and spoiling of valuable streaks of coasts from tank ship accidents are others.

The basis of the anthropogenic greenhouse effect is a reduced transparency of the atmosphere with regards to the heat radiation that is emitted from the surface of the Earth[1]. While the larger part of this radion is absorbed by the air itself and clouds there are (very small) regions in the spectrum of the electromagnetive radiation where the atmosphere actually is transmittant, the most prominent one being the *atmospheric window* between 8 and 10 μm.

In absolute terms water vapour is the most important of the greenhouse gases, ie the gases that absorb heat radiation. But the contribution of the socalled dry[2] greenhouse effect is far from insignificant. About 40 % of the total, or wet, greenhouse effect is due to carbon dioxide, methane, CFCs and nitrous oxide. And it is the growth of the dry greenhouse effect that is of importance in the question of the man made global warming. The opacity of the atmosphere with regards heat radiation increases, so to speak looking from space the image of the Earth in the infrared region of the spectrum gets less clear with the increasing greenhouse effect, as the atmospheric window and the amount of heat radiation that is emitted directly to Space is reduced.

One consequence of the enhanced greenhouse effect is the increase of the surface temperature of the Earth. Ignoring feedback processes very simple considerations lead to a value of 1,2 Kelvin for a doubling of the atmospheric CO_2 concentration. This value is modified strongly by various feedback processes, the most important being the water vapour feedback. It implies that the primitive 1.2 K heating of the surface will increase the evaporation of water, as the relative humidity is about constant[3]. Water vapour in itself is a greenhouse gas so this process enhances the warming brought about by the dry greenhouse effect[4].

One could argue that it was necessary to completely stop antropogenic CO_2 emissions to stop the further increase of the atmospheric CO_2 concentration. Only then could a natural balance be reestablished. This is not the case. But even though not all the CO_2 emitted by human activity is known to remain in the air, a large part, 44 per cent, does[5].

CO_2 is a building material for plant tissue – and so for all later trophic levels. Compared to the preindustrial todays CO_2 concentration is higher by 28 per cent. Plant growth is stimulated by these somewhat higher atmospheric concentrations, but only when both nutrients, light and water are amply available!

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[1] This is why dynamical climatologists talk of the radiative forcing of the atmosphere. It means that greenhouse gases reradiate heat back to the surface of the Earth, from where most energy flows originate in one way of the other. The extra energy, or radiative forcing, of the Earth-Atmosphere climate system is the radiative forcing.

[2] The 'dry' resp. 'wet' greenhouse effect is defined in Flohn *et al* (1990) to mean the radiative forcing from all the greenhouse gases without, resp. inclusive, water vapour.

[3] This observation has been reported by Möller, F.: 1963, 'On the influence of changes in the CO_2 concentration in air on the radiative balance of the Earth's surface and on the climate', *J. Geoph. Res.*, **68**, 3877-86.

[4] IPCC, 1990.

[5] Often a value of 55 % is mentioned as the 'atmospheric fraction'. This only applies to the energy related emissions.

Another important factor is the absorption in the surfaces layers of the oceans. There are two very important places on the Earth where the surface water is cooled and so becomes heavy enough to sink into the deep sea. At the same time only as much CO_2 as has been accumulated at the lower preindustrial concentrations is released in the upwelling zones of the tropical oceans. So currently there is a net removal of atmospheric CO_2 into the deep sea.

The plants' increased productivity and the downwelling in the oceans mean that we do not have to completely stop anthropogenic emissions to keep atmospheric CO_2 concentration constant. If we choose to stabilize at todays levels, the intensification of the natural ecosystems' absorption of this gas helps us to reach this goal. Therfore the global 80 per cent emission reduction, mentioned by IPCC, is sufficient to stabilize atmospheric CO_2 concentrations[6]. On the other hand it also is clear that such a reduction is a rather difficult step to realize for the World as a whole, especially as the means to reach it and the necessitiy to do so are currently not widely accepted; and the economic development in some regions of the World opposes worldwide emission reductions, anyway.

If we take the values given by the climatologists then the enhanced dry greenhouse effect of today 2.5 Wm^{-2} is caused by the increase of the atmospheric concentration of CO_2 with only 55% (=1.4 Wm^{-2}), CH_4 (15%), N_2O (5%) and CFCs (20%) and other gases (5%)[7]. The 7.5 Gigatons Carbon that today are emitted in the form of CO_2 every year together with the other greenhouse gas emissions are equivalent to a greenhouse forcing of 6 GtC (≈22 Gt CO_2)[8].

When externalities of the CO_2 emissions are considered, one could fear that reaching the reductions would diminish the very necessity of the externalities. The policy of reducing the emissions might be so successful that the chosen value of the externalities can not be defended if the greenhouse effect could be stabilized at reasonably low levels. The question is whether this can be achieved at all, and whether the trustworthiness problem exists at all?
For the question of choosing the right reduction trajectory we can for the moment assume that the whole world basically wants to reduce emissions and that the aim is reaching a 80 per cent reduction compared to today (1990) at about the year 2050. There are then three basic trajectories that describe the paths chosen:

- The first »no regrets« would be a path where the World trusts the climatologists and the climate models even though they do not discriminate climatic change in Hintertupfingen from Vorderflecken. As a result there is agreement on rapid and global emission reductions here and now which basically can be described by an exponential reduction path in the form of: $E_0 \exp(-æ \cdot t)$, where $æ^{-1}$ is the halving time and E_0 todays carbon emissions. This scenario would mean that all the necessary steps would be taken today to ensure

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[6] IPCC, 1995.

[7] ibid.

[8] Taking into account that today only 44 % of the total anthropogenic CO_2 released, remains in the air, and that it is responsible for 55 % of the increase of the anthropogenic greenhouse effect, it is easy to calculate the rise of the total (=equivalent) greenhouse effect.

rapid emission reductions: like realising stringent and fast efficiency standards in energy consuming appliances, and the energy conversion processes, too; and by quickly imposing the proper externalities on energy prices. The last point is not very popular with many people, which very much restricts the realization of this strategy.

- In the second scenario the World follows a linear reduction path. This is equivalent to the excuse that one has chosen to believe the climatologists and their models and actually one would like to do much more for the global environment, but that there simply is not enough money to perform even the profitable efficiency strategies, less the change to an energy system based on renewables.

- Last in the row is a scenario where the World »waits and sees« whether for example the climatologists forecasts of more and stronger tropical cyclones really turn out to be true – until such a hurrican shaves Tokio off the shores and leads to disturbances of the global economy in the wake of several insurances companies failing to serve their obligations. First then would public opinion allow the politicians to realise more, and really, stringent measures. This scenario is the opposite of the first one, in that reductions would be virtually nonexisting in the start – but drastic at the end of the period[9]..

And as we all know drastic changes do need time. The targets described in the LTI-scenarios will not be effectuated before 1996 at least, and the political decisions needed for realizing the reductions will of course take time, too. The developing countries would – taking the Montreal agreement to phase out CFCs as an example – plead for longer periods until they have to reach the agreed upon reduction targets; here we assume a ten year lag. So it is only fair to assume that the reduction paths will be entered globally not before the year 2000. This assumption might be overoptimistic. Newer investigations[10] indicate , that the industrialized countries only contribute 55 to 60 per cent of the global manmade CO_2 emissions. And the developing world's share of 40-45 % is rapidly growing, mainly in the growth regions around the Pacific Basin[11].

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[9] Unfortunately for the World this looks like the situation today. Changing course is only an element of politicians sundays' speeches, and public awareness on the necessity to change our life style and energy system in particular is so low that even the most profitable measures are deemed unattractive by the political parties in the West, with the rest of the World in much greater difficulties. Partly this falls back on the opinion makers that have neglected to create an atmosphere of optimism and benevolence on the solutions to the global change challenges.

[10] Subak S, Raskin P & D von Hippel: 1993, 'National Greenhouse Gas Accounts: Current Anthropogenic Sources and Sinks, *Clim. Change*, **25**, 15-58, gives 46 % for the developing world's CO_2 emissions; data from the *World Resources Institute*, Washington, D.C. and *Centre for Science and Environment*, New Dehli, give 40 %. A new report from the *World Energy Conference* mentions the developing world's share of 28 % of the energy related CO_2 emissions alone. When care is taken to include land area related emissions the share increases to 40 %. According to the U.S. American Department of Energy the developing world's share has already surpassed that of the industrialized countries, Information, p. 10, 31.dec/1.jan. 1994/5.

[11] Therefore it is rather doubtful whether the global CO_2 emissions could be reduced in the first half of the 21st century at all.

Graphically the three emission path scenarios look as follows:

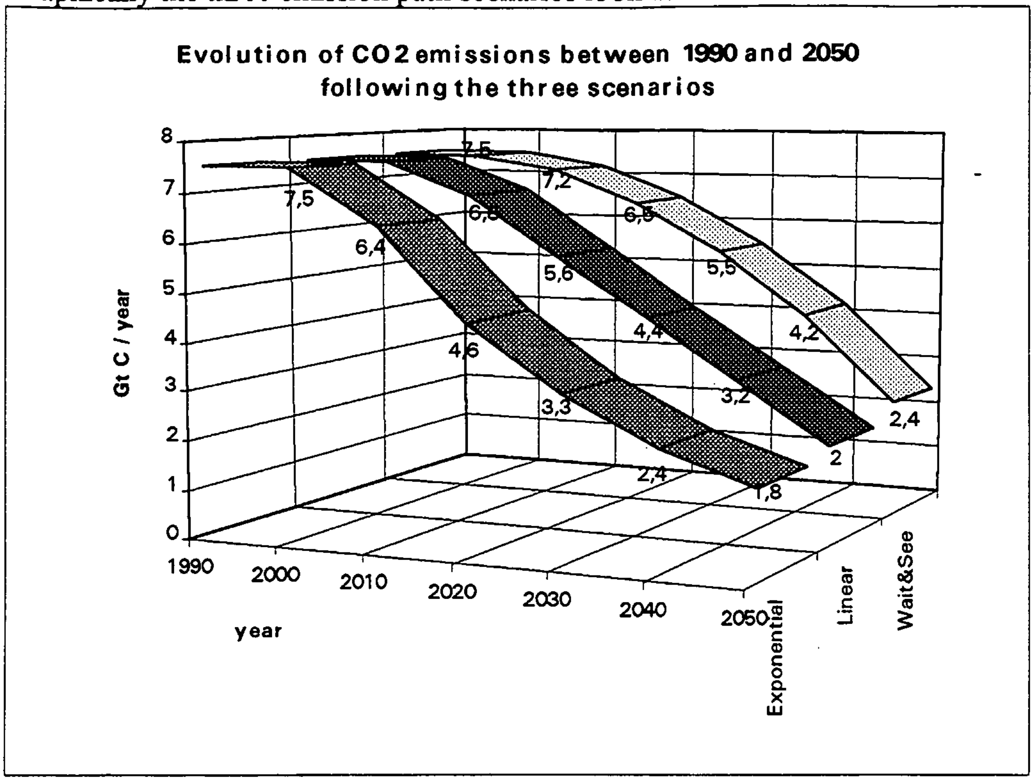

Fig. 51. The evolution of the CO_2 emissions between 1990 and 2050 under the mentioned assumptions shows that because of the slow decline of the developing countries emissions the aim of a complete 80 per cent reduction is not reached in the year 2050 even in the most optimisic scenario, following the exponential decline.

But how do this emission scenarios influence the future's actual and resultant equivalent CO_2 concentrations, and therefore what greenhouse effect will one expect in the middle of the next century? Will a more rapid approach relieve us with certainty from the equivalent doubling of the preindustrial CO_2 level?

In order to calculate the future equivalent CO_2 concentration shown in the next figure we have exploited the fact that today only 44 per cent of the CO_2 emitted stays in the atmosphere. The rest is absorbed in the surface waters of the oceans or in terrestrial ecosystems. We also assume that this ratio, the 44 per cent socalled airborne fraction, is going to stay constant even though the commenced global warming will mean an increasing stress on a.o. forests. We have assumed similar reductions for the other greenhouse gases so that their share stays the same as the current 45 per cent (growth in the equivalent greenhouse effect). And we have scaled the allowable (100-80=) 20 % emissions today; ie at 360 ppm; with the reached atmospheric compared to the natural concentration of 280 ppm.

The differences regarding the emission paths seemingly are of minor importance, and the goal of a complete 80 per cent CO_2 emission reduction is not reached even in the most optimistic exponential decline scenario. On the other hand our assumptions on scaling the offset emissions that are allowable at a certain atmospheric concentration level make somewhat up for this. This becomes clear when we present the resultant equivalent CO_2 concentrations during the period:

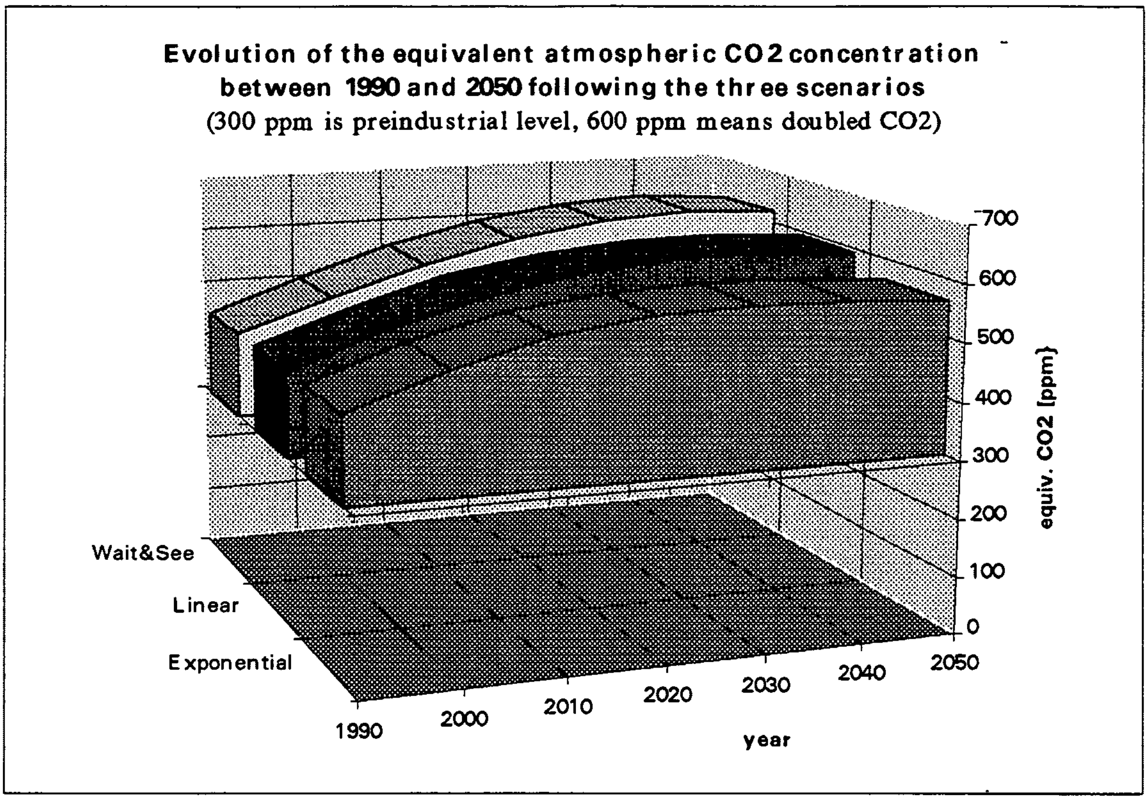

Fig. 52. Considering the three scenarios, the differences of the equivalent atmospheric CO_2 concentrations are minor at the end of the investigated period. The results indicate that it will be uttermost difficult to avoid a doubling of the greenhouse effect in the next century. The wait&see scenario results in somewhat more than a doubling. A quadrupling, however, does not seem impossible to prevent. The figure also shows that the man made greenhouse effect already now is equivalent to a fifty percent increase compared to the preindustrial level.

It can be seen that in the end the World will experience a situation that is equivalent to about a doubling of the atmospheric CO_2 concentration. In any case it looks like the choice of a specific reduction path does not make a great difference. It seems as if humanity has to consider that anthropogenic climate change is going to manifest itself in the next decades. And we have even assumed (somewhat unlikely) that the emission reductions are realized globally

When we take into consideration that our scenarios mean a massive reduction of fossil fuel use, we also have to mention that sulphate aerosols apparently have caused a regional cooling opposed to the rising greenhouse effect (Charlson *et al*, 1991). Both the direct reflection of solar radiation and the indirect effect of the enhancement of clouds' life times play a rôle. Moreover there are some dynamical consequences caused by the regional atmospheric forcing of tropospheric aerosols that have not been considered properly yet[12].

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[12] Dynamical meteorology has shown that regional scale heating can be compared to a forcing that would be derived from a heightened topography. In both cases airmasses are forced to change their paths, this implies a northward drift over the northern middle latitudes. When the airmasses again flow over undisturbed topography or ground with a normal temperature the forcing ceizes so that the airflow again is parallel to the original direction.

This also implies that it is wrong to state that the warming over Europe over the last years was not brought about by the increased greenhouse effect but by changed circulation patterns. This argument does not take care of the dynamical changes that the regional cooling patterns imposed on the large scale warming imply. The strength of the aerosol

The typical life times of sulphate aerosols is typically only about 8 days in the middle latitudes – compared to the life times of greenhouse gases that typically are several decades or even centuries[13]. So their influence, assuming a typical atmospheric velocity of 10 ms^{-1}, only extends up to about 7000 kilometres from the SO_2 source[14]. With the short atmospheric lifetimes of sulphur aerosols reductions of the SO_2 emissions will immediately weaken the aerosol induced radiative cooling[15]. In other words the growing sulphur emissions in East and South Asia will only have neglibible influence on the radiative forcing over Europe.

Meeting the targets described by the LTI-scenarios globally will not even prevent further global warming after the year 2050. The climate system lags the changes in the radiative forcing. On the other hand, the realization of our scenario is the only way to prevent the quadrupling of the equivalent CO_2 concentration that very likely will have disastrous consequences, and that the World might not be able to prepare for in any way. Even after stabilisation of the greenhouse effect the speed of local climatic change in some areas may be higher than what natural systems are expected to be able to adapt to. But we have to stress that stopping the growth of the greenhouse effect is the only way to land the human induced global warming smoothly.

Many people living today think that climate change is going to happen only many decades from now and that it only will be a problem for coming generations. There is general ignorance about the fact that without major initiatives the doubling of the greenhouse effect is only about 30 years away. Or if this is accepted than the statement is made that the models are not good enough yet to actually estimate the consequences for humanity[16]. Apparently most people also assume that the changes will happen gradually and smoothly, be of small magnitued, so that it is not necessary to adapt to them. One typical misunderstanding also seems to be that the problems only will arise once the climatic system has responded to the forcing and reached a new steady state. This of course prevents preparations for the most obvious changes in due time.

As one example one can mention that despite the quite short time scale of the expected changes intensive research in innovations of the agricultural systems to cope with changed climatic conditions is not taking place. The same is true for forestry or investigating the response of soils to the climatic changes. Worse still, even in industrialized countries, areas are being developed that in some years obviously will be endangered by flooding, inundation or a rising ground

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cooling is currently about -1 Wm^{-2} over the Northern hemisphere (up to 4 Wm^{-2} over Southeast Europe), compared to a much more evenly distributed greenhouse radiative forcing of +2.5 Wm^{-2}.

[13] Nitrous oxide has a lifetime of about 200 years, CFCs of up to 350 years. CO_2 has an atmospheric life time of about 120 years.

[14] The so called meso-scale of Rossby waves that describes the typical steering patterns of middle latitude weather systems.

[15] This will lead to a quite rapid relative warming over those areas where the aerosol cooling has been most pronounced in the last few decades (see also Wigley, 1991).

[16] Even if we had a perfect climate model we would not know this, as all of our measurements contain errors.

water table. Such developments bind capital in infrastructure and buildings that better had been used in a more long sighted manner. It is, in fact, unworthy of intelligent human beings.

While the primary aim of this project is not to investigate the actual consequences of the highly probable climatic changes for an energy system based mostly on renewables, we will shortly describe some other obvious changes.

Unchanging conditions for the biomass production except for the changes made in the sustainable scenario to assure a sustainable agricultural system might be a too optimistic approach. It is by far secured that agriculture in the industrialized countries really will be able to adjust smoothly to the changing environmental situations.

The greenhouse warming will be most pronounced during the winter time. This has importance for the space heating demand. On the other hand a higher occurence rate of very warm spells in the summer time would normally lead to an increased demand for space cooling and ventilation. Both LTI-scenarios describe an improvement of the housing stock, so that the cooling demand in summer is reduced by intelligent architecture. Better insulation and solar architecture reduce the space heating demand in the winter time.

Rising water levels of the seas mean that coastal areas will become exposed to flooding and inundation. This diminishes the agriculturally useful area and might be accompanied by a welcomed extension of marshlands like the Wadden Sea. The necessary rehousing of inundation victims might as a side effect offer an improvement of the housing standards in the EU generally. On the other hand incrising the height of dykes could be rather expensive so that countries like the Netherlands would loose international competitiveness due to rising tax pressure. These small examples might indicate the necessity of further investigations of the consequences.

Climate models have shown global warming to be most pronounced at the higher latitudes, especially over the Northern hemisphere land areas. However, in the industrialized World, mostly situated in the northern hemisphere middle latitudes, not much is done to investigate the consequences of global warming specifically over that region. This rests in the general understanding that climatic change will not pose larger problems in the industrialized countries which does not seem to be justified.

It is interesting to see that decision makers today do not take into consideration even the most probable changes. The consequences of global climatic change are not really understood in terms of neither time scale or importance. Rising sea level is not considered in even very elaborate economic decisions that bind lots of capital in near coastal installations or infrastructure. Changing rainfall patterns are not included in planning sewer systems. A very likely warming trend in the next decades is not taken care of in long term investments in for example forest regrowth scedules. And so on.

It can be concluded that even at the present time no proper schedules have been laid to try to adapt to the ongoing climatic change. This lack of strategy definitely means that most of the forecasted costs will not be avoidable. Those costs are even only built on our present understanding of both the climate system and the way it influences society. We know that we do not have a complete knowledge of all the externalities. The real costs of climatic change may quite well turn out to be much higher than assumed today[17]. Therefore at the present even the high figures for externalities given by some researchers rather might underestimate the problems that Europe faces.

This investigation justifies the chosen externalities, gained from investigations of the consequences of a doubled CO_2 forcing, throughout the investigated period of the LTI-project. The difficulties of reaching a worldwide understanding on a reduction strategy – considering the poor results of the Berlin Conference of Parties in the spring of 1995 – even indicate that preventing a doubled effective CO_2 concentration might be unrealistic. Hopefully this is not the case for a quadrupling, which will have truely catastrophic consequences.

Currently both the ignorance regarding the physical basis of the greenhouse effect and its – seemingly unavoidable – consequences, together with the unwillingness to take the most pronounced changes of global warming into consideration, prevent us from avoiding many of the climate change related costs. It seems as if the industrialised countries most likely threaten to experience a bunch of climate change induced environmental changes completely unprepared for. This should be investigated in further studies.

Considering the vast consequences of a changing climate on the global living conditions allows the conclusion that posing externalities on fossils of the size of the ones chosen in the LTI-project is logical, as we have shown that even under very optimistic assumptions regarding global emission reductions this will not leave the Earth's climate undisturbed, nor necessarily that the greenhouse effect will not mean a *dangerous anthropogenic perturbation of the climate system*[18].

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[17] For example the question of the thermohaline circulation in the North Atlantic interrupted by an extra influx of fresh water, when global precipitation patterns move towards the poles, is discussed in the literature at the moment. This interruption of the commonly called Golfstream would lead to a major cooling over Europe and lead to a situation very similar to an ice age. This could happen within only a couple of a few years. While the warming might be prepared for in good time, such a local cooling will have devastating impacts on the European agriculture and economy.

[18] The UN Climate Change Convention (UNEP, 1992).

Biomass potentials from the viewpoint of natural geography

Climatology

Europe consists climatologically speaking of a variety of smaller subgroups. In the larger scale the Köppen classification modified by Trewartha (Akin, 1990, p.51) declares that Europe falls into the Marine West Coast class for Western Europe, including the middle and north of Spain and Portugal. In Southern Europe Meditarranean climate can be found in southern Italy, Spain and Portugal. Greece and northern Italy apparently lie in the humid subtropical zone.

Southern Sweden and Finland belong to the humid continental climate with cool summers while their northern parts belong into the subarctic group.

The climatological factors determine the agricultural and vegetational patterns to a very high degree, but human interference can modify the actual vegetation and especially agricultural patterns so that natural vegetation patterns not necessarily can be found in the agricultural ones.

Soils

Soils in Western Europe, Greece, Italy and Southern Sweden are of the podzolic type in temperate climates, where the top soils are depleted in some nutrients and minerals but respond well to common agricultural praxis..

In Ireland, Scotland, Finland and Northern Sweden the soils are podzolic of the cool climate type.
In parts of Spain and Southern Portugal chernozemic soils (mollisols) that can be very rich like the ones in the North American Great Plains.

In Northern Italy (Po-Plain), but in places on a smaller scale in other parts of Europe, too, alluvial soils can be found that are very rich in nutrients.

Vegetation

As a combination of the climatology and the soils (that themselves depend on the climatology to a certain degree) Europes vegetation patterns have developed.

Most of Europe belongs to the natural broadlead and mixed broadleaf coniferous forest type.
Exceptions are:

- Southern Portugal and Spain, Italy and Greece belonging to the class of Mediterranean scrub forest.

- Middle and Northern Sweden, Northernmost Scotland and Finland that belong to the coniferous forest class.

Importance for Biomass production

The natural vegetation patterns have some importance for biomass production, especially concerning the establishment of biomass plantations.

It looks like there should not be any problems in Central and Western Europe as the factors: soil, climate (excluding adverse climatic change in the next decades), and natural vegetation patterns indicate quite high productivity.

In Southern Europe the lack of suffcient water and the shorter vegetation period due to too high temperatures, that force maturation and thereby decrease production of typical mid-latitude products, might mean reduced productivity, unless trickle or subsurface drip (SDI) irrigation is performed.

In the Middle and North of the Nordic Countries Sweden and Finland productivity in crops will be lower due to their specific heat requirements. On the other hands energy plantation managers can exploit the potential of coniferous forests to assimiliate at lower temperatures, which stabilizes the maximum productivity at not too low values.

Following Hall it might therefore in the first place be possible to reach at least an annual production of 20 tonnes per square kilometer over the whole of Europe. On the other hand this figure can only be reached technologically. For Southern Europe water requirements might be too high to make intensive energy plantations uneconomical.

It seems to be necessary to reduce the expected production of energy plantations in Southern Europe to the amounts that we can expect in Northern Europe, ie about half the Western Europe average. On the other hand imposing sufficient externalities on the fossil fuels might lead to intensive plantation techniques becoming economically viable in Southern Europe, too.

References

Akin, WE, 1990, *Global Patterns: Climate, Vegetation, and Soils*, University of Oklahoma Press, Norman/US and London/UK, pp..

Hall, D, 199?

LCA inventory database

Bent Sørensen

Formation of a database of LCA impacts of energy production, conversion, transmission and end-use technologies

The project has collected impact data from a number of Danish and international externality, social cost or LCA studies. These are presently being incorporated into a database suited for energy system analysis. The problem is that for energy planning purposes, the data needed are fairly generic, with only a general dependence on location of facilities (which in many cases is only partially known at the planning stage, although the country or region will normally be fixed). As regards technology dependence, it is necessary to use present state of the art, or in some cases (emerging technologies) extrapolated data. Typically, for each technology component, we have access to different studies giving different impact data. We use this as a way of determining the range of estimates or "uncertainty", taking of course also into account any uncertainty actually stated in the studies used. The entries might look as in the following scheme:

Aggregated externalities used in study (mEURO/kWh)

Technology	**Current average**			**Best present techn.**			**Future (2050)**		
	c.e.	l.b.	h.b.	c.e.	l.b.	h.b.	c.e.	l.b.	h.b.
Coal based power	**230**			**150**	**25**	**1340**	**146**		
GHG	150			130	15	1300	130		
pollution	50			10	5	20	8		
social impacts	30			10	5	20	8		
Gas based power				**85**					
GHG				65					
pollution				10					
social impacts				10					
Passenger car (oil)	**850**			**525**			**400**		
GHG	250			125			100		
pollution	400			200			100		
social impacts	200			200			200		
Industrial boilers									
GHG									
pollution									

social impoacts									
Transmission lines									
GHG									
pollution									
social impoacts									
End-use elec. appl.									
GHG									
pollution									
social impoacts									
Etc.									

c.e.: central estimate, l.b./h.b.: lower/higher bounds, understood as mean deviations.

Presentation of selected, calculated impacts

Based on recent studies of impacts, including both critical assessment of literature and in a few cases independent data collection, Tables 108-111 show the pathways employed and results obtained, for coal, nuclear, and wind technologies. This allows a comparison of the very different impact profiles of fuel-based and renewable energy systems.

The state-of-the-art coalfired power plant considered in Table 108 is based on a proposed (but never built) plant located in England, with 99.7% particle removal. The quantified impacts are from a recent study performed under the EC JouleII Programme (vol. 3 of European Commission, 1995), except for the greenhouse warming impacts, which are estimated in Table 5 on the basis of work performed by the IPCC Working Group II for the second assessment report (IPCC, 1995). One of the central assumptions in the EC study is to monetise deaths using a value of a statistical life (SVL) amounting to 2.6 Mecu in all cases. If the value of life and health in developing countries were taken as zero, the global warming impacts estimated in Table 107 would diminish by a factor of 40.

The impacts estimated in Table 107 are for the IPCC reference scenario assuming a doubling of greenhouse gases in the atmosphere by the middle of the 21st century, as compared with the pre-industrial level. However, the impacts themselves are accumulated over the 21st century, as many of them occur over a period of time. Power production using fossil fuels currently amounts to some 7000 TWh/y (all reference to TWh in the Tables refer to electric output) and is responsible for about 9% of greenhouse gas emissions. Thus the share of impacts may be taken as 70 Tecu. It is more difficult to express this per kWh, but assuming that the impacts are the result of 50 years of producing on average 10500 TWh/y (consistent with a doubling in 50 years), one obtains 0.13 ecu/kWh. This is the estimate used in Table 108 for the greenhouse warming impact.

The impacts of the coal fuel cycle is dominated by the global warming effects. However, the impacts associated with other emissions may be a factor ten lower than for an average British coal-fired plant, inferred from comparing the emission standard assumed here with typical emissions from current installations. In any case, many of the impacts presented in Table 108 are not quantified, so an assessment must deal with the qualitative impacts as well. In those cases where it has been feasible, uncertainties are indicated (L: low, within about a factor of two; M: medium, within an order of magnitude; and H: high, more than an order of magnitude), and the impacts are labelled according to whether they are local, regional or global (l, r or g), as well as whether they appear in the near term (n: under one year), medium term (m: 1-100 years) or distant term (d: over 100 years into the future).

A similar analysis of a state-of-the-art nuclear power plant is shown in Table 109, again based on the EC study (vol. 5 of European Commission, 1995) except for the impact of major accidents described in Table 106. The emphasis is on impacts from release of radioisotopes, and again monetising is involving a statistical value of life amounting to 2.6 Mecu, and a monetised value of hospitalisation equal to 6600 ecu, an emergency room visit set at 186 ecu, a work day lost at 62 ecu, bronchitis at 138 ecu, an asthma attack at 31 ecu, and a symptom-day at 6 ecu. The largest normal operation impacts are from the reprossessing step, but for deposition of high-level waste, no quantitative estimate was made of accidents that may occur over the required long deposition periods. Also the impact of proliferation of nuclear materials and know-how has not been quantified. The use of empirical data for the power plant large accident analysis may be critizised for not taking technological progress into account (cf. the discussion above on average and state-of-the-art technology). However, the present expansion of nuclear power takes place in developing countries, so it would seem prudent not to count on the higher standards of operational safety achieved in industrialized countries over the last decade. For example, reduction of impacts through early warnings, indoor confinement with controlled closure and opening of windows, evacuation and food bans is much less likely to function in developing countries. In fact, the early recognition of and public information on a problem, that is essential for certain accident types, have not characterized the historic examples of accidents.

For a wind power plant, the similar impact evaluation presented in Table 110 (based on Meyer et al, 1994; vol. 6 of European Commission, 1995) shows modest negative impacts, most of which occur during the construction phase, and substantial positive impacts in the area of impacts on the local and global society. The impacts during construction are to a large degree resulting from the use of fossil fuels in manufacture and transport, according to the marginal approach taken in the sources used. A comprehensive analysis of a renewable energy scenario would instead use the new energy system to determine indirect energy inputs, with substantially altered results as a consequence. Work along these lines are in progress within a project on life-cycle assessment of future energy scenarios for Denmark, carried out for the Danish Energy Agency.

For a silicon-based photovoltaic system integrated into a building, the similar impact evaluation presented in Table 111 (based on Sørensen and Watt, 1993; Katic et al, 1995; Yamada et al,

1995) shows modest negative impacts, most of which occur during the manufacturing phase, and substantial positive impacts in the area of impacts on the local and global society. The impacts during manufacture are to a large degree resulting from the use of fossil fuels for mining, manufacture and transport, according to the marginal approach taken in the sources used. A comprehensive analysis of a renewable energy scenario would instead use the new energy system to determine indirect energy inputs, with substantially altered results as a consequence. The photovoltaic case is special, because the direct cost at present is far higher than that of the alternatives. If the cost is going down in the future, many of the impacts will also go down, because they are associated with material use or processes that will have to be eliminated or optimized in order to reach the cost goals. The lower cost estimate for 2010 is based on the stacked cell concept of Wenham et al. (1995). The source used for energy pay-back times and carbon dioxide emissions (Yamada et al., 1995) quotes about 50 mecu/kWh for amorphous cell systems integrated into roofs. The cost per kWh produced obviously also depends on the location of the building. The different spans of economic benefits from the power sold, exhibited in Tables 108-111, are meant to reflect the differences in load-following capability of the three different types of plants.

For intermittent renewable energy systems, there will be additional costs in case the penetration becomes large compared with the size of the grid system (say over 30%), because in that case additional equipment must be introduced to deal with the fluctuating power production and addition of storage or back-up to the system (Sørensen, 1995a). The tabular impact values presented in Tables 108-111 may be presented as impact profiles for a multicriterion assessment.

Table 107. Estimated global warming impacts during 21st century for IPCC reference case.

Impact description:	Valuation (Tecu)
Additional heatwave deaths (1M, valued at 2.5 Mecu each)	2.5
Fires due to additional dryspells	1.0
Loss of hardwood- and fuelwood-producing forests	3.0
Increase in skin-cancer due to UV radiation	2.5
Additional asthma and allergy cases	2.0
Financial impact of increase in extreme events	2.0
Additional crop pests and adaptation problems for new crops	2.0
Increase in insect attacks on livestock and humans	1.0
Increased death from starvation due to crop loss (100M deaths, the affected population being over 300M)	250.0
Deaths connected with migration caused by additional droughts or floods (100M deaths, the affected population being over 300M)	250.0
Increased mortality and morbidity due to malaria, schistosomiases, cholera, etc. (100M deaths, the affected population being over 1000M)	250.0
Other effects of sanitation and freshwater problems connected with droughts, floods and migration	25.0
Total of valuated impacts	795.5

Based on discussions in IPCC, 1995; valuation estimates made separately. Uncertainty is very high.

Table 108. Impacts from coal fuel chain (state-of-the-art technology)

Enviromental impacts	type of impact: emissions (g/kWh)	uncertainty	monetised value mecu/kWh	uncertainty & ranges*
1. Plant construction/decommissioning	NA		NA	
2. Plant operation				
CO_2	880	L		
SO_2 (may form aerosols)	1.1	M		
NO_x (may form aerosols)	2.2	M		
particulates	0.16	M		
CH_4	3	M		
N_2O	0.5	H		
Greenhouse warming (cf. Table 2)	from CO_2,CH_4,...		130	H,g,m
Degradation of building materials	from acid rain		0.8	H,r,n
Reduced crop yields	from acid rain		NQ	
Forest and ecosystem impacts			NQ	
Ozone impacts			NQ	
	cases:			
Mortality from particles (PM_{10})	1 per TWh	H	2.7	H,r,n
from aerosols	0.2 per TWh		0.5	H,r,n
from chronic effects	7 per Twh		NQ	
Morbidity from dust and aerosols,				
major acute	0.4 per Twh		0	M,r,n
minor acute	40000 work days lost/TWh		0.6	M,r,n
chronic cases	150 per TWh		0	M,r,m
Noise (from power plant)			0.1	M,l,n
Occupational health and injury				
1. Mining diseases			0.1	M,l,m
Mining accidents, death	0.1 per TWh		0.2	L,l,n
major injury	3.1 per TWh		0.4	L,l,n
minor injury	27 per TWh		0.1	H,l,n
2. Transport, death	0.02 per Twh		0.1	L,l,n
major injury	0.15 per Twh		0	M,l,n
minor injury	0.69 per TWh		0	H,l,n
3. Construction/decommissioning	0 per TWh		0	M,l,n
4. Operation	0 per TWh		0	L,l,n
Economic impacts				
Direct economy			25-45	
Resource use	low but finite		NQ	
Labour requirements			NQ	
Import fraction (UK plant)	local coal assumed		NQ	
Benefits from power			50-150	

Other impacts				
Supply security	many import options		- NQ	
Robustness (against technical error, planning errors, assessment changes)	fairly low for large plants		NQ	
Global issues	competition		- NQ	
Decentralisation and consumer choice	not possible		NQ	
Institution building	modest		NQ	

NA= not analysed, NQ= not quantified. Sources: data from one specific site in the UK, vol. 3 of European Commission, 1995, and own estimates (cf. Table 2). Values are aggregated and rounded (to zero if below 0.1 mecy/kWh). * (L,M,H): low, medium and high uncertainty. (l,r,g): local, regional and global impact. (n,m,d): near, medium and distant time frame (cf. text).

Figure 109. Impacts of nuclear fuel cycle

Environmental emissions	dose commitment man Sv/TWh	un-certainty	monetised value mecu/kWh	uncer-tainty & ranges*
CO_2 , SO_2 , NO_x , particles	NA		NA	
Noise, smell, visual impact	NA		NA	
Radioactivity				
1. Fuel extraction and refinement	0.1	L	0.1	M,l,n
	0.1	L	0	M,r
	0	L	0	M,g
2. Normal power plant operation	0.4	M	0.1	M,l,m
	0	M	0	M,r
	1.9	M	0.3	M,g,d
3. Power plant accidents (cf. Table 1)	5	H	2	H,l,m
	10	H	3	H,r,m
	15	H	5	H,g,d
4. Reprocessing and waste handling	0.2	H	0	H,l,d
	0	H	0	H,r,d
	10.2	H	1.9	H,g,d
Social impacts				
Occupational injuries	0		NQ	
Occupational radioactivity				
1. Fuel extraction and refinement	0.1	L	0	M
2. Construction and decommissioning	over 0.02	M	0	M
3. Transport	0	L	0	L
4. Normal power plant operation	0	M	0	M
5. Power plant accidents	0	M	0.003	H,l,n
6. Reprocessing and waste handling	0	H	0	H
Accident handling (evacuation, food ban, clean-up, backup power, cf. Table 1)			15	H,r,m
Indirect accident impacts (expert time, loss of confidence, popular concern, cf. Table 1)			5	H,g,m
Economic impacts				
Direct costs			30-50	L
Resource use	not sustainable without breeders		NQ	
Labour requirements	low		NQ	
Import fraction (for France)	low		NQ	
Benefits from power (consumer price)			45-135	L

Other impacts				
Supply security	medium		- NQ	
Robustness (technical, planning, assessment)	important		NQ	
Global issues (proliferation and weapons)	important		NQ	
Decentralization and choice	not possible		NQ	
Institutions building (safety and control)	fairly high		NQ	

Based on a particular nuclear power plant in France, cf. vol. 5 of European Commission, 1995; supplemented with own estimates, cf. Table 106. See also notes to Table 108.

Table 110. Impacts from wind energy systems

Environmental impacts	impact type: emissions (g/kWh)	uncertainty	monetised value mecu/kWh	uncertainty & ranges
Releases from fossil energy used:				
1. Turbine manufacture (6.6 GJ/kW rated)	12.1			H,g,m
CO_2 (leading to greenhouse effect)	0.05	L	1.8	H,r,n
SO_2 (leading to acid rain and aerosols)	0.04	L	0.1	H,r,n
NO_x (possibly aerosols and health impacts)	0.002	L	0	H,r,n
particulates (lung diseases)		L	0.1	
2. Operation (2.2 GJ/kW over 20 year lifetime)	3.8			H,g,m
CO_2 (leading to greenhouse effect)	0.01	L	0.5	
SO_2 (leading to acid rain and aerosols)	0.02	L	0	
NO_x (possibly aerosols and health impacts)	0	L	0	
particulates (lung diseases)	other:	L	0	
	<1 dB(A)			H.l.n
Noise from gearbox at inhabited areas	<3 dB(A)		0.1	
from wind-blade interaction	$10m^2/kW$		total	
Land use			NQ	
Social impacts				
Occupational injuries (manuf. & materials):				
1. Turbine manufacture, death	0.03/Twh	L	0	L,l,n
major injury	0.9/TWh	L	0.1	L,l,n
minor injury	5/TWh	M	0	M,l,n
2. Operation (same categories combined)			0	M,l,n
Economic impacts				
Direct costs			40-90	
Ressource use (energy payback time given)	1.1 y	L	NQ	
Labour requirements (manufacture)	9man y/MW	L	NQ	
Import fraction (for Denmark)	0.28	L	NQ	
Benefits from power sold (penetration < 30%)			40-120	
Other impacts				
Supply security (variability in wind is high, entry based on plant availability)	high		NQ	
Robustness (up-front investment binds, entry based on technical reliability)	high		NQ	
Global issues (non-exploiting)	compatible		NQ	
Decentralisation & choice (less with large size)	good		NQ	
Institution building (grid required)	modest		NQ	

Based on Meyer et al, 1994; a specific UK wind farm studied in vol. 6 of European Commission, 1995; Sørensen, 1994, 1995a. See also notes to Table 107.

Table 111. Impacts from rooftop photovoltaic energy systems based on p-Si or a-Si cells

Environmental impacts	impact type: emissions (g/kWh)	un-cer-tainty	monetised value mecu/kWh	uncer-tainty & ranges
Releases from fossil energy if used in the steps of the PV conversion cycle (*):	75, 30			H,g,m
CO_2 (p-Si now and around 2010)	44, **11**	L		H,r,n
(a-Si now and around 2010)	0.3, 0.1	L		H,r,n
SO_2 and NO_x(p-Si now and around 2010)	0.2, **0.04**	L		H,r,n
(a-Si now and around 2010)		L		H,g,m
Greenhouse effect from fossil emissions (p-Si)			11, 4	H,g,m
(a-Si, both either now or in 2010)			7, **1.6**	
(if PV production energy use around 2010 is			**or**	
primarily from non-fossil sources)			**0**	
Mortality and morbidity from fossil air pollu-				H,r,n
tion described above (p-Si, now and 2010)			0.4, 0.1	H,r,n
(a-Si, now and 2010)	**0**		0.2, **0**	L,l,n
Land use			**0**	
Visual intrusion			NQ	
Social impacts				
Occupational injuries:				
1. From fossil fuel use(p-Si now and 2010)			0.1, 0.03	L,l,n
(a-Si now and 2010)			0.05, **0.01**	L,l,n
2. From panel manufacture			NA	
3. From construction and decommissioning (differential from using other building materials)			**0**	L,l,n
4. From operation			**0**	L,l,n
Economic impacts				
Direct costs (at present)			300-600	
(around 2010)			**30-90**	H
Energy payback time (now and 2010, a-Si)	3y, 0.5y		NQ	
Labour requirements (now and 2010)	40, 4 man y/MW		NQ	
Benefits from power sold (penetration < 20%)			**40-120**	H

Other impacts				
Supply security (variability in solar radiation is high, entry based on plant availability)	high		NQ	
Robustness (up-front investment binds, entry based on technical reliability)	high		NQ	
Global issues (non-exploiting)	compatible		NQ	
Decentralisation & choice	good		NQ	
Institution building (grid required)	modest		NQ	

Based on Sørensen & Watt, 1993, Sørensen, 1994, Yamada et al. 1995. See also notes to Table 107

Discussion of selected evaluations

The examples of the previous section indicate the level of analysis undertaken at present. It is evident, that each number to be provided requires large amounts of effort, and still cannot be given without substantial uncertainty. It is also clear, that the largest undertainties are found for the most important impacts, such as nuclear accidents and greenhouse warming. Clearly there is a general need to improve data, by collecting information pertinent to these types of analysis. Even using national input-output data often discloses failure of statistical data to align with the needs of characterising transactions relevant for the energy sector. Also there are still a number of important impacts left as qualitative impacts. Some of these might be quantified, but if quantification and further monetising results in a large increase in the uncertainty, not much has been gained. It is one conclusion, that there still is an urgent need to be able to present qualitative and quantitative impacts to a decision-maker in such a way, that the weight and importance of each item become clear, despite uncertainties and possibly different units used. Some progress along these lines is in the construction of impact profiles (Sørensen, 1993; Sørensen and Watt, 1994), which can be labelled as a form of multivariate analysis and multicritera decision-making.

The difficulties encountered in presenting the results of externality studies and life-cycle analyses in a form suited for the political decision-making process may be partly offset by the advantages of bringing into the debate the many impacts often disregarded (which is of course the core definition of "externalities", meaning issues not included in the market prices). It may be fair to say that life-cycle analysis and the imbedded risk assessments will hardly ever become a routine method of computerized assessment, but that they may continue to serve a useful purpose by focussing and sharpening the debate involved in any decision-making process, and hopefully help increase the quality of the basic information, upon which a final decision is taken, whether on starting to manufacture a given new product, or to arrange a sector of society (such as the energy sector) in one or another way.

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Externalities from Fossil Fuels
Bernd Kuemmel, January 1996

Radiative Equilibrium

Fossil fuels contain carbon that despite being the basic element of life on Earth in the combination with oxygen as carbondioxide (CO_2) has certain radiative qualities that cause changes in the Earth's radiative balance and therefore changes in the surface temperature and climate of the Earth.

Without changes in either solar irradiation or the composition of the atmosphere regarding the radiatively active trace substances, aka greenhouse gases, the climate system on Earth is balanced (Michell, 1985)(?). The amount of the solar radiation entering the climate system and the heat radiation from the surface are then the same. This can be illustrated in the following short formula:

Formula 1 $$\Delta F = \overline{S_0}(1-\alpha) - \sigma T_s^4 ,$$

where $\overline{S_0}$ is the average solar irradiation reaching the top of the atmosphere (TOA), which is about 341 Wm^{-2}, is the albedo of the Climate System (Surface plus Atmosphere), the Boltzmann constant (5.67E-8 Wm^{-2}K^{-4}), and T_s the average temperature of the Earth's surface (about 288 K today).

Now in equilibrium ΔF of course is zero. The sensitivity of ΔF with regards T_s is the primitive sensitivity (ie no account has been taken of any feedback processes like the positive water vapour feedback or the assumed negative cloud short wave radiative forcing effect). The primitive sensitivity solely explains the changes of the surface temperature regarding changes of the radiative flux within the climate system. It can be calculated simply by differentiating Formula 1:

Formula 2 $$\frac{\Delta F}{\Delta T_s} = -4\sigma T_s^3 = \frac{-4\overline{S_0}(1-\alpha)}{T_s} .$$

Primitive Climate System Sensitivity

Assuming that the changes in the climate system of the Earth will not be grave we may linearise the changes in the surface temperature and introduce the primitive climate sensitivity, :

Formula 3 $$\Delta T_s = \gamma\, \Delta F \quad \Leftrightarrow \quad \gamma = \frac{T_s}{4\overline{S_0}(1-\alpha)} ,$$

which in our case means that the Earth's climate system has a primitive sensitivity of 0.3 K per unit Wm^{-2} change in the TOA forcing. To put this into perspective: the doubling of the atmospheric CO_2 concentration is equivalent to a TOA forcing of about 4.4 Wm^{-2} (IPCC, 1995). Therefore according to the primitive sensitivity this forcing would be equivalent to a surface warming of 1.3 K.

The primitive change in the Earth's surface temperature is, however, strongly modified by various feedbacks, the most prominent being the water vapour feedback. A slight surface warming due to the increase in the greenhouse effect of course also means an increased evaporation of water from the Earth's surface. As water vapour is an excellent greenhouse gas itself, and in the current climate system is responsible for more the half of the total natural greenhouse effect (?), global warming is enhanced by the water vapour feedback. Climate models do account for it, but there has also been speculation that a possible rise in the cloud cover of the Earth could mean somewhat lesser global heating from the increase in the greenhouse effect.

The International Panel on Climate Change (IPCC) has collected a number of scientific results on the greenhouse effect, the radiative forcing of the Earth, the feedback mechanisms (Working Group 1), the influence the global changes will have for human systems (WG 2) and the means that humanity has to mitigate and adapt to the coming changes (WG 3). The results of these investigations have been published in various reports, the most prominent is the 1990 report (IPCC, 1990).

In the longer time scale the equivalent doubling of the CO_2 concentration (the changes in the atmospheric concentrations of the other greenhouse gases like methane, CH_4, nitrous oxide, N_2O or freons, CFCs is calculated to be equivalent to a certain amount of CO_2) will result in a global warming of between 1.5 and 4.5 Kelvin. IPCC has also stated that their so-called best estimate is 2.5 K.

The value given in the 1990 report, and also in the first supplementary report two years later (IPCC, 1992; IPCC, 1995) has recently been somewhat reduced after the radiative cooling effect of sulphate aerosols (aka acid rain) was included in the climate models. But we want to stress that sulphate aerosols due to their, compared to most greenhouse gases very short life time of a few days, are not necessarily a reliable factor in the radiative forcing of the Earth's climate system.

Impact analysis of CO_2 emission

When we want to determine the changes in the climate system that most easily can be described by the change in the global temperature, we have to establish a relationship between the emissions of CO_2 and the resultant warming. To do this we first have to establish the resultant change in the atmospheric abundance of CO_2, this relationship is given by (EC, 1994/7):

Formula 4 $C = 1.28\ 10^{-16}$ ppm / g CO_2,

and the resultant increase of the radiative forcing of the climate system by:

Formula 5 $$F = 6.3 \frac{\Delta C}{C_0} \text{ Wm}^{-2},$$

with the concentration, C_0 and C, measured in ppm. We can then use Formula 3 to calculate the rise in the global surface temperature but will scale with a factor of 1.9 (=2.5/1.3) to comply with the IPCC best estimate.

Our technique in principle allows a calculation of the resultant temperature change, as the total concentration change obviously depends on the emissions in the other regions of the world, too. But opposite to the dependency of the total concentration change on the emissions, the radiative forcing of each incremental emission itself does not vary much with the emission paths (Caldeira & Kasting, 1993).

So in order to calculate the incremental change of the atmospheric CO_2 concentration we have to make some assumptions on the emission paths followed in the other regions of the world. The easiest way is to use the IPCC Business as usual (BAU) path for this purpose. Such an approach has been followed in the ExternE project (EC, 1994/7) where the resultant global warming has been scaled to the electricity generation (K/kWh), which then allows to estimate the damage amount.

Monetization of CO_2 Emissions

A reasonable value for the damage potential from fossil fuel use is about 130 mECU/kWh for the coal power cycle (Sørensen, 1995), and taking CO_2 emissions equivalent to about 812.5 grams per kilowatthour (using a fair estimate of the data given in EC, 1994/7). In other words: the average damage value of a gram CO_2 emitted from fossil fuels is about 160 ECU/g CO_2 on the background of the future global emissions following more or less the BAU path. This assumption is not so bad, as even a comparatively rapid global reduction of the emissions would not lead to a stabilisation of the greenhouse effect very much below the equivalent doubling of the atmospheric CO_2 concentrations (Kuemmel, 1996). Thus, the use of the value given above seems very reasonable.

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Economy of CHP with fossil externalities included

Bernd Kuemmel, January 1996

Introduction

Cogeneration and Combined Heat and Power (CHP) are means to improve the energy economy by combining two technologies, that normally are running seperately. Combining heat and power generation extends the revenue base of a site, either through enabling one to sell a complementary product, or by reducing the need to buy energy out of the house. As the price incremental for a cogeneration site compared to a pure generation site is quite low, the potential profit span is quite high.

But power and heat are two different kinds of energy. Basically one may state that power is more valuable, as its exergy content is higher. Heat is statistically nondirected movement and its energy quality therefore lower. It is easy to substitute heat by electricity, but nearly impossible to substitute electricity by heat – unless there is a quite high heat differential to a cold reservoir.

Methodology

For reasons of simplicity we have here assumed that the price of electricity will be twice the heat price to display the price differential between the two energy forms. This has been done by correcting the prices that we had given only for the electrical capacity or the operation and maintainance costs of the cogeneration sites using the ratio of heat to power efficiencies and scaling it so that the power price would share double the amount the heat price would carry. All of our prices are social economic costs, ie they do not contain any privat profits that by definition will be internal to the national economy.

Eternalities from the fossil fuel chains are not internalized in the economy and are not reflected in the current prices. There are currently some environmentally founded taxes on energy prices, but these do not necessarily reflect the externalities that arise from the climatological and environmental effects of the increasing greenhouse effect. A special difficulty with these externalities is that they have a rather large intregenerational share, ie costs that will arise long after the greenhouse gas emissions have occured.

On the other hand for some other energy technologies the share of externalities that arise during the very operation is comparatively high. For example for wind energy a comparatively large part is from the construction and the loss of a site's pristine values, while for coal fired power stations most of the externalities are climate based.

The value of 160 μECU/g CO_2 has been defended in another text in this publication (Externalities from Fossils), so it depends very much on the carbon content of a fuel how high the fossil externality turns out to be. For example the CO_2 content of natural gas is equivalent to 57 kg/GJ, while for fuel oil it is 87 kg/GJ. The externality of oil can therefore be expected to be much higher than from natural gas, that chemically has the same composition as methane, or biogas (although biogas is not as pure as methane). On the other hand when grown sustainably biomass and biogas have a negligible fossil externality.

Results

So when generation prices have to be compared for different technologies we shall take into consideration the fair price that includes externalities. This approach is very different from todays, where the costs that arise outside of the actual consumers and providers of energy services, and where energy prices do not represent those costs, the externalities. We have chosen in this project to make the prices fair by including the externalities. This is to indicate that the established energy system that rests heavily on cheap fossil fuels and cheap access to financing only is advantageous unless fair prices are enabled. Regarding the standard price approach fossils are cheap; if one cares for the wellbeing of the Earth's climate and of humanity both now and in the future, fossils are too expensive to be used. Figure 53 shows how the electricity generation prices behaves in three typical conversion technologies.

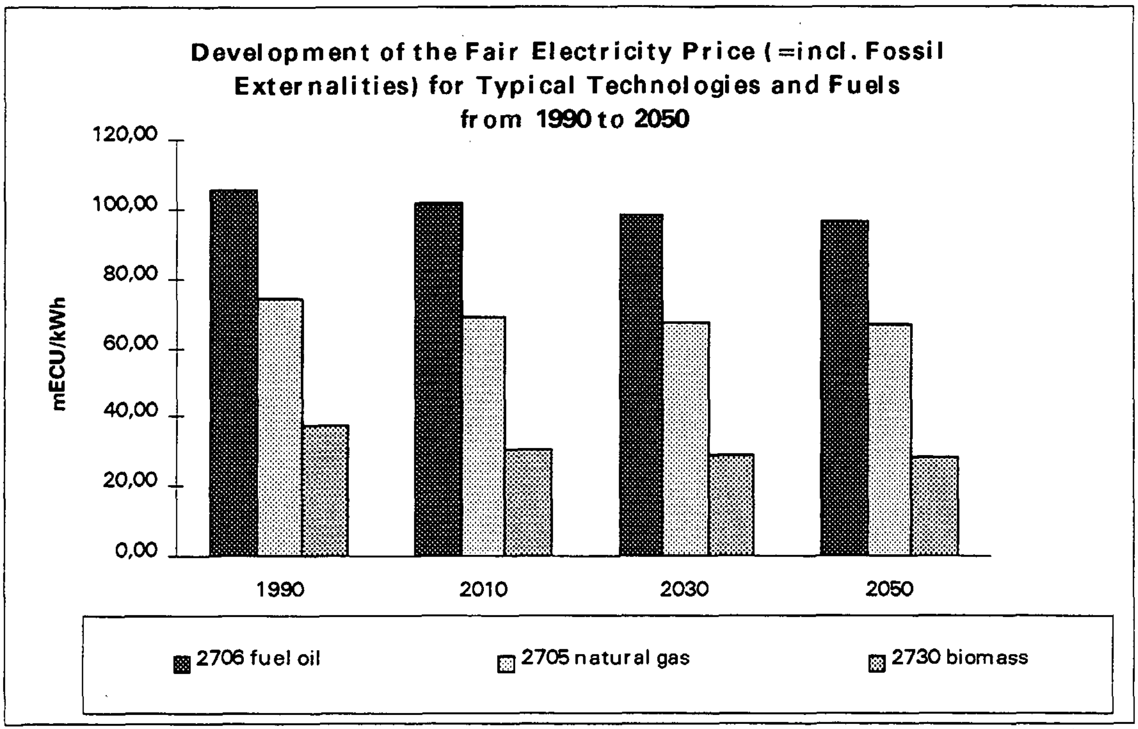

Figure 53. When externalities are included the production price of electricity for the fossil based conversion processes is several times the biomass based conversion. The technologies are 2706: oilfired industrial gasturbine less than 10 MW electrical capacity; 2705: naturalgasfired large scale industrial gasturbine between 10 MW and 75 MW electrical capacity; and 2730: biomass fired cogeneration capacity larger than 10 MW electrical capacity.

As can be seen biomass fired cogeneration has a price advantage of more than 50 per cent; ie taking fossil externalities into account, biomass generated power is only half to a third as expensive as fossil fuel generated power[1]. It seems as if the price advantage for a biomass based energy system is enormous, and it is this margin that this project exploites when it shows that fair prices will lead to a transgression {overgang(?)} from todays fossil based energy system towards an energy system that is based on renewables.

Discussion

The basis for our scenario is not a normative approach that asks people to behave in a certain way. Rather we argue for the necessity to include the external costs in the energy conversion chains, and via this approach reach a new energy system that minimizes the externalities. It is important to stress that this approach is much nearer to the common assumption of the economical systems that define {auszeichnen(?)} market economies with a strong social background than a normative approach. In a way we only take up the trends that society presents us today and extend them from their currently rather restricted basis to a broader base.

Externalities are nevertheless not the most important means to convey our present energy system to one that is more environmentally friendly. Information is another very important aspect. People can choose to prioritize in a way that would seem unlogical from an economical point of view. The large scale change from public transport systems to a system based on private car ownership is such an example. This development is made possible by the rising disponible income in large population groups. It also is made possible by a row of pull and push factors, that on the one hand make private transport very attractive and on the other public transport unattractive. And investigations indicate that people rather would pay more for their private mobility than to change their transport mode[2].

So while people may choose to act irrationally, it depends on the process of information dissemination to make people aware of their prioritization[3].

Database information

The following data have been used in our calculations:

Technology:

Technology ID	**Considered technologies:**
2700	aeroderivative Combined Cycle (CC) Gas Turbine (>75 MW) cogeneration capacity
2705	*smaller scale (<75MW) CC (industrial) Gas Turbine cogeneration capacity*
2706	*micro scale (<10MW) CC (industrial) Gas Turbine cogeneration capacity*
2710	Dual Fuel Gas/Diesel Engine
2715	Pressurised Injection Dual Fuel Gas/Diesel Engine
2720	Ignition gas Engine cogeneration capacity
2725	very small (<500 kW) reciprocating cogeneration capacity

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[1] Even though our calculation excludes the externalities from biomass this could not possibly change the picture. Biomass externalities will never reach the scale that fossils reach due to their global influence on climate and environment.

[2] Stefan, jeg har brug for en reference her!

[3] Like in the process of making people stop smoking.

2728	Lean Combustion Gas Engine
2730	*Biomass/Incineration steam turbine cogeneration capacity (>10 MW)*
2735	small scale (<10 MW) Biomass/Incineration steam turbine cogeneration capacity

Table 112. The technologies that have been used in the full database. *Italics* indicate the three technologies that are included in Figure 53 shown in the text.

Energy prices:

Used fuel prices: mECU/kWh	**Source**
1963	2.5 1990-USD/GJ hybrid poplar
2733	3.48 1990-USD/GJ hybrid poplar
3085	6.33 1990-DEM/GJ natural gas
4144	1390 1990-DKR/Mt fueloil

Table 113. Energy Prices of different fuels. Two examples of biomass and one for natural gas and fueloil are given.

Calculations & Formulæ:

The annualized capacity prices, c_{prod}, have been calculated according to the following formula:

Formula 1 $$c_{prod} = C_{cap.} \cdot \frac{i}{1 - \frac{1}{(1+i)^N}} \cdot \frac{1}{Avail \cdot DTime} + OM.$$

Here C_{cap} is the Capacity cost[4] in mECU/$W_{p,\ el}$, *Avail* is the average availability of reaching the typical drifttime, *Dtime*, in kilohours per year. i is the discount rate – in the LTI project assumed to be 3 % per year –, and *OM* are the operation and maintainance costs per kWh_{el}. These capacity production prices, and the share of the fuel costs, have been scaled to represent the chosen relation between power and heat prices – here taken to be a ratio of 2:1. For this the efficiencies of the conversion processes, η_{el} and η_{th}, have been exploited.

When the operation and maintainance costs are not given as average values per produced kWh, but as a percentage of the Capacity costs, *OM%*, then the average *OM* per produced kWh is simply calculated as:

Formula 2 $$OM = OM\% \cdot \frac{1}{Avail \cdot DTime}.$$

---

[4] The factor $C_{cap}.i/(1-(1+i)^{-N})$ is also called the Capital Recovery Rate.

LCA ANALYSIS OF SCENARIOS

Using the impact database and the scenario descriptions, the total impacts for the end-point as well as the trajectory reference years will be calculated.

FINAL EVALUATION AND CONCLUSIONS

[to be written when everything else is in place]

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Et 3.modul matematik projekt

af: Anders Marcussen, Anne Charlotte Nilsson, Lone Michelsen, Per Mørkegaard Hansen

Vejleder: Jesper Larsen

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LIFE-CYCLE ANALYSIS OF THE TOTAL DANISH ENERGY SYSTEM

an example of using methods developed for the OECD/IEA and the US/EU fuel cycle externality study

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292/95 Fotovoltaisk Statusnotat 3

af: Bent Sørensen

293/95 Geometridiskussionen - hvor blev den af?

af: Lotte Ludvigsen & Jens Frandsen

Vejleder: Anders Madsen

294/95 Universets udvidelse - et metaprojekt

Af: Jesper Duelund og Birthe Friis

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af: Maria Hermannsson, Sebastian Horst,
Christina Specht

Vejledere: Jeppe Dyre og Peder Voetmann Christiansen

299/95 ADAM under figenbladet - et kig på en samfundsvidenskabelig matematisk model

Et matematisk modelprojekt

af: Claus Dræby, Michael Hansen, Tomas Højgård Jensen

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by: Bent Sørensen

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af: Glenn Møller-Holst, Marina Johannessen, Birthe Nielsen og Bettina Sørensen

Vejleder: Jesper Larsen

302/95 KOMPRESSORER - Analyse af en matematisk model for aksialkompressorer

Projektrapport sf: Stine Bøggild, Jakob Hilmer,
Pernille Postgaard

Vejleder: Viggo Andreasen

303/95 Masterlignings-modeller af Glasovergangen

Termisk-Mekanisk Relaksation

Specialerapport udarbejdet af:

Johannes K. Nielsen, Klaus Dahl Jensen

Vejledere: Jeppe C. Dyre, Jørgen Larsen

304a/95 STATISTIKNOTER Simple binomialfordelingsmodeller

af: Jørgen Larsen

304b/95 STATISTIKNOTER Simple normalfordelingsmodeller

af: Jørgen Larsen

304c/95 STATISTIKNOTER Simple Poissonfordelingsmodeller

af: Jørgen Larsen

304d/95 STATISTIKNOTER Simple multinomialfordelingsmodeller

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304e/95 STATISTIKNOTER Mindre matematisk-statistisk opslagsvæ
indeholdende bl.a. ordforklaringer, resuméer og tabeller

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And The Spectral Flow Formula

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306/95 Goals of mathematics teaching

Preprint of a chapter for the forthcomming International Handbook of Mathematics Education (Alan J.Bishop, ed)

By: Mogens Niss

307/95 Habit Formation and the Thirdness of Signs

Presented at the semiotic symposium

The Emergence of Codes and Intensions as a Basis of Sign Processes

By: Peder Voetmann Christiansen

308/95 Metaforer i Fysikken

af: Marianne Wilcken Bjerregaard,
Frederik Voetmann Christiansen,
Jørn Skov Hansen, Klaus Dahl Jensen
Ole Schmidt

Vejledere: Peder Voetmann Christiansen og
Petr Viscor

309/95 Tiden og Tanken
En undersøgelse af begrebsverdenen Matematik udført ved hjælp af en analogi med tid

af: Anita Stark og Randi Petersen

Vejleder: Bernhelm Booss-Bavnbek

310/96 Kursusmateriale til "Lineære strukturer fra

algebra og analyse" (E1)

af: Mogens Brun Heefelt

311/96 2nd Annual Report from the project

LIFE-CYCLE ANALYSIS OF THE TOTAL DANISH

ENERGY SYSTEM

by: Hélène Connor-Lajambe, Bernd Kuemmel,
Stefan Krüger Nielsen, Bent Sørensen