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K. L. Brockmann, J. Hemmelskamp

and O. Hohmeyer

Certified Tropical Timber

and Consumer Behaviour

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With 66 Figures



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Preface

This book is based on the findings of the European research project

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into the European Energy System and
its Potential Economic and Environmental Impacts".***

The work was partially supported by the European Commission under the DG XII Non-Nuclear Energy Programme APAS, contract no. RENA-CT94-0041. The project was carried out by a consortium of five research teams which make up the ***LTI-Research Group***:

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Mannheim, Germany, January 1998

The LTI-Research Group

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Executive Summary

Helmuth-M. Groscurth

Objectives and Methodology

A sustainable European energy system, mitigating global climate change and solving a number of other key environmental problems, will require massive reliance on renewable energy sources combined with a sharp increase in energy productivity. Considering that most of the technologies necessary for such a development have already been invented and tested at least on the level of prototypes, today's most important questions are:

- How can renewable energies and the efficient use of energy be integrated into the European energy system at sufficiently high diffusion levels?
- What are the costs and benefits of such a strategy?
- What are the major bottlenecks and obstacles to such a development?
- What measures are necessary to support this development?

Within the project *Long-Term Integration of Renewable Energies into the European Energy System ...* – hereafter abbreviated to *LTI-Project* – two scenarios were developed for a future European energy system which no longer has severe impacts on the environment. Such scenarios are descriptions of conceivable and consistent future developments which include simplifying assumptions and large uncertainties. Therefore, they are in no way an attempt to predict future developments or to provide a master plan to be carried out literally, but a means to check concepts for a sustainable future energy supply for Europe for their technical and economic feasibility and to provide a positive vision for decisions to be made in the near future.

The basic objective of the scenarios designed was to reduce CO₂ emissions by 80% until 2050 and to phase out nuclear energy at the same time. The CO₂ reduction goal is in line with demands from the IPCC and many national committees. Even though it is ambitious, it should be stressed that such a reduction will not buy a 100% insurance against negative consequences resulting from potential changes of the global climate. It is rather a rate of emissions which – according to our current knowledge – will lead to limiting climate change to a level that we can cope with and which is thus a meaningful target under the precautionary principle. Nevertheless, it may turn out that further reductions in CO₂ emissions in industrial countries will be necessary, especially considering the need to provide acceptable living conditions not only in the industrialised part of the world, but everywhere on earth.

The scenarios developed are in line with a cohesion of living standards in the whole of Europe until 2050, which will be similar to those currently experienced in Northern Europe. The rest of the world beyond Europe is not modelled explicitly in our scenarios, but we assume it behaves in such a way that the development in Europe is not hampered. This would, for instance, be the case, if other important countries like the US and Japan followed the development in EU countries with a time lag of not more than 10 years. It is self-evident that the development in Europe should not be at the expense of other regions in the world, especially the poor ones.

Technologies and Potential

As a prerequisite for scenario design, a comprehensive database was derived on the energy-demand situation in Europe as well as on the trend of efficiencies and costs of conventional and renewable energy technologies. The renewable energy sources considered in this book are biomass, solar radiation, wind energy, and hydropower. Other sources like geothermal or wave and tidal energy were discussed in the project, but not used since a joint assessment of their overall availability and their costs showed only small EU-wide potential. This does not mean, however, that these technologies should be disregarded. They should rather be used whenever they have promising potential locally.

On the technology side, we consider the following technologies for exclusive electricity production: Wind turbines, solar-thermal power plants, photovoltaics, existing large and additional small hydropower plants. Heat may be produced by solar-thermal collectors, boilers and furnaces fired with solid and gaseous biofuels or hydrogen (produced on the basis of renewable energy sources), heat pumps, or electricity and it may be stored in hot water tanks. Combined production of heat and electricity is possible via cogeneration units and fuel cells. Biomass may be turned into different gaseous fuels ranging from biogas to pure hydrogen for the use in reversible fuel cells. In addition, it may be converted into liquid fuels for transport purposes. In some cases, where efficiency measures and renewable energies are not yet sufficient to meet the demand for energy services, fossil fuels may be used up to the 20% CO₂ emission limit. This is mainly the case in the transport sector and for some residual backup.

Scenario for a Sustainable Future Energy System

A socio-economic system is regarded as *sustainable*, if it can be maintained over very long periods of time, that is a large number of generations. Sustainability does not only refer to the economic situation, but at least equally to the state of the environment and of society. Consequently, first it

has to be ensured that human economic activities will not endanger the living conditions which support our very existence. Second, welfare has to be distributed equitably among the generations living today and among current and future generations. This is a necessary precondition to avoid social conflicts endangering any sustainable economic development. Finally, the resources available should be allocated efficiently, a task for which free markets have proven to be an appropriate instrument.

One important guideline following from these general considerations is the *precautionary principle* of avoiding impacts which may cause very large damage to humanity even if the probabilities of them occurring are small or if their existence has not been proven beyond doubt.

Therefore, the *Sustainable Scenario* of the future European energy system tries to minimise anthropogenic impacts on the ecosystem subject to the restriction that comfortable living standards are to be maintained. Consequently, its guidelines are

- to create and preserve development options for future generations and peoples outside the EU,
 - to avoid waste or restrict it to substances which occur naturally, and
 - to rely on energy technologies which do not endanger political stability.
- In addition, some uses of energy may well be consciously renounced on the basis of the sufficiency principle.

The world of the Sustainable Scenario is, thus, not characterised by *having more* but by *feeling better off*. This different perception of wealth includes a higher valuation of immaterial goods like education, health, security, absence of violence, liberty, equal rights etc. A society following these principles will probably show greater identification with the regions in which people live. It is there that people can become involved in most of the decisions that are important for their everyday life.

The idea of sustainability has consequences for many fields of society. In residential planning, for example, it will be necessary to find common spatial structures for industrial, commercial, and living areas. Only then will it be possible to reduce traffic to an environmentally benign level. People will have to change their diet considerably, the most important factor being lower consumption of meat, the production of which is very resource intensive as the same amount of calories from grain requires about a factor of 10 less input in acreage and energy. This is a prerequisite for changing land use in a way that 10% of the total area can be set aside as totally protected nature reserves, that the use of fertilisers, pesticides and herbicides may be reduced by a factor of five, and that the areas producing agricultural products exported from and imported into the EU are equal in size.

For the energy system, this means moving away from a situation in which heat is produced individually, while electricity is supplied from centralised power plants. In the future, municipal supply structures may be preferable in

which heat and power generation are integrated and combined with short-distance district heating.

Energy Demand

For a successful restructuring of the energy system, it is inevitable to substantially reduce the demand for primary energy. Only then will it be feasible to meet the remaining demand through renewable energy sources. Therefore, as a first step for the scenario design, the future European energy demand of the different economic sectors is estimated.

In *industry*, it is assumed that material output is reduced by a factor of 4. This can be achieved by a careful design of products which reduces their weight and size, by prolonged product lifetimes, and by changing consumption patterns. The latter may, for instance, include the sharing of products which are used infrequently. Combined with an average recycling rate of 50%, the input of primary raw materials may, thus, be reduced by a factor of 8. For some industrial sectors, however, specific assumptions were made: Due to the still increasing floor space per capita and the necessity of retrofitting the stock of buildings, we assume that the demand for cement remains unchanged and that there is a 20% increase in glass production. A substudy of the LTI-Project, which examined energy efficiency improvements in industry on a sector-by-sector basis, found possible savings of 20-50% for fuels and 10-50% for electricity on average. In some areas, using secondary materials will result in even larger savings. Secondary aluminium, for instance, may be produced with 40% less fuel and 97% less electricity than the primary material.

In the *residential sector*, it is assumed that floor space per capita will increase to 42 m² until 2050, which corresponds to the current top level within the EU. Household sizes will decrease to 2.24 persons with the number of households increasing from 140 to 164 million. The availability of appliances is assumed to be similar to the current situation in Denmark, Germany, and the Netherlands. Their energy efficiency can be improved by 60-85%. The specific heating demand of existing buildings will be reduced by retrofitting them from 150 kilowatt-hours per square meter and year [kWh/(m²·a)] to 40 and 30 kWh/(m²·a) in Northern and Central Europe, respectively. These values are also considered for new buildings even though buildings with lower specific energy demand are already commercially available.

The *tertiary sector* will grow by a factor of 1.5 until 2050. This will mainly be due to additional services in the areas of recycling, repairing, and re-manufacturing. Simultaneously, efficiency gains for office heating, computers etc. will limit the increase of the respective energy demand.

The most drastic assumptions are made for the *transport sector*. Total transport of goods will go down by 60% due to the decreasing material throughput of industry. For air travel, it is assumed that all short and medium distance flights are abandoned, something that applies to most inner European flights. Public and individual passenger transport are assumed to have an equal share. People will travel shorter distances, especially during leisure time, according to the sufficiency principle. The number of trips, however, need not decrease by the same degree. Major efficiency improvements, e.g. cars using only 2l/100km and trucks using 34% less diesel fuel than today, will contribute to a total decrease in the energy demand for transport by almost a factor of 10. However, it can be shown that relaxing these rather restrictive assumptions significantly will still not compromise the scenario objectives.

The development outlined so far can be characterised as dematerialisation of the economy with qualitative growth of the wealth experienced by people. However, it cannot be described in terms of conventional gross domestic product (GDP). The overall energy demand within the European Union will be reduced from 4 500 watts per capita (W/cap) in 1990 to 1 700 W/cap in 2050, that is to 38% of the current demand.

Energy Supply

The shares of the different energy-supply technologies considered to meet the remaining energy demand are set normatively due to heuristic evaluation of conceivable figures. The temporal trajectories for their introduction into the energy system are determined by logistic S-curves starting in the year 2000, which means that there is an accelerated introduction until 2025 after which the development slows down until it reaches saturation in 2050.

500 W/cap of *biomass* for energy uses will come from energy crops and residues. The latter consist of waste wood and textile materials from industry and of the 50% of food which is usually thrown away in industrial societies. It will, however, not comprise residues from forestry or agriculture since these may have to be left in or brought back to the respective areas in order to maintain their content of nutrients. Energy crops can be grown on excess land which will be available if the diet is changed. The energy use will, however, have to compete with food production for exports to countries with less favourable conditions for agriculture. Biomass will partly be burnt directly, partly gasified. In both cases, fuels derived from biomass have the advantage that they can be stored to compensate for fluctuations in the energy supply from other renewable sources. Where necessary for electricity production, cogeneration units will be applied to burn fuels from biomass.

In 2050, *photovoltaic modules* will have been installed on 30% of all suitable roofs and façades, producing 150 W/cap of electricity. The respective potential was estimated using statistical methods linking population densities with roof and façade areas. It was calibrated with German data. Module efficiencies will have risen from 10 to 18.4% until 2050.

The remaining 50% of the suitable roof and façade areas will be used for *solar-thermal collectors*. Their yield of 330 W/cap will cover 80% of the hot water demand and 50% of the room heating demand in Northern Europe. In Southern Europe, they will supply all the room heat and hot water, and there will even be some roof space left on which additional photovoltaic modules may be installed for cooling purposes. The temporal mismatch of supply and demand requires the use of individual heat storage.

Wind energy will contribute 50 W/cap of electricity from on-shore and 160 W/cap from off-shore turbines. *Solar power plants*, contributing 180 W/cap to the electricity production, will be used for electrolysis producing hydrogen. This will either be distributed via pipelines and burnt directly, or it will be fed into fuel cells for electricity generation. No large *hydropower plants* will be added to the existing ones. In contrast, the exploitation of the technical potential of small hydropower plants will increase from today's 20-25% to 90%. Some of the existing hydropower plants will have to be retrofitted to serve as pumped energy storage. The total contribution of hydropower plants is 140 W/cap. *Environmental heat* can be utilised via *heat pumps*, which will have a performance index of 4.5 in 2050. In this way, some 90 W/cap of heat are supplied, including 20 W/cap of electricity driving the heat pumps. Finally, 5% of the total energy supply in 2050, corresponding to 80 W/cap, will be in the form of liquid *fossil fuels* used in the transport sector.

All in all, some 1600 W/cap of renewable energy will be supplied to meet the European energy demand in 2050.

Economic and Environmental Impacts

Technology Costs

Together with the efficiencies and potential of renewable energy technologies, their specific costs were estimated on the basis of literature surveys and consultations with experts. All cost figures are given in 1990 ECU, the interest rate used in cost calculations is 3% (real). Specific energy production costs are calculated by deriving annuities from investments using the lifetime of the equipment, adding annual operation and maintenance costs, and dividing the sum by the energy produced within one year. Specific fuel costs are added where applicable.

For *small hydropower plants*, that is those with a capacity of less than 10 MW, we assume no cost reductions, because the technology is mature and

no significant economies of scale can be expected. The technical lifetime of this technology is taken as 30–60 years and operation and maintenance costs amount to 1% of the investment per year.

For *wind turbines*, which have a lifetime of 20 years, we expect the current exponential decrease in costs to continue. Off-shore installations are assumed to be 30% more expensive per kilowatt-hour than on-shore ones.

The largest cost reduction we expect is for *photovoltaics* due to a sharp increase in module efficiencies and strong economies of scale once this technology is produced in large numbers. The lifetime is taken as 25 years, operation and maintenance requires 1% of the investment per year. Production costs depend heavily on solar irradiation. For example, the same technology will produce 54% more electricity when installed in Spain rather than in Germany.

Solar-thermal electricity production is only considered for Southern Europe, that is Italy, Spain, Portugal, and Greece. Costs are estimated for an artificial technology representing an average of parabolic trough plants, tower plants, dish/Sterling plants, and anabatic wind power plants. The lifetime is 20 years and the energy yield is expected to increase due to efficiency improvements from 950 kilowatt-hours per kilowatt peak capacity and per year [$\text{kWh}/(\text{kW}_p \cdot \text{a})$] in 1990 to 1 550 $\text{kWh}/(\text{kW}_p \cdot \text{a})$ in 2050.

Solar-thermal collectors which can be used for room heating and hot water production have a lifetime of 20 years.

To calculate average costs of *biomass* utilisation is difficult, because of the many different technologies involved. Nevertheless, we established an average technology using data from numerous studies. As lifetime of the technology we assume 20 years, operation and maintenance costs are taken as 8% of the investment per year. The fuel costs were estimated to be 2.7 ECU/GJ for the industrial biomass residues considered in the Sustainable Scenario and 13.8 ECU/GJ for energy crops.

Heat pumps for the utilisation of environmental heat are taken to last 20 years, operation and maintenance require 2.5% of the investment per year.

For comparison, conventional energy technologies are taken into account via three aggregated technologies providing electricity, low-temperature heat, and high-temperature heat. The assumed specific capital costs for coal-fired power plants are 19 mECU/kWh in 1990 rising to 22 mECU/kWh in 2050 and for gas-fired plants 9.3 and 12 mECU/kWh, respectively. For nuclear electricity, a constant value of 50 mECU/kWh is assumed until 2010 after which this technology is not used any more. The specific capital costs of low-temperature heat equipment are 11 and 12 mECU/kWh for gas- and oil-fired installations, respectively. The corresponding values for high-temperature heat from gas and oil are 8.8 and 11 mECU/kWh. Investments in the transport sector are not considered to belong to the energy system. In this case, only fuel costs matter. Fuel prices in the transport sector are assumed

to increase from 40-50 mECU/kWh in 1990 to 60-80 mECU/kWh in 2050 (including consumer taxes, but without VAT). Prices of other fuels increase from 10-20 mECU/kWh to 20-40 mECU/kWh based on estimates made by the German Enquete Commission in 1995.

Economic Impacts

The Sustainable Scenario of a future European energy system is to a large extent based on the introduction of energy efficiency measures, which will reduce the energy demand by more than 50%. Such measures, however, can hardly be described as parts of the energy system. Often, one cannot distinguish between the part of the respective investment which should be attributed to the original purpose of a good and the part which should be regarded as the cost of energy saving. In addition, obtaining data on the future cost of energy efficiency measures on a European level was beyond the scope of the LTI-Project. Therefore, we restrict our analysis to the cost of future energy supply systems, which will primarily be based on renewable energy technologies in 2050.

Using the cost estimates described above, the annual costs for operating the existing renewable energy installations in the European Union are calculated to be about 42 billion ECU (1 billion = 10^9) in 1990, the total cost of the energy system being 510 billion ECU. In the Sustainable Scenario, the first figure will rise to 250 billion ECU/a in 2050, which seems high at first, but amounts to only half of the costs of the system in 1990 or about 5% of the 1990 GDP of the EU. That is less than 700 ECU per citizen and year. While costs rise by a factor of 6 during the 60 year period considered, the installed capacity will increase from 140 GW_p to 2300 GW_p, that is by a factor of 16. In the Sustainable Scenario, there is a large jump in the amount of money required for the installation of renewable energy technologies in the year 2000 which is the assumed starting point of most developments considered. In practice, however, this demand for investments can probably be spread over a number of years.

To allow for a better judgement of the costs of renewable energy, we compare them with the costs of the remaining conventional energies, which amount to 20 billion ECU/a in 2050. They are calculated using the cost assumptions and trajectories of the Sustainable Scenario. The combined costs of the conventional and renewable energy supply decrease to almost half the amount spent in 1990. However, it has to be taken into account that the future cost figures do not include efficiency measures which involve substantial restructuring of the economy and could, thus, not be calculated for this book. One may conclude that the large amount of money saved in the energy-supply sector represents a more than sufficient basis for financing efficiency measures.

Finally, we consider a reference case for the year 2050 in which the energy demand of the Sustainable Scenario is met exclusively via the best fossil-fuel fired technologies currently available. The respective technologies are gas-fired combined-cycle power plants, condensing-value boilers, heating plants and oil-fired boilers. The total annual cost of such an energy system amounts to 200 billion ECU per year and is, thus, 25% cheaper than the system derived in the Sustainable Scenario consisting of the renewable part, which costs 250 billion ECU/a plus 20 billion ECU/a for the remaining fossil fuel in the transport sector. The cost difference of 70 billion ECU/a can be viewed as the cost of mitigating global warming and other energy-related externalities. It amounts to about 20 mECU/kWh which is moderate.

Taking into account that calculations of future costs involve large uncertainties, one may nevertheless conclude that even though average specific energy costs per kilowatt-hour will rise by almost 50% until 2050, the total cost of the energy system including efficiency measures will most probably not increase.

We used an economic input-output model to calculate employment effects of restructuring the energy-supply system according to the Sustainable Scenario. Such a model captures not only direct effects of economic activities, but also indirect impacts caused by the production of investment goods and raw materials. Unfortunately, at the time of our analysis, input-output tables were only available for West Germany in 1988. These tables therefore had to be used as an approximation for the whole of Europe. Being a highly rationalised region with high work force productivity, this may, however, be a good reference case with respect to the assumed future convergence of living standards and economic structures in Europe. Keeping in mind the uncertainty of the calculations, 4 million person years of employment per year (at 1988 labour productivity) are necessary to manufacture and operate the renewable energy based part of the energy system in 2050. Of the 1.6 million person years needed for operating biomass technologies in 2050, two thirds are created in agriculture and forestry.

For comparison, we calculated the employment effects of the reference case, where building and operating the energy system (again without the part of the transport system still based on fossil fuels in 2050) requires 1.7 million person years per year in 2050. However, this is not the only relevant effect. To make the two cases comparable, we assume that the difference in energy costs of 70 billion ECU per year is spent on additional private consumption in the reference case. Consequently, 1.5 million person years of employment are created by private consumption if the average 1990 German savings rate of 14% and the 1988 German economic structure are assumed. If all the additional costs are spent on consumption, which is likely in view of the long time horizon considered, the figure rises to 1.7 million person years. If only a single national economy was considered, one would have to

subtract the amount of goods imported. Since most of the trading of EU member countries occurs inside the EU, this effect is neglected here. In total, there are 3.2 to 3.4 million person years of employment in the reference case.

Comparing the employment effects of the Sustainable Scenario with those of the respective reference case yields a net effect of 340 000 to 580 000 additional person years per year for the renewable energy based system. When assessing these results, one has to keep in mind that one reason for the relatively small difference is the fact that the production of goods for private consumption in 1988 is more labour-intensive than the energy sector. Furthermore, if prices of imported fossil fuels rise faster than assumed, the cost difference is reduced considerably and, consequently, the employment due to additional consumption falls drastically.

Effects of the Sustainable Scenario on sectors of the economy other than the energy system have not been taken into account. However, almost identical effects can be expected for the reference case since it has the same energy demand as the Sustainable Scenario. Thus, the respective economic impacts cancel each other out when one assesses the difference between the scenarios. Furthermore, under business-as-usual assumptions, the energy demand and costs of the reference case would be substantially higher, leaving less money for additional consumption.

Consequently, the net figures calculated here can be viewed as conservative estimates. This justifies cautious optimism that – in spite of the many simplifying assumptions and large uncertainties involved in these calculations – an economy running on renewable energies will provide more employment than one driven by conventional energies. This finding is also supported by the fact that domestic labour is needed to produce the capital goods within the EU which substitute for imported fossil fuels.

Environmental Impacts

The emission of pollutants is also analysed with the input-output model to include indirect effects due to the manufacturing of the energy conversion technologies in addition to the direct effects covered by emissions factors for the different fuels. Again the 1988 German data base is used. It is scaled to the EU level proportional to the primary energy consumption. A test run showed that this approach yields 1990 CO₂ emissions which deviated from statistical values by only 1%.

The CO₂ emissions are reduced from 3 100 million tons in 1990 to 310 million tons in 2050, that is by 90%. Thus, the objective of the LTI project is more than fulfilled, leaving room to buffer effects of too optimistic assumptions such as technological or social developments which may turn out to be slower than expected.

The figures presented so far do not include the CO₂ emissions released by renewable energy technologies in 2050. An upper limit for these emissions can again be determined using the 1988 economic structure, that is assuming that these technologies are still produced with fossil fuels. The CO₂ emissions from constructing and operating renewable energy technologies under this unrealistic assumption are below 65 million tons in 2050. If this figure were used CO₂ emissions would increase by 20%, but would still meet the project objective. As a crude estimate, one could further assume that the CO₂ emissions from the production of renewable energy technologies are reduced by 90% as calculated for the whole economy. In this case, only 6.5 million tons or 2% would have to be added for the construction and operation of renewable energy technologies, a negligible figure compared to the overall uncertainties involved in these calculations.

A Fair-Market Scenario for the European Energy System

While the Sustainable Scenario assumes slow changes in attitudes, behaviour, and thus decisions made by society, the second scenario involves drastic measures in the near future. It is assumed that industrial societies come to the conclusion that the external effects of our current energy use are so large that they have to be internalised quickly. Thus, prices of conventional fuels are substantially increased to make alternatives economically efficient. Thus, another scenario was constructed describing the impacts of the price increase. Even though not only the fundamental assumptions differed considerably in the two scenarios, but also a number of technical assumptions, the findings turned out to be similar.

Basic Assumptions of the Fair-Market Scenario

The *Fair-Market Scenario* is based on development trends already discernible in present European societies. These include continued economic growth, a continuing gradual shift from industrial production towards information activities, as well as technologies aimed at improving environmental standards. The value system upheld by the European population must support the emphasis on those activities. The scenario assumes that market forces should be utilised to trigger the transition governed by the preferences already emerging as prominent in the most advanced European nations. Government intervention will only be invoked to the extent that markets are distorted and do not presently reflect the existing trends in value systems and preferences. These interventions could take the form of imposing environmental taxes in cases where proven or publicly perceived environmental costs are not currently reflected in prices. From a consumer's point of view,

the observed trends could be expressed in terms of expected changes of price elasticity in the course of time.

For the Fair-Market Scenario, both aspects are important, the trend in value systems or price elasticity in the course of time and the inclusion of external costs in the prices of energy. The large uncertainties found in estimating external costs make it important to reach public agreement on the assessment of impacts. It may then be interpreted as an accepted level of external costs, which will consequently define energy prices used in the scenario. The reduction of greenhouse gas emissions is triggered by falling prices of renewable energy technologies and by internalising substantial external costs in fossil fuel prices. Removing all current taxes and subsidies from energy prices and adding external costs will, on average, lead to roughly a doubling of energy prices in Europe.

This pricing of conventional energy sources will make a wide range of efficiency measures and renewable energies cost-efficient. Nevertheless, the Fair-Market Scenario also includes trends increasing the energy demand due to additional uses.

Energy Demand in the Fair-Market Scenario

The estimate of the future energy demand in EU15 is based on an account of the present situation as described by OECD and IEA and involves three steps: First, improvements in energy efficiency are considered. Then, likely changes of the activity levels per capita are taken into account and, finally, the resulting figures are scaled according to the population development assumed.

Based on the "Low-Electricity Europe" study by Nørgård and Viegand and on Danish experiences regarding the reduction in heating demand, it was estimated that 75% of the energy demand of households and in the service sector can be avoided in a cost-efficient way until 2050, for instance through improved insulation of buildings. As in the Sustainable Scenario, industrial energy demand is modelled according to a substudy of the LTI-Project, which revealed an industrial savings potential of 50% for electricity and 66% for fuels, adding up to a total of 60%. In the transport sector, technical improvements reduce specific energy consumption by 75% for road vehicles, by 50% for trains and airplanes, and by 25% for ships. Most of the efficiency improvements considered are based on well-known and proven technologies, the rest being available at least on a prototype level.

According to the assumption of future economic growth made for the Fair-Market Scenario, activity levels per capita will increase in all fields, thus consuming part of the efficiency gains. On average, the use of electricity in households is assumed to double. This is partly caused by an increasing number of appliances in the households of EU countries which currently

have comparatively low living standards. Furthermore, additional applications for electricity will emerge in the market, especially in the field of information technology and communications. The average floor space heated per person will increase by 30% due the convergence of living standards in the EU. Nevertheless – in contrast to the Sustainable Scenario – it is assumed here that people in countries with a warmer climate will require less heated floor space than people living in colder areas. The requirements for heating water and cooking are unchanged. While the activity of the industrial sector remains constant, the service sector is assumed to grow by a factor of 2.5 until 2050. This will lead to a tripling in electricity demand and a 43% increase in other energy use in this sector. The internalisation of the external costs of transport fuels will alleviate the current dramatic trends in the transport sector. Nevertheless, the remaining increases amount to 50% for road and water transport, 46% for rail and 200% for air transport.

In a last step, the resulting energy demand figures are adjusted according to the expected development of the population. Based on World Bank projections, we assume that the population of the European Union increases by 4% until 2020 and then decreases towards a level in 2050 which is only 1% higher than in 1990. In 2050 both the specific energy demand per capita and the absolute demand will amount to 43% of the 1990 requirements.

Energy Supply in the Fair-Market Scenario

In the Fair-Market Scenario, the technical potential of renewable energies estimated within the LTI-Project is diminished due to environmental restrictions. This leads to a situation in which all the remaining potential will have to be used in 2050. Nevertheless, this will almost suffice to meet the whole energy demand. Altogether about 2000 W/cap are supplied from renewable energy sources inside EU15, with biomass contributing 940 W/cap, wind energy 370 W/cap, solar-thermal electricity 350 W/cap, hydropower 150 W/cap, solar-thermal heat 94 W/cap, and environmental heat 84 W/cap. The remaining demand is covered by fossil fuels (490 W/cap) and/ or imported renewable energies (200 W/cap).

The whole development towards using renewable energy sources is triggered by imposing external costs on the use of fossil fuels as discussed above. The trajectories for this development are constructed via taking into account the times at which an individual technology becomes cost efficient, assuming that market obstacles are removed, sufficient industrial capacities are built, and financial resources are available. For some of the technologies, such as photovoltaics, the assumed cost degressions will initially have to be supported through government subsidies.

All the efficiency measures considered in the Fair-Market Scenario, which reduce specific energy consumption by a factor of 4, are assumed to

be cost effective on the spot and in many cases to be even cheaper than any supply option based on renewable energies. Even today wind energy is cheaper than fossil energy including externality adders. Thus, its development is not a question of economic efficiency, but of availability of funds, infrastructure and production capacities. Solar-thermal energy will be cost effective in Southern Europe as of the year 2000 and in Northern Europe as of 2020. Photovoltaics follow as of the year 2010, again starting in southern regions. Finally, liquid biofuels for transportation will be cost effective as of 2030. It is assumed that new equipment is essentially introduced when old installations go out of operation. Due to the fact that many of the efficiency improvements are realised at the beginning of the transition period, not all of the existing energy conversion equipment has to be replaced.

For the use of energy-conversion technology in the Fair-Market Scenario, the following assumptions are made: Biogas derived from agricultural and municipal waste is distributed through pipelines and storage systems with losses amounting to 15%. Alternatively, biomass residues and energy crops may be converted to hydrogen or methanol with 50% and 56% efficiency, respectively. The hydrogen is again distributed to CHP units, fuel cells, or direct combustion units by pipelines with 15% losses. 50% of the primary electricity produced by renewable sources has to go through a storage system where fuel cells convert electricity to hydrogen with 10% losses. Half of the road transport is done with electric vehicles, the rest being covered by biogas and methanol. For rail transport, electricity is used exclusively, while air and water transport are still being based on fossil fuels in the future. Industrial low-temperature heat as well as heat for households and the service sector is supplied via heat pumps, district heating grids, and solar systems. High-temperature heat is produced with hydrogen or electricity. It has to be stressed that there is a considerable exchange of energy among EU15 member countries and – in the order of 5% – with outside regions.

Bottlenecks and Obstacles

In the preceding sections, we have seen that by the year 2050 it is possible to build a sustainable European energy system around the efficient use of energy and the massive exploitation of renewable energy sources. Thus, two ambitious targets are attained at the same time: the reduction of CO₂ emissions from energy conversion processes to a level of 20% of the emissions of 1990 and the reduction of nuclear power to zero. Consequently, climate protection and the protection from major nuclear accident risks can be achieved simultaneously.

If this is possible the question remaining is: Why are we progressing so slowly towards such a sustainable energy future? The answer is that there are many obstacles and bottlenecks in the way. These need to be removed or

widened by decisive political action if we want to secure a sustainable energy future. *Obstacles* are interpreted as structural, legal, social or technological hindrances which prevent users and suppliers from supporting and promoting renewable energies. Due to their characteristics, obstacles can only be removed as a whole. *Bottlenecks* are hindrances to the development of renewable energies which are caused by a lack of technological, personal and financial resources or by a lack of knowledge. They differ in terms of impact and strength and can be removed gradually.

The first problem a large scale introduction of renewable energy sources into the European energy system faces is that either their costs are too high or the cost for conventional energy sources are too low. This problem is partly due to the technological stage of development of some of the renewable energy technologies like photovoltaic installations or solar-thermal electricity generation, which are substantially more expensive than conventional electricity. As for these technologies, it is obviously necessary to improve their technical performance and to reduce their production costs quite drastically to make them viable options for the grid-connected production of substantial amounts of electricity. Even in the case of renewable energy technologies much closer to the market like wind energy or the use of biomass, the energy produced is still not competitive in entirely unregulated markets. Although we can expect the cost of renewable energy sources to be reduced in the future due to both technological improvements and a scaling up to industrial mass production, they will only be competitive in niche markets if exclusively based on the current internal costs.

Furthermore, the intermittent nature of wind and direct solar energy can increase the system costs of energy due to the need for substantial back-up capacities. This problem becomes the more pronounced the larger the overall share of intermittent energy sources in the system. Fortunately biomass energy can be stored seasonally without huge extra costs and may thus play the part of back-up energy source. A factor reducing the necessary volume of back-up capacity in the overall European system is the sheer number of decentralised production units spread out all across Europe.

Although technologies for the use of renewable energy sources have come a long way in their technical development mostly due to private initiative and public research and development (R&D) spending, there are still a number of bottlenecks relating to public R&D policies. First of all, the overall public R&D spending for renewable energies seems to be far too low compared to the necessary role they have to play in a future sustainable European energy system. What is more, R&D budgets for renewable energy technologies seriously lack long-term stability which is necessary for their continuous development from the laboratory to mature proven technologies to be used in the field. Even under the existing public R&D programs, participation is made rather difficult by the high portion of funds that compa-

nies are required to provide from their own resources and by the complicated and time-consuming procedures for the approval of government grants. One obstacle relating to the R&D programs of the European Union is the fact that all research institutes with full cost accounting are only eligible for 50% project funding just like companies.

The most important bottlenecks and obstacles to the market introduction and large scale use of renewable energies are adverse market conditions and the political forces fighting such a development. The central obstacle is the lack of internalisation of external costs of conventional energy sources. This fact is widely acknowledged in political circles as well as in the literature, nevertheless, it seems to be a long way until the internalisation of at least the most important parts of the external costs of conventional energy sources like health or environmental damage will be accomplished. In some countries, this hindrance is even more pronounced as not even a fair price based on the avoided internal costs is paid for renewable energies.

Another central set of hindrances relates to the fact that renewable energy sources must enter into an existing energy system that is characterised by lack of knowledge about the new technologies, traditional behaviour and investment patterns, as well as by crippling laws and guidelines. What is more, the electricity sector of the existing energy system in most European countries has accumulated large overcapacities, so any additional electricity producer will make the economics of the existing installations even worse. Thus, the existing utility companies see their interests threatened by any large scale introduction of renewable energies.

Additional obstacles renewable energies face are preferential conditions and tax privileges for conventional energy sources, which have developed historically and need to be removed in order to create a level playing field giving fair and even chances to renewable energies.

Due to the historical development of the existing energy systems in the different European countries there are legal and institutional settings which are tailor-made for the major conventional energy sources used. As renewable energy sources have totally different technical structures (small, decentralised and dispersed sources compared to huge, centralised power plants and installations), they hardly fit into the existing legal and institutional frameworks.

Another category of bottlenecks is the present shortage of available capital and a lack of adequate financing measures. Looking at the sheer volume of financing necessary for the large scale introduction of renewable energies as envisioned in our scenarios, substantial amounts of capital will be necessary as annual investments. The need for capital will be greater than for conventional energy supply systems as the technologies for the use of renewable energy sources are more capital intensive with only little operation

and maintenance costs – with the exception of biomass –, and as the total internal energy costs will be higher than for most conventional alternatives.

A large area of different bottlenecks is due to a lack of knowledge and training as well as to a lack of awareness of the specific advantages of renewable energies. One hindrance are the adverse thinking patterns of engineers and architects and the lack of trained installers and maintenance personnel. Like most of the other bottlenecks and obstacles, this one is also relevant for the efficient use of energy. Its removal is extremely important since improving the energy efficiency of buildings is a cornerstone of the Sustainable Scenario.

Whenever failures of installed renewable energy technologies occur, it is extremely important to analyse the reasons for the failures and to collect all experiences from them in order to speed up the learning process. What is more, all experiences should be exchanged through networks of operators and installers of renewable energy technologies as fast and as thoroughly as possible.

Potential investors seem to know rather little about the opportunities of renewable energies and the availability of supplementary public financing. But we find that this bottleneck seems to disappear as soon as renewable energies start to produce good returns on capital. Neither in Denmark, nor in Germany or the UK do we find a shortage of investors for wind energy. We find that the financing of the installations has created its own markets and that specialised companies have been started for the collection of investment capital.

Another important lack of knowledge about renewable energies concerns the general level of knowledge and awareness of policy makers. Many of them neither know the actual potential and importance of renewable energies for a sustainable energy future – and still think of renewable energies as niche technologies – nor do they appreciate the great advantages of renewable energies in the field of environmental impacts or national and local employment benefits. Without this knowledge the political support for renewable energies from most policy makers is still rather weak.

In some cases, we find that some parts of the local public are not quite aware of the environmental and local employment benefits of renewable energy technologies. This has led to a situation where some local groups oppose wind converters on the basis of potential visual intrusion and a general 'NIMBY' (Not In My Back Yard) attitude. In cases where the involvement of the local public in the development of wind farms was secured quite early in the planning process, practically all resistance was overcome. In general, public acceptance of all renewable energy developments is a crucial factor today and will be even more important for any large scale development of renewable energies as a major part of a sustainable European energy system.

There are all kinds of obstacles in connection with the management of and access to the electricity grid. Electricity from renewable energy sources will be mostly produced by a vast number of independent power producers. Except for electricity from biomass, the electricity produced needs to be fed into the grid whenever the wind is blowing or the sun is shining. The management of such dispersed intermittent power sources is far more complicated than the present dispatch management system. With an increasing share of renewable energies on the grid, this problem becomes ever more important.

One level above actual grid management, integrated energy planning seems to be necessary to allow the best possible use of renewable energies in co-ordination with the efficient use of energy. If no integrated planning takes place, over-capacities on the supply side will result as more and more energy will be saved on the demand side by better appliances and a more intelligent use of energy. Without integrated planning the necessary back-up for a large scale integration of intermittent renewable energy sources especially into the electricity grid may not be made available on time, creating a serious bottleneck for the expansion of the share of renewable energies.

If we envisage a large scale use of renewable energies in the European energy system, we find that with regard to electricity generation high-voltage grid infrastructure is lacking in the areas with the best renewable energy resources. These bottlenecks can be overcome with the help of an integrated European energy master plan earmarking certain areas with prime renewable energy resources for infrastructure reinforcement.

If the large scale integration of renewable energy sources into the European energy system is to be achieved in the context of the Sustainable Scenario outlined above, major changes of life style will be necessary ranging from adjustments in our daily diet, to changes of our use of cars and public transportation and all the way to major changes in the way we spend our annual vacations. Although the necessary lifestyle changes on the road to a sustainable energy future will be serious bottlenecks, it needs to be said that many of these changes are not only necessary to reduce our energy consumption or to make renewable energy sources viable options, but that these changes are necessary to secure a sustainable development of mankind. Thus, these bottlenecks will have to be removed for far more fundamental reasons than just for the achievement of a sustainable energy future. Therefore, we assume that these bottlenecks will be removed by the time they would be crucial for the further introduction of renewable energies. What is more, the targeted reductions in energy consumption needed as preconditions for the large scale introduction of renewable energies can be achieved by drastic price increases for energy just as well. Thus, voluntary changes in lifestyle are no crucial precondition for a sustainable energy future.

Conclusions and Messages

From our analysis, the following measures seem to be the most important ones (items are not listed in order of importance):

1. Decrease the internal costs of renewable energies through technological improvements, mass production, and increased reliability.
2. Increase public R&D budgets substantially and give them greater long-term stability.
3. Drop the 50% financing clause of the European Union for research projects.
4. Internalise the external costs of conventional energy.
5. Overcome and if necessary break the resistance of utility companies to renewable energies.
6. End all privileges for conventional energy systems and fuels.
7. First analyse and then remove all legal and institutional barriers to the large scale use of renewable energies.
8. Improve the general level of information about renewable energies and the training of engineers, architects and craftsmen possibly dealing with renewable energies.
9. Improve the grid access for renewable energies and reinforce the high-voltage grid in areas of prime renewable energy resources.
10. Develop a long-term European energy master plan outlining the future role of all the different sources of energy and the necessary steps for a transition to a sustainable energy future.
11. Set stringent standards for the energy use in new and existing buildings.

Finally, the support of the population for the necessary restructuring of the energy system has to be enlisted. Decision-making processes have to be transparent and the people affected should be involved as early as possible.

Above all, the development towards sustainable energy use in Europe will only take place if a broad consensus is found and the resulting policies are actively pursued by the governments involved and the respective societies. A start should be made as soon as possible since each year which passes without decisive action will create further bottlenecks due to additional money being invested in long-lasting conventional equipment.

1 Introduction

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1.1 Tackling the Energy Problem

Mitigating global climate change is one of the central challenges to humankind in the coming decades. The problem is largely caused by man-made emissions of carbon dioxide (CO₂) and other infra-red active trace gases which are released from energy-conversion processes. The expected impacts on human living conditions range from changing precipitation patterns to rising sea levels and from decreasing harvests to an increase in extreme weather conditions. All of this has been examined and documented by numerous national and international committees such as the Intergovernmental Panel on Climate Change (IPCC 1995 and 1996a-c).

Today, we must conclude that there is a substantial risk that we are about to change the global climate and that this may have severe negative impacts on large parts of the world's population. Following the precautionary principle and considering the very long time constants governing the natural climate system as well as man-made energy systems, it is therefore high time to take decisive action in favour of a more sustainable energy system.

A socio-economic system is regarded as *sustainable*, if it can be maintained over a very long period of time, that is a large number of generations. Sustainability does not only refer to the economic situation, but at least equally to the state of the environment and society. Consequently, first it has to be ensured that human economic activities will not endanger the living conditions which support our very existence. Second, welfare has to be distributed equitably among the generations living today and future generations. This is a necessary precondition to avoid social conflicts endangering any successful economic system. Finally, the resources available should be allocated efficiently, a task for which free markets have proven to be a suitable instrument (Daly 1996).

One important guideline following from these general considerations is the *precautionary principle* of avoiding impacts which may cause very large damage to humanity even if the probabilities of them occurring are very small or if their existence has not yet been proven beyond doubt.

The IPCC concludes that, if one follows this train of thought, carbon dioxide emissions have to be reduced by 50-60% globally in order to confine the CO₂ concentration in the atmosphere to twice the preindustrial level of 280 pm and to mitigate, albeit not completely avoid, climate change. Since developing countries will need more energy in the future to ensure acceptable living conditions for their people, most of the necessary reductions will have to be achieved in industrialised countries. Thus, we assume in line with

the Enquete Commission of the German Parliament (Enquete 1991) that these countries will have to decrease their absolute CO₂ emissions by 80% compared to the 1990 level until the year 2050. This figure was taken as the primary objective for the project *Long-Term Integration of Renewable Energies into the European Energy System and Its Potential Economic and Environmental Impacts* – hereafter abbreviated to *LTI-Project* – upon which this book is based (LTI 1996).

Even though the CO₂ reduction goal is ambitious, it should be stressed that such a reduction will not buy a 100% insurance against negative consequences resulting from potential changes of the global climate. It is rather a rate of emissions that will – according to our current knowledge – lead to limiting climate change to a level that we can hopefully cope with and which is, therefore, a meaningful target under the precautionary principle. Nevertheless, it may turn out that further reductions in CO₂ emissions in industrial countries will be necessary, especially when considering the need to provide acceptable living conditions not only in the industrialised part of the world, but everywhere on earth.

In principle, there are the following options to tackle the problem of climate change:

- The production of synthetic gas (hydrogen) and pure CO₂ from fossil fuels and the removal and storage of the CO₂ from the syngas production; end-of-the-pipe cleaning, i.e. removal of CO₂ from stack gases, which is technically feasible, but will reduce conversion efficiencies and economic viability dramatically;
- switching to fuels with low carbon content or exploiting other forms of chemical or nuclear energy;
- increasing the efficiency of energy utilisation by decreasing the demand for useful energy, e.g. through better insulation, improved process designs, or recovery of waste heat, all of which are based on pushing processes substantially further towards their thermodynamic limits;
- and, finally, the use of renewable energy sources, which is ultimately based on realising that the earth is an almost closed system which may not exchange material with its surroundings, but which receives considerable amounts of energy from the sun.
- In addition, there is of course also the option of renouncing some of the current or future energy applications, e.g. based on the view that – after providing for basic needs – our well-being is not so much dependent on having more, but on feeling well.

The removal and subsequent storage of CO₂ will be expensive and – with the possible exception of limited capacities in empty oil and gas fields – the ecological consequences of storing large amounts of CO₂, e.g. in the oceans, cannot be assessed at the moment. Thus, it is not considered an option for a sustainable energy system in this book.

Nuclear energy poses unresolved problems with respect to the enormous damage caused in the event of an accident, very long-term storage of highly dangerous waste materials, and proliferation of nuclear technology, which can be abused for military purposes. Again following the precautionary principle, this energy source is not considered part of the future energy system here.

Switching from carbon rich fuels such as coal to fuels which have a lower carbon content such as natural gas will contribute to mitigating climate change. Nevertheless, this will aggravate the scarcity of low-carbon fuels and will therefore create new problems in the medium-term. Consequently, the long-term strategies considered in this book will not be based on fuel switching, even though the latter may contribute in a limited way when it comes to selecting the remaining fossil fuel supply.

Under these assumptions, a sustainable future European energy system will have to rely on

- a massive reduction in the energy demand due to improved energy efficiency in combination with the sufficiency principle and on
- the substantial, large scale use of various renewable energy sources.

Considering that most of the technologies necessary for a sustainable energy system have already been invented and tested at least on the level of prototypes, today's most important questions are:

- How can renewable energy sources and the efficient use of energy be integrated into the European energy system at sufficiently high diffusion levels?
- What are the costs and benefits of such a strategy?
- What are the major bottlenecks and obstacles to such a development?
- What measures are necessary to support this development?

Within the LTI-Project, we developed two *scenarios* for the future European energy system which meet these conditions. Such *scenarios* are in no way meant to predict the future. This would be a futile attempt since there are principle limits to scientific findings when it comes to predicting developments of systems for which the starting conditions cannot be determined with sufficient precision and for which the rules governing the system are subject to change. Thus, drawing up scenarios is an attempt to show possible or likely consequences of assumptions on technological, social, economic, and political developments in a consistent and structured way.

We decided not to develop a business-as-usual scenario since there are many around, but to concentrate on two optimistic scenarios. The *Sustainable Scenario* is based on the principles of sustainability and assumes substantial changes in our way of living over the whole time horizon. The *Fair-Market Scenario*, on the other hand, starts out with adjusting energy prices

to include environmental damage and discusses the consequences for the energy system.

We concentrate on the development within the European Union (EU15). The rest of the world is not modelled explicitly, but we assume it behaves in such a way that the development in Europe is not hampered. This would, for instance, be the case if other important countries like the US and Japan followed the development in EU countries with a time lag of not more than 10 years. It is self-evident that the development in Europe should not occur at the expense of other regions in the world, especially the poor ones.

The purpose of developing scenarios is to examine whether there are any basic physical, technological, or economic barriers to achieving a sustainable energy system. If this is not the case, the resulting scenarios may provide a positive vision of a desirable future. They will, however, not serve as a master plan which has to be realised in the shortest possible time. Instead they may provide guidelines for decisions which have to be taken today and in the near future and which will start shifting our energy systems towards sustainability. The whole process of changing the way we use energy will have to remain under constant supervision and discussion in order to ensure that it is carried out in a socially acceptable and accepted way and that it can be adapted to unforeseeable technological, economic and social developments as they occur.

In the next two sections, we will briefly describe the current energy demand and supply situation in Europe and its environmental impacts. The main part of this book contains the scenario descriptions which demonstrate the technical feasibility of a European energy system which is based on energy efficiency and renewable energy sources. Subsequently, economic impacts are estimated by calculating the investments necessary to build the equipment for exploiting renewable energy sources and the resulting annual costs including operation, maintenance and fuels. These figures are compared to a reference case, in which the most advanced fossil-fuel driven equipment is used, and to current investments into energy conversion equipment. Furthermore, we estimate how much employment will be created within this new economic sector. Finally, we will discuss why we are not moving towards a more sustainable use of energy at the moment and we will derive measures that should be taken as soon as possible to start such a development.

1.2 The Current European Energy Demand and Supply

1.2.1 Energy Demand

Figure 1.1 indicates the energy demand in the industrial, residential, tertiary, agricultural and transport sectors of the 15 member countries of the

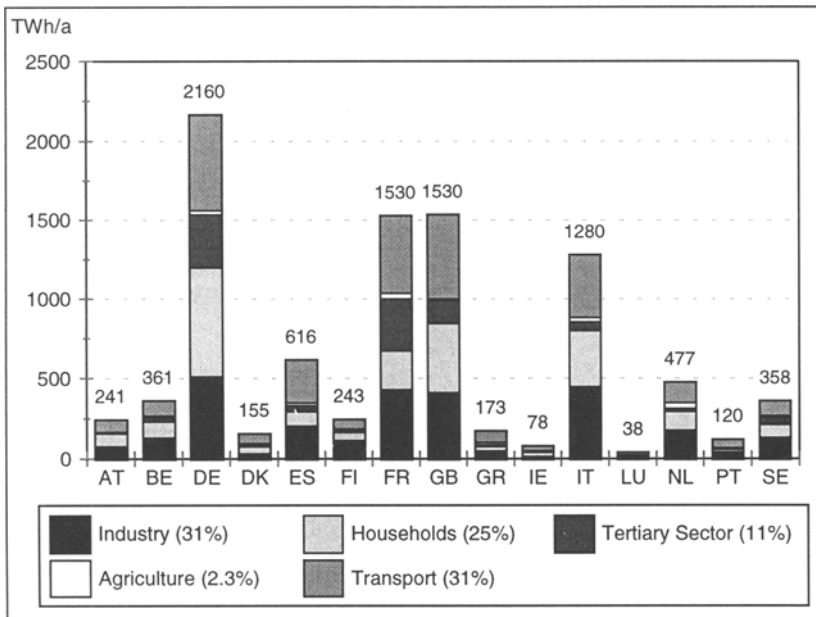


Figure 1.1 Final energy delivered to different economic sectors in the member countries of EU15 in 1990 (IEA 1995).

European Union (EU15). It reveals two major facts. First, it is obvious that Germany, France, Great Britain, and Italy are the major energy consumers in EU15 accounting for 70% of the European energy demand. Second, the most important sectors in terms of energy consumption are transport (31%), industry (31%), and households (25%), while the tertiary sector (11%) and agriculture (2%) are of minor importance.

1.2.2 Energy Supply

Figure 1.2 indicates the energy sources by which the energy demand shown in Figure 1.1 is met. 84% of the energy supplied stems from solid fuels, oil and gas, 14% from nuclear energy, and only the remaining 2% are provided by other sources. The latter include hydropower with the largest share of renewable energies currently used. Additionally, biomass is listed under 'solid fuels', but accounts for less than 3% of the total energy supply. Accordingly, renewable energy sources contribute not more than 5% to the current European energy supply.

Nuclear energy has a substantial share in some European countries. Thus, phasing out nuclear energy as targeted in this book will have a significant impact on the energy supply systems of France, Sweden, Belgium, Germany and the UK. Natural gas plays a dominant role in the energy supply system

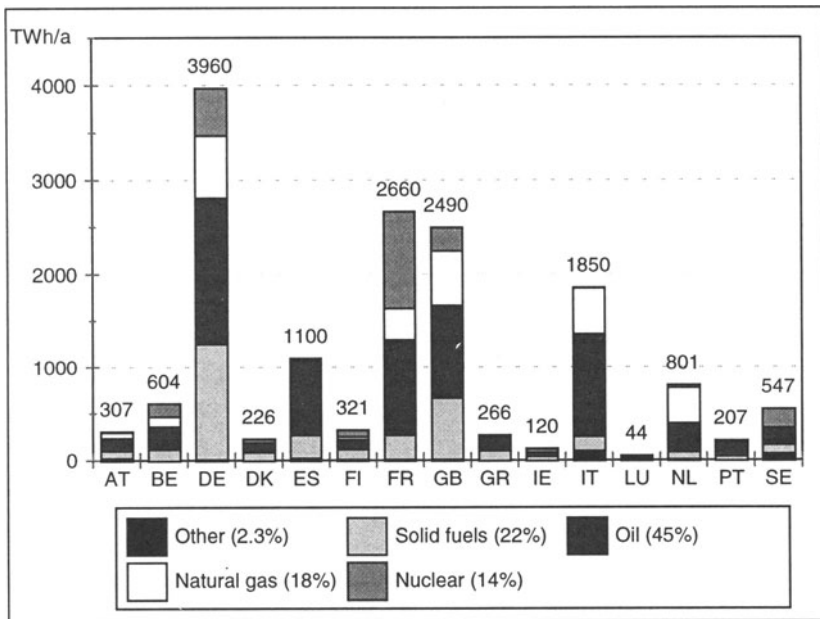


Figure 1.2 Primary energy sources of EU member countries in 1992 (IEA 1995).

of the Netherlands whereas the Mediterranean countries rely heavily on oil. Consequently, the transition from today's energy supply system to a system without nuclear energy and with an only minor share of fossil fuels means the European energy system has to be totally redesigned.

1.3 Environmental Impacts of the Current Energy Use

A wide variety of environmental burdens and resulting impacts relating to our current energy system have gradually been identified over the past decades. The term *burdens* summarises the broad spectrum of relevant human activities ranging from resource use to the generation of waste and emissions. The respective environmental impacts are diverse in nature as well as in their spatial and temporal extension. The most troublesome impacts emerge on a global scale such as global warming or depletion of the ozone layer. Other impacts occur regionally, for instance acidification, or are of mainly local importance such as surface water contamination. While short- and medium-term impacts are often recognised and tackled rather fast, long-term problems are hard to communicate and thus to counter.

In principle, present fuel cycles release flows of potentially problematic substances into all environmental media, that is air, water, and soil. Local and regional pollution through atmospheric dispersion of emissions has for a

long time proven to be the main source of negative impacts on human beings as well as on man-made and natural ecosystems (Sec. 1.3.1). Nowadays, the focus is shifting towards the issue of human induced global warming caused by otherwise less problematic gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). In the eighties, world-wide energy consumption (including transportation) was responsible for about half of these so-called greenhouse gas emissions (Enquete 1995, 76). Anthropogenic climate change is an environmental problem of a so far unknown dimension. It has been discussed extensively over the past years (e.g. IPCC 1996a-c). A brief, separate overview will be given in Sec. 1.3.2. To facilitate comparison between different energy technologies and to be able to formulate strategies for future energy policies, economists attempt to measure all positive and negative impacts in common monetary units. For this purpose, environmental burdens are translated into so-called external costs (Sec. 1.3.3).

1.3.1 Air Pollution and Possible Impacts

Among the 'classical' air pollutants attributable to energy use are the primary emissions of nitrogen oxides (NO_x), sulphur dioxide (SO₂), total suspended particulates (TSP), carbon monoxide (CO), and hydrocarbons (HC) with the subcategory volatile organic compounds (VOCs). Ammonia (NH₃), hydrogen chloride (HCl) and air toxicants such as dioxin should be mentioned in addition. Many of these substances are also precursors of secondary pollutants formed by chemical reactions in the atmosphere. Ground level ozone (O₃) as well as nitrate and sulphate aerosols have the most significant impacts which may occur up to thousands of kilometres away from the source of primary emissions.

A number of impact categories have been developed by the Society for Environmental Toxicology and Chemistry (SETAC) charged with standardising life-cycle analysis (LCA) internationally. The impact categories in Table 1.1 have been adapted from SETAC (1993). External cost studies, on the other hand, which estimate damage in economic, that is monetary, terms (cf. Sec. 1.3.3), use a somewhat different and not yet standardised categorisation. Externality studies usually focus on the quantification of priority impacts instead of a detailed account of all direct and indirect energy and material flows associated with a system or process. They typically analyse impacts of air pollution on human health, on building materials, on commercial crops, forests, freshwater fisheries, unmanaged ecosystems, as well as the effects of accidents in the workplace, and the impacts of smell, noise and visual amenity (Column 3 in Table 1.1). Table 1.1 is an attempt to link the two concepts of classification. The list is not exhaustive, but tries to cover the priority effects.

Table 1.1 Categorisation of fuel cycle impacts (own survey based on SETAC, 1993; CEC, 1995).

Impact categories	Burdens	Impacts
Human health	<i>Primary pollutants:</i> NO _x , SO ₂ , TSP, CO, HCs, heavy metals, toxicants <i>Secondary pollutants:</i> Sulphate and nitrate aerosols, O ₃	Mortality, acute / chronic morbidity, accidents
Aquatic and terrestrial ecotoxicity	Organic and inorganic toxicants	Forestry and crop yield, biodiversity loss
Acidification	Acid aerosols from NO _x , SO ₂ , NH ₃ , HCl	Forestry and crop yield, biodiversity loss, material damage
Photochemical oxidant formation (Smog)	O ₃ from NO _x , VOCs	Forestry and crop yield, material damage, ecosystems
Rural amenity	Noise level, smell, TSP (changes of landscape)	Recreational value, nuisance, visibility, visual intrusion
Depletion of the ozone layer	N ₂ O	Morbidity (carcinogenic)
Global warming	CO ₂ , N ₂ O, CH ₄	(Cf. Sec. 1.3.2)
Land demand		Biodiversity loss, impacts on soil ecology
Resource use	E.g. fuel use	Depletion, scarcity

Note on impact categories:

Human health comprises health problems through exposure to substances via air, water or soil. Morbidity includes respiratory illnesses and cancer.

Aquatic and terrestrial ecotoxicity includes effects on the functioning and integrity of non-human ecosystems caused by exposure to toxic substances.

Acidification refers to wet acidic deposition (acid rain) and dry acidic deposition onto soil, water, and materials.

Photochemical smog results from reactions between nitrogen oxides (NO_x) and hydrocarbons (HCs) and is the formation of atmospheric aerosol particles.

Rural amenity refers to positive and negative impacts on human senses.

Land demand comprises the two categories biodiversity and soil ecology.

Resource demand covers the extraction and use of non-renewable and renewable energy sources and raw materials.

Eutrophication – the reduction of the oxygen concentration in water or soil through nutrients (e.g. nitrogen), which may lead to excessive plant growth – is not an issue in the current energy system, and therefore not included here.

The most relevant impacts listed are those on human health. They primarily affect the respiratory system and range from immediate and indirect fatalities to severe illnesses such as bronchitis and asthma as well as troubles like hospital admissions or restricted activity days.

Even though substantial reductions in the emission of pollutants have been realised in the past years, the European Environment Agency concludes in its recent report "Air Pollution in Europe 1997" (EEA 1997):

- "It is uncertain whether the EU ... will reach the target set by the UN Economic Commission for Europe's second sulphur protocol of a 60% reduction in emissions of sulphur dioxide (SO₂) from 1980 levels by 2000."
- "It is unlikely that the EU will meet its target of cutting nitrogen oxides (NO_x) emissions by 30% between 1990 and 2000"
- "It is uncertain whether the EU target of cutting emissions of non-methane volatile organic compounds (VOCs) by 30% between 1990 and 2000 will be met"
- "About 20% of Europe's ecosystems are still above their critical loads for acidification"
- "Ozone pollution in 1995 exceeded the EU threshold for the protection of vegetation (a daily average of 65 µg/m³) for more than 150 days of the year over 27% of the EU area, in some cases by a factor of three."

1.3.2 Climate Change and Possible Impacts

At the end of 1995, the Intergovernmental Panel on Climate Change (IPCC), established by the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP) in 1988, completed its Second Assessment Report. It confirms that there has been an anthropogenic global warming effect in the past and that it will continue. The IPCC synthesis report states that "global mean surface temperature has increased by between about 0.3 and 0.6 °C since the late 19th century, a change that is unlikely to be entirely natural in origin. The balance of evidence, from [that change] and from changes in geographical, seasonal, and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate" (IPCC 1995, 4). In addition, a 10-25 cm sea level rise has been observed over the past century, and "much of the rise may be related to the increase in global mean temperature" (IPCC 1996a, 4). The scenarios analysed by IPCC Working Group I indicate that temperature increases could range from 1 °C to 3.5 °C by 2100. The new "best estimate" of the global mean surface temperature increase is projected to be about 2 °C between 1990 and 2100, that is 0.5 °C less than estimated in the First Assessment Report of IPCC. This correction is due to

- lower emission scenarios as well as

- "improvements in the treatment of the carbon cycle" (IPCC 1996a, 6) and
- to the fact that cooling by the on-going formation of aerosols is masking part of the warming.

The latter effect may disappear in the medium-term after SO₂ emissions will have been reduced globally. Besides temperature increase and sea level rise, human interference with the global atmosphere may further result in a changed hydrological cycle. As the climate system is governed by non-linearities, other "unexpected, large and rapid climate system changes" may arise as well (IPCC 1996a, 7).

Among the possible consequences of climate change are reduced availability of drinking water, lower agricultural yields, erosion of fertile soil, loss of biodiversity, and the spreading of pathogens, parasites, and pests. Together with the fast growing population in some parts of the earth, climate change may thus lead to severe social tensions in the respective regions and possibly even to wars over drinking water or food reserves (Enquete 1995).

It is likely that, in the long run, the ecological system on earth will be able to cope with all of these changes and their impacts. However, anthropogenic changes in the atmosphere currently occur faster than any natural climate variation observed so far. Thus, it is the risk, that the life-supporting ecosystems may not be able to adapt to the new constraints fast enough, which is threatening our way of living.

1.3.3 External Costs of Energy Use

The traditional economic approach to tackling environmental problems is among other things based on the concept of external costs. External costs are defined as the monetary values of negative impacts, imposed on society or parts of it by activities of an individual or a group, that are not accounted for in the market price and therefore not in individual decision-making processes either. The market failure to reflect these costs in the price results in a misallocation of resources in the economy. Avoiding this misallocation involves understanding the value of the external effects, and then finding a mechanism for integrating those values into the original decision (Baumol and Oates 1988). Thus, economic theory provides established arguments to identify, quantify, and monetise the external environmental effects of energy supply and demand, and to internalize them through various instruments, for instance taxes, in decision and policy making processes.

In the past 15 years, there have been a number of empirical studies on environmental externalities of energy. All studies note that their results contain substantial uncertainty and cannot incorporate all relevant categories of externalities. The studies differ in the methodology applied and in the fundamental assumptions made. Thus, their resulting monetary values vary widely and have to be assessed in the context in which they were derived.

Three extensive studies have recently been completed: one for the European Commission (CEC 1995), also known as ExternE project, one for the US Department of Energy (ORNL/ RFF 1994), and one for different New York state organisations done by RCG/Hagler, Bailly and Tellus Institute between 1992 and 1995. They all use a common methodology, the so-called damage function or impact-pathway approach which begins with an engineering characterisation of the emissions, and then ideally models the pathway from the emission to changes in pollutant concentrations, to impacts, and to monetary damage. This type of analysis offers a tool to determine marginal external costs and benefits. The impacts assessed are incremental impacts due to an additional power plant at a specific site using a specified technology. The external costs derived in the European study are in the order of 10 mECU/kWh for oil and coal and 1 mECU/kWh for natural gas. The lower health damage calculated in American studies can partly be traced to the lower population density in the United States (cf. Table 1.2 and Table 1.3).

On the other hand, earlier studies on externalities in the energy sector (completed before 1994) were based on top-down approaches. They are primarily literature reviews, and calculate externalities, for example, from estimates of national damage and aggregated emission of pollution activities. This type of analysis results in estimates of average damage costs (cf. Table 1.2 and Table 1.3).

Apart from the methodological differences, the up to ten times lower emissions that the more recent studies assume by analysing best available technologies rather than a mix of existing technologies play an important role. This assumption particularly affects the impacts on health associated with SO₂ – the health impact category accounts for the highest percentage of damage costs in all studies but the British one by Pearce, Bann and Georgiou (1992). Here the damage to buildings from acidic deposition represents 64% of the externality added for older coal technology. Some of the differences between the estimates in the two German studies can also be explained by the reference technologies chosen. Hohmeyer (1988) bases his estimates on 1982 emissions and average available technologies of that year in Germany. Friedrich et al. (1989) obtain emission figures of new 1990 standard technologies operating with much better control equipment.

The earlier studies estimate the externalities of electricity generation from renewable energy sources to be substantially lower than those from fossils. They generally do not consider biomass, except for Ottinger et al. (1990) who give comparatively high external costs for this energy source.

In the more recent studies, differences between external costs of fossil and renewable energy sources are smaller than in the earlier ones. While damage caused by indirect emissions during fuel production and the manufacture of the equipment have not been included for fossil fuel cycles, they

Table 1.2 Estimates on environmental external costs of fossil-fuel based energy technologies in 1990 mECU/kWh from selected studies.

	Oil	Gas	Coal
CEC (1995)	11 – 12	0.7	6 – 16
ORNL/ RFF (1994)	0.12 – 0.16	0.01 – 0.16	0.41 – 0.89
RCG/Hagler, Tellus (1995)	1.1	0.17	0.64 – 2.1
Pearce et al. (1992)	78	5.3	17 – 70
Ottinger et al. (1990)	25 – 65	6.6 – 9.9	23 – 56
Friedrich et al. (1989)			2.3 – 2.4
Hohmeyer (1988)	6.4 – 34	6.4 – 34	6.4 – 34

Notes:

The studies often refrain from presenting their component external cost results in an aggregated form, since some impacts are interrelated and others have not been quantified or monetised due to a lack of information or to impossibility.

The results of the first three studies listed are plant, i.e. site and technology specific. Ranges given do not represent uncertainty ranges, but the respective upper and lower values of various plant specific calculations.

The lower and upper limits given for coal in the Pearce et al. (1992) study reflect estimates for a new and old coal plant, respectively.

Ranges in the Ottinger et al. (1990) study derive from the analysis of various existing and new technologies with different control equipment and sulphur contents of the fuel.

The results of the two German studies listed describe uncertainty ranges. Hohmeyer (1988) determines one estimate range for all fossil fuels.

are assessed for some of the renewable fuel cycles, because the majority of burdens arises from other (than the generation) stages of the fuel cycle. The absence of direct emissions and the low level of other damage imply that they can be a significant fraction of (low) total damage. In this regard the energy use of biomass is an exception. Since it is mostly converted by conventional combustion technologies, biomass produces external effects similar to those of fossil fuels with respect to conventional emissions. It has, of course, substantial advantages as far as CO₂ is concerned since the carbon dioxide emitted was taken in from the atmosphere during growth. The time constant of this cycle is short compared to the temporal dimension of climate change.

To sum up, the external cost estimates of environmental effects of energy supply differ widely due to different methods and assumptions in different studies. For that reason, the resulting figures are difficult to combine or compare; they are variable and uncertain. "Many of the differences can be addressed through further research and analysis. Some critical disagreements over methodology, however, mask deeper disputes over values, basic policy goals, and the intended role of environmental cost studies. It is unlikely that

Table 1.3 Estimates on environmental external costs of renewable energy technologies in 1990 mECU/kWh from selected studies.

	Photo-voltaics	Solar energy	Wind energy	Hydro-power	Bio-mass
CEC (1995)	*	*	1 – 2	2	*
ORNL/ RFF (1994)	*		*	0 – 0.11	1.3
RCG/Hagler ... (1995)			0.01		2.4
Pearce et al. (1992)	0.98	0.98	0.56	0.56	
Ottinger et al. (1990)		0 – 3.3	0 – 0.8		0 – 5.8
Friedrich et al. (1989)	0.31 – 0.46		0.15 – 0.31		
Hohmeyer (1988)	2.5		0.06		

Notes:

* Results have not yet been published, but should be available soon.

Again, the ranges of the first three studies listed reflect estimates from different locations and technologies.

these disputes can be resolved by technical analysis or scientific research" (US Congress and OTA 1994, 2). Nevertheless, it is important to realise that conventional cost calculations governing individual decision-making may leave out substantial portions of the total costs to society and may, thus, be misleading.

Ottinger (1996), however, came to the conclusion that the values adopted in the three recent studies are irrelevant for any policy formulation or resource selection decision, as important impacts like climate change or ozone-related chronic respiratory illnesses are omitted. However, these impacts might be by far the most serious ones. Omitting these damage categories in monetary estimations has severe consequences for the total component external costs. The available monetary damage estimates of global climate change could alter the external cost figures calculated in the more recent studies by orders of magnitude.

Scientific research on the impacts of the greenhouse effect has focused primarily on a scenario which considers the atmospheric CO₂ concentration to be twice the pre-industrial level. Due to the lack of knowledge and the complexity of processes, studies usually deal with only a subset of impacts, and are often restricted to a description of physical impacts. The best studied impact categories are agricultural impacts and the costs of the sea level rise. The estimates of non-market damage, such as human health, risk of human mortality and damage to ecosystems, are regarded as highly speculative and incomplete, and thus as a source of major uncertainty in assessing the implications of global climate change for human welfare. Furthermore, several kinds of impacts have been virtually ignored so far, e.g. migration and tropical diseases, since they could not be adequately quantified (IPCC 1996c).

Table 1.4 Global warming damage estimates in 1990 mECU/kWh for a discount rate of 0% (CEC 1995, 163).

	Cline (1992) (shadow values)	Fankhauser (1995) (marginal costs)	Tol (1995)* (marginal costs)
Oil	10	6	12
Gas	6	4	8
Coal	15	10	18
Lignite	19	12	22

* Figures are based on a discount rate of 1%.

The aggregate estimates of damage from a 2-3 °C warming tend to be a few per cent of the world gross domestic product (GDP), with, in general, considerably higher estimates of damage to developing countries as a share of their GDP (IPCC 1996c). The literature on social costs of anthropogenic climate change is mainly based on research done on developed countries, then often extrapolated to developing countries. There is no consensus about how to value statistical lives or how to aggregate statistical lives across countries. In this context, IPCC notes that "in virtually all of the literature discussed ... the developing country statistical lives have not been equally valued at the developed country value nor are other damages in developing countries equally valued at the developed country value" (IPCC 1996c, 10). However, there is a consensus that vulnerability in most developing countries seriously exceeds that in developed countries.

Looking briefly at the values from selected studies summarised in Table 1.4 and comparing them with the marginal cost estimates of the more recent studies in Table 1.2, one can stress that the figures would approximately double the figures of the ExterneE study. The environmental cost values of the US studies would turn out to be almost negligible. IPCC WG III (1996c, 11) cites a range of marginal damage estimates from about 5 to 125 US \$ (1990) per ton of carbon emitted today which is based on the same studies from which the specific values given in Table 1.4 were derived. Then, IPCC explicitly states that it "does not endorse any particular range of values for the marginal damage of CO₂ emissions" and that the range published does not reflect the full range of uncertainty, either (IPCC 1995c, 11). The range reflects, however, "variations in model scenarios, discount rates, and other assumptions". This issue is further illustrated by Azar and Sterner (1996), who show that, using the same model as other studies, values up to 590 US \$ per ton of carbon can be derived by dismissing discounting, assuming longer retention of CO₂ in the atmosphere, and weighting damage by income.

Nevertheless, even though "our current understanding of many critical processes is limited; and systems are subject to multiple climatic and non-climatic stresses, the interactions of which are not always linear or additive"

(IPCC, 1996b) it has to be concluded that global warming poses a major risk to the opportunity of future generations to live comfortably and in peace. Furthermore, "the literature indicates that significant 'no regrets' opportunities are available in most countries and that the risk of aggregate net damage due to climate change, consideration of risk aversion, and application of the precautionary principle, provide rationales for actions beyond no regrets." (IPCC 1996c, 1). Thus, we propose to base global energy policies on the basic principles of strong sustainability: "Only a safe minimum standard for greenhouse gas emissions ... seems to be a reasonable approach to man-made global warming" (Hohmeyer 1996). In other words, environmental damage should not be regarded as being compensated for by economic benefits, but should be considered separately. Consequently, in the following chapters, we describe in two scenarios how an ambitious CO₂ reduction goal of 80% for industrialised countries can be realised. The respective strategies will also decrease damage from conventional pollutants substantially.

2 Scenario for a Sustainable Future Energy System

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2.1 Technical Description

The Sustainable Scenario represents a normative look into the future, in which specified ecological target values are achieved by the year 2050. Laws and regulations introduced and enforced by the European Union, together with economic and fiscal measures, are the inherent forces towards achieving these goals. The transition from the present situation (documented in Sec. 1.2) to the desired future state in the year 2050 is described on the basis of plausible trajectories which are derived from logistic (s-shaped) market diffusion curves.

The scenario requires fundamental changes in resource use with regard to efficiency and sufficiency as well as a sharply increased, if not total coverage of the remaining energy demand through renewable resources. The resulting changes of the European energy system will be described in the following sections. New and better technologies may contribute substantially to the realisation of the ideal situation proposed, but without changes in the value system of our society the savings they could bring about will be rendered almost totally ineffective. Therefore, – after introducing the scenario philosophy (Sec. 2.1.1.1) – we roughly sketch the preconditions for a viable future society (Sec. 2.1.1.2).

To make it easier for the reader to imagine the scenario, the following sections are written in rather prescriptive language. Nevertheless, we are not trying to predict future developments, but describe necessary and/ or sufficient conditions for the realisation of the scenario.

2.1.1 Basic Assumptions

2.1.1.1 Scenario Philosophy

The Earth and its inhabitants are linked in a system of mutual dependence. In the course of recent history, one group of these inhabitants, human beings, brought about an increasing imbalance in this intricate network of interactions and interdependent cycles. Biosphere and technosphere are extremely complex systems permanently undergoing reorganisation. The basic laws governing the behaviour of these systems are non-linear and, thus, minor causes may lead to sudden, major effects over a short period of time.

Science can provide little, if any, information on the effects of human action, neither with regard to the intensity of the ecosphere's reaction nor to the time scale involved. The discovery of the ozone hole is a good example of this. The substances which now threaten the stratospheric ozone layer had passed several ecobalance tests before their effects in the stratosphere were discovered.

Therefore, our actions must be guided by recognising how little we know about our Earth's "survival" system and its susceptibility. As a precautionary measure, we should attempt to minimise anthropogenic effects on this system, and thus prevent any negative consequences as far as possible. To argue that ways will be found to "repair" the biosphere later is irresponsible, for it implies the assumption that we are capable of repairing a system which science has so far failed to fully comprehend, and, secondly, it ignores the fact that global effects such as a reduction of stratospheric ozone or climate change are irreversible, that is beyond repair.

The operation of a sustainable energy technology should involve neither direct nor indirect effects which may impede the development of future generations. Material flows, even of naturally occurring, harmless substances, should be as small as possible. "Waste" from an energy technology, if it cannot be avoided, should then be in the form of substances already occurring naturally in the biosphere. If substances which do not occur naturally are produced through the use of an energy technology, long-term storage facilities must be provided, and, to achieve a maximum of isolation from the biosphere, dissipative losses, where unavoidable, should be low (i.e. only a very small proportion of the total quantity used should end up being finely distributed in the biosphere, e.g. as a result of leakage or evaporation). Energy technologies must, in the long run, not be based on finite resources since these will be exhausted sooner or later and will therefore not be available to future generations. A final, essential point is that such energy technologies must not contribute to political instability, i.e. constitute a security risk, and it must be possible to use them in many regions all over the world. This is particularly relevant for technologies with high toxic hazard potentials or when substances involved may be misused for military purposes as is the case for plutonium. In both cases, a high degree of supervision is required, which can easily be circumvented or abused.

All the conditions listed are only met in part, if at all, by energy technologies currently in use, and it is unlikely that any single technology will ever completely fulfil them. They do, however, provide a fundamental yardstick for decision-making with regard to technologies or combinations of technologies now being considered for use in the energy system of the future (Lehmann 1994a).

The utilisation of renewable energies is the first of four pillars of a sustainable future energy system. The next two pillars are the efficient use of

energy and materials, the fourth pillar being conscious renunciation of energy and material use (Lehmann and Reetz 1995). While the first three pillars can easily be described in terms of technical data, sufficiency may only be discussed in terms of changes of the social values within our societies.

Renewable energy resources

A wide variety of technologies, ranging from decentralised to centralised, from intermittent to stable, permit the exploitation of solar energy. An energy supply based on renewable energy technologies will require the different technologies to complement each other at various times with regard to their individual strengths and weaknesses, as may be the case, for example, for wind and photovoltaic energy in Europe. As experience has shown over the last few years, these two technologies complement each other with respect to the times of availability. In summer, when the wind is generally light, photovoltaic technology reaches the peak of its output, while, during the cold season, the wind is stronger and more constant. Biomass, thermal power stations and hydroelectric power stations can be used to provide a controlled supply of energy all year around.

Efficiency

Total reliance on renewable energy technology is not sufficient in itself. To achieve a maximum coverage of energy demand through solar power, we must also become more efficient in the ways in which we use energy. A number of studies forecast considerable increases in efficiency even though they vary in their absolute size due to the basic assumptions made. The Enquete Commission of the German Parliament estimated the total savings potential of rational use of energy in what used to be West Germany to be about 35 to 45%, which means a reduction in energy costs by 60 to 80 billion DM (Enquete 1991). A study on Germany finds that, in a scenario running to the year 2020, total energy consumption can be reduced by 50 to 55% and electricity consumption by 20 to 25% (Traube 1992). Considerably higher potential savings are technically feasible, and some scientists envisage increases in energy and material flow efficiency of a factor of 10 (Schmidt-Bleek 1994a).

Sufficiency

The combination of efficient energy technologies and energy production based on renewable energy technologies may, however, still not be enough to achieve the aim of a sustainable energy system. Some studies which assume increasing demand for energy services predict a higher rate of growth in energy consumption than can be met directly with renewable energy technologies and rational energy techniques, thus implying an increase in the use

of fossil fuels. In the recent past, too, increases in efficiency achieved over the last few decades have been more than offset by increased consumption in industrialised countries.

Two examples may illustrate this point. Although, in Germany, only half as much energy is used per square metre of living space for heating purposes as was required several decades ago, the living space per capita has increased by 100% during this period due to a trend towards bigger apartments and smaller households of only one or two persons. Similarly, vehicle capacity and the total number of vehicles on our roads have risen during this period and cancelled out all the advances made in automotive engineering. All this is strong evidence of vastly increased standards of living at the expense of the environment.

In the future, we may have to make serious and grave decisions on the energy services we really need. Today, 72% of the energy is consumed by 23% of the world's population. If, in the future, the right of all people in the world to receive a fair share of global energy supplies is recognised in a just and sustainable world economy, the rich countries will have to reduce their energy consumption substantially.

Material intensity

Human-induced material flows have grown exponentially since the beginning of industrialisation. This has led to a situation in which material flows caused by industrial production on the continents by far exceed those occurring naturally in the geosphere, with anthropogenic movement and displacement of materials surpassing the natural movements by a factor of 1.5 or possibly even 2 (Brown 1992; Schmidt-Bleek 1994a). The human-induced material flows primarily involve excess burdens from mining, excavations, drilling, ploughing, dam terrace and road building, geological raw and construction materials (including fuels, sand, gravel, minerals and ores), air and water, and agricultural and forestry products (Schmidt-Bleek 1994a). These massive and ever-increasing displacements of material affect the Earth's natural, evolutionary balance of material flows. Whenever human beings interfere with the natural material flows of the ecosphere, they force it to respond to the new circumstances. The more widespread and intensive the interference, the more wide-ranging the ecological response. "The limiting factor on future economic development will, therefore, not be the actual availability of natural resources, but the ecological consequences of today's extremely low resource productivity. Or to put it another way, the ecological consequences of reckless treatment of material flows will constitute the limits on long-term economic development" (Schmidt-Bleek 1994b).

First estimates indicate that the total throughput of raw materials of the world economy must be cut by about half in order to reach a sustainable level of use (Friends of the Earth 1995). Since considerably more material

and energy is subject to economic exploitation in industrialised countries than in countries of the third world, a reduction of material flows in the industrialised nations of between 80 and 90% will be necessary to meet this requirement. For this reason, reducing material flows by a factor of 10 is put forward by a growing number of experts as an important objective for the next century (Factor 10 Club 1995).

2.1.1.2 Social Changes

Use of resources and consumerism

Safe, rational and frugal housekeeping – proper division of provisions: these are the original meanings of the word "economy" in Greek. Safe housekeeping means living from returns without eating into capital; rational housekeeping stands for using these returns sensibly; frugality refers to not wasting anything; and proper division means sharing the prosperity achieved through our endeavours with one another. According to these definitions, there is no inherent conflict of interests between economy and ecology, since safe and rational housekeeping must obviously include conservation of the Earth itself. Living exclusively from returns is equivalent to getting by on the surpluses of raw materials which can be cultivated on the Earth. This implies a society which, in terms of its energy system, lives solely on renewable resources. The challenge not to waste anything focuses our attention directly on the issues of closed-loop economies and maximum productivity in the use of resources. Just distribution within a generation requires that all regions of the world receive their share of the common prosperity, and that those who take more than a fair share at present will have to content themselves with less (Lehmann and Reetz 1995).

Current societies – living on the consumption of fossil and nuclear fuels – constantly strive for more, faster, and fancier things. Consumption of goods is associated with prosperity and, therefore, represents a potent leitmotif for many members of our societies. But this orientation towards possession and consumption leads to extreme forms of dependency, bondage and egoism (Scherhorn 1995; Sachs 1995). And, as a consequence of such behaviour, natural resources must increasingly be exploited and depleted to meet the ever-rising demand for goods and secure the prosperity strived for. But is this really "prosperity"? It certainly is in the sense of having or possessing and also in the sense of being able to demonstrate one's social rank and status, in accordance with the philosophy of "If you've got it, flaunt it". But it is certainly not prosperity in the sense of well-being, of having time for oneself, of experiencing the ultimate joys of life. Prosperity in a wider sense includes occupation, education, health, social and political security, absence of violence, information, liberality, communication, free time, equal rights, the rule of law, and a high-quality environment. The society envisaged in

this scenario aspires to a different way of living within the community. Active and productive participation on the part of the individual will replace passive consumerism. Non-material things, like enjoying intact natural surroundings or developing one's own personality, will rank higher than possessing and consuming material, tangible goods like a car of one's own. People will identify themselves more with the region in which they live, and will take on more social and ecological responsibility.

Thus, one path towards a viable future society will be leasing and renting goods as opposed to owning them, recycling and efficient use of resources for the production of material goods and energy as opposed to unbridled growth in consumption. Food from ecological farms as opposed to food from conventional production will become more and more established as a leitmotif for the majority. People will become more critical, and there will be no room left in this visionary world for those who randomly consume goods (Wuppertal Institut 1996).

Residential planning

The basic objective of the Charter of Athens, formulated at the beginning of this century, was to create hospitable residential areas, because it had become clear at that time that living in the direct vicinity of industrial plants carries risks to human health. This led to a systematic segregation of the domains of work and residence. Today, this development has progressed further, and now aspires to a tripartite spatial division of industry, commerce and residence. But ultimately, this leads to enormous volumes of transport of goods and people, and to the appropriation of ever more land for residential settlements. The Charter of Athens, however positive and philanthropic the idea originally was, has now, in view of the traffic-related increases in noise and air pollution it implies, been rendered counterproductive. The Sustainable Scenario envisages changes through cuts in the turnover of natural resources in industrial plants which will lead to drastic reductions of the environmental impact in their vicinity (cf. Sec. 2.1.2). Further measures for the abatement of emissions will help to decrease negative effects on the environment through industry. This will result in a renaissance of a common spatial structure for industry, commerce and residence. It is precisely this sort of reappraisal, as formulated in the Charter of Florence in 1993, that can already be observed in the work of an increasing number of residential planners and architects (CEC 1993).

Through such a development, regions will – hopefully – gain greater leisure amenities in the eyes of their inhabitants, which will help to reduce the amount of short-stop holiday travel to distant countries. This does not mean that no one will go on holiday to other European countries or countries in other continents any more. But the absolute number of such long-distance recreational trips will decrease and, in contrast, the length of stays abroad

will increase. The volume of business travel will be reduced through video-conferencing, which makes it no longer necessary to pay a physical visit to a business associate in another country or city. First signs of the benefits of this form of communication can already be observed in today's business world.

Goods produced in a region will be used and consumed there. Butter from Ireland will become a rarity on German breakfast tables, just as Spanish olive oil will in Greece. Extra-regional flows of goods which might suppress comparable local products will be strictly limited. The shorter transportation distances of local commodities and a greater identification of the populace with the region they inhabit and its products will reduce the mobility of goods and persons. The measures described here will lead to a drastic reduction in demand for transport services, both for freight and for people, which will allow substantial energy savings to be made (cf. Sec. 2.1.6).

Nutrition

Nowadays, nutrition is becoming more and more of a trivial pursuit. Fast-food is the solution. In keeping with the maxim "Time is money", nutrition, which is actually one of the most important businesses human beings have to attend to, is increasingly relegated to second place and must fit in where it can with the more pressing tasks of the day. Such behavioural patterns inevitably result in poor health (Lehmann et al. 1995).

In spite of the abundant food supply, currently many people do not receive certain nutrients in optimum quantities. People in industrial countries eat too much fat, too much sugar, and products with too much protein. Germany is a good example of the effects and consequences of wrong nutritional behaviour, and it is a reasonable assumption that the situation in Germany is representative of other European countries. Inquiries into food consumption patterns indicate that in (West) Germany the intake of nutritional energy rose by about 15% in the period from 1965 to 1985. Consumption of fat is 1.8 times higher, consumption of meat even three times higher than the amounts recommended by the "Deutsche Gesellschaft für Ernährung" (German Society for Nutrition). The cholesterol intake, mainly through meat and eggs, rose by about 29% between 1965 and 1985. At the same time, there was an increase in sugar and alcohol consumption of 15-20%. The increase in the consumption of animal products and sugar was accompanied by a decrease in the consumption of high-quality sources of carbohydrates, dietary fibre and minerals such as potatoes, grain, or bread. The consequences for people's state of health are severe. Overweight is one of the primary causes of nutrition-related diseases, such as heart and circulation problems, gout, and Diabetes Mellitus. In Germany, arteriosclerosis is the prime cause of death (50% of all deaths in 1983). Animal fats, containing mostly saturated fatty acids, are responsible for hypercholesterolaemia and concomitant

elevated bloodfat levels. The purines, proteins and the saturated fatty acids contained in meat promote typical "diseases caused by civilisation" such as gout and cardiovascular diseases. The diseases mentioned above are some of a wide range of direct or indirect consequences of wrong patterns of nutrition. The financial costs resulting from nutrition-related "diseases caused by civilisation" amounted to DM 42 billion in (West) Germany in 1980 (DGE 1988).

A further negative characteristic of our consumer society is the wasteful way in which we treat food. In the industrialised countries of the world, including the EU15, about 50% of the calorie intake supplied is thrown away in the end. This stands in strong contrast to the situation in threshold countries (e.g. China), where currently only 30% of the calorie intake supplied is wasted even though figures are admittedly increasing. In the developing countries the respective figure is only 10% (Millieu Defense 1994). These statistics illustrate that people in industrialised countries attach little importance to nutrition. The Sustainable Scenario projects a radical change in the attitude of these populations towards produced foodstuffs and an increase in the value of agricultural products.

Conventional methods of agriculture involve the application of large quantities of fertilisers and pesticides. This sort of farming, however, leads to excessive levels of nitrate and biocide pollution of drinking water resources, soil and, ultimately, the foodstuffs themselves. The chain of consequences leads back to human beings, who are thus exposed to additional health risks. A switch to ecological farming methods would counteract this trend. Energy- and land-intensive enhancement of basic foodstuffs (i.e. meat production) will be substantially decreased through greater consumption of fruit, vegetables, grain and pulses. It is not assumed here that a future Europe will forego consumption of animal products altogether, but that meat consumption, for example, will decrease substantially. Ecological farming methods will greatly reduce the strain on the soil caused by agrochemical products. This change-over will be endorsed and encouraged by changes in the nutritional habits of the population.

2.1.1.3 Land Use

Changes in nutritional patterns and consumer behaviour towards foodstuffs are obviously correlated with changes in the form of agricultural exploitation. However, the patterns of agricultural activity in a viable future society must also be considered with respect to other forms of land use (e.g. built-up areas, protected areas, etc.). It will therefore be necessary at this point of the discussion to elaborate a plan for land and soil use in the European Union. The concept of "environmental space" provides a useful tool for this task. Environmental space defines the ecological tolerance of an ecosystem, that is the capacity for regeneration of natural resources and the avail-

ability of resources. If these criteria are to be applied to land use, the question of an appropriate indicator must be settled first. However, an indicator allowing the quantification of anthropogenic changes and environmental impact on soil remains to be found. In the absence of such an indicator, other parameters will have to be used to assess the environmental impact on soil or the environmental space of land use. A naive approach might be to take the conservation of the total mass of fertile soil as a first order indicator of sustainable land use, but, unfortunately, the lack of statistical data does not even permit such an approach. Sustainable land use is therefore defined here on the basis of the area required to feed the population of a region. This definition is only a tentative and anthropocentric approach to a definition of sustainable land use. It does not mean that the soil will keep its ability to function under the given form and intensity of human use. Future research should provide a better definition of sustainable land use. The changes in land use up to 2050 envisioned in this scenario are based on the following assumptions (Lehmann et al. 1995):

10% of the total land area protected from human use and exploitation

Temperate and boreal forests are important sources of global biological diversity. They have been modified through human activities for centuries. The majority of the surviving forest and wooded areas are relatively small, cultivated fragments. For this reason the International Union for the Conservation of the Nature (IUCN), in co-operation with the United Nations Environmental Program (UNEP) and the World Wide Fund for Nature (WWF), has drawn up a catalogue of measures for the conservation of biological diversity, centring around the establishment and maintenance of protected areas to be "returned to nature". In order to sustain biological diversity and ecological resources, more than 10% of the total surface area of the Earth will need to be converted into or maintained as "natural" forest (forest in which trees have never been felled, or at least not for the last 250 years – also called virgin forest, primary forest or old forest stand) (IUCN 1991). However, because there are other biotopes in Central Europe which also require protection (heathland, moorland, etc.), the IUCN demands cannot be fully integrated into the Sustainable Scenario. Therefore, we assume that the designated protection rate will be fulfilled through protection of 10% of presently unprotected wooded area, a further 10% of surface area currently classified as other land, the rest of the rate being made up from agricultural areas. This would add up to the reservation of 10% of the total land area of the EU15 for nature. These areas could be partially afforested depending on regional conditions.

The provision of healthy nutrition for the population

Our recommendations with regard to healthy nutrition are based on the nutritional recommendations of the DGE (German Society for Nutrition). We put the recommended foodstuffs into concrete terms according to the criteria, added the food group pulses because of their high mineral content, and made a more precise distinction between the generic terms fats, oil and dairy products.

Just as European countries differ in geography and climate, they also differ greatly in the eating habits of their inhabitants. Food consumption patterns in the various countries provide information on traditional or culturally-founded preferences for certain food groups. Our intention is to avoid reducing the diversity of eating habits to a nondescript homogeneity, and our divergence from DGE guidelines should be understood as an attempt to preserve gastronomic culture as far as possible and to take local preferences into account. We thus assigned all European countries to regions (Northern, Central, and Southern Europe) according to climate and geographic location.

Preferences for certain food groups in the population of a country can be determined from per capita consumption figures. Our nutritional recommendations take the particular eating habits of the regions into account to the extent that they can be endorsed from a nutritional-scientific point of view. In determining the recommendations, we took the preferred food groups of one country of a region (United Kingdom for Northern Europe, Germany for Central Europe, Italy for Southern Europe) as representative of the other countries of the region in question and extrapolated consumption for the total regional population (cf. Table 6.1 in the Appendix).

Re-orientation of agriculture towards ecological farming methods

Present farming methods may pollute the environment – especially the ground water. The main problems are caused by the leaching of soluble fertilisers (particularly nitrates) and pesticides as well as by the introduction of phosphate into the ecosphere through erosion. Another factor, which is usually underestimated, is air pollution. 85% of the nitrogen input into the air is caused by ammonia emissions from the agricultural sector (Friends of the Earth 1995).

The Third International Conference for the Protection of the North Sea in 1990 agreed on reducing nitrogen and phosphorus emissions by 50% compared to 1985 levels. The main reason for this decision were the devastating effects of eutrophication in the North Sea, causing epidemic growth of algae and resultant oxygen depletion, mass-dehydration and toxification of fish, with all the obvious implications for the human food chain.

In inland waters, eutrophication has toxic effects on limnic micro-organisms through increased nitrite and ammonia concentrations. Due to overly high nitrite concentrations, some inland waters no longer qualify as a possi-

ble source of drinking water. Excessive nitrogen levels have also been detected in wells fed by ground water.

A further argument for a re-orientation towards ecological farming methods for arable and pasture land is the problem of progressive soil degradation. The situation in Bavaria and Eastern Germany is a good illustration of the potential extent of erosion today. On 2/3 of the arable land in Bavaria, soil losses through water erosion presently exceed permissible limits. An annual average of 8 tons of soil is lost per hectare, amounting to 17 million tons of soil per year. Average soil erosion rates for the rest of Germany are in the same order of magnitude. In Eastern Germany, peak rates of soil loss through water erosion of more than 100 tons per hectare per year have been reached (Bosch 1994).

Wind erosion, on the other hand, is only regionally significant, especially in coastal regions with marshy soils, although losses can be as high as 10 tons per hectare per year, too (Bosch 1994). Appropriate forms of livestock farming and the closure of material and mineral cycles are further issues which should be mentioned as reasons for a changeover from conventional to ecological farming methods.

Concomitant 20 % yield loss compared to conventional farming methods

Average values for crop yields under ecological farming methods in EU15 are not yet available, and achievable yields must therefore be estimated. Comparative studies of conventional and ecological farming indicate that 10-30% lower average yields must be expected from ecological farming (Greenpeace 1993; BMELF 1991; Böckenhoff et al. 1986; Vereijken 1986; Priede 1990). A detailed breakdown of actual yields of the individual nutritional crops discussed here under ecological farming throughout the EU is not possible at present because of the lack of data. In addition, it is very difficult to make generalisations for the EU as a whole, in view of the significant role played by particular soil and climatic conditions. Another problem involved in estimating potential yields is that these are also dependent on the length of time during which ecological methods have been applied since soils take a long time to regenerate to the point where yields can begin to approach the production levels of conventional farming. For these reasons, an average European yield 20% lower than the current conventional farming yield is projected for the year 2050.

Import-export balance of land surface

Through international trade, agricultural raw materials and products are imported and exported from and to countries all over the world. Import of agricultural products implies the indirect exploitation by EU citizens of land areas in other regions. Conversely, EU surface areas are put at the disposal of the inhabitants of other regions when agricultural goods are exported

from the EU. This raises the question of the balance between EU land surface areas exploited for domestic food supplies and those used for export production. For imported agricultural goods and products (like coffee beans, cocoa beans, cotton, tea, tobacco, natural rubber etc.) we assume 50% of the current per capita consumption for the Sustainable Scenario. The equivalent of the areas required for their production in countries outside the EU 15 will have to be made available within the geographical borders of the European Union for the production of agricultural export goods (e.g. cereals) in order to achieve a neutral import-export balance of land. This is a rough estimate and does not imply that the assumed level of consumption is sustainable.

No import of animal fodder in the year 2050

Animal fodder is transported all over the world. The enormous distances covered clearly underline the problematic implications of commodity traffic. Total animal fodder imports into the EU12 in 1989 amounted to about 37 million tons. The fact that 60% of this volume came from developing countries also indicates the ethical aspects of trade in fodder for the enhancement of EU food supplies. In the Sustainable Scenario, we assume zero import of animal fodder into the EU15 by 2050. However, animal fodder is not the only commodity which is transported over great distances.

Reduction in surface area utilised for settlements and transport

Estimates of average world-wide surface area requirements for residential, commercial and industrial zones and for transport systems are given in an FAO population capacity study as 560 m² per capita. According to a breakdown of this figure for individual continents, average future area requirements for transport and settlements in Europe are assessed at 570 m² per capita (WBGU 1994). This higher rate is ascribed to higher mobility in industrialised countries, an assumption which will have to be examined in more detail, but is beyond the scope of this study. Because of inconsistencies in the data available on the development and historical growth of built-up land in Europe, it will be assumed here that land use in this category is approaching a saturation point and will have reached a plateau by 2050. Considering the present destruction of natural areas, and the need for a network of protected areas for nature conservation, we have estimated the environmental space for housing, roads, etc. to be 570 m² of land area per capita minus 10%, meaning that, in 2050, 513 m² of land area per capita will be sealed for transport and settlement purposes. Further increases in the absolute size of built-up land areas beyond 2050 will have to be prevented through political measures to avoid the danger of further encapsulation of fertile land areas. This is only a rough estimate and does not imply a sustainable pattern of use. Further studies on this issue will have to discuss in detail the ways in which these figures can be reduced.

Production forest

In the Sustainable Scenario, we project that there will be no increase in the present land area used for production forests. By 2050, about 10% of currently unprotected forests will be protected in the interest of nature and biodiversity. Thus, only 90% of forest areas currently subject to commercial exploitation will be available (Friends of the Earth 1995).

Degraded areas

Soil degradation has long ceased to be regarded as something affecting surfaces in developing countries only. Ever since soil experts and environmentalists from all over the world, co-operating under UNEP (United Nations Environmental Programme) and ISRIC (International Soil Reference and Information Centre) in the GLASOD (Global Assessment of Soil Degradation) programme, drew up a world map of human-induced soil degradation, a rough quantification of the extent of soil degradation in industrialised countries has been available (ISRIC 1991). However, interpreting the mapping done by ISRIC and UNEP scientists is a complicated undertaking and must be approached with great caution, since the results presented are based on estimates. There are, therefore, discrepancies with official statistics, which do not contain all forms of degradation. Forest floor degradation, for example, and latent forms of impact which accumulate over longer periods of time, as well as changes in the communities of soil biota, are not included (WBGU 1994).

For the whole of Europe (including the European regions of the former USSR) degraded areas account for 2.2 million km², or roughly 23% of the total land surface area examined, i.e. the equivalent of almost the total area of the EU12. Of this, 31 000 km² are extremely degraded and completely lost to agriculture, an area the size of Belgium. A further 107 000 km² is so severely degraded that major engineering will be required to successfully reclaim these soils and restore their full productivity. About 1.4 million km² of Europe are moderately degraded and in urgent need of remedial action if irreversible damage in the future is to be prevented. 606 000 km² are only slightly degraded in their function and can be completely regenerated if modifications are made to the management system, although there is already clear evidence of reduced yields on slightly degraded areas.

In Europe as a whole, extremely and severely degraded areas account for 1.4% of the total land surface area. This value can be used as a basis for an assessment of the extent of degradation in the territories of EU15. It should be noted, however, that such an estimate will probably represent the minimum values for soil degradation in the EU. The reason for this is that large stretches of the European part of the former USSR are unexploited terrain and that the average ratio of degraded areas to total area in the statistics is therefore substantially lowered.

Table 2.1 Assumed land use pattern in EU15 in 2050.

Land distribution	1990 (ha/cap)	1990 (1000 km ²)	2050 (ha/cap)	2050 (1000 km ²)
Agricultural land	0.428	1 590	0.305	1 120
Unprotected wooded area	0.302	1 100	0.27	993
Built-up land	0.053	195	0.051	189
Other land (including degraded areas)	0.093	340.6	0.095	350
Protected area	0.005	19.4	0.085	313
Unused agricultural area	–	–	0.045	167
Total land area	0.89	3 245	0.85	3 132

Land free for other uses

If a balance sheet is drawn up of the land-use categories listed above, after deducting the surface area required for the provision of foodstuffs for the population and for other specific purposes, surplus land area remains free for other uses, for example for the cultivation of either energy crops, renewable raw materials or foodstuffs for export.

Total land distribution today and in the future

The conclusions of this land use scenario for EU 15 are summarised in Table 2.1. Altogether, 89% of the total land area or 2.9 million km² were accounted for in 1990 by cultivated land, including agricultural land, wooded areas (without protected areas) and built-up land. Currently, 6% of the total land area is built-up and only 19 400 km² are fully protected in compliance with the IUCN categories I-III, corresponding to 0.6% of the total land area. In addition, an import surplus (import-export balanced) of 117 000 km² of arable land through the consumption of additional agricultural products like coffee, tea, cotton, etc. must be taken into account (included in agricultural land).

The land distribution figures for our Sustainable Scenario in 2050 show that only 1.12 million km² will be necessary for the provision of healthy nutrition for the populations of the EU15 countries. Furthermore, 1 million km² will be available for the planting of trees and timber production. In conclusion, our projections show that, for the EU about 167 000 km² of unused agricultural area will be available for the planting of energy crops, industrial raw materials or foodstuffs for export purposes. In addition, the unprotected wooded areas and the agricultural sector represent sources of biomass residues which can be used for energy production purposes. We assume that the envisaged changes in land use patterns will have been accomplished by the year 2050 (Lehmann et al. 1995).

2.1.1.4 The Energy System

Decentralisation of the energy system

To fully realise the potential of solar energy, a decentralised, regionally oriented energy supply may be inevitable. It requires local exploitation of the available resources of renewable energies:

- wind power on the coasts,
- biomass in rural areas,
- photovoltaic arrays, and
- both passive and active heat exchange technologies in built-up areas.

Thus, we are moving away from the current situation in which heat is produced individually while electricity is supplied from centralised power plants. In the future, municipal supply structures may be preferable in which heat and power generation are integrated and combined with short-distance district heating. The redistribution of regional surpluses by means of a super-regional network is another feature of this future energy-supply structure. The network may be a decentrally fed electricity grid or gas network. Transportation of high-grade biofuels (e.g. liquid fuels like methanol, ethanol, etc.) is another possible form of energy surplus redistribution. Such a super-regional network will also function as a store for energy surpluses, using biogas or electrically produced hydrogen as a storage medium. Only the remaining power requirements will then be generated in centralised, large scale power stations. These centralised power plants could be hydro-power stations, solar-thermal installations, wind parks or large scale biomass installations. Power plants which use fuels produced in other regions, like hydrogen or biogas, are parts of the system. In this study, power plants with an installed capacity of more than 10 megawatts (MW) are considered central energy installations.

Energy distribution

With regard to energy supply, a new legislative structure for the whole of Europe needs to be developed. Realistic starting points already exist. The present electricity industry has a dual function, being the producer and the distributor of electricity in one. It is a natural consequence of such a monopolistic situation that, unless the industry changes its self-perception, it will automatically be against reductions in power plant output and against substituting renewable energies for conventional energies. Thus, if a change in the structure of the power industry is to be achieved, the functions of producer and distributor must be separated from each other. The power industry in its present form will not assume the function of producer of regenerative energies, since this mainly requires a decentralised energy production structure and also implies different forms of distribution.

In order to attain the necessary decentralisation, the distribution network should be managed as a public institution. Appropriate power transmission regulations for both large centralised and decentralised electricity suppliers will ensure fair chances of market entry for renewable energy technologies. In the Sustainable Scenario, unimpeded access to the network for every energy producer is therefore assumed.

To promote local and regional energy supply plans, the supply of non-local power generated through renewable energy technologies should be permitted via a super-regional network and should be facilitated through the introduction of a special power transmission regulation (on the medium voltage level) in case of solar electricity. This will allow producers and users to organise their relationships according to their particular supply and demand profiles. It will, however, require that the electrical power transmission facilities argued for as well as heat redistribution facilities are made easily available.

Through technological improvements and more flexible ways of distributing electricity via a super-regional network, it will be possible to make better use of fluctuating and intermittent renewable energy sources. In addition, we also envisage an exchange of biogas via gas pipelines from the South to the North of Europe and vice versa.

Energy categories in terms of supply and demand

In the following description of the energy system, we differentiate between the supply side, that is primary energy production, and the demand side, i.e. application of the power supplied. Present energy demands are met primarily through exploitation of the non-renewable energy sources coal, mineral oil, natural gas and uranium (ca. 96% in 1990). In a viable future energy system, the greater part of the demand will be covered by renewable energies.

On the supply side, we consider the following technologies for exclusive electricity production: Wind turbines, solar-thermal power plants, photovoltaics, existing large and additional small hydropower plants. Heat may be produced by solar-thermal collectors, boilers and furnaces fired with solid and gaseous biofuels or hydrogen, heat pumps, or electricity and it may be stored in hot water tanks. Combined production of heat and electricity is possible via cogeneration units and fuel cells. Biomass may be turned into different gaseous fuels ranging from biogas to pure hydrogen for the use in reversible fuel cells. In addition, it may be converted into liquid fuels for transport purposes. In some cases, where efficiency measures and renewable energies are not yet sufficient to meet the demand for energy services, fossil fuels may be used. This is mainly the case in the transport sector and for some residual backup.

On the demand side, we differentiate between the economic sectors industry, households, services, transport and agriculture. Regarding energy demand and consumption, the following discussion differentiates between electricity and heat, the latter being roughly divided into two temperature levels: high-temperature (above 100 °C) and low-temperature (up to 100 °C) heat. The reason for this is that decentralised technologies, like cogeneration units and power stations (cf. Table 2.5 below), solar collectors or heat pumps, can only supply heat at temperatures of up to about 100 °C.

2.1.2 Energy Demand in the Industrial Sector

2.1.2.1 Dematerialisation

According to the "equity principle", the limited amount of non-renewable raw materials must be distributed equally on a global scale. Table 2.2 shows the average production and consumption of selected materials in the European Union in 1990. A comparison of these figures with the rate of reduction in raw material consumption (50%), postulated in Sec. 2.1.1, allows for calculating the necessary reduction rates for these materials in the industrialised countries. The stipulated ranges of the reduction rates for key indicators like pig iron, aluminium, etc. indicate the maximum and minimum reductions in consumption of the respective raw materials in the EU in order to achieve a drop in global consumption rates of between 40% and 60%.

How big the increase in efficiency in the various sectors of technology will actually be is not foreseeable at present. We know that, for some technologies, reductions of up to a factor of 10 and more are already technically feasible. It is for this reason that some scientists demand an increase in ma-

Table 2.2 Reduction rates necessary for raw material consumption in industrialised countries during the next century (Friends of the Earth 1995).

Material (primary based)	Recorded use	EU15 use in 1990 (kg/capita)	Reduction target (kg/capita)	(%)
Pig iron	Production for steel making	272	36 (29 - 43)	87 (84 - 89)
Aluminium	Apparent con- sumption*	12	1.2 (1.0 - 1.4)	90 (88-92)
Chlorine	Production	23	3.2 (2.6 - 3.8)	86 (83 - 89)
Copper	Apparent con- sumption	5	0.75	85
Lead	Apparent con- sumption	4	0.39	90

* Consumption of produced materials not including substances used during manufacture of the product.

terial productivity by a factor of 10 for a future ecological industrial society (Schmidt-Bleek 1994a). In the Sustainable Scenario, we assume that raw material consumption can be reduced by a factor of 8 by 2050 and by a factor of 10 by 2100. Inputs from the ecosphere into the technosphere consist of raw materials, for example iron ore. The ores flow into an industrial production process and are refined to steel, moulded, and used, for example, in the manufacture of an automobile. This automobile is used and, after a longer or shorter service life, scrapped. Since the process involves the use of the raw material iron ore, it will be considered in the following as raw material consumption. Thus, even if only part of the produced steel chassis of the automobile is recycled, this will reduce the raw material consumption involved by the corresponding amount. The sum of raw (or primary) materials and secondary materials used for the manufacture of a product is defined as total material consumption. Waste products which are released from the technosphere back into the ecosphere are referred to as outputs.

In summary, application of the following elements of a dematerialisation strategy in EU15 up to the year 2050 is projected:

- Reduction of total material in the industrial cycle by a factor of 4;
- reduction in raw material consumption by a factor of 8 through 50% recycling of raw materials used.

Current (1990) average material consumption volumes per capita in EU15 are used as a starting point for calculating target values. It is assumed for the subsequent time steps that a reduction in material consumption will begin in the year 2000.

Reducing material consumption in the assumed order of magnitude can be achieved through

- prolongation of the technical service life of products,
- increases in their reparability, and
- sharing of goods.

The following examples illustrate that such visions are viable in practice: Statistics indicate that about 2 seats in a car are sufficient for the needs of city traffic. If raw materials suppliers to the automobile industry were able to dematerialise their products by a factor of 2, and parts suppliers were able to improve their manufacturing technology by a factor of 1.5, and if – apart from that – a city vehicle could be produced whose design allowed a reduction in material requirements by a factor of 3 and if, in addition, a service life three times longer than that of present vehicles could be achieved for the car, this would already add up to a factor of almost 30 in reducing material consumption. If it were also viable for 10 families to share such a car, an increase in material productivity of the same magnitude could be attained (Schmidt-Bleek and Tischner 1996).

The second example refers to an evaluation of the materials flows of two comparable methods of building 110 kV high-voltage poles. Such poles can

be constructed of concrete, or, using sheet steel, as steel lattice poles. The findings showed that pre-stressed concrete poles require approximately 3 times more primary raw materials (including energy) than steel lattice poles (Merten et al. 1995).

A further example from the industrial sector clearly illustrates that progressively-minded enterprises are already pointing the way to a viable future. One company in the chemicals branch offers to lease rather than sell chemicals to its potential customers: A solvent for cleaning purposes is rented out and, after use, is cleansed by the manufacturer and then rented out again. The customer pays a rental fee determined by the volume of solvent rented and the amount of cleansing needed when it is returned. The example shows how producers, who are essentially only interested in selling their products, can transform themselves into service providers for whom the re-applicability of their product is a major concern.

2.1.2.2 Recycling

In the Sustainable Scenario, recycling plays an important role in EU societies when reducing raw material use to a sustainable level. Both non-renewable and renewable materials will be recycled at high rates. The recycling rates for paper, cardboard and glass for selected countries in the year 1989 are shown in Table 2.3.

The technical recycling potential of paper is 75%, of steel up to 90%, of waste from the building sector up to 70%, and of packing material up to 75% (Spangenberg 1995). On the other hand, recycling raw materials or products may sometimes require more energy and materials than their natural or original production. For this reason, we assume an average material recycling rate of 50% in Europe, indicating that 50% of the output generated by industry will be re-utilised in the production of new products.

In the case of organic substances or mineral oil products like wood, textiles, plastics or waste products from the food-processing industries, the scenario envisages recycling for energy purposes. Although this form of recycling involves waste incineration, it does not automatically provide an argument in favour of the installation of waste incineration plants on a large

Table 2.3 Recycling rate of paper, cardboard and glass in different EU member states in 1989 (Eurostat 1992).

	Paper and cardboard	Glass
Denmark	30 %	—
France	46 %	29 %
Germany	43 %	42 %
Netherlands	58 %	55 %
United Kingdom	27 %	18 %

scale. We feel that, especially in a viable future society, the prevention of waste will be consistently preferred to the incineration of waste. Nevertheless, there are valuable carbons in waste materials which should not be returned to the ecosphere without being first exploited for their energy content. It should be kept in mind that incineration of textiles and wood products does not generate any more carbon dioxide than was required for the growth process of the plants which originally provided the raw materials. Plastics made from mineral oil generate surplus carbon dioxide when they are incinerated and, in this respect, are in a different category to the products made of renewable raw materials. In general, thermal exploitation of waste materials will be the last resort in the downcycling of materials.

The scenario suggests the emergence of a whole new recycling industry. Sectors of this industry will specialise in recycling specific product types and will be paid by the producers for the waste management provided. Some branches of the recycling industry may also specialise in the recycling of materials from old waste dumps. The redevelopment of old landfills will create new industries, technologies and also jobs.

2.1.2.3 Efficient Energy Use in the Industrial Sector

Status quo

As indicated in Figure 1.1, the industrial sector made up 30% of the total energy demand in 1990. Within this sector, there are a few branches, which are responsible for most of the energy consumption. Figure 2.1 illustrates the distribution of the industrial end-use demand between the most important industrial branches in EU15. Germany, France, UK, and Italy contribute the largest shares. Among the industrial branches considered, iron and steel, the chemical and petrochemical industry, and non-metallic minerals are the most energy consuming ones. In Finland and Sweden, the most important industrial branch in energy terms is paper, pulp and printing.

In general, most energy efficiency measures can be related to the following areas (ISI 1996):

- electric drives,
- process heat, and
- space heating.

Efficiency measures for electric drives usually relate to power control, especially for applications which have to cope with varying loads. Water pumps, for example, are conventionally controlled by a throttle, that will be closed if the volume pumped has to be reduced. Such a system features a driving source to pump the water and a retaining force to control the water stream, which will impose additional load on the driving source. This procedure is equivalent to stepping on the brake and gas pedal of a car at the same time. In contrast, modern electric drives use electronic devices – so-called

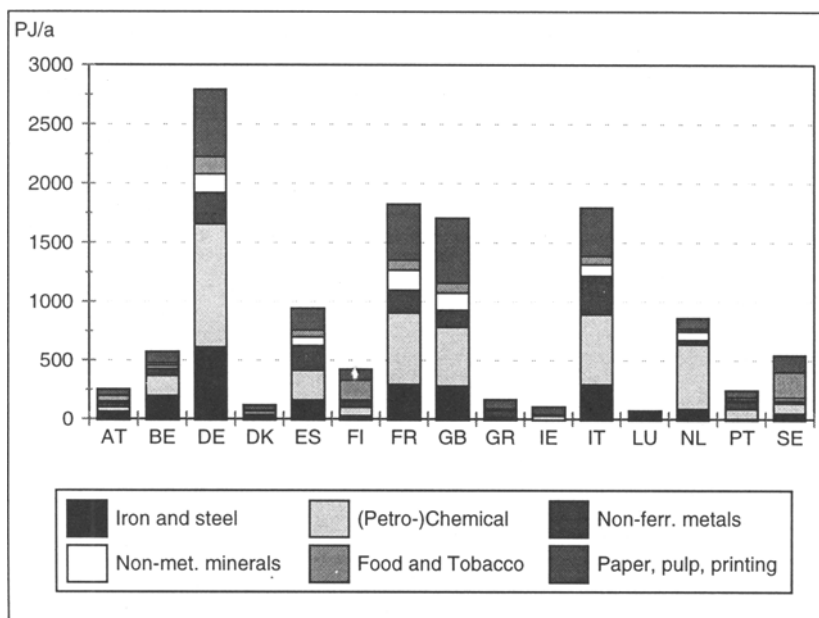


Figure 2.1 End-use energy demand in European industries with respect to branches (Eurostat, OECD, IEA: several years).

frequency converters – to control the revolutions of a drive. Replacing throttles by frequency converters can reduce the energy demand of an electric drive by up to 90%. Although there are already a number of electronically controlled drives in use, a substantial potential remains which may reduce the industrial electricity demand by a few percent.

The efficiency of providing process heat can be increased by electronic regulation of combustion air flows. Introducing electronics instead of conventional regulation decreases the surplus volume of air which has to be heated additionally to ensure a proper burning process in the conventional case featuring manual regulation. In addition, energy demand for process heat can be reduced by better insulating combustion chambers, tubes etc.

Space heating in industrial buildings can be reduced by similar measures as in the residential sector (cf. Sec. 2.1.3 below). In addition, efficiency measures in the areas of warm water supply, room lighting and heat recovery can contribute substantially to an overall efficiency improvement in the industrial sector.

Future development

Since the energy demand in the industrial sector is closely related to material consumption rates, dematerialisation can be expected to bring about

substantial reductions in industrial energy consumption. In addition, an expected increase in energy efficiency until 2050 is considered, which will be due to technical developments and reductions in energy consumption in material-processing procedures and equipment. It would have been beyond the scope of the LTI-Project to simulate each efficiency measure in the industrial branches until 2050. Thus, the scenarios use a single efficiency indicator (energy use per unit of gross national product) based on other studies to describe the efficiency development from 1990 to 2050 disregarding economic growth. The assumptions made in the following are based on a sub-study of the LTI-Project carried out by the "Fraunhofer Institut für Systemtechnik und Innovationsforschung" for Germany and are then extrapolated to the European level (ISI 1996).

The energy saving potential calculated by ISI is divided into two categories for each of the EU15 countries. The standard variant considers measures which will be applicable because of projected developments in energy prices or as a result of automatic technological progress. The progressive variant also includes additional energy savings through additional improvements in processes and procedures. The energy saving potential for both variants is calculated for 2020 and 2050. Since the basic projection of this scenario is a radical social reorientation towards a viable future society, we base our calculations on the progressive variant. Therefore, we assume that, in the year 2050, a level of energy efficiency will have been attained within the whole EU which corresponds to the best available technologies of the year 2020. The rationale behind this assumption is that, by 2050, the best technologies of 2020 will be standard products. Machines and equipment will have much longer service lives and, accordingly, the replacement of plants and components will occur at longer intervals than at present. Today, large furnaces for steel production manage about 30-50 years of operational life before being replaced. Some industrial plant components, such as ventilation and lighting systems, are replaced every 10-15 years. Other machines are operated product-dependent and replaced at even shorter intervals, e.g. compression moulding machines for manufacturing automobile parts. It can be concluded that, on average, industrial equipment is currently replaced every 15 to 20 years.

The average savings in EU15's industry which can be realised with more efficient equipment, machines and procedures by 2050 according to ISI's progressive scenario are given in Table 2.4. In the iron and steel producing industry, for example, they amount to about 40% in fuel and 9% in electric power compared to 1990. In general, specific fuel use decreases more than electricity use. This is due to a shift from fuel intensive processes to electronically controlled methods which reduce fuel consumption considerably by slightly increasing the amount of electricity used. Consequently, specific fuel use in industry can be reduced to about a third of the 1990 level (efficient case) whereas electricity use can only be reduced by about 40%.

Table 2.4 Assumed energy savings in various industrial sectors of EU 15 in the Sustainable Scenario by the year 2050 (ISI 1996.)

Industrial sector	Fuels	Electricity
Iron and Steel	40 %	9 %
Chemical and Petrochemical	35 %	48 %
Non ferrous metals	19 %	51 %
Non metal minerals	26 %	26 %
Food and tobacco	44 %	15 %
Paper, pulp and printing	47 %	28 %
Textile and leather	48 %	14 %
Other industries	48 %	32 %

2.1.2.4 Different Qualities of Heat

Industrial processes require heat at various temperature levels. Due to data restrictions and in order to simplify calculations, we merely divide the required heat into two temperature zones above and below 100 °C. Not even this simplified approach is covered by the data gathered by ISI.

An analysis of the industrial energy consumption in Germany shows that practically the whole demand for process heat in the textile, food processing, paper and capital goods industries is located in a temperature zone of up to 200 °C. The ISI study also indicates that heat requirements in the iron and steel processing, non-ferrous metals, chemical and non-metallic minerals industries are predominantly in a higher temperature zone above 200 °C. Although these figures refer to Germany, in the absence of detailed findings for the EU15, it was agreed with ISI to assume that the whole fuel demand of the iron and steel processing, non-ferrous metals, non-metallic minerals, chemical and petrochemical industries within EU15 can be assigned to the high-temperature heat class. In contrast, the fuel demand for the paper and printing industry, textile and leather production, the food-processing industry and the capital goods industry is assigned to the low-temperature heat class.

Through this shift in the demand profile, heat energy requirements on the high-temperature side (above 100 °C) decrease by 10%, while at the same time demand on the low-temperature side (below 100 °C) increases by about 60%. The bias created by this assumptions is put into proportion by the following consideration: Table 2.5 lists the temperature levels at which heat can be recovered from power plants working on the cogeneration principle. It is evident that even in smaller, decentralised combined heat and power stations (with capacities of around 1 MW_{el}) temperatures of the heat recovered are up to 300 °C. In centralised plants with installed capacities of above 20 MW_{el} even 500 °C are possible. These temperatures are well above the temperature demands of the low-temperature heat class and fall in the

Table 2.5 Cogeneration plants and their temperature levels (Enquete 1995).

Type of cogeneration plant	Installed capacity (MW _{el})	Temperature level of heat recovered (°C)	Fuels
Cogeneration units	0.05 - 10	90 - 120	Natural gas, fuel oil, sewage, landfill and biogas
• Gas motor			
• Diesel motor			
Gas turbine cogeneration plants	1 - 100	100 - 300	Natural gas, fuel oil
Steam turbine cogeneration plants	20 - 250	100 - 250	Natural gas, fuel oil, coal, biomass
• Back-pressure turbine			
• Condensation turbine			
Combined cycle power plants	20 - 500	400 - 500 ¹⁾	Natural gas, fuel oil, coal
• Back-pressure turbine		100 - 250 ¹⁾	
• Condensation turbine			

¹⁾ At the gas turbine outlet.

¹⁾ At the steam turbine outlet.

category of high-temperature heat. Cogeneration units, which are often used in residential areas or administrative buildings in the industrial or service sectors, attain temperatures of up to 120 °C.

In order to compensate for the bias in the assessment of the heat demand profile of the low-temperature heat class, the scenario assigns all the heat produced by cogeneration plants to the low-temperature heat class.

2.1.2.5 Future Energy Requirements of Industrial Sectors

Iron and steel processing industry and non-ferrous metal production

Due to the high level of recycling in this sector of industry, the target is 50%, it is necessary to differentiate between energy consumption for primary and secondary production of the materials. Special attention must be paid to the production of steel and aluminium, since these two metals account for the by far largest shares in the total production volume. The production of aluminium from bauxite is very energy intensive. Production of 1 ton of primary aluminium requires about 70 GJ of energy. Secondary aluminium, on the other hand, has a specific energy consumption of only 8 GJ/t. Table 2.6 shows the specific energy consumption, in terms of fuel and electricity, for the production of aluminium in Germany.

Presently, these figures are only available for Germany. It is assumed that they are applicable to the other countries of EU15 when calculating the energy consumption for the production of secondary aluminium.

Table 2.6 Energy consumption of secondary aluminium production in Germany (ISI 1995b).

Product	Primary aluminium	Secondary aluminium
Energy form		
Fuels (GJ/t)	10.5	6.3
Electricity (GJ/t)	60.8	1.8

Non-metal mineral industry

Cement and glass production currently dominate the material consumption and the energy requirements of the non-metal mineral industry.

In the residential buildings sector, we have two predominant trends today. On the one hand, household sizes are decreasing while living space available per capita is increasing. Currently, there is an evident north-south gradient for both parameters within EU15 (cf. Sec. 2.1.3). On the other hand, most existing buildings will have to be retrofitted in order to reduce their demand for heating energy. Both trends lead to a continuously high demand for cement in the future. Thus, a stagnation of per capita cement production at 1990 levels is assumed in contrast to the substantial reductions in material flows in other industrial sectors.

Although longer product lifetimes are assumed, an increase is to be expected in the production of glass for windows which provide better thermal insulation as well as for the production of photovoltaic modules and solar collectors. On average, glass production is assumed to grow linearly during the time period up to the year 2050, finally reaching a value 20% above 1990 levels.

Chemical and petrochemical industries

Projected reductions in all chemical and petrochemical products are limited to a factor of 4 since no recycling is envisaged in this sector. The only exception are plastics, for which material and thermal recycling rates of 50% and 20%, respectively, are targeted for 2050, resulting in a total recycling rate of 70%. The recycling of plastics will put pressure on the chemical industry to reduce the number of different types of plastic on the market so that effective sorting can be carried out.

Application of agrochemical products like fertilisers, pesticides, herbicides, and fungicides will have been reduced by a factor of 5 by 2050. The rationale here is that for a viable future agriculture and forestry substantially fewer chemical substances will suffice than today (cf. Sec. 2.1.5). The remaining fertilisers and pesticides used will be tailored specifically to the particular crops, thus allowing optimal treatment at the lowest dosage levels possible. In addition, nutrients, minerals and protective substances will only be added to the soil and plants in the form of artificial chemical products as

a last resort, that is if no alternative is available through recycling organic residues from agriculture and forestry or through natural protective substances.

Paper and printing industry

To assess future production levels in the paper, pulp and printing sector, the rate of round-wood production today is compared to the environmental space requirements (cf. Sec. 2.1.1.3) proposed in the study "Sustainable Europe" (Friends of the Earth 1995). Applied to the forestry sector, the basic implication is that we cannot permit ourselves to take wood out of the forests any faster than its grow-back rate. Furthermore, the various functions of the forest floor must be protected against permanent damage. Presently, an average 0.67 m^3 of round-wood are harvested from the forests per capita and year in EU15. According to environmental space calculations, this rate will have to fall to $0.57 \text{ m}^3/(\text{cap}\cdot\text{a})$ until 2050. By then, 50% of the products will be subject to material recycling, while a further 25% of the production volume is being used for energy production. Thus, a total recycling rate of 75% is assumed.

Textiles and leather production

For textiles, a collective recycling rate of 50% for the materials used is projected, consisting of 25% material recycling and 25% thermal use.

Food-processing industry

In Sec. 2.1.1.3, conditions were described for sustainable land use. An important criterion in this concept is the healthy nutrition of the population, comprising a shift in consumption patterns from animal to vegetable products. The energy requirements of this industrial section are proportional to the volume of food produced, considering energy savings estimated by ISI (cf. Table 2.4).

Other industries (capital goods industry)

In the absence of detailed data on per capita consumption patterns in EU15 for the sector "Other industries", reductions in the materials that are processed can only be calculated indirectly. Since raw materials in the industrial cycle, such as steel, aluminium, copper etc., will be reduced by a factor of 4 until 2050, there will be a concomitant reduction in the output of the processing industry by a factor of 4. This is taken into account in the scenario calculations by multiplying energy demands by a factor of 0.25. In addition, increases in efficiency as envisaged by ISI are taken into consideration (cf. Table 2.4).

2.1.2.6 The Future Industrial Energy Demand in EU15

Figure 2.2 shows the decrease in the industrial energy demand within EU15 from the current 1 060 to 402 watts per capita (W/cap) until 2050. The respective numerical values can be found in Table 6.2 in the Appendix. We use the unit 'W/cap' because it facilitates comparison between different countries and sectors. It does not stand for a power rating, but denotes energy delivered or demanded per unit of time in the sense of watt-hours per hour or watt-years per year.

The reduction in the energy demand is based on the assumption that the development of the industrial sector described above as a viable option for the future will start in the year 2000. An important aspect of the projection is the shift between energy forms. In 1990, process heat above 100 °C accounted for almost 60% of the total industrial energy demand while low-temperature heat and electricity each held some 20%. In the target year 2050, demand for the different energy forms is almost equal. The reason for this development is that industrial sectors with a peak demand for high-temperature heat will be most affected by the projected reduction in materials input and by the resulting reduction in the materials flow in the industrial cycle. Other industrial sectors, for example, the timber or food-processing industries, which are primarily characterised by their larger demand for low-temperature heat, will be less affected in their output. In addition, there will also be a shift from the use of fuels to a greater use of electrical power.

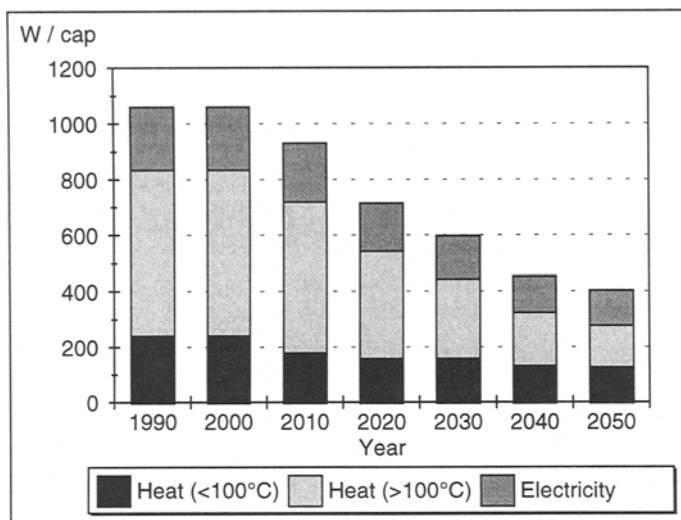


Figure 2.2 Development of the industrial energy demand within EU15 in the Sustainable Scenario; numerical values in Table 6.2 in the Appendix.

In total, the measures discussed above cut industrial energy demand by about 62%, which corresponds to a moderate average reduction rate of 1.6% per year.

The total material consumption (steel, non-ferrous metals, cement, glass, chemical and petrochemical products, textiles, wood and food) within EU15 amounted to 4.4 tons per person in EU15 in 1990. 59% of the materials are processed by primary industries, the rest being supplied from renewable raw materials for the wood, textiles, and food-processing industries. These figures refer to the total mass of primary and secondary materials in the industrial cycle of the Union. This level of consumption is reduced to about 2.2 tons per capita by 2050. The total reduction in terms of mass is not any larger, because, although a reduction factor of almost 6 will be achieved with respect to the turnovers of materials for metal and chemical products, only minor mass reductions are assumed for the timber and food-processing industries. In addition, the demand for cement will remain constant up to 2050 and there is a slight rise in the demand for glass as a construction material. By 2050, about 45% of the raw materials used (approximately 0.9 tonnes per capita) will originate from non-renewable resources. The greater portion of this, about 0.6 t/cap, will be required for cement and glass production, which will not experience reductions in output. Altogether this implies a reduction in consumption of non-renewable resources of 64%. If decreases in metals and primary materials for the chemical and petrochemical industries are considered exclusively, the reductions in demand amount to 85% or a factor of 6.5. In 2050 some 55% of the raw materials (about 1.1 t/cap) will be supplied from renewable resources, which implies a reduction in demand for renewable raw materials of about 35% compared to 1990.

2.1.3 Energy Demand in the Residential Sector

Except for transport, the residential sector uses energy mainly for room and water heating as well as household appliances. The energy demand can be split into fuel and electricity demand, the shares of which vary substantially in the different EU countries (cf. Figure 2.3). The share of electricity is comparably high in France, Sweden, and Spain. However, fuel based heating systems are the major energy consuming application in the residential sector.

As will be demonstrated later, the Sustainable Scenario is compatible with a cohesion of living standards and domestic comfort in all countries of EU15 until the year 2050. On this basis, an average European household size of 2.24 persons per household is assumed, which corresponds to the present average size of households in the reference countries Denmark, Germany and the Netherlands. These households will provide about 42 m² of living space per person and will have achieved a level of availability of electrical appliances comparable to that of homes in the three reference

Table 2.7 Availability and relative efficiency of electrical appliances in the European Union in 2050 (Eurostat 1993a; Nielsen 1995).

Appliance	Average availability in 2050	Relative efficiency in 2050 (1990: 1)
Refrigerator	70 %	0.15
Deep freeze	54 %	0.20
Combined radio/disk player	—	0.20
Washing machine	83 %	0.30
Tumble drier	33 %	0.35
Dish washer	21 %	0.33
TV	96 %	0.25
Electric cooker	100 %	0.40
Lighting	100 %	0.20

The basis for calculations of the domestic demand for electric energy in 2050 is the number of households in the individual countries, which can be estimated with the help of the projection of population growth (World Bank 1993) and the assumed size of households. A further significant factor is the availability of various electric appliances in households. The status quo (1990) could be obtained for most of the countries from Eurostat statistics. The average European availabilities that we assumed and the relative efficiency gains for the different technologies are listed in Table 2.7. Furthermore, it is assumed that there will be no increases in electric lighting and cooking in the households of EU15.

For lack of literature on the availability of electrical appliances in Finland, Luxembourg, Austria, and Sweden, it is assumed that the projected average target levels of availability of electrical appliances were already attained in these countries in 1990. This assumption is reasonable in view of the fact that an elevated standard of domestic comfort, equivalent to the projected average standard for 2050, can already be found in these countries.

The analysis indicates that the two variables, household size and level of technical equipment, will cause an increase in demand for domestic electricity in the households of the Union, especially in the southern regions of the EU, the only reducing factor being the increase in the efficiency of domestic appliances. The effect is quantified, using data from studies on domestic electricity demand (Nielsen 1995) and assuming that the current best technology in the laboratory will be the standard equipment in 2050.

2.1.3.2 Domestic Heating Requirements

Heating efficiency may be enhanced by improving the heat protection of houses, that is by providing for a better insulation of walls and roofs, windows with lower heat transmission, and by making houses air-tighter. The latter will, in turn, lead to a need for advanced air ventilation systems that

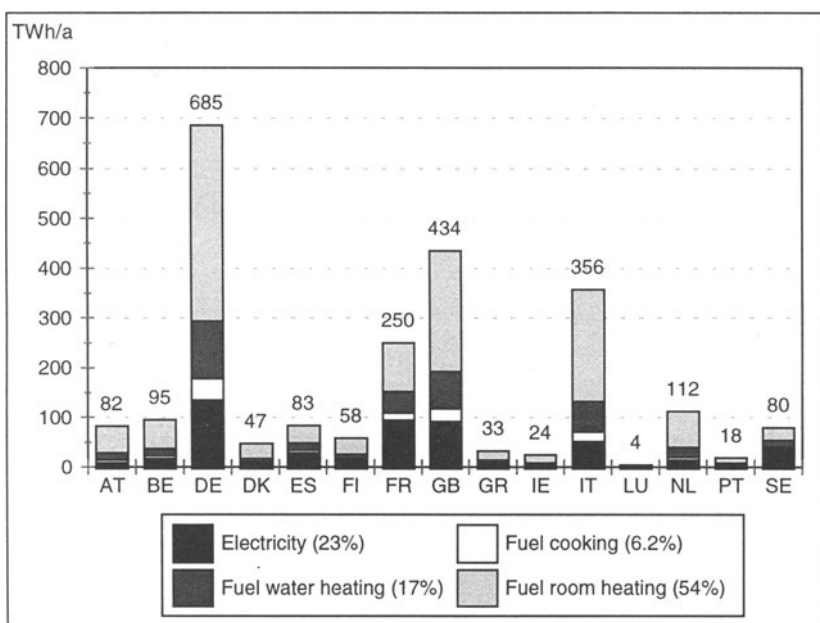


Figure 2.3 Final energy delivered to the residential sector in EU12 in 1990 (IEA 1995).

countries today. Consequently, the number of households within EU15 is expected to increase by 17% from the present 140 to 164 million. A predominant feature of this development will be the dramatic decrease in the average number of persons per household in the southern member states of the Union (Greece, Italy, Portugal and Spain), where the number of households will correspondingly increase by 29%, from 38 to 49 million. There will also be a greater relative increase in living space per person in the southern regions of the Union, while in the central and northern member states the growth rate of this particular parameter will be small.

2.1.3.1 Domestic Demand for Electricity

The efficiency of electricity consumption can be improved by replacing old and inefficient devices by modern technologies (Nørgård and Viegand 1994). Conventional light-bulbs, for instance, can be replaced by compact fluorescent lamps. Old refrigerators can be substituted by devices which are better insulated and have more efficient cooling equipment. Efficiency improvements are achieved via penetration of presently "best available technologies" and "advanced efficiency technologies", which are presently under development, into the households of the EU citizens.

may be combined with heat exchanger systems, which will further reduce heat losses from the dwellings. Further efficiency improvements can be achieved by substituting old burners of heating systems with more efficient ones.

Likely changes of the living space available per person within EU15, which are due to the cohesion of living standards in Europe, are a particularly relevant factor for the assessment of future heating energy requirements. It is assumed that the living space available for every person in EU15 reaches about 42 m² by 2050. Another important factor is the projected increase in the demand for working space within private households. It is likely that a growing number of employees will be able and willing to work on-line at home. This may, in turn, lead to a reduction in the working space to be provided by the industrial and service sectors. It is assumed here that these two contrary trends will be of the same order of magnitude and will thus cancel each other out.

However, the targeted increase in living space per capita will lead to an increase in residential building activities. In view of the constraints on land use for residential purposes (cf. Sec. 2.1.1.3), compact structures of 3-4 storeys are to be preferred. This leads to an increased demand for domestic energy. In the long run, however, the renovation of existing buildings and better thermal insulation standards in new buildings should not only compensate for increases in space heating demands, but should even lead to substantial reductions. The amount of energy currently consumed for household heating (Eurostat 1993a) is documented in the statistics (1990 figures) for a number of member states of the EU 15, which indicate an average of about 150 kilowatt-hours per square meter and year [kWh/(m²·a)]. Calculations of future household heating energy requirements are based on a renovation rate of 2% per year.

Buildings renovated in 2010 will require 50 kWh/(m²·a) for heating in Northern Europe (Denmark, Ireland, Finland, Sweden and Great Britain) and Central Europe (Austria, Belgium, Germany, France, Luxembourg and the Netherlands). In subsequent years, improved technology for existing buildings will render possible further cuts in heating requirements to 40 kWh/(m²·a) in northern and 30 kWh/(m²·a) in central European regions. In the southern countries of the Union (Greece, Italy, Portugal and Spain) retrofitting of buildings will achieve thermal insulation standards which will bring space heating requirements down to 10 kWh/(m²·a). By 2050, newly constructed residences will fulfil standards for heating energy of 40 kWh/(m²·a) in northern, 30 kWh/(m²·a) in central, and 10 kWh/(m²·a) in southern regions. All of these figures are conservative as technologies for further reductions in the heating demand are already available on an experimental level.

Considering that buildings in towns stand more closely together, solar energy will cover only a small part of the energy demand in space heating. However, in buildings which are not restricted on account of their location or urban planning, solar energy will substitute for more conventional energy carriers. Because of the expanded lifetime of products and especially of buildings in the Sustainable Scenario, structural changes in construction norms and building design will also slow down. This fact is another reason for the rather conservative assumption of the future energy demand for space heating.

A further important element contributing to the demand for low-temperature heat ($< 100\text{ }^{\circ}\text{C}$) is the heating of domestic water. This demand is calculated as follows: Daily hot water consumption is put at 50 litres per person. The average temperature difference between cold and hot water is defined to be 50 Kelvin (K) in the northern and central European countries, and 40 Kelvin in the southern nations (Greece, Italy, Portugal and Spain).

Heat at temperatures higher than $100\text{ }^{\circ}\text{C}$ is only required for cooking and baking in households. Some of this heat is supplied through electrical appliances, which were discussed earlier. In terms of non-electric heat requirements for cooking and baking, energy savings of 50% by the year 2050 are envisaged in the scenario.

2.1.3.3 The Future Energy Demand of Households in EU15

Summing up, Figure 2.4 indicates the 65% decrease of the domestic energy demand, from the current 844 to 296 watts per capita (W/cap). This corresponds to an annual reduction rate of 1.7% per year over the whole time horizon of the scenario in spite of the projected rise in average living standards in the European Union. Demand for domestic electricity can be reduced by more than 70% even with an increase in the availability of technical appliances and in the number of households. This is not only due to the projected increase in efficiency of household appliances, but occurs also because electricity as a source of energy for heating purposes will be replaced by other processes, which will directly supply thermal energy in an appropriate form.

The smallest achievable reduction in energy consumption will be in the supply of higher temperatures for cooking and baking by means of gas cookers and other non-electrical appliances, namely from 46 to 23 W/cap, i.e. a 50% reduction compared to 1990 levels.

2.1.4 Energy Demand in the Tertiary Sector

In the service or tertiary sector, new market opportunities will appear and existing fields of activity will expand as a result of the transition from a resource consuming to a resource conserving economic structure in which pro-

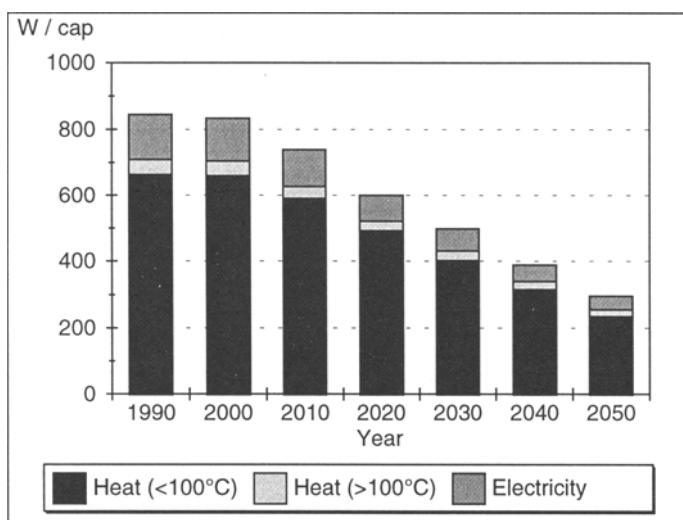


Figure 2.4 Development of the residential energy demand within EU15 in the Sustainable Scenario; numerical values in Table 6.3 in the Appendix.

ducts and goods with longer lifetimes will be in circulation. A viable future society will be geared towards re-using, repairing, re-manufacturing or recycling materials and goods. Thus, even at the design stage, product developers are required to ensure that this will be possible and practical. Demand will develop for products with high reparability (Schmidt-Bleek and Tischner 1996).

Another line of business in the tertiary sector which will expand its services is that of renting and leasing utility objects like electric tools. Nearly every household in Germany has, for instance, one or two power drills although these appliances are only used once or twice a year. Examples of such future-oriented service systems can be found, for example, in Switzerland, where the Zurich-based company "ShareCom" rents cameras, bikes, power drills, computers, sailing boats, cars, etc. – all of which are things that people use only occasionally in the course of a year.

2.1.4.1 Development of the Tertiary Sector

The social re-orientation towards a viable future way of living described above will undoubtedly involve a structural shift in the economic structure, with the industrial sector becoming smaller and the service sector growing. At this stage of analysis, it is only possible to speculate on the magnitude of future increases in the demand for services. The scenario for industry envisages a total reduction of mass volume in industrial circulation of about 50%

(cf. Sec. 2.1.2.1). If it is assumed that this reduction of material throughput will be counter-balanced by recycling activities in the tertiary sector, with a concomitant rise in the energy demand for collection and sorting, an expansion of the services industry in the same order of magnitude can certainly be expected. For the further course of the scenario, we therefore assume that the service sector grows by a factor of 2.5 until 2050 (O'Connor 1996).

2.1.4.2 The Future Energy Demand of the Service Sector in EU15

The development of the energy demand in the tertiary sector in EU15 follows a pattern different from those of the industrial and domestic sectors. By 2030, total energy requirements will have risen from 329 to 444 W/cap. In the following period, the growth rate will decelerate, and projected efficiency gains will even lead to a decrease in the demand for energy so that, by 2050, consumption will have dropped back to 389 W/cap. This development is shown in Figure 2.5.

In other words, the growth in energy consumption in the tertiary sector through the expansion of services offered will be more than balanced by better technology from 2030 onwards. The projected rates of efficiency increase are the same as for domestic electrical appliances. Furthermore, it is assumed that heating energy requirements can be reduced by 50% (O'Connor-Lajambe 1996). In absolute terms, energy consumption in the service sector in the year 2050 will be about 18% higher than in 1990.

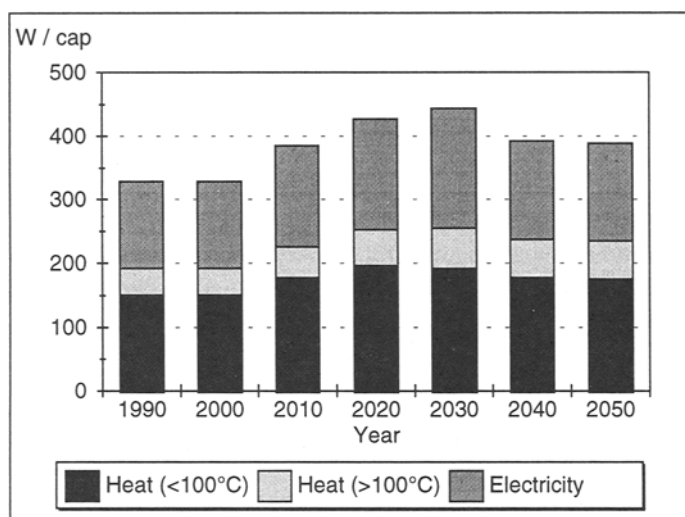


Figure 2.5 Energy demand in the tertiary sector of EU15 in the Sustainable Scenario; numerical values in Table 6.4 in the Appendix.

2.1.5 Energy Demand in the Agricultural Sector

As discussed in Sec. 2.1.1, a transition to ecological farming methods is assumed for the Sustainable Scenario, implying an average decrease in yield from arable land of 20%. The transition from conventional to ecological farming will be supported and endorsed by changes in the nutritional habits of the population. Meat will no longer be consumed in the quantities it is today, leading to substantial reductions in the demand for animal fodder crops (energy fodder) for the purpose of so-called nutritional enhancement.

On the other hand, demand will grow for cereals, vegetables, fruit and pulses for the dinner tables of the inhabitants of EU15. The use of fertilisers and pesticides will be strictly limited, which will in turn allow considerable savings in energy consumption to be made in the chemical industry, a reduction taken into account in the energy demand balance of the chemical industry, not in the calculation of future energy requirements in the agricultural sector. In addition, a 45% reduction in the demand for electrical power and a 40% drop in fuel consumption as a result of improved machine and process technology are assumed for the calculations. In the scenario, it is assumed that all heat demand in this sector is high-temperature heat since it mostly involves temperatures higher than 100 °C.

As a whole, energy consumption in the agricultural sector will decline by 42%, from the current (1990) 67 to 39 W/cap by 2050, which is equivalent to an increase in efficiency of 1.4% per year (cf. Figure 2.6).

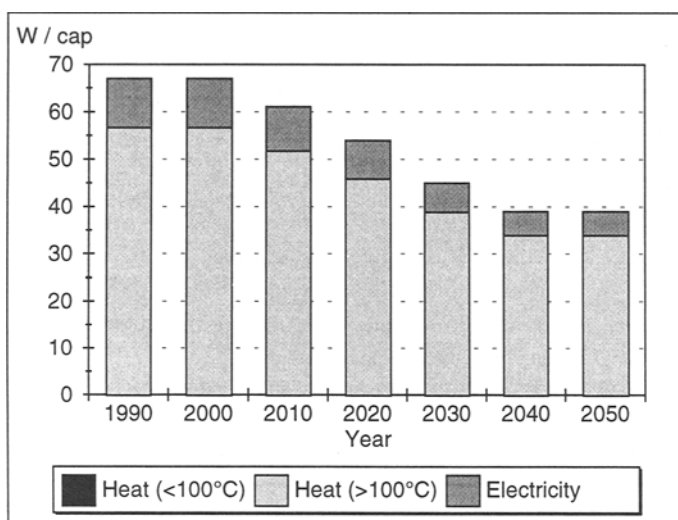


Figure 2.6 Development of the energy demand in the agricultural sector of EU15 in the Sustainable Scenario; numerical values in Table 6.5 in the Appendix.

2.1.6 Energy Demand in the Transport Sector

Status quo and options

During recent years, the transport sector had the highest growth rates in energy consumption in Europe. The transport system is characterised by

- road orientated infrastructure policies,
- an increasing share of goods transport by trucks,
- the introduction of transport management systems via telematic application,
- increasingly fast trains so as to compete with the fast growing air traffic,
- the transport requirements for just-in-time production, and
- an increasing use of private cars for business and leisure time purposes.

Most of these trends have to be reversed to reach a significant reduction in fuel consumption. To that end, technological, economic, structural and behavioural measures are being discussed. The respective keywords are efficiency improvements, avoidance of traffic, change of modal split, sufficiency, and fair and efficient prices (CEC 1995b).

One technological option is to decrease the specific energy consumption of vehicles, trains, aeroplanes, and ships per person kilometre or ton kilometre. Schallaböck (1996) considers it possible to reduce the specific energy consumption of cars by 45-70% and of trucks and trains by 20-40% until 2050. The higher reduction figures for road transport are due to the introduction of higher prices by internalising the traffic related external costs. This measure provides an incentive to develop more efficient vehicles. For air transport, specific energy consumption may be improved by 70-80% until 2050 while reductions of only about 20% are expected for shipping. In addition, the specific energy consumption per person-km or tonne-km can be decreased by slowing down the travelling speed, since the energy consumption grows proportionally to the square of the velocity. Therefore a speed limit on highways of, for instance, 100 km/h and a limit of 200 km/h for long-distance railway traffic is an option.

Specific energy consumption may be reduced further by improving load and occupancy factors of the transport systems. Especially in the case of goods transport, journeys without load (the return trip) have to be avoided.

Another very important parameter is the modal split, that is the shares of the different transport systems. Passengers may switch from aeroplanes and cars to trains for medium- and long-distance travelling and to public urban transport systems or even bicycles for shorter distances. For goods, trains, ships and pipelines are important alternatives to trucks.

Avoiding traffic requires a change in today's regional structures. Workplaces, dwellings and shopping facilities have to be arranged in closer vicinity to each other. New information technologies like computer home-working or video conferencing may result in a reduction in traffic. Reversing

the trend of increasing goods transport activities due to a decentralised production structure (globalisation) requires multiple changes in the whole economic system as well as higher transport prices.

Last but not least people have to realise that any transport process causes negative environmental and health impacts by emitting air pollutants and noise as well as creating a high accident risk. Hence, serious decisions have to be made on which transport service is really needed and which journey could be avoided or replaced by a less transport intensive one.

Assumed development in the scenario

The scenario differentiates between air transport, earth-bound passenger transport and earth-bound goods transport. However, it is assumed that most goods and passengers within EU15 will be transported by earth-bound vehicles (Schallaböck 1996). This implies a drop in the domestic air-transport volume from a current growth rate of 7% per year (from 1990 to 1995) to a negative growth rate of -6% per year (from 2040 to 2050). In all, the volume of air transportation will then have decreased by 77% against 1990 figures. Nevertheless, long-distance transportation of passengers and goods will continue to rely on air transport with the result that specific fuel consumption rates (measured in kilogram kerosene per ton of transport volume) will only fall by 24%. Taken together, the two values (air transport volume and specific energy consumption) show a total decrease of 83% in the demand for kerosene from 99 (1990) to 17 W/cap (2050).

For earth-bound passenger transport, an increase of 6% is assumed by the year 2000 compared to 1995 levels. In the following period up to 2050 a decrease in the volume of 1.6% per year is envisaged, resulting in a total volume reduction against 1990 figures of 50%. Travel needs will be covered in equal shares by rail and public local transport and private transport. In addition, average fuel consumption rates of motor vehicles will decrease to about 2 litres per 100 kilometres (l/100km). In all, energy requirements for passenger transport will fall from the current 600 to 62 W/cap, a reduction of about 90%.

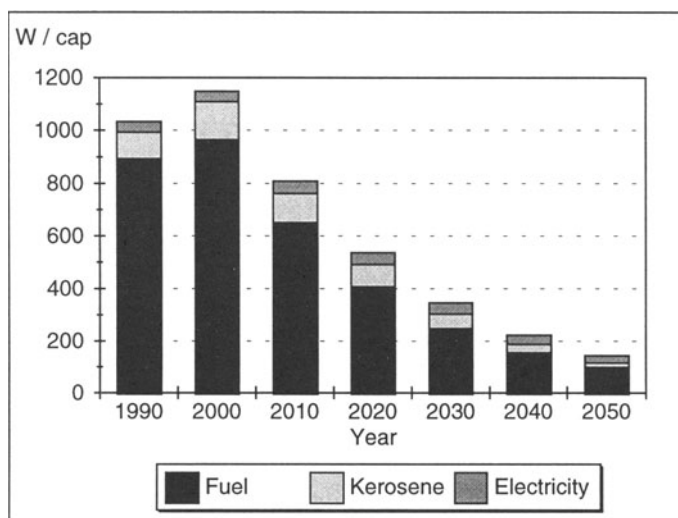


Figure 2.7 Development of the energy demand in the transport sector of EU15 in the Sustainable Scenario; numerical values in Table 6.6 in the Appendix.

A 60% reduction in the volume of earth-bound goods transport is conceivable by the year 2050 as a result of the projected reductions in transportation range and the shorter distances, even when considering the slight counter-effect of recycling-related increases in transportation volume. In addition, an increase in the efficiency of engine technology can be expected, through which the average fuel consumption per 100 tonne-kilometres will be brought down by 34%. Energy demand for earth-bound goods transport will therefore drop from 334 to 65 W/cap, a reduction of 82%.

Energy consumption of the whole transport sector will decrease by 86%, from 1033 to 144 W/cap, which is by far the greatest reduction compared to the other sectors (cf. Figure 2.7). Averaged over the total 60-year time horizon of the scenario, this implies a decrease in energy consumption of about 2% per year. The assumptions made seem very optimistic. It turns out that if the assumptions are less favourable, e.g. the energy demand in the transport sector in 2050 is twice as high as projected so far, the general scenario objectives are not compromised.

The modal split, i.e. the distribution of transport volumes between the different types of vehicles, will experience a significant shift. Whereas fuels still accounted for about 87% of total fuel volume consumed in 1990, this figure will fall to 71% by the year 2050. In contrast, the demand for electrical power will rise from about 4% to 17% of the total volume, with kerosene requirements also rising slightly from 9% to 12% of the total fuel volume consumed.

2.1.7 Summary of Energy Demand Projections

The resulting development of the overall energy demand in EU15 is illustrated with respect to economic sectors in Figure 2.8 and with respect to energy types in Figure 2.9.

First, there will be a slight increase in the energy demand within EU15 up to the year 2000, from the present level of about 3 300 W/cap to a peak of 3 400 W/cap. This continued growth will be due to the present dynamics of the transport sector. On the other hand, energy demand for households will fall slightly in the same period. All other sectors will start changing as from the year 2000.

At that point in time, the dematerialisation process in the economy will commence, changes in the consumer behaviour of the population will begin to develop, and new service markets for re-manufacturing, recycling, leasing and renting products will increasingly open up (cf. Sec. 2.1.1). These developments will lead to a 62% decrease in the energy demand from 3 330 to 1270 W/cap.

This reduction corresponds to an annual rate of 1.6% per year. At present the established industrial nations of the world, which include a majority of the member states of EU15, already show an annual rate of increase in energy productivity of about 1% (Weizsäcker et al. 1995). Thus, the 1.6% efficiency "revolution" envisaged in the Sustainable Scenario is, in fact, not excessive and should be readily achievable.

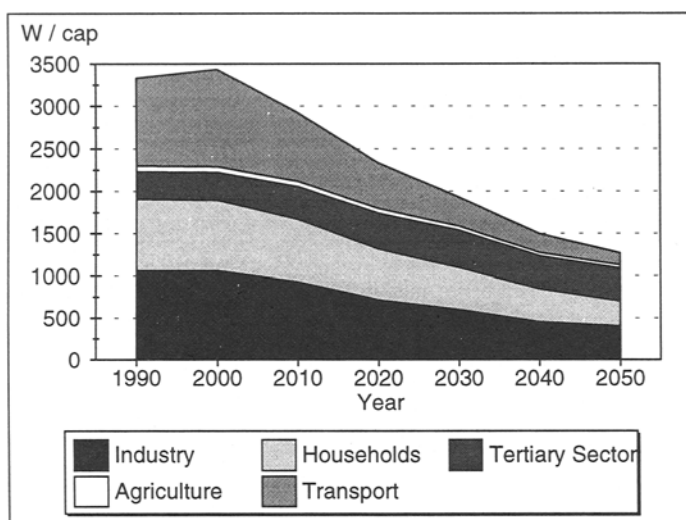


Figure 2.8 Development of the total energy demand in the different sectors of EU15 in the Sustainable Scenario; numerical values in Table 6.7 in the Appendix.

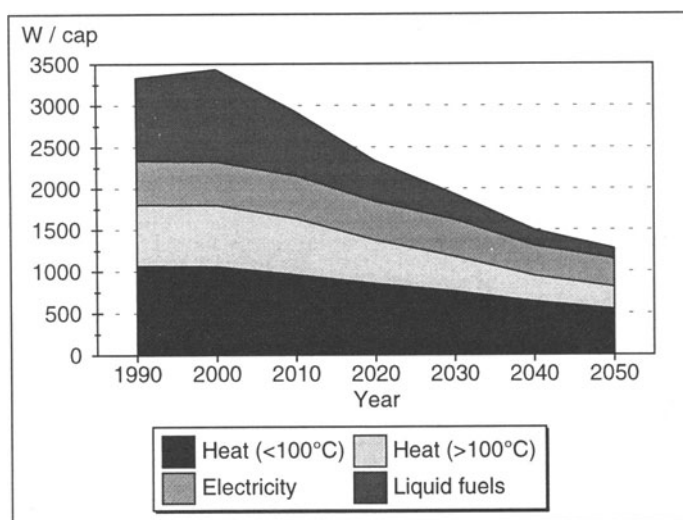


Figure 2.9 Development of the demand for different types of energy in the Sustainable Scenario.

In 1990, the industrial and transport sectors each accounted for about 30% of total energy consumption, with households making up a further 25%, services 10%, and agriculture 3%. According to the scenario, there will be a shift in energy demand between the sectors. While the industrial, residential and agricultural sectors will retain roughly the same relative proportions as in 1990, services and transport will experience significant changes. Energy demand in the services sector will grow to 30% of the total volume, while the share of the transport sector will fall steeply to 12%. It should be remembered, however, that the transport sector is very much characterised by the behavioural patterns of individuals. In contrast to the demand scenarios of the other sectors, the assumptions made for the transport sector are "softer" and are more dependent on social and attitudinal changes. The projected reduction in energy consumption in the transport sector assumes a substantial drop in transportation volume, both in passenger and goods transport, as well as an increasing regionalisation of persons, goods and personal spheres of activity.

2.1.8 Renewable Energy Supply

The remaining energy demand in the Sustainable Scenario will be met as far as possible with renewable energies. However, any viable future scenario must recognise that the exploitation of the potential of renewable energies has physical and ecological limits. These limits are consistently taken into consideration when the scenario envisages a constantly rising relative con-

tribution of renewable energy technologies to meeting the energy demand in EU15.

The renewable energy resources considered for electricity supply are on-shore and off-shore wind turbines, existing large and additional small hydropower plants, photovoltaic installations, and solar-thermal power plants in southern EU countries. In addition, biomass will be used via cogeneration and fuel cells for heat and electricity supply. Furthermore, heat is supplied by solar-thermal collectors and heat pumps. Geothermal, wave and tidal energy are not taken into consideration as supply options because their overall importance is small. However, there may well be considerable local potential which should be used if possible.

2.1.8.1 Biomass

Electricity and heat can be provided from biomass throughout the year since the biomass produced can be stored, with storage being comparatively cheap. Hence, electricity and heat production from biomass may serve as a back-up for intermittent renewable energy sources like wind and solar energy.

Technology

The inputs for fuel production from biomass originate from the agricultural and forestry sector, the food-processing industry and – if properly selected and separated from other wastes – organic household residues. In principle, very different forms of fuel can be derived from biomass:

- solid fuels such as wood chips or straw pellets via physical conversion of farm and forest residues, short-rotation coppice, or energy crops;
- gaseous fuels such as biogas from biological conversion of manure or producer gas from thermo-chemical conversion of wood residues or short-rotation coppice;
- liquid fuels such as methanol, ethanol, bio-diesel, or methyl-ester from physical and/ or chemical conversion of energy crops.

Physical conversion refers to the compression of biomass or extraction of oil, the main objective being to increase energy density in the fuel which in turn reduces transport, storage, and processing volumes. In addition, the undesirable moisture content in biomass materials can be reduced. In Europe, the extraction of oil is mainly connected with the cultivation of sunflowers and rape. There are basically two methods to extract oil from the harvested crops, a full-scale refinery process or modern cold-pressing techniques. The latter do not require a chemical conversion process, but adaptations of the energy conversion technology, whereas the final product of the former can directly be used in diesel motors almost without adaptation.

Physical conversion efficiencies from biomass into biofuel are well above 90%.

Gasification and liquefaction are the main thermo-chemical conversion methods for organic materials. The gasification process requires atmospheric oxygen or steam under high temperatures. It converts biomass mainly into carbon monoxide and hydrogen. The final gas can be used as fuel for combustion engines or steam-injected gas turbines. The efficiency of the gasification process, that is the relation between the energy content of the biomass and the final gas, lies between 50 and 80%. The basic liquefaction process for biomass is the synthesis of methanol from biomass which reaches an overall efficiency of about 50%.

The final products of biological conversion processes (biogas) are methane and ethanol, the former being produced by methanogenic bacteria whereas the latter is produced by micro-organisms such as yeast. The methane content in the final gas is about 60 to 70% accompanied by 30-35% carbon dioxide and other gases like hydrogen, oxygen etc.

Biofuels can easily be added to conventional fuel based combustion processes. Combustion processes that solely use biomass need to be more resistant to corrosion than conventional coal, lignite, oil, or natural gas based combustion chambers, mostly due to the high sulphur or chlorine content of the biofuels.

Biomass residues

A range of biotic residual materials can be used for energy production in the Sustainable Scenario. Firstly there are the residues which are incurred during the recycling of various materials in the industrial cycle such as wood residues, textiles and plastics. The latter are combined with the other two in the relevant statistics. Since their share is very small, there is no need to separate plastics and to create a new category. In addition, residues are produced in agriculture and forestry which can also be used for energy production, although, in the course of the envisaged transition to ecological farming methods, the amount of disposable residues from this sector will decrease (cf. Sec. 2.1.1.3). Livestock, for example, will no longer spend most of the year in sheds and stables as is presently the case in livestock farming. Instead, animals will be kept on meadows and pastures resulting in a steep drop of the production rate of liquid manure, which may be used as a resource for the production of biogas. Furthermore, organic residues like manure or residual straw from livestock farming or crop harvesting will be redistributed to the fields to fertilise the soil. Nevertheless, there are other links in the food chain where organic residues will continue to occur and be available for energy purposes. For instance, 50% of the supplied calorie intake in industrial countries ends up being thrown away, in strong contrast to behavioural patterns in threshold countries (e.g. China) and developing

countries. The Sustainable Scenario assumes that, by 2050, the population of EU15 will have developed a different attitude to food, and that by then only 30% of produced foodstuffs will be thrown away instead of being eaten. These organic residues can be used for energy purposes, and the scenario projects that about 50% of food wastes will be collected and fermented in biogas plants which will not only produce biogas but also compost. The compost produced can then be spread on the fields and pastures as fertiliser, while the biogas can be used in cogeneration units to produce electricity and heat.

As forestry becomes increasingly aware of ecology, residues occurring from harvesting or forest thinning will stay in the forests where they will return essential nutrients to the forest floor. Thus, the availability of residues from forestry for energy production purposes will decrease continually, until it reaches zero in the target year. This is a very severe assumption which substantially limits the resource of biomass residues. It is made according to a strict interpretation of ecological concerns. If, however, one reaches the conclusion that the concerns put forward are exaggerated and that measures such as the redistribution of ashes from biomass power plants will suffice to meet the needs for nutrients, the biomass potential considered in the Sustainable Scenario will increase considerably. Thus, we have here a substantial buffer, which may compensate for possible reductions in the potential of renewable energy, which may result from new insights or public discussions on the proposed scenario at a later point in time.

The only source of wood residues for energy production considered will thus be the timber processing industry (carpentry shops, furniture producers, etc.). They are classified as industrial residues (cf. Figure 2.10).

Energy crops

Taking into account the projected transition of EU15 towards ecological farming, the envisaged changes in the composition of the population's "bread basket", and the fact that 10% of the total surface area of the territories are to become protected areas for the sake of biodiversity and nature conservation, the size of the remaining unused land can be determined. Calculations indicate that this unused area, consisting of arable and pasture land, will amount to about 17 million hectares in the year 2050 (cf. Sec. 2.1.1.3). One way to make use of this land is to plant renewable raw materials for energy production.

It should, however, be emphasised that this is only one of many possible exploitations of the unused fertile land surface. Cultivation of food crops for export to other countries such as, for instance, Northern Africa, would be conceivable for ethical reasons. These countries have less favourable climatic and soil conditions for the cultivation of crops than the member states of the European Union, and this could be the start of food exports from the

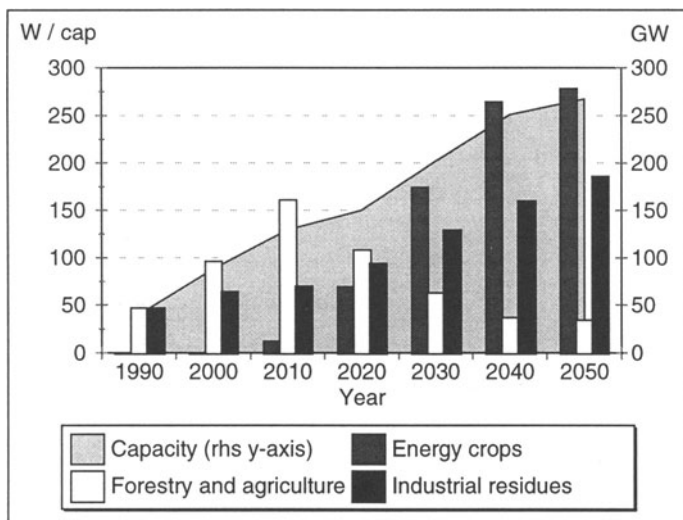


Figure 2.10 Technical potential of biomass residues and energy crops (in W/cap) as well as installed capacities of biomass installations (in GW) in the Sustainable Scenario; numerical values in Table 6.8 in the Appendix.

European Union to these countries. In return, solar energy, either in the form of electricity from solar-thermal and photovoltaic power stations, or in the form of solar-generated hydrogen could be exported to EU15. Transportation means for electricity and gas already exist today. They bridge the Straits of Gibraltar and go on to Andalusia in Southern Spain.

The projected average yield of 11 tons of dry matter per hectare used in the calculations corresponds to the average European yields for cereals. It should be noted, however, that with C4-plants, for example *Miscanthus Sinensis*, higher yields can be achieved especially in the southern countries of EU15 if the conditions for the cultivation of this type of plant are favourable (Reetz 1995).

Summary

All in all, the contribution of biomass to primary energy production will grow from 94 W/cap in 1990 to almost 500 W/cap in the year 2050.

Table 6.8 shows the projected development of the energy production potential of biotic residues from the present to the year 2050. There is a clear rise in the potential of agricultural residues to a peak of 161 W/cap in the year 2010, before they fall to a minimum of about 34 W/cap in 2050, while the potential of residues from forestry falls steadily from about 45 W/cap in 1990 to zero by the target year. In contrast, the contribution of industrial residues to the production of heat and electricity will rise from 64 W/cap in

2000 to 186 W/cap in 2050. Exhaustive exploitation of the total energy potential of available residues will only start in 2010 according to the projections of the scenario. Statistics indicate that, in 1990, about 94 W/cap worth of biomass and other residues (usually called "other solid fuels") were used for energy production in EU15. Thus, in 2050 it will be possible to cover about 220 W/cap of primary energy needs through residues from agriculture and industry.

There will be 167 000 km² of arable land left for the planting of energy crops in the target year. Assuming possible yields of 11 tons of dry mass per hectare (dm/ha), with a gross calorific value of 17.5 gigajoule per ton (GJ/t), the maximum energy output to be achieved would be 280 W/cap. Projected energy returns from this sector will rise from 12 W/cap in the year 2000 to 280 W/cap in 2050 (cf. Figure 2.10).

There are not any exact figures available from Eurostat statistics on the installed capacity of biomass plants in the countries of EU15. Future capacities needed were calculated assuming 6000 full-load hours per year for biomass plants, which is rather optimistic. Accordingly, the installed capacity of biomass conversion plants will grow from 88 gigawatt (GW) in 2000 to 267 GW in the year 2050 (cf. Figure 2.10).

2.1.8.2 Photovoltaic Technology

The photoelectric effect may be used to generate electrical current directly from sunlight. Energy conversion takes place without moving parts, and does not make any noise or produce any smell. Photovoltaic installations (PV) are emission-free during operation, require no use of land and cause little visual intrusion if integrated into buildings. Solar radiation is more abundant than any other renewable energy and represents a virtually inexhaustible power source. PV is applicable on very different scales. Small systems in the range of milliwatts are feasible as well as PV power stations with several megawatts peak capacity. Terrestrial PV systems can be categorised according to the three types of application:

- consumer goods such as watches, toys, calculators, etc.,
- remote or stand-alone systems, and
- grid-connected systems.

Stand-alone systems, which cover 2/3 of the present world market, are used in locations without access to a public grid. In this book, however, we consider grid-connected PV systems only, because these applications have the largest market share in Europe today and the largest market potential in the future. The number of PV systems that are integrated into buildings with grid connection has increased dramatically during recent years, which is mainly due to special support programmes like the German 1000-roofs programme.

Technology

Photovoltaic materials are usually solid-state semiconductors which generate an electrical potential when exposed to light. Currently, 99% of these cells are made of mono-crystalline, polycrystalline, or amorphous silicon (Baumgärtner 1994, 6). World shipments were made up, more or less evenly, of the three forms of silicon in 1990 (Wrixon et al. 1993, 66). A PV module consists of 18 to 180 solar cells which are connected and encapsulated in a sealed standard unit.

The efficiency of a PV module is calculated as the ratio of electric energy generated to the solar energy reaching its surface (standardised 1000 W/m², temperature 25 °C). In the laboratory, efficiency of mono-crystalline cells has reached about 30%. In production, however, efficiencies range from 13 to 16% for crystalline silicon and 6-9% for amorphous silicon (Eurosolar 1994; EUREC 1994b). There is a huge difference between the values for amorphous silicon cells achieved in the laboratory and in production due to the system inherent degradation during the use of these cells.

Another parameter to describe the performance of a PV system is the time of energy amortisation. Values range from 2-7 years for crystalline silicon modules while amorphous silicon modules have an energetic pay-back time of only 3-15 months (Knaupp 1995; Baumgärtner 1994; Palz and Zibetta 1992).

Most commercial PV-modules have a lifetime of at least 20 years; the maximum lifetime is up to 30 years (EUREC 1994b; DIW/ISI 1991; Staiß et al. 1994; Hohmeyer 1994). Thus, we assume an average lifetime of 25 years.

Future developments

Currently, photovoltaic installations are only economically viable for some stand-alone applications. For grid-connected electricity generation, they are far too expensive. One of the main causes for this lack of competitiveness are the high production costs of solar modules. Nevertheless, there are a number of future developments which may bring down the costs of PV, for instance, the start of mass production.

The improvement of cell efficiency will also have a strong impact on the electricity generation costs by reducing all array-related cost components, which make up a large part of the total investment. The development of module efficiency as well as the development of the efficiency of an average PV system integrated into a building is estimated to improve from today's 10.1% to 18.4 % in 2050 (Weinreich and Hohmeyer 1995).

Furthermore, the efficiency of the other system components has to be considered, especially that of the inverter. Finally, new technologies may emerge from intense R&D efforts in the field of thin film applications and other new cell materials, new production methods (for example multi-wire

saw cutting of the cells), concentrator and sun-tracking technologies, improvements in module reliability and standardisation as well as building-specific modules which combine solar-module technology and roof-sealing techniques.

Area potential of roofs and façades

In order to assess the potential contribution of photovoltaic technology to the future energy supply, the surface area available for the installation of the respective equipment has to be determined first. Considering the underlying concept of a viable future exploitation of land and soil, and the competitive edge over other forms of renewable energy, calculation of this surface area potential will be restricted to encapsulated surfaces only, that is roofs and façades of residential and non-residential buildings. Installations on open ground are given no further consideration in the scenario; again they serve as a buffer for possible additional needs.

To arrive at an assessment of the energy production potential of photovoltaic and solar-thermal installations, it is necessary to estimate the total area of appropriate roof and façade surfaces in EU15.

Using statistical methods, a German study determined the solar energy potential in one region of Germany (Mohr 1993). Among other things, the study defined the surface area potential for solar installations on buildings in North-Rhine Westphalia, differentiating between residential and non-residential buildings and between flat and sloping roofs. The study indicates a correlation between the population density of the region investigated and the roof and façade area per person exploitable for solar installations. Using this correlation and population data of EU15, the potential of roof and façade surface area for the whole Union was calculated.

The analysis was carried out with a regional resolution of the individual countries, taking into account north-south distribution patterns of flat and sloping roofs within Europe. The increase in potential roof and façade surface area resulting from new residential buildings was considered via a factor derived from future projected and currently available living space. This factor does not take into account a different, possibly denser, residential building style, but assumes that the relationship between solar-technically exploitable areas on the building surface and the living space inside the building will remain the same as today. Accordingly, the surface area theoretically available for solar installations in EU15 amounts to about 5 600 km² of roof area and about 4 300 km² of façade surfaces. This gross potential surface area is reduced through module frames, support structures and structures to attach the modules to the buildings, leaving a future net potential of 5 300 km² of collector or module surface on roof tops and a further 3 900 km² of façade surfaces. To be on the safe side, only 30% of the potentially available and exploitable roof and façade surface area will be em-

ployed for the photovoltaic production of electricity in the Sustainable Scenario by the year 2050.

The photovoltaic industry

Exploitation of the large potential of photovoltaic technology will require a new branch of industry to deal with the processing of enormous quantities of glass and silicon. For this reason, the production volume of the non-metal minerals branch is expected to remain at the same level as at present, while the volume of glass production will increase by 20% by the year 2050 (cf. Sec. 2.1.2).

Summary

Under the assumptions made above, a contribution of 23 W/cap from photovoltaic (PV) technology can be expected from the year 2010 on. In the years following, the feasible supply of electricity from PV modules will rise to 153 W/cap in 2050. In the Sustainable Scenario, a large scale introduction of this technology is projected, starting in the year 2000. Figures on installed capacities for the individual countries are calculated from the amount of electrical energy produced and the hours of sunshine per year. To reach the projected capacity per capita in the target year, 2 770 km² of module surface with a capacity of 405 GW will have to be built (cf. Figure 2.11).

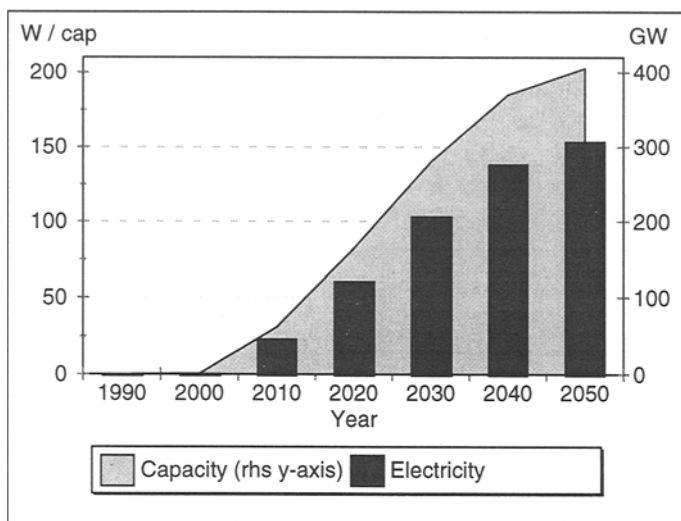


Figure 2.11 Electrical energy produced by (in W/cap) and capacity installed (in GW) of photovoltaic installations in the Sustainable Scenario; numerical values in Table 6.9 in the Appendix.

2.1.8.3 Solar-Thermal Heat Production

Solar-thermal technologies can in principle be used for a number of applications such as water heating, low-temperature water heating in swimming pools, space heating in buildings, space cooling in buildings, process heat for agricultural purposes, or process heat for industry. However, costs and applicability of solar-thermal heat technologies vary substantially among these applications.

Technology

The general design of a solar-thermal system features a solar collector absorbing solar radiation which is connected to a heat distribution system that is transporting a working fluid either to a heat storage or directly to the respective application.

The standard design of a solar collector for the production of warm or hot water is either a glazed tube which is sometimes evacuated or a flat plate absorber under a glass cover. Some collectors have surfaces that select some of the different wavelengths of incoming radiation, thus increasing the collector's efficiency. Unglazed absorbers, made of polypropylene panels or rubber tubing, may be applied economically for heating outdoor swimming pools.

Domestic hot water systems in Southern Europe are usually designed as so-called thermosiphon systems, in which the working fluid circulates only due to temperature differences.

Exploitation in the scenario

For solar-thermal exploitation of the sun's energy in the low-temperature heat class ($< 100\text{ }^{\circ}\text{C}$), the scenario envisages the availability of 50% of the total roof and façade potential of building surfaces in EU15, the other 50% being reserved for photovoltaic installations. Thus, there is an area of $2\,650\text{ km}^2$ available for the installation of solar collectors. Thermal insulation measures or passive solar systems can be applied to façade surfaces, which will primarily help to reduce the heating requirements of the building. These gains through solar power will not be specified here (Lehmann 1996).

Low-temperature heat produced by solar collectors on the roof surfaces calculated can be used for two purposes in the scenario: to heat water in residential buildings and to provide auxiliary space heating, that is to say, act as a substitute for the conventional energy sources used for heating. Solar heat will be used in the following way: In 2050 80% of the hot water demand of the population will be met through solar collectors. The remaining roof surface will be used for auxiliary heating, assuming a system efficiency of 50%.

To quantify the contribution of solar energy to auxiliary heating, data from a study on the potential of renewable energies in the EU were used, providing specific values for the substitutable heat in kilowatt-hours per square meter of collector surface installed (kWh/m^2). According to this study, it will be possible, for example in Germany, to provide some 126 kWh of heat per year for each m^2 of collector surface for auxiliary heating (Lehmann and Balters 1995).

In spite of exploiting 50% of the roof surface potential, only 50% of the heating requirements for buildings (hot water and space heating) in the Northern and Central European member states of the Union will be covered through active exploitation of solar energy in the year 2050. In contrast, in the southern member states solar collectors on the roofs of residential buildings will be able to meet the entire demand for domestic heat in the low-temperature class in 2050. In these countries, there will even be enough remaining surface area (approx. 450 km^2) to install absorption cooling devices or additional photovoltaic arrays. Altogether, an energy yield of 326 W/cap can be attained from solar collectors by 2050, if $2\,200 \text{ km}^2$ of collector surface with a performance of more than 900 GW have been installed by then (cf. Figure 2.12). In 1990, about 0.6 watt per capita (W/cap) of heat were produced by 3 km^2 of collector surface in EU15 (Eurostat 1995; TN 1992). Installed capacities were calculated from the annual volume of heat produced and the hours of sunshine per year.

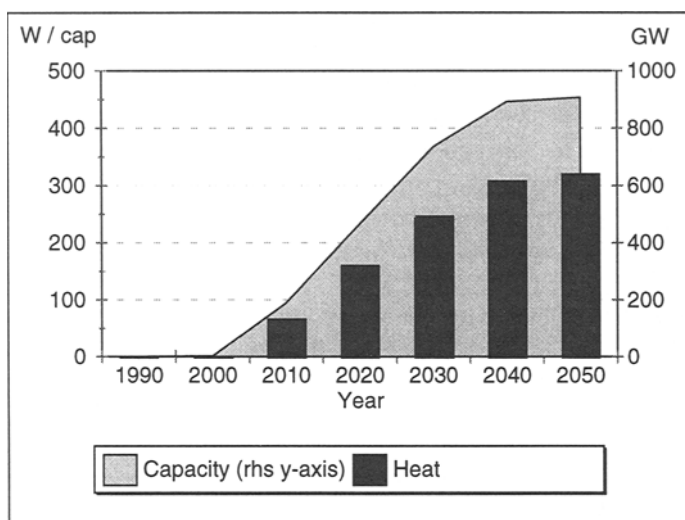


Figure 2.12 Heat produced by (in W/cap) and capacity installed (in GW) of solar-thermal collectors in the Sustainable Scenario; numerical values in Table 6.10 in the Appendix.

2.1.8.4 Solar-Thermal Production of Electricity

One option for meeting the electricity demand in Europe is to generate electricity in Southern Europe through solar-thermal power plants. Surplus electricity, generated at low costs by these technologies in Southern Europe or North Africa, can be transmitted to Central and Northern Europe via high-voltage DC power lines.

Technology

Thermal exploitation of solar energy for the production of electricity requires a high density of irradiation and optical concentration of the sun-rays on a heat-transfer medium. The latter is heated up to the temperature required by the direct radiant energy of the sun. Five technologies for solar-thermal electricity generation are considered:

- Parabolic trough solar-thermal plants with one-axle sun-tracking technology;
- solar-thermal tower plants with two-axle mirrors for sun-tracking, focusing on a central receiver;
- dish/ Stirling engine power plants with parabolic mirrors and two-axle tracking where several small units (10-50 kW_p) are put together,
- anabatic wind power plants and
- photovoltaic power plants (which are considered here rather than in the previous section because they are more like the other central power stations than like building-integrated PV systems).

Today, commercially operated solar-thermal power stations in California provide electricity at a price of 0.07 ECU/kWh using 25% fossil fuel co-firing. As a further reference, central power plants in the range of 100-200 MW_p in Southern EU countries and Northern Africa are taken into account. The annual average for solar energy in Southern Spain – the most promising region – is 1 800 kWh/(m²a). We assume a yield of 2 300 kWh/(m²a) for the reference place in Northern Africa. Smaller plants or building-integrated systems may be used for local and regional electrification. The potential of these technologies is limited even in the Southern EU due to competing land-uses.

Due to climatic conditions, power stations of this kind can only be operated profitably in Southern Europe. The following figures for the use of solar energy for electricity production thus solely refer to the Southern European countries Greece, Italy, Portugal and Spain. Competition for land between power stations of this kind and biomass cultivation is not an issue, since no fertile land is being sealed. The arid areas needed for the installation of solar-thermal power stations and their respective potential were estimated in a study by the German Aerospace Research Centre (Deutsche Forschungsanstalt für Luft- und Raumfahrttechnik) to be about 1 400 TWh/a

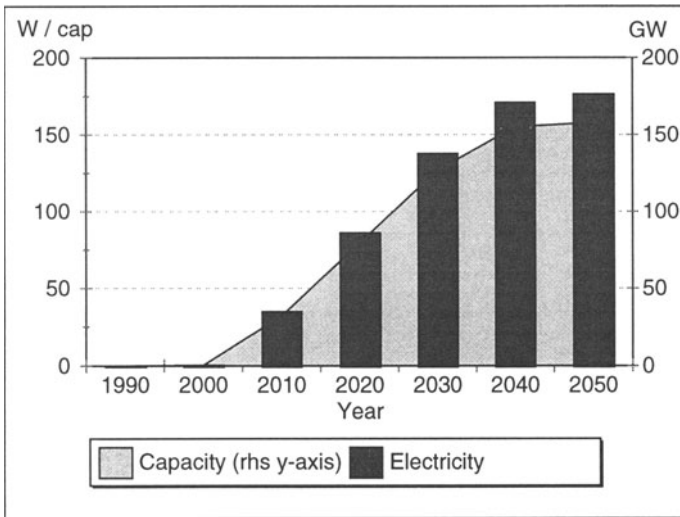


Figure 2.13 Electrical energy produced by (in W/cap) and capacity installed (in GW) of solar-thermal power plants in the Sustainable Scenario; numerical values in Table 6.11 in the Appendix.

(i.e. 440 W/cap) of electrical energy. The study concentrated on the evaluation of arid areas which have good infrastructure connections (power lines, roads, etc.) and where little ecological damage through the installations is to be expected. It is assumed for this scenario that about 40% of the technical potential can be exploited by the year 2050, corresponding to 177 W/cap of electricity (cf. Figure 2.13).

A further assumption is that large scale production and installation of solar-thermal power stations will begin in suitable areas of Southern Europe in the year 2000. Performance has been calculated under the assumption that, equipped with thermal reservoirs, the plants will be able to produce electricity for a full operational year of about 3 600 hours (Klaiss and Staiss 1992).

2.1.8.5 Wind Energy

Technology

The kinetic energy of the wind that can be converted into mechanical energy is a function of the rotor surface exposed to the air-flow, the air density and the difference in wind speed in front of and behind the rotor blade. The energy conversion process is governed by the respective aerodynamic, mechanical and electrical efficiencies of the individual wind turbine. A generator converts the mechanical energy into electrical energy, which is then

transmitted by the electricity grid. Rotor and generator are controlled by and adjusted to each other.

Wind turbines can be classified according to several technical criteria, the most important ones being the axis of rotation (horizontal or vertical axis machines) and the size (indicated by the nominal capacity installed in kilowatts (kW_p) or the rotor diameter). The most common design is a horizontal axis machine with three blades and a rotor diameter of 30-35 m. These machines generally consist of a rotor hub with blade pitch mechanisms, rotor brake, gearbox, electrical switch box and control, generator, yaw system for adjusting the nacelle of the wind turbine to the current wind direction, tower and foundation, and grid connection including the transformer.

Modern wind turbines are highly sophisticated machines built on aerodynamic principles, incorporating advanced materials (i.e. fibre-reinforced plastics for the rotor blades) and electronics. They are designed to produce electric energy at different wind speeds (3-25 m/s) and to withstand stormy weather. Electricity is generated with a load factor of generally 25-35%, which describes the ratio of the actual amount of electricity generated to the electricity which could be generated at full load conditions all year round.

For economic and practical reasons large scale electricity generation requires a number of machines to be grouped together in a windpark. Off-shore applications will most likely be in large wind parks to minimise grid connection and maintenance costs. They do not require any major technical modifications except for a stronger foundation.

In 1990, some 500 MW of wind turbines were installed in EU15. The capacity increased to about 2 700 MW in 1995, of which 900 MW were installed in that year alone. Currently, the wind energy market is dominated by 500-800 kW wind-energy generators, but machines larger than 1 MW are entering the market in small numbers. Presently, two large Danish wind-parks with 80 1.5 MW machines are planning to go into operation no later than 2008.

Improved aerodynamic design and control mechanisms lead to an increase in turbine efficiency. The average tower height will increase (5 to 10 meters) slightly for better utilisation of the wind resource. Generator, gearbox, and grid connection are already of a high standard and only slight improvements can be made. Reliability of today's commercial turbines is already good (> 95%) and will increase only slightly whereas the reliability of machines with capacities beyond 1 MW will increase substantially from today's 80% to more than 95% in 2020.

Exploitation in the scenario

Several assessments of the wind energy potential have been made for regions of the European Union. In the Sustainable Scenario, we use the on-shore potential assessment made by the European Wind Energy Association

(EWEA), and a study on the off-shore potential conducted by "Germanische Lloyd". Both studies are based on the geographical area of the member states of EU12, that is without Finland, Austria, and Sweden. Data from other sources are used for the Scandinavian countries, Finland and Sweden (Lund and Peltola 1991). No literature data were available for Austria.

According to the EWEA study, the technical potential of on-shore wind energy installations amounts to 365 TWh/a or 113 W/cap. This figure was estimated by taking into account all zones that have wind speeds of more than 5 meters per second (m/s) according to the European Wind Atlas. The technical potential was defined as 30% of the total capacity which can theoretically be installed in this area. This rather rough assessment is supported by a regional survey within the European Union (EWEA 1991). Applying very stringent ecological criteria, another assessment puts the on-shore wind energy potential in the EU and Sweden at about 160 TWh/a (Grubb and Meyer 1993). This figure represents a standard for an ecologically sensible exploitation of on-shore wind energy potential in the Sustainable Scenario. Consequently, it is assumed that 45% of the technical on-shore potential calculated by the EWEA will be exploited in EU15 by 2050 (cf. Figure 2.14).

The off-shore exploitation of wind energy, that is in coastal waters, has been subject of discussion for years. The advantages are obvious: wind speeds over water are higher, resulting in a better energy yield, and space for

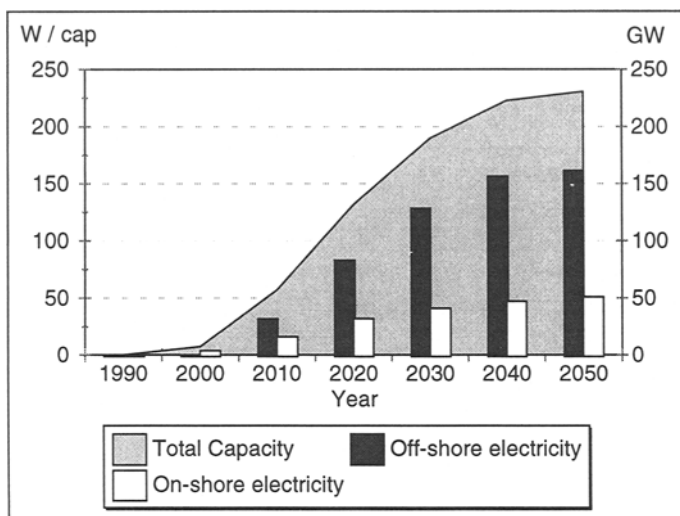


Figure 2.14 Electrical energy produced by (in W/cap) and capacity installed (in GW) of wind-energy converters in the Sustainable Scenario; numerical values in Table 6.12 in the Appendix.

the installation of wind turbines is abundant. On the other hand, there are disadvantages like high investment costs and difficult access for installation and maintenance. The Germanische Lloyd study estimates the off-shore technical potential of wind energy in waters with a maximum depth of about 50 m and 30 km off the coast at about 3 000 TWh/a or 940 W/cap for the countries of the EU (Garrad et al. 1993). This calculation excludes waters belonging to shipping routes, restricted military waters, waters belonging to nature reserves, and waters with other uses (oil platforms, gas and oil pipelines, as well as underwater electricity cables). In the Sustainable Scenario, only 17% of this potential will be exploited by 2050. At that time, wind energy, on- and off-shore, will provide about 212 W/cap of electricity (cf. Figure 2.14). For the calculation of the installed capacities, it is assumed that 2 000 full-load hours are feasible on-shore and 3 500 hours off-shore (EWEA 1991; Garrad et al. 1993).

2.1.8.6 Hydropower

Hydropower utilisation is a form of renewable energy exploitation that was already known some thousand years ago. It was used for all kinds of milling purposes by converting hydro energy into rotational energy. At the turn of this century hydropower started to be used for electricity generation. Since then, the number of hydro-electric schemes operated in the EU has increased. Currently, hydropower is the renewable energy source with the largest share in energy-supply systems. In Europe, 95% of the potential large hydropower sites within reasonable distance to the electricity grid are already being exploited (IT Power et al. 1995). Therefore, we only consider additional small hydro-electric schemes in this study, which are defined as having a capacity of less than 10 Megawatts. The technical devices for converting the potential and kinetic energy of the water into rotational energy (turbines) and further into electrical energy (generators) are well developed. Consequently, there is not any large potential for cost reductions.

Technology

Hydro-electric sites can be divided into running water, diversion, and storage sites, the first two of which are most common for small hydro schemes. Storage sites are viable when energy production is combined with other purposes like irrigation or municipal and industrial water supply or when old sites are being rehabilitated. Storage sites are more viable for large scale hydropower plants. However, the principles of operating small-scale and large scale hydropower plants are basically the same. A scheme consists of the following items (ETSU 1994, 59f):

- a suitable rainfall catchment area,
- a hydraulic head,

- a water intake placed above a weir or behind a dam,
- a method for transporting the water from the head to a turbine,
- a flow control system,
- a turbine, a generator, associated buildings and grid connection,
- an outflow, where the exhaust water returns to the main flow.

Low-head schemes use Kaplan, Francis and straight flow turbines which are chosen from a range of standard sizes whereas turbines for large scale schemes are custom-made for the site. Efficiencies of turbines alone reach up to 92%, but depend on the cost. System efficiencies of hydropower plants lie between 60 and 85%, depending on the efficiencies of the turbine, generator and transformer as well as the density of the water, and the useful water quantity and height (IT Power et al. 1995, CEC 1994).

Future developments will include turbines with a variable speed, which can improve efficiency by 3 to 4% due to optimal adjustment of the machinery to the actual water flow. The other main technical devices are already well developed.

Exploitation in the scenario

The technical potential of small hydropower stations (with capacities of less than 10 MW) in the EU has only been exploited to about 20-25% so far. Thus, we assume that 90% of the unused potential will be exploited by

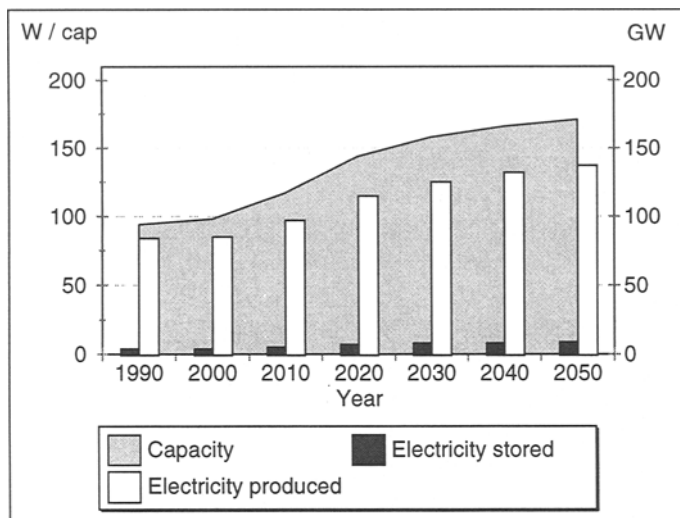


Figure 2.15 Electrical energy produced and stored by (in W/cap) and capacity installed (in GW) of hydropower plants in the Sustainable Scenario; numerical values in Table 6.13 in the Appendix.

2050. Altogether, electricity production from hydropower will rise from the current 84 to 137 W/cap in 2050 (cf. Figure 2.15). Moreover, additional storage power stations will be built and will provide an energy volume of 9 W/cap by 2050. It is assumed that this additional hydro storage system is derived from hydropower plants which are converted into storage plants. In all, hydropower capacity will have expanded to 171 GW in 2050 (Bräuer 1996a, 1996b).

2.1.8.7 Solar Architecture and Heat Pumps

In the Sustainable Scenario, solar-architectural components of buildings are *not* regarded as contributing to the energy supply, but as a technology which reduces the heating requirements of the building. Therefore, no energy supply figures are given here. The technology was, however, taken into account in the reductions in the projected domestic heat requirements (cf. Sec. 2.1.3) and in the assessment of active solar-thermal systems integrated in houses (cf. Sec. 2.1.8.3), where 1 950 km² of façade surfaces that can be exploited via solar technology were not considered for active solar-thermal elements, but were reserved for passive solar technologies.

Heat pumps make use of environmental heat by exploiting the otherwise useless low-temperature heat in the ground water, soil, or air. The advantage of heat pumps lies in the fact that the largest share of the heat supplied to an

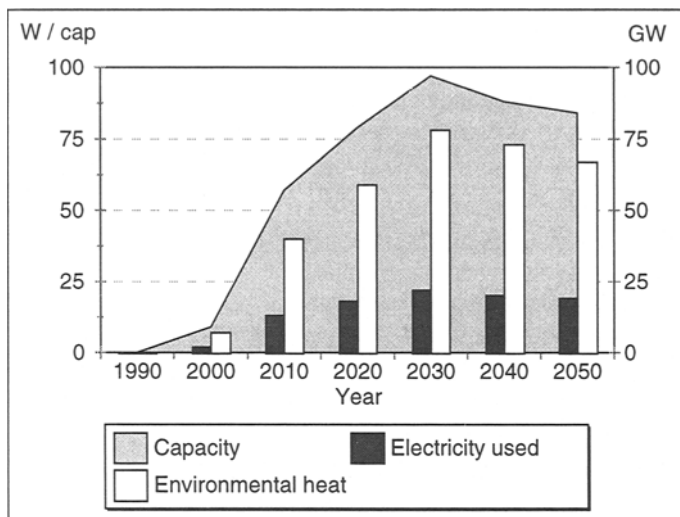


Figure 2.16 Environmental heat and electricity used by (in W/cap) and capacity installed (in GW) of electrical heat pumps in the Sustainable Scenario; numerical values in Table 6.14 in the Appendix.

application is not contributed by the energy driving the pump, but is gained from the heat reservoir. Only a relatively small amount of high quality energy in the form of chemical fuels or electricity is necessary to operate a heat pump.

The main components of a heat pump are similar to those of a refrigerator, namely a motor driven compressor and an evaporator. For heating purposes, heat pumps work in the opposite way than refrigerators. Sensible heat outside a building is used to evaporate a working fluid which gives off latent heat by condensing inside the building to be heated. Sufficient heat sources outside the building include ambient air, soil, or ground water.

In the Sustainable Scenario, 86 W/cap of heat will be supplied by heat pumps in 2050 (cf. Figure 2.16). Assuming a ratio of heat supplied over high-quality energy used (performance index) of 4.0 to 4.5 in 2050 will result in a net yield of 67 W/cap from the air, water or soil. The remaining 19 W/cap are exclusively supplied by electrical heat pumps in the scenario. Installed capacities are assessed on the basis of the performance index, population figures, and an assumed 2 000 full-load hours per year. After 2030, the installed capacity of heat pumps will decrease, because of the declining energy demand for space heating.

2.1.8.8 Storage of Heat and Electricity

The use of biomass as a back-up for intermittent energy sources is limited, since back-up systems require considerable investments, transportation of biomass is comparatively expensive, and the potential of biomass varies substantially over Europe. Consequently, a European energy system mainly based on renewable energies requires different forms of energy storage to smooth the seasonal availability of solar-thermal technologies. In general, heat can be stored as

- sensible heat,
- latent heat, and
- via reversible thermo-chemical reactions,

the latter reaching the highest energy densities, but requiring active management of thermo-chemical reactions and flows of sensible heat. The resulting chemical energy can be stored and transported without losses. Although the opportunities seem to be promising and applications can be found in some niches, it has so far remained a subject of research.

The storage of latent heat is based on the different energy levels of the solid, liquid and gaseous phases of each substance. For small temperature differences, the energy density may be 10 times higher than for storage of sensible heat. The loading and unloading processes require considerable effort due to the fact that several media are involved and that input and output temperatures have to be kept within small intervals. On the other hand,

this has the advantage of constant efficiency during the loading process. Storage of latent heat is only on a small scale state-of-the-art technology and there is a great need for additional research and development.

The energy density that can be reached for storage of sensible heat depends on the specific heat capacity of the storage medium. Due to its known and favourable properties as a storage medium, water has gained renewed attention during recent years, especially for seasonal heat storage. For the purpose of room heating, water is stored in insulated steel tanks, earth pits, rock caverns, and aquifers. Heat may also be stored directly in soil, clay, or rock. High-temperature storage applications for industrial processes typically have storage intervals of several hours. Homogenous stores employ a liquid storage medium like oil, whereas heterogeneous stores use a solid storage medium and a liquid transport medium.

Storing electrical energy poses a major problem. Directly, it can only be kept in capacitors or superconducting toruses; both methods involve large losses and high costs. It is usually easier to store other energy forms from which electrical energy may then be easily produced, i.e.

- mechanical energy in pumped storage or flywheels,
- chemical energy in batteries and chemical fuels, and
- thermal energy in the form of sensible or latent heat.

The most commonly used technologies are pumped storage and batteries. The former have an efficiency of about 80 percent. Hence, storage costs depend not only on investment costs and loading-unloading frequencies, but also on the costs of the electricity lost.

2.1.8.9 Conventional Fuels

Based on the definition of a viable future energy system elucidated in Sec. 2.1.1, renewable energies and energy efficiency will be given priority in the Sustainable Scenario. Consequently, conventional energy sources are only applied to fill the gaps left in the energy supply. To determine the relative contributions of the various fossil fuels to the total energy supply of EU15, the following assumptions are made:

Fuels with a low carbon content are given preference, thus, leading to a ranking of natural gas, mineral oil, hard coal and lignite. The definition of a viable future energy supply is not compatible with the use of nuclear energy. Thus, in the Sustainable Scenario nuclear energy is phased out by the year 2010. As a consequence, demand for conventional fossil fuels will rise to 4 310 W/cap in the year 2000. This will also be due to the developments in the transport sector described in Sec. 2.1.6 and to the fact that efficiency improvements in the other sectors will not start until the year 2000. Thus, the demand for natural gas will continue to rise until 2010. Altogether, however, there will be a reduction in the use of conventional carbon-based fuels

from 3 760 W/cap in 2000 to 3 350 W/cap by the year 2010. This will be due to the progressive use of renewable energy sources for the production of electricity and heat, and to the application of more efficient technologies. In the year 2050, only 82 W/cap of conventional fuels will be used, exclusively in the transport sector (cf. Figure 2.17 and Table 6.15).

2.1.8.10 *The Future Energy System of EU15*

In the Sustainable Scenario, consumption of primary energy is brought down from the 4 500 W/cap in 1990 to 1 700 W/cap in the year 2050, which corresponds to a reduction of primary energy input of 63%. Of the remaining energy demand, 95% are covered by renewable energy sources and only 5% are still covered by fossil fuels, namely oil products for the transport sector. In 1990, the ratio was the other way round. The whole development of the energy system is summarised in Figure 2.17, Figure 2.18, and Table 6.8 to Table 6.15. The resulting energy system in 2050 is shown in Figure 2.19.

The energy consumption will peak in the year 2000. Conventional fuels, with the exception of natural gas, will decrease constantly, while contributions from renewable energies will rise steadily. Consumption of coal and natural gas will fall to zero by 2050, although it should be noted that even after 2050, steel will continue to be manufactured, and, at least for this sector of industry, a certain amount of coal will still have to be supplied. How-

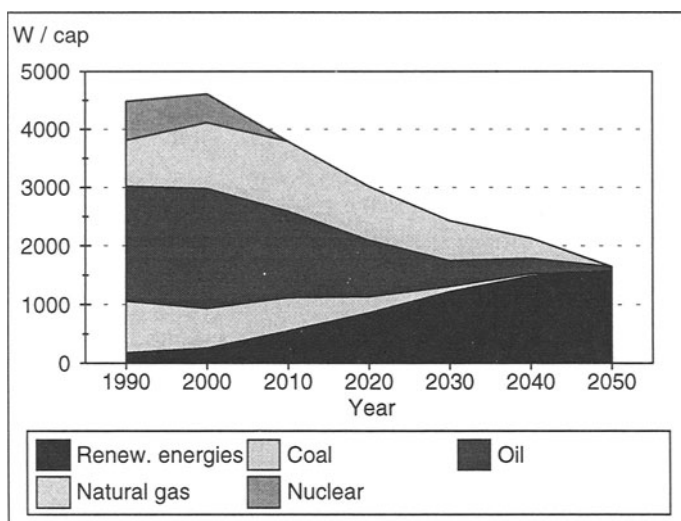


Figure 2.17 Phase-out of fossil and nuclear energy in the Sustainable Scenario; numerical values in Table 6.15 in the Appendix.

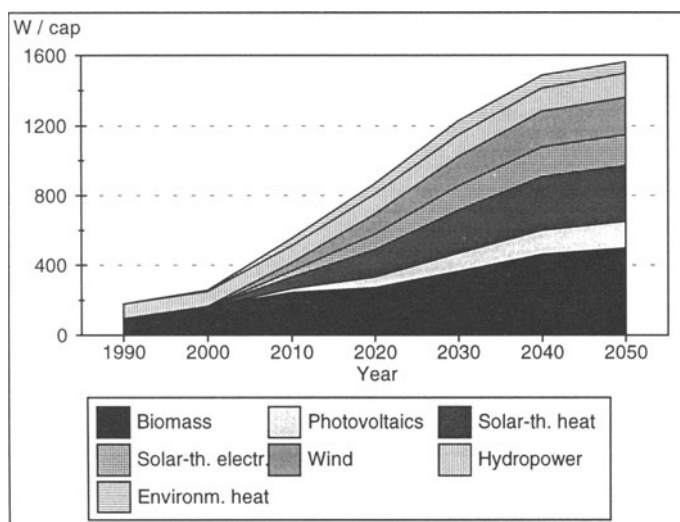


Figure 2.18 Phase-in of renewable energies in the Sustainable Scenario; numerical values in Table 6.8 to Table 6.15 in the Appendix.

ever, since it is the energy consumption of the EU15 which is being discussed here, no further details will be given on this matter. The use of mineral oil will shrink to only a small portion of primary energy consumption, and this will be exclusively in the transport sector.

The increase in the use of renewable energies necessary to meet the target of a 95% coverage of the total energy demand by 2050 amounts to about 3.6% per year. This growth rate does not seem too high in comparison to the findings of another study on the European area. In that study, commissioned by Greenpeace and conducted by the Stockholm Environmental Institute (SEI), a long-range scenario up to the year 2100 was proposed (Lazarus et al. 1993), in which by 2030 a 60% coverage of primary demand through renewable energies within the EU was projected, corresponding to an energy content of 32 exajoule ($1 \text{ EJ} = 10^{18} \text{ J}$). In the Sustainable Scenario, an energy contribution from regenerative sources of about 18 EJ (1500 W/cap) is targeted for the same year (2030). Thus, SEI's study envisages growth rates for renewable energies that are almost twice as high. A German study calculated that, in order to achieve a viable future development, an annual growth rate for renewable energies of 5% per year until 2050 will be necessary (Wuppertal Institut 1996).

Realisation of the Sustainable Scenario would bring about radical changes in the energy system of the European Union. As more electricity from intermittent energy sources such as wind energy or solar radiation is fed into the power distribution networks, considerable fluctuations may occur.

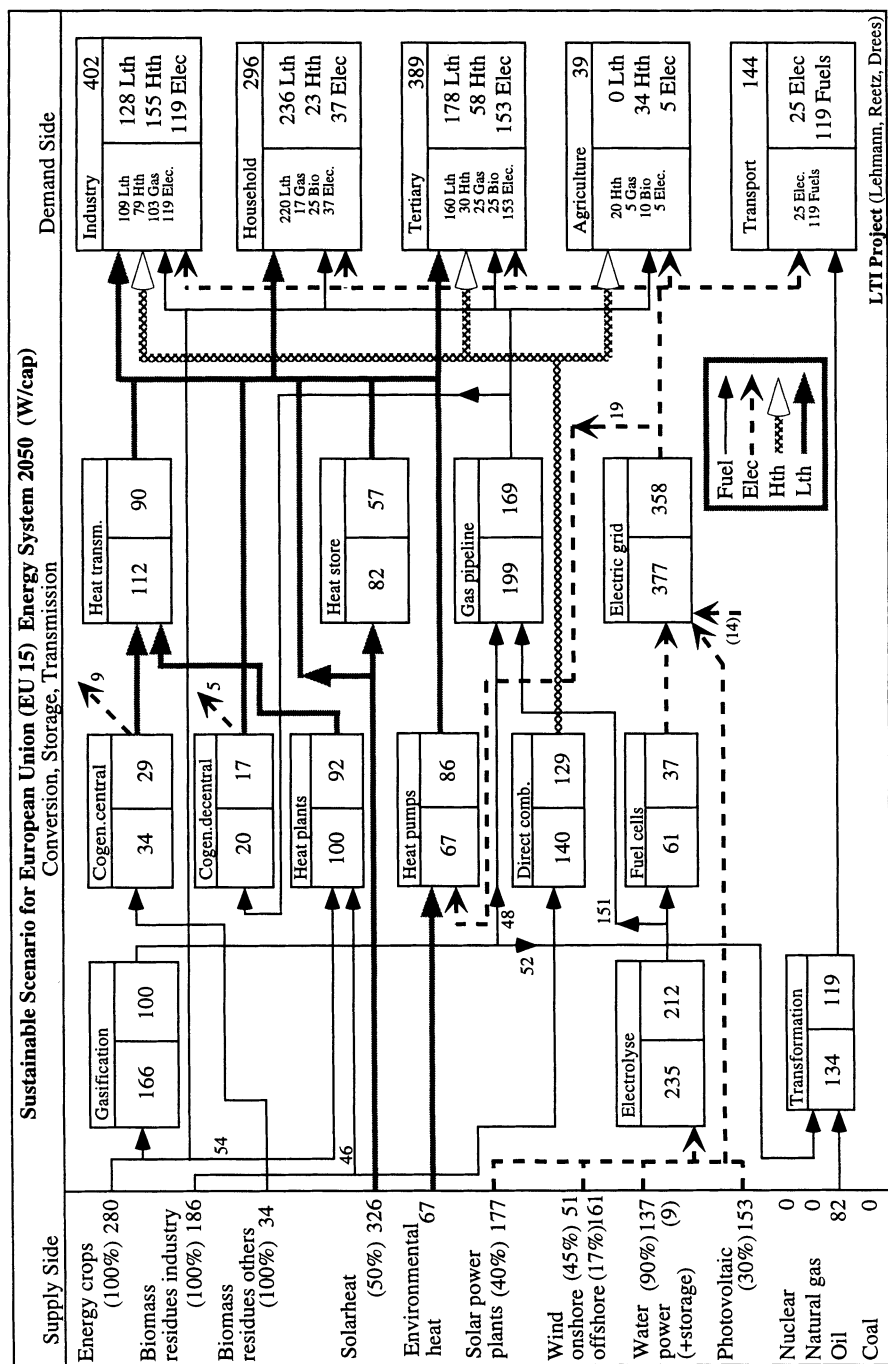


Figure 2.19 The energy system of the Sustainable Scenario in 2050. Figures in brackets on the supply side indicate the share of the technical potential used.

Therefore, a back-up system will be needed to feed power into the electricity network at times when wind and/ or photovoltaic installations are not sufficiently available. The volume of such contingency energy will increase as the relative contribution of intermittent sources to the total energy production grows. In 2010, wind and solar power will be supplying about 106 W/cap, or 19% of the total electrical demand. It is assumed, that 30% of the total annual production of intermittent sources will be additionally provided by a back-up system in order to ensure a secure supply of electricity. This energy will come from hydro-storage power stations and cogeneration units. Part of the back-up system will be run by hydrogen, produced by electrolysis of water. Today the efficiency of water splitting reaches 75% for the best electrolysis technology. The Enquete Commission of the German Bundestag pointed out that electrolysis could reach an efficiency level in the range of 80 to 94% after 2025, which refers to the lower heating value of hydrogen (Enquete 1991). For our scenario, we assume an efficiency level of 90% for water splitting. In 2050, approximately 80% of electrical energy consumption will be met by wind and solar power. Back-up requirements included in the calculations will reach some 40% of the peak load. Modern power management facilities should be available by then to avoid peak loads when the supply of renewable energies is low.

Solid residues from industry or agriculture will be combusted in more centralised plants to cover part of the demand for high and low-temperature heat in the different sectors. In these centralised installations, exhaust gas cleaning technologies with high efficiencies may be applied. Biogas is used directly in cogeneration facilities to produce both heat and electricity. Low-temperature heat produced by centralised cogeneration plants and heating plants has to be transmitted by hot water pipelines with heat losses, which are of course taken into account in the scenario. Heat produced by decentralised cogeneration facilities with small capacities in individual houses does not require central heat transmission grids.

The large proportion of photovoltaic and solar-thermal collectors resulting from rigorous exploitation of exploitable roof and façade surfaces, and a similar predominance of cogeneration units and heat pumps lead to a high degree of decentralisation in the future energy system. This underlines the ideas of regionalisation and fits in with the social changes discussed in Sec. 2.1.1.2.

2.1.9 Critical Assessment of the Sustainable Scenario

The scenario description and the discussion of the results in the previous sections demonstrated that an energy system which is primarily based on renewable energies is a conceivable proposition. The task of a sensitivity analysis is to further elucidate the probability and speed of the application of

energy efficiency improvements on the demand side and of the introduction of renewable energy technologies on the supply side.

Concerning energy efficiency, an average decrease in the energy demand of 1.6% per year over the whole time horizon of the scenario – that is 60 years – is assumed for all economic sectors and countries of EU15. Compared to the current increase in energy productivity of 1% per year in the industrialised countries, the projected development appears significant, but certainly feasible. On the other hand, the countries of the European Union have a growth rate of the gross domestic product (GDP) of about 2.8% per year (Eurostat 1994). If the existing increases in efficiency were balanced against the increase in the gross domestic product, little would actually change in terms of the development trends in total energy consumption. Previous developments in energy consumption show that the gains through rational use of energy have been more than counter-balanced by the increased consumption largely resulting from economic growth. Thus, energy consumption would continue to grow and follow an opposite trend compared to the desired development.

The Sustainable Scenario may be described as a dematerialisation scenario with qualitative growth. However, the relationship between economic growth and energy consumption was intentionally excluded from the description of the scenario, since it does not make sense to describe the economic development of a future sustainable society with the criteria of the present economic world. Economic growth as measured by GDP has often been criticised as a misleading indicator. If at all, it is valid for the current economy, but certainly no longer a meaningful parameter in a sustainable economy. Alternative methods need to be established to ensure valid comparisons – a task which is certainly beyond the scope of this study, but which may be a rewarding field for further research.

The situation is similar when it comes to the potential costs of renewable energy systems. It is precisely the higher costs of these technologies compared to conventional energy transformation technology that create an inhibiting barrier to their introduction, a threshold which must first be overcome. When constructing the scenario, such economic considerations were also intentionally left out of the discussion. Economic impacts will, however, be discussed in the next section. Thus, the introduction of renewable technologies is prescribed normatively in the Sustainable Scenario and endorsed through a change in social values. This shift in terms of values will have to be supported and promoted through legislation. Possible instruments range from economic incentives (e.g. an ecological tax reform) to regulations (e.g. thermal insulation regulations for buildings) and to standardisation. This social change is not an argumentative construct of the scenario, but a continuation of an already emerging re-orientation of social values. For instance, the number of farms using ecological methods grew from about

500 in 1980 to well over 5 000 in 1995 in Germany alone. This demonstrates the increased turnover in and the growing demand for ecological farm products (Hamm 1995). The same development can be seen in various fields of renewable energy technology. For example, the installed capacity of wind energy converters increased over a period of 10 years (1982 to 1992) from 26 MW to 930 MW, an almost exponential rate of growth (Nacfaire and Naghten 1994). This kind of development can also be found in Germany, where the annual rate of newly installed capacity of wind energy amounted to about 40 MW in 1990, 70 MW in 1992, 155 MW in 1993, and 480 MW in 1995 (DEWI 1995 and 1997; cf. Figure 4.1). Another relevant aspect of this particular example is the fact that wind energy conversion in Germany is promoted through official support programmes and through established buy-back arrangements for electricity from regenerative sources. All of this suggests that the development of the other renewable energy sources described, e.g. photovoltaic technology, is also feasible if favourable conditions are created. In the Sustainable Scenario, we assume a growth rate for regenerative energies of 3.6% per year, while various national and international studies demand higher growth rates. It should also be noted that, according to the projections of this scenario, only about 60% of the total estimated technical potential of regenerative technologies will be exploited by the year 2050. The calculation of the technical potential was done under very strict ecological constraints. Under less stringent constraints, the respective potential, especially for biomass, is much larger. Solar-thermal power stations and off-shore wind parks, in particular, have only been included in the projection to a fraction of their full technical potential. This means that, even if efficiency developments do not follow the predicted tendencies, primary energy demand can theoretically exceed the envisaged demand in the scenario by more than 1 000 W/cap without endangering the basic conclusion of the study, namely the feasibility of meeting the total energy needs of EU15 from regenerative energy sources.

A consistency check performed with an hour-by-hour simulation model showed that the scenario has a potential problem supplying sufficient low-temperature heat in winter (Sørensen 1996). This is due to the higher demand and lower insolation during that time of the year and may be tackled either by introducing seasonal heat storage or, in the worst case, by supplying the lacking heat by fossil fuels. An additional model run revealed that adding some 450 W/cap would solve the problem. Nevertheless, this additional supply of conventional fuels will not compromise the original objective of reducing CO₂ emissions by 80% (cf. Sec. 2.2.3). Other measures apart from using fossil fuels remain possible. More hydrogen and biomass-derived fuels could be produced and dwellings could be even better insulated. The capacity of photovoltaics could be reduced, since there is an electricity surplus in summer. Thus, roof area for additional solar-thermal instal-

lations would be freed, which, in turn, may also require additional heat storage capacity. However, the consistency checks underline that building codes are one of the crucial bottlenecks for the success of any attempt to improve the European energy system.

2.2 Economic and Environmental Impacts

So far, the Sustainable Scenario represents a conceivable technical path of introducing energy efficiency measures and renewable energy technologies into the European energy system to a degree which will help to mitigate global climate change. The question remains, what economic and environmental impacts are caused by the restructuring of the energy system:

- What are the costs of integrating renewable energy technologies?
- What are the impacts on employment?
- To what extent are CO₂ emissions reduced?

2.2.1 Costs of the Future Energy System

The Sustainable Scenario for a future European energy system described above is to a large extent based on the introduction of energy efficiency measures, which will reduce the energy demand by more than 50%. However, such measures are hard to describe as parts of the energy system. Often, one cannot distinguish between the part of the investment which should be attributed to the original purpose of a good and the share that should be accounted for as cost of energy saving. In addition, obtaining data on the future cost of energy efficiency measures on a European level proved to be beyond the scope of the LTI-Project. Therefore, we restrict our analysis to the cost of the future energy-supply system, which will be primarily based on renewable energy technologies in 2050.

2.2.1.1 Review of the Cost of Renewable Energy Technologies

Our cost evaluation comprises three categories, namely

- specific investments measured in ECU per kilowatt peak capacity installed (ECU/kW_p),
- annual costs, which are composed of annual capital costs (annuities) plus fixed operation and maintenance costs (O&M costs) measured in ECU per kilowatt peak capacity per year [ECU/(kW_p·a)], and
- production costs measured in milli-ECU per kilowatt-hour of energy supplied (mECU/kWh).

The investments in renewable energy technologies, which will be necessary during the transition phase from 1990 to 2050, are calculated as annual capital expenditure. Therefore, the additional capacity of each technology

installed per year or period is multiplied by the specific investment cost of the respective year or period. The total investment derived is evenly distributed over the whole lifetime of the equipment of N years by multiplying it with the *annuity factor* $(1+r)^N \cdot r / [(1+r)^N - 1]$, where r is the interest rate. Finally, production costs – measured in mECU/kWh – are examined which comprise variable costs such as fuel costs in addition to the fixed cost components considered so far. While most renewable energy technologies have high fixed costs and low variable costs, this is different for biomass where fuel supply contributes substantially to the full production costs. All cost data are stated in real prices of 1990. In this book, we assume a real interest rate of 3% for all cost calculations.

Figure 2.20 indicates the development of the specific investments for the technologies considered over the time horizon of the LTI-Project: small hydropower plants, on-shore and off-shore wind turbines, photovoltaic installations, solar-thermal heat, solar-thermal electricity (in Southern Europe), biomass, and environmental heat supplied by heat pumps. Solar architecture reducing the heat demand of dwellings is treated as an efficiency measure.

For *small hydropower plants*, that is those with capacities of less than 10 MW_{el}, we assume no further cost reduction, because the technology is already mature and economies of scale are not expected. Capital costs include construction (50%) as well as hydraulic (10%) and electrical equipment (40%). The specific investment for an average 100 kW_p hydropower plant amounts to about 10 700 ECU/kW_p and for a 5 MW_p power plant to 6 700 ECU/kW_p (Bräuer 1996a). The estimated lifetime of the plant is 60 years. However, the cost figures include rehabilitation of the hydraulic and electric equipment after 30 years. From this information, the annual costs including O&M costs of 1% of the total investment may be calculated. If one assumes 4 300 full-load hours per year, production costs of the electricity generated by small hydropower plants amount to 73 mECU/kWh. The future development of production costs is shown in Figure 2.21.

Wind energy is one of the most promising future energy technologies in Europe because of its advanced state of development and the current cost situation. The investment costs comprise the costs of the turbine, foundation costs, grid connection costs, infrastructure and telecommunication costs as well as assembly, commissioning, and planning costs. Their development has been evaluated in several studies (Enquete 1991; CEC 1994; ETSU 1994; Altner et al. 1994; Wiese et al. 1994; EUREC 1994d). In 1990, average wind-energy generators of 500 kW_p capacity cost about 1 500 ECU/kW_p including infrastructure and grid connection cost. A reduction to 950 ECU/kW_p is estimated for 2050. The lifetime of turbines is taken as 20 years. For the calculation of production costs, a specific energy yield is assumed which increases from 2 000 kWh/(kW_p·a) in 1990 to 2 500 kWh/(kW_p·a) in 2050. In 1995, the average specific energy yield of all wind turbines operating in

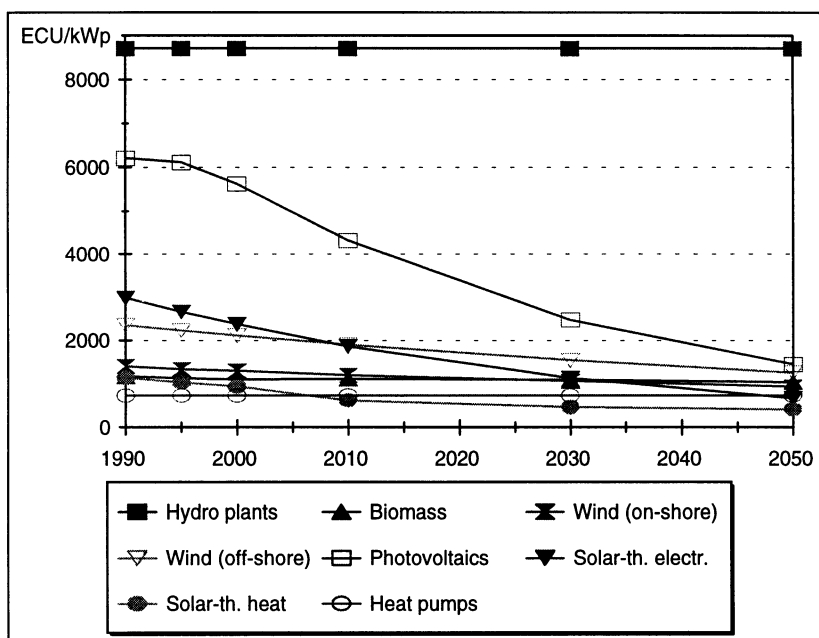


Figure 2.20 Assumed development of specific investments for renewable energy technologies. Numerical values stated in Table 6.16 in the Appendix.

Germany was more than 2 300 kWh/(kW_p·a) (DEWI 1996). Production costs decrease from 50 mECU/kWh in 1990 to 25 mECU/kWh in 2050 (cf. Figure 2.20 and Figure 2.21).

Today, the costs of off-shore wind energy are at least 30% higher than the corresponding on-shore costs. Due to the so far restricted experience with this technology, estimates of future costs are difficult. Thus, we continuously use 30% higher costs for off-shore wind turbines than for on-shore installations until 2050 (Bräuer 1996c).

The largest reduction in specific investments during the time-horizon of the LTI-Project is expected for *photovoltaic (PV) installations*. It is due to a sharp increase in efficiency and large economies of scale (Weinreich and Hohmeyer 1995). Investment costs of *building-integrated PV systems* cover the PV-module (> 50%), support structure, DC/AC inverter, cables, infrastructure, engineering, and other electronic components. In 1990, the average investment cost was about 6 200 ECU/kW_p. With increasing cell efficiency and growing mass production of cells, inverters, and all other system components, investments are estimated to decrease to 1 450 ECU/kW_p in 2050 (cf. Figure 2.20). The same investment costs are taken for all EU countries. In 1990, annual capital costs were 360 ECU/(kW_p·a), assuming a real interest rate of 3% and an average lifetime of 25 years.

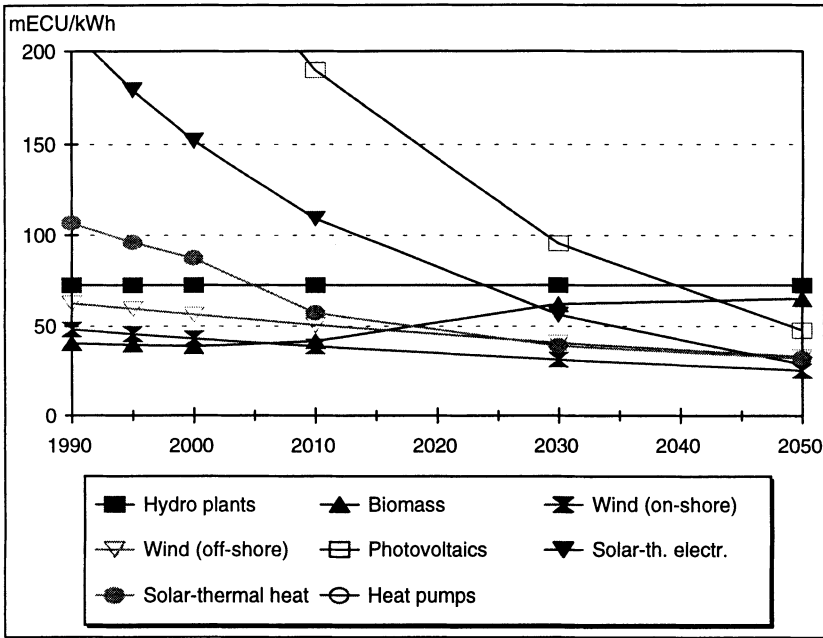


Figure 2.21 Assumed development of the average production cost of renewable energy technologies. Numerical values stated in Table 6.17 in the Appendix.

In addition to the capital costs one has to consider O&M costs, which are composed of insurance, maintenance, and personnel costs. We assume O&M costs of 1% of the investment per year (Staiss et al. 1994, Strese 1990).

Production costs depend on the solar irradiation and the resulting specific energy yield given in kilowatt-hours of electricity generated per year with one kilowatt of peak capacity installed. Solar irradiation values differ substantially between different countries, the UK reaching 960 kWh/(m²·a) while Portugal receives 1 670 kWh/(m²·a) at the same time. Several studies (Staiss et al. 1994; EUREC 1994b; DIW/ ISI 1991; Hohmeyer 1994; ETSU 1994; Räuber 1990; Altner et al. 1995) are used for estimating a cost trend until 2050 for two regions, namely the Southern EU including Spain, Portugal, Greece and Italy, and the Central and Northern EU comprising all the other member countries. For the Southern EU, electricity production costs for building-integrated PV systems are assumed to decrease from 300 to 40 mECU/kWh while in the Central EU cost are taken to fall from 450 to 60 mECU/kWh.

Figure 2.21 shows the average development of production cost (Weinreich 1996). Photovoltaics will not be economically viable before 2030, es-

pecially in Northern and Central Europe, compared to electricity production from conventional energies.

The production costs of the four *solar-thermal power plant technologies* and central PV power plants for 1990, 2005 and 2020 provided by Staiss et al. (1994; 118f) were recalculated assuming a lifetime of 20 years and an interest rate of 3 %. The energy yield increases from 950 kWh/(kW_p·a) in 1990 to 1 550 kWh/(kW_p·a) in 2050 (Staiss et al. 1994). The resulting cost differences between the five technologies are small. Thus, an artificial average technology is introduced and respective production costs are calculated and extrapolated until 2050. For Southern Europe (Northern Africa) production costs of 211 (170) mECU/kWh are calculated for 1990, which decrease to 29 (19) mECU/kWh in 2050.

If long-range transmission to Central Europe is used, additional transmission costs of about 50 mECU/kWh from Southern Europe and 63 mECU/kWh from North Africa have to be added (Langniss 1993). These costs result from the investment in overhead and sea cables and in two inverter stations for high voltage DC transfer.

Costs of imported solar electricity will not differ very much between the two regions, because the higher transmission costs in the case of Northern Africa compensate for the lower production costs in this region compared to Southern Europe, especially in the long run. According to Figure 2.21, solar-thermal electricity generation in Southern Europe may be an economic option within the next 10 years (Weinreich 1996; EUREC 1994c).

Systems for *solar-thermal heat production* have mainly been developed for space heating and hot water supply (Nast and Nitsch 1994, 21ff). As for solar-thermal electricity a lifetime of 20 years is assumed. The production costs of solar-thermal low-temperature heat differ substantially between Southern EU-countries and Northern and Central European member states. Thus, Figure 2.21 shows average production costs for all the regions (Groscurth 1996, Andrew and Bougard 1996a).

The cost estimate for *biomass* involves the largest uncertainties, because many different technologies have to be included. Currently, no satisfactory estimates of the future costs exist for the various technologies. Biomass power plants may be operated on solid, liquid and gaseous fuels. The conversion of biomass takes place via cogeneration and direct combustion. Investments in these power and heating plants have been obtained from several studies (Boldt 1995, Reetz 1995, EUREC 1994c, IEA 1994). Since the scenario does not specify which conversion plants are used, we calculate costs for an artificial average biomass technology. Furthermore, fuel cells for power conversion are applied from 2010 onwards. The costs of this technology are in the range of biomass technology cost and are, thus, consistent with the average cost estimate. Figure 2.20 shows that investments in biomass power plants will not fall substantially as they are based on standard

technology. The average lifetime of the various technologies considered is 20 years. O&M costs are assumed to be 8% of the average investment costs. When calculating production costs one has to add the cost of biofuels. Here, we have to distinguish between biomass residues and energy crops. The fuel costs of residues are taken to be 2.7 ECU/GJ, while the average costs for energy plants are 13.8 ECU/GJ (Reetz 1995). When calculating average fuel costs, the shares of residues and energy plants are taken from the Sustainable Scenario. Like in the scenario, we assume 6 000 full-load hours of operation for biomass plants, which seems rather high and is therefore subject to the sensitivity analysis below. Production costs of energy from biomass will increase, because the share of energy crops will grow at the end of the time horizon (cf. Figure 2.21).

For the utilisation of environmental heat via *heat pumps*, investment costs are derived from several German studies (DIW/ ISI 1991, GEMIS 1994). We assume no future cost reductions and a lifetime of 20 years. Thus, the resulting annual costs are 70 ECU/kW_p. This figure includes annual operation and maintenance costs of 2.5% of the investment cost. In the Sustainable Scenario, all heat pumps run on electricity rather than fuel.

Nast and Nitsch (1994) estimate the present *storage* costs of low-temperature water systems to be 68 mECU/kWh heat supplied as back-up for heating systems with low fractions of solar heat supply. There are studies that indicate that direct storage in soil, clay and rock may be cheaper. Nast and Nitsch assume that, in the future, storage costs of water systems may drop to between 32 and 54 mECU/kWh with low solar fractions and to between 54 and 72 mECU/kWh for high solar fractions. High-temperature storages can supply heat at costs that are two to three times higher than those of low-temperature storages. There are no future trends to be seen at the moment that could reduce these costs substantially.

Costs of *electricity storage* are estimated to be 975 to 1950 ECU per kilowatt rated power whereas the volume dependent costs are 0.49 to 1.46 ECU per kilowatt-hour storage capacity (Sierig 1991). Batteries are able to supply electricity at minimum costs of about 100 mECU/kWh. In the medium-term, further development of sodium-sulphur batteries might reduce the storage costs in batteries to 60 mECU per kilowatt-hour supplied electricity (Enquete 1991).

The cost developments described are summarised in Figure 2.20 and Figure 2.21, numerical values are stated in Table 6.16 and Table 6.17 in the Appendix.

2.2.1.2 *Costs of Introducing Renewable Energy Sources in the Sustainable Scenario*

In the Sustainable Scenario, primary energy consumption decreases from 4 490 W/cap in 1990 to 1 670 W/cap in 2050 in EU15. While in 1990 about 96% of the primary energy demand was met through conventional fuels and only 4 % through renewable energy sources, in 2050 renewable energies will cover 95% of the demand, with only 5 % or 82 W/cap still being supplied through oil products in the transport sector. The corresponding final energy demand decreases from about 3 300 W/cap in 1990 to 1 270 W/cap in 2050. Eight renewable energy technologies contribute different amounts of energy to meeting this demand in 2050. They are introduced into the energy system along S-shaped trajectories starting in the year 2000 (cf. Sec. 2.1.8). The cost analysis of the scenario is based on the resulting accumulated capacities and the capacities added annually.

As shown in Figure 2.22, renewable energy technologies with a total capacity of about 140 GW_p were installed in 1990. Mainly, these were large hydropower plants and biomass power plants. The annual costs of operating these technologies were about 42 billion ECU in EU15 (cf. Figure 2.23). In the Sustainable Scenario, the estimated installed capacity of all renewable energy technologies increases continuously to about 2 300 GW_p in 2050, which is roughly 16 times the capacity installed in 1990. Annual costs grow to a maximum of 257 billion ECU in 2040, but fall to 253 billion ECU afterwards. Thus, annual costs only increase by a factor of 6 during the 60

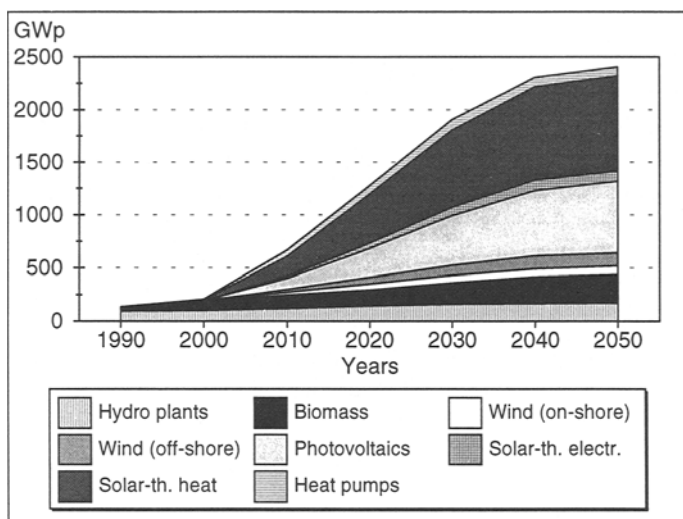


Figure 2.22 Development of the accumulated capacities of renewable energy technologies in the Sustainable Scenario.

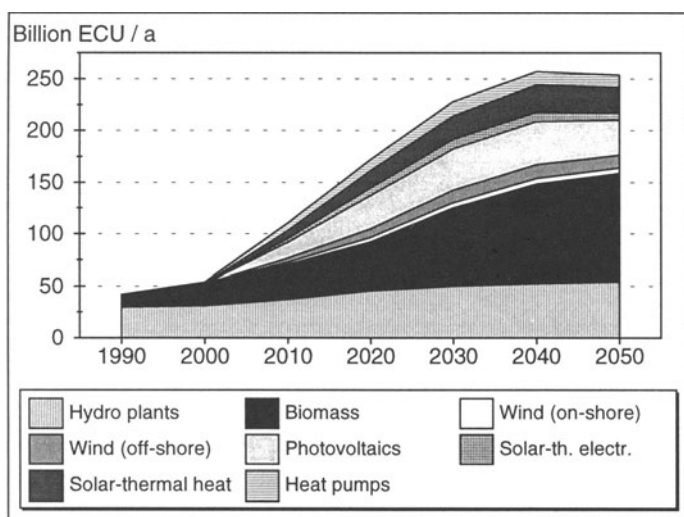


Figure 2.23 Development of annual costs of renewable energy technologies in the Sustainable Scenario; numerical values in Table 6.18 in the Appendix..

years covered by the LTI-Project, which is due to cost reductions expected for most of the renewable energy technologies.

Annual costs are very helpful to discuss the costs of the renewable energy supply system. The total costs of introducing the new energy system are calculated by adding up the annual cost over the whole time horizon of the Sustainable Scenario (1990-2050). They amount to 9 850 billion ECU. The relative size of this figure may be assessed by comparing it to the gross domestic product (GDP) of EU15, which was about 5 250 billion ECU in 1990 (Statistisches Bundesamt 1993). Thus, less than the current GDP of two years is required to run the renewable energy supply system for 60 years. On average, the costs of the renewable energy system come to roughly 3% of the current GDP. The 253 billion ECU annual cost in 2050 are about 4.8% of 1990's GDP.

Another helpful indicator is the average per capita spending. In 2040 the expected 373 million Europeans are confronted with the highest annual costs of 257 billion ECU for renewable energies, which is equal to 689 ECU per capita. In 2050 per capita costs decrease to 678 ECU.

The largest additional capacity has to be built in 2030. In that year, capital worth 126 billion ECU is required to install 111 GW_p of renewable energy technologies (cf. Figure 2.24). On average, the annual capital requirement for investments is 89 billion ECU from 1990 to 2050.

In the Sustainable Scenario, the introduction of renewable energy sources starts in the year 2000 for most technologies. Following the exponential part

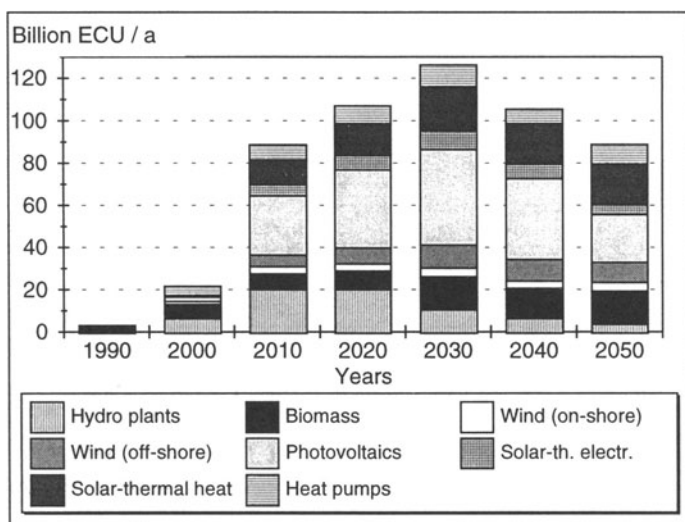


Figure 2.24 Development of the annual capital requirements for renewable energy technologies in the Sustainable Scenario.

of the S-curve, the rate of installation grows sharply in the beginning. Thus, especially in the year 2001 a lot of additional capacity has to be installed. This requires a large capital expenditure. In the year 2001, an additional 88 billion ECU have to be made available in the EU, which is equivalent to 1.6% of the 1990 GDP. This may influence European capital markets as the large capital requirements might cause interest rates to go up. Nevertheless, such negative side effects can probably be avoided by spreading investments over a few more years.

The shares of the different technologies in terms of energy supplied, capacities installed and annual costs are stated in Table 6.20 in the Appendix.

A cost comparison between the renewable energy technologies shows that the extensive use of biomass, which supplies about 500 W/cap or 32% of the renewable energy supply of 1580 W/cap in 2050, results in the largest cost share in the Sustainable Scenario, namely 41% of the annual cost in 2050. Looking at the development of annual costs, wind energy, solar-thermal electricity, and environmental heat combined make up only a small share of 14% of the total cost in 2050 while providing more than 29% of the renewable energy input. In the beginning, hydropower is a cheap option, but in 2050 its 21% share in the annual costs contributes only 9% to the energy supply. Photovoltaics are no longer prohibitively expensive in 2050 due to the expected cost reduction. In 2030, photovoltaics contribute 9% to the renewable energy supply and 17% to the total annual cost.

It has to be stressed that this estimate of the costs of the renewable energy supply system as described in the Sustainable Scenario is a rather rough one

due to a number of simplifying assumptions and data uncertainties. However, long-term cost estimates inevitably entail such uncertainties. The most critical points are:

- Cost estimates for some of the renewable energy technologies, especially for biomass, solar-thermal heat, heat pumps, and storage are more uncertain than other cost estimates.
- The cost estimates always aggregate different regional costs, especially in the Southern and Northern EU.
- For some technologies, very different types of power plants have been aggregated into one artificial technology.
- Cost calculation is based on specific annual costs; an alternative method would be to use the energy production costs of each technology.
- In the Sustainable Scenario, the installed capacities are calculated on the basis of the estimated energy supply (W/cap) of each renewable energy technology. Here, rough assumptions about the annual utilisation of the power plants – expressed as full-load hours – are included. Constant average figures are used for the full-load hours, even though these values may differ from year to year for some conversion technologies like co-generation, direct combustion, or fuel cells.
- The need for storage capacities was estimated only roughly.
- In the Sustainable Scenario, electricity from hydropower plants and biomass-fired cogeneration is used as a back-up system for wind and solar electricity in order to ensure a secure supply of electricity. On the other hand, full-load hours of biomass plants of 6000 h/a are assumed.

The last point requires special attention. A sensitivity analysis shows that the annual costs of biomass use in 2050 will rise from 105 to 145 billion ECU/a, that is by nearly 40%, if the number of full-load hours is reduced from 6000 to 3000 hours per year.

2.2.1.3 *Costs of the Remaining Conventional Energy System*

Not all the energy demand is met by renewable energy sources in 2050. Thus, the costs of the conventional rest of the new energy system have to be estimated. The shares of conventional fuels in the Sustainable Scenario are given in Figure 2.17 above.

We calculate production costs for the four basic categories of energy use – electricity, low-temperature heat, high-temperature heat, transport – for four different fuels – gas, oil, coal, nuclear. These costs consist of two parts:

- annual cost of investing in new power plants (annual capital cost) including O&M cost and personnel cost of building and operating the power plants and
- annual fuel cost.

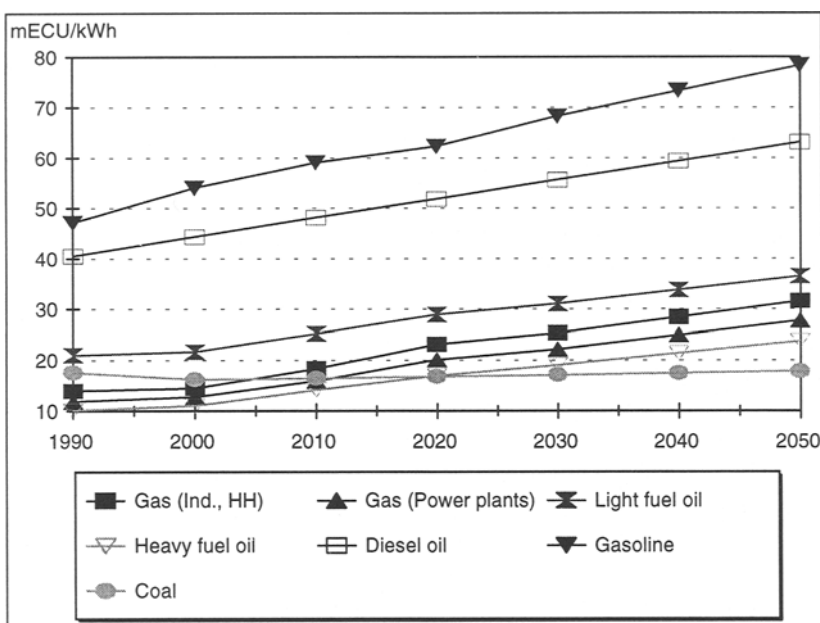


Figure 2.25 Assumed development of specific fuel prices (producer prices, without value added tax, including consumer taxes). Values 1990-2020: (Enquete 1995); 2020-2050: own trend estimation.

The assumed development of the specific capital cost is shown in Table 6.21 in the Appendix, while the development of specific fuel costs is given in Figure 2.25.

The transport fuel prices include increasing consumer taxes. For gasoline the tax on oil rises from 30 mECU/kWh in 1990 to 49 mECU/kWh in 2050 and for diesel oil from 24 mECU/kWh in 1990 to 30 mECU/kWh in 2050.

To estimate annual costs, we assume that 20% of the natural gas is used for electricity production, 50% for the generation of low-temperature heat, and 30% for high-temperature heat. Fuel oil serves half and half for both heat categories (high and low-temperature heat). Transport applications mainly use mineral oil in the form of diesel oil, gasoline, and kerosene. Costs are calculated via end-user prices which include the cost of refining oil. In addition, the transport sector has a demand for electricity which is produced through nuclear power, coal, gas, and renewable energy sources.

The resulting annual costs of the *conventional energy system* in the Sustainable Scenario are given in Figure 2.26. Costs will rise from 472 billion ECU in 1990 to a peak of 505 billion ECU in 2000 and then fall steadily to 19 billion ECU in 2050 due to the remaining small scale use of mineral oil in the transport sector. The phase-out of nuclear energy is completed in

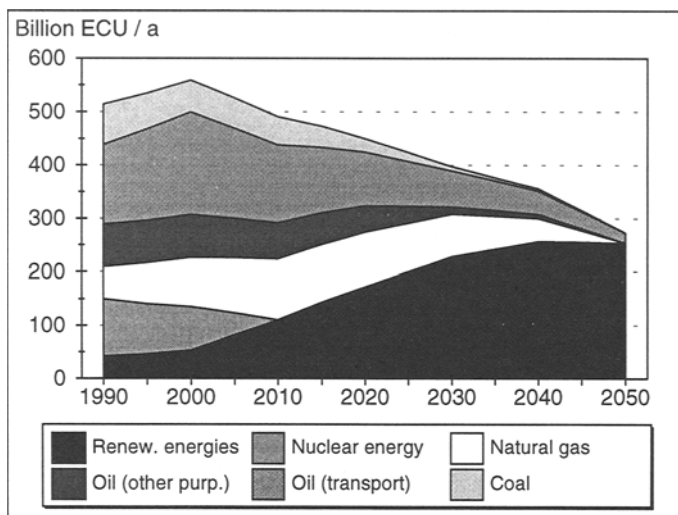


Figure 2.26 Development of the annual cost of the whole energy supply system in the Sustainable Scenario.

2010. The costs of the final disposal of nuclear wastes are not taken into account. The cost estimates do not include external costs, either.

In 1990 the *total* costs of the energy system were about 514 billion ECU with a share of 8% for renewable energies. Due to the predicted increase in energy use until the year 2000 the costs rise to about 559 billion ECU. After 2000 the reduction in energy use, the introduction of renewable energy sources, and the resulting massive reduction in fossil energies lead to the demonstrated cost reductions. In 2030 renewable energies contribute more than 57 % to the cost of the whole energy system while supplying half of the primary energy. In 2050 only about 7% of the annual costs are due to conventional energy use.

The cost for supplying the energy in the new energy system rises from 36 mECU/kWh in 1990 to about 51 mECU/kWh in 2050. This corresponds to a real cost increase of about 42 % over a time span of 60 years.

2.2.1.4 Calculation of a Reference Case for 2050

To evaluate the costs of energy supply from renewable energy sources calculated for the Sustainable Scenario, the costs could be compared to a trend scenario forecasting the development of conventional and renewable energy sources in the EU. We decided not to build this kind of business-as-usual scenario. However, we estimated the costs of supplying the energy demand in 2050 with the currently best available conventional technologies except for nuclear energy instead of using renewable energy sources.

Fuels for transport applications (82 W/cap) are supplied by oil in the Sustainable Scenario. The annual cost of these transport fuels were already calculated in the previous section to be 19 billion ECU in 2050 and are therefore left out in the following calculations. The other categories of energy requested are

- electricity: supplied by gas-fired combined-cycle power plants [lifetime 35 years; efficiency 55%; specific annual cost including personnel and O&M: 31.4 ECU/(kW_p·a) (Voss and Fahl 1990, 210); 4 500 full-load hours per year (average of German power plants; BMWi 1995, 61)];
- low-temperature heat: 50% supplied by gas-fired condensing value boilers [lifetime 10 years, efficiency 98%, specific annual capital cost including O&M: 18.1 ECU/(kW_p·a), 1 600 full-load hours per year, (Groscurth 1996)], 50% by oil-fired boilers [lifetime 10 years, efficiency 98%, specific annual capital cost including O&M: 19.1 ECU/(kW_p·a), 1 600 full-load hours per year (Groscurth 1996)],
- high-temperature heat: supplied by gas-fired heating plants [lifetime: 25 years, average efficiency: 92%, specific annual capital cost: 21.9 ECU/(kW_p·a), 2 500 full-load hours per year (GEMIS 1994; Groscurth 1996; Voss and Fahl 1990, 213 f)].

The calculation of the annual cost of the energy system in 2050 based on conventional fuels is given in Table 2.8. In a second step, external costs of energy are added. For comparison, the values for the renewable energy system of the Sustainable Scenario are also listed in Table 2.8.

The annual costs of the conventional energy system in the reference case are about 201 billion ECU. 70% of these costs are due to the use of natural gas. Thus, the annual costs of the renewable energy system of the Sustainable Scenario are 71.2 billion ECU higher than those of the conventional energy system in the reference case. If external costs of energy use without global warming are considered, the difference is reduced to 57-36 billion ECU per year, depending on the external costs estimate used. If external costs of global warming are taken into account, according to Sørensen the Sustainable Scenario will be 500 billion ECU cheaper per year than the conventional scenario (Nielsen and Sørensen 1996).

Table 2.8 Cost of the reference case and the renewable energy system in the EU in 2050.

	Electricity	Low-temperature heat	High-temperature heat	Conventional energies	Renewable energies
Final energy demand (W/cap)	376 ¹⁾	576	236	1190	1190
Final energy demand (TWh)	1210	1860	760	3830	3830
Full load hours (h/a)	4500	1600	2500	–	
Installed capacity (GW _p)	269	1160	304	1730	2300
Investment cost (ECU/kW _p)	900	135	82	–	
Efficiency of the power plants (%)	55	98	92	–	
Primary energy (TWh) ³⁾	2200	1890	827	4920	
Costs (in billion ECU)					
Annual cost ²⁾	8.5	21.5	6.7	36.7	
Annual fuel cost ⁴⁾	61.2	58.4	26.1	146	
Total annual cost	69.6	80.0	32.8	182	254
Annual fuel cost E1 ⁵⁾	62.9	70.1	26.8	160	
Total annual cost E1 ⁵⁾	71.4	91.6	33.4	196	254
Annual fuel cost E2 ⁶⁾	74.7	75.1	31.2	181	
Total annual cost E2 ⁶⁾	83.1	96.7	37.8	218	254
Annual fuel cost E3 ⁷⁾	458	191	68.6	717	
Total annual cost E3 ⁷⁾	466	213	75.3	754	254

Note: The costs of the conventional energy system of the reference case (Column 'Conventional energies') and of the renewable energy system of the Sustainable Scenario (Column 'Renewable energies') do not include the cost of the use of oil in the transport sector of 19.1 billion ECU in the EU in 2050.

- 1) Demand for electricity: 314 W/cap; transport sector: 144 W/cap; 82 W/cap of oil have not been added because they are also used in the Sustainable Scenario, the rest amounting to 62 W/cap is added to electricity (simplifying assumption).
- 2) Including capital cost and O&M cost, but without fuel cost.
- 3) This value is calculated with the help of the installed capacities and specific efficiencies.
- 4) The assumed producer fuel prices in 2050 are: gas (power plants): 28 mECU/kWh, gas (industry): 32 mECU/kWh, oil (HEL): 36 mECU/kWh, oil (HS): 24 mECU/kWh (cf. Figure 2.25>).
- 5) Including a low estimate for external cost without global warming (CEC 1995a): gas 0.8 mECU/kWh, oil 11.5 mECU/kWh.
- 6) Including a higher estimate for external cost without global warming (Hohmeyer 1994): gas 6.1 mECU/kWh, oil 11.5 mECU/kWh.
- 7) External cost with global warming (Nielsen and Sørensen 1996): gas electricity 180 mECU/kWh, gas heat 51 mECU/kWh, oil heat 89 mECU/kWh.

2.2.2 Analysis of Employment Impacts

Manufacturing renewable energy technologies creates employment in the year the additional capacity is produced and installed. Hence, the basis for the calculation of the employment impacts are the investment costs which have been calculated in Sec. 2.2.1. In addition, labour is required to operate renewable energy technologies during their whole technical lifetime. Except for biomass, only little service is needed for renewable energy technologies compared to conventional energy systems. Thus, the operation and maintenance costs (O&M costs) of renewable energy technologies are relatively low. In the case of biomass, labour for growing, harvesting, and transporting the biofuels has to be added. The calculation of labour required for operating the renewable energy technologies is based on the annual O&M cost plus the (bio)fuel cost for the installed capacity.

Before estimating the employment impacts of the Sustainable Scenario, we will give a short overview of the input-output model "EMI 2.0", which is used for the economic and environmental calculations.

2.2.2.1 The EMI 2.0-Model

Every economic activity affects employment and the environment directly and indirectly. Direct impacts are those which are created during the manufacture and the use of the economic goods in question. However, manufacturing intermediate products, such as glass for solar absorbers, and providing the raw materials from which product components are made also has effects on employment and the environment, which have to be attributed to the end product. All this is of course also valid for the production of different energy forms.

Indirect effects are of special importance for technologies such as photovoltaics, which have comparatively small impacts attributable to their direct use, but where larger impacts are made by producing the intermediate goods needed for their own manufacture. It may be possible to capture first order intermediate effects through a process chain (life-cycle) analysis for technologies such as wind turbines. The analysis of second order intermediate effects and first order effects for more complex technologies such as biomass cogeneration plants, however, is rather difficult, if not impossible, with that method. Thus, a comprehensive analysis of the total impacts requires a separate instrument allowing the capture of intermediate employment effects and emissions. An appropriate tool for this task is the augmented input-output analysis including branch specific employment and emission coefficients.

Input-output analysis is a standard tool of economics. It is based on a tabular description of the interdependencies of an economy. The general layout of the input-output table used is outlined in Figure 2.27. The economy is disaggregated into a production segment (I and III) consisting of dif-

Economic submodel	Inter-industry transaction matrix A Inputs of industry $j = 1, 2, \dots, 58$	Final demand
Outputs of industry $i = 1, 2, \dots, 58$	I. $A(a_{ij})$	II. $Y(y_i)$
Primary Inputs	III. Pi_j	
Emission submodel	Branch specific emission coefficients	Emission coefficients of final consumption
Gaseous	E_a	E_y
Liquid		
Solid		

Figure 2.27 Schematic representation of an input-output table, together with a matrix of branch specific emission coefficients.

ferent branches or industries like steel production or telecommunication services, and a segment of final demand (II) consisting of private demand, investment of industry, and public demand. The branches of the production sector combine primary inputs (III) like labour and capital with intermediate inputs (I) like tires for cars which they receive from other industries for their production. Their products are delivered to final demand (II) or to other industries as intermediate inputs (I).

Input-output tables list all transactions inside the production sector as well as between the production sector and final demand in monetary terms on an annual basis. Rows indicate industries delivering goods (outputs), while industries and final demand (II) receiving the goods are listed in columns (inputs). The different kinds of primary inputs (III) making up the value added of an industry are listed in rows underneath those representing delivering industries. The branch-specific employment coefficients are given in an additional row in terms of person years per million DM gross production value. The sum of each column represents the total annual value of production of each industry (gross production), while the sum of each row indicates the total production delivered to final demand and other industries.

If all entries of a column are divided by its sum, we receive a table of input-coefficients (A) in segment I. with each coefficient (a_{ij}) representing the

part of the production of an industry which is bought as an intermediate product from another industry. The column for industry j can be interpreted as a vector of direct input coefficients (a_j) of an aggregate production function. If we look at the part of the matrix representing the inter-relationships within the production sector (I), we can see how production is interlinked. If we multiply an industry vector of direct input coefficients (a_j) by a given level of output of the industry ($y_i, i=j$), we can actually calculate the necessary direct inputs from other branches ($A_j \cdot y_i, i=j$).

For many types of analysis of indirect effects of economic activities we need to know more than just the first step of induced production in other branches. To account for secondary effects we have to multiply the vector of intermediate demand for direct inputs by the emission coefficients of each of the 58 branches. For the third level this needs to be repeated 58 times and for each further level the number of calculations is 58 times the number of the previous level. What is more, this has to be done for an infinite number of intermediate production levels. Mathematically, this is equivalent to the calculation of a geometric chain of effects. Fortunately, in linear algebra this phenomenon can be represented by the inversion of the matrix of the direct input coefficients A . The resulting inverse matrix $(I-A)^{-1}$ is called a 'Leontief-Matrix'. The inverse provides us with coefficients which simply need to be multiplied by a given final demand Y to derive the total production X necessary to produce Y and all intermediate products $X = (I-A)^{-1} \cdot Y$ (cf. Figure 2.28).

If economic calculations of direct and indirect production effects are combined with the knowledge about branch specific employment effects per unit of output in the form of employment coefficients (row 'Emp' of coefficients 'emp_j'), the direct and indirect employment effects of a given final demand can be calculated as $\text{Emp}_y = (I-A)^{-1} \cdot Y \cdot \text{Emp}$. Furthermore, we combine the direct and indirect production effects with branch specific emission effects per unit of output in the form of emission coefficients (matrix 'E' of coefficients 'e_{jk}'). Thus, the direct and indirect emissions of a given final demand can be calculated as $E_y = (I-A)^{-1} \cdot Y \cdot E$. Figure 2.28 schematically represents this type of calculation based on the combined input-output and emission tables.

Software for a combined input-output and emissions model as described above has been developed for Germany at the Fraunhofer Institute for Systems and Innovations Research – ISI (Hohmeyer and Walz 1992). The schematic structure of the model is shown in Figure 2.27 and Figure 2.28. The basic input-output model is a functionally disaggregated open Leontief-Model disaggregated into 58 branches. Based on the official German input-output tables of the year 1988, the employment coefficients, and a large technoeconomic database containing specific emission coefficients, the software makes it possible to analyse direct and indirect employment effects as well

Economic submodel	Induced production of industry 1,2,...58	Sums	Final demand	Total production
Outputs of industry $i = 1,2,...,58$	$(I-A)^{-1} X$	Sum	Y	X
Sums	Sum	Sum	Sum Y	Sum X

Employment submodel	Directly/indirectly created jobs	
Created jobs	$Emp(I-A)^{-1} X$	Sum

Emission submodel	Direct and indirect emissions		Sum of all emissions
Gaseous	$E (I-A)^{-1} X$	Sum	E_y
Liquid			
Solid			Sum

Figure 2.28 Structure of the input-output model EMI to calculate direct and indirect employment and emission effects based on combined input-output and emission tables.

as emissions of a number of relevant air (CO_2 , CO, NO_x , SO_2 , VOCs, or particulates) and waste water pollutants plus many types of solid waste.

2.2.2.2 Final Demand Vectors for Technologies

The employment impacts of the Sustainable Scenario arise from manufacturing and operating the eight renewable energy technologies considered. Calculations require annual expenditures which are *final demands* in economic terms and which are split into primary or intermediate inputs from other sectors. Thus, two kinds of input vectors are produced:

- The first one maps the construction costs attributed to the year in which the investment is made. This vector is based on the annual capital requirements for the investments calculated in the previous section.
- The second input vector includes the operation and maintenance costs as well as costs for biofuels over the whole lifetime of the equipment.

The input vectors used are designed as averages of the different technology options representing the renewable energy technologies considered. Espe-

cially for biomass, a large number of energy conversion processes are melted into a single input vector.

For wind energy converters, for instance, the final demand is split into the intermediate demand of the following sectors: machinery and equipment 22%; electrical products 21%; aircraft and spacecraft 13%; structural and civil engineering services 11%; steel and light metal products, rail vehicle 9%; office equipment, data processing hardware 9%; other sectors 15%.

We calculate the employment impact of operating the renewable energy technologies from annual O&M costs. For small hydropower plants, these costs are assumed to be 1% of the investment cost for the installed capacity. For on-shore wind energy, we assume a value decreasing from 3.5% of the investment cost in 1990 to 2% in 2050. For off-shore wind energy the value decreases from 6% (1990) to 3% (2050). The annual O&M costs for heat pumps are assumed to be 2.5% of the investment cost. For these technologies, the structure of the input vectors does not change compared to the demand for construction. In the case of biomass, PV and solar thermal applications, new input vectors are designed for the operation of these technologies. For PV and solar thermal technologies the operation and maintenance requirements mainly refer to the replacement of electrical products. Operating the biomass technologies requires agricultural products (65% of the final demand) and forestry, fishery products (7%) as well as machinery and equipment (11%), other transport services (11%), and insurance services (6%). The annual costs of operating biomass technologies are about 30% of the total annual costs of biomass.

2.2.2.3 *Impacts of the Sustainable Scenario on Employment*

Gross impacts on employment created by manufacturing and operating the renewable energy based part of the energy system

In this section, gross effects on employment in the Sustainable Scenario described in Sec. 2.1 are calculated using the static input-output model EMI 2.0 described in Sec. 2.2.2. In the next section, these effects will be compared to those of the alternative conventional supply system (Sec. 2.2.1.4) to determine net employment effects.

Unfortunately, the input-output tables required were only available for West Germany in 1988. Nevertheless, these data are used as an approximation for the whole of Europe. Being a highly rationalised region with high labour productivity, Germany is believed to be a good reference case with respect to the assumed future convergence of living standards and economic structures in Europe. Thus, at the beginning of the time horizon of the LTI-Project, employment effects are underestimated, while in 2050 the number of person years calculated may be too high if the average labour productivity in EU15 increases substantially beyond current German standards.

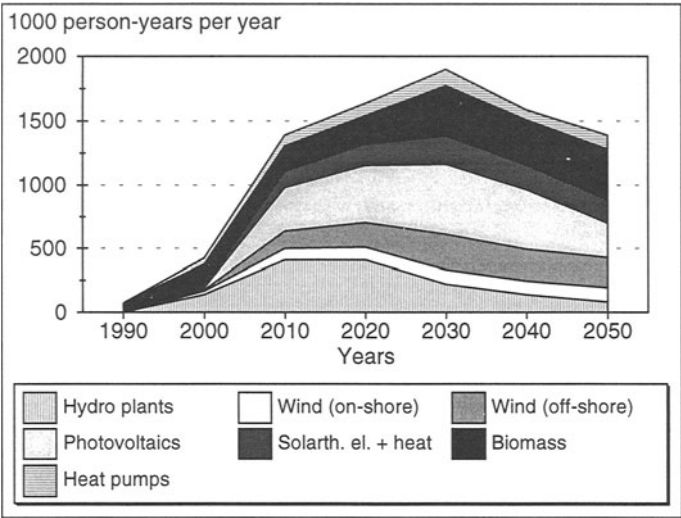


Figure 2.29 Gross development of employment in the Sustainable Scenario due to the *manufacturing* of renewable energy technologies in EU15 (labour productivity of Germany 1988; numeric figures in Table 6.22 in the Appendix).

As illustrated in Figure 2.29 (and Table 6.22), the massive introduction of renewable energies in the Sustainable Scenario starts after the year 2000 and requires 1.4 million person years of employment to manufacture the respective technologies in EU15 in 2010. This figure increases to a maximum of 1.9 million person years in 2030, while decreasing afterwards to 1.4 million person years in 2050. As expected, the construction of photovoltaic systems that are integrated in buildings requires the largest number of person years – namely 550 000 in the peak year 2030. This calculation includes economies of scale, because capital requirements are based on decreasing specific investment costs, especially for PV. The construction of small hydropower plants requires more than 400 000 person years per year during the period from 2000 to 2020.

The development of the annual O&M costs is similar to the development of annual costs described in Sec. 2.2.1.2. The resulting employment impacts are shown in Figure 2.30 (and Table 6.23). In 2050, almost 2.4 million person years of employment are required to run the renewable energy system then installed in EU15. Over the whole time horizon, the largest share of employment is contributed by operating biomass technologies or, more precisely, by producing biofuels. Of the 1.6 million person years needed for operating biomass technologies in 2050, two thirds are created in agriculture and forestry. Obviously, operating wind energy, solar-thermal, and photovoltaic equipment does not require that much employment. In 2040, only about

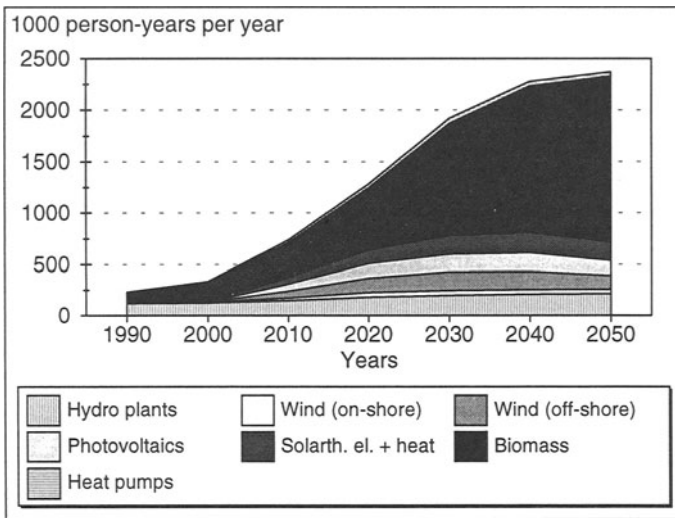


Figure 2.30 Gross development of employment in the Sustainable Scenario due to *operating* renewable energy technologies in EU15 (labour productivity of Germany 1988; numeric figures in Table 6.23 in the Appendix).

600 000 people will be employed in these fields. The operation of renewable energy technologies in 1990 required some 230 000 person years, most of which were due to the operation of existing hydropower plants.

In a final step, the gross employment effects induced by manufacturing and operating all of the renewable energy technologies are aggregated (cf. Figure 2.31). The introduction and operation of the renewable energy technologies in the Sustainable Scenario almost constantly requires some 3.8 million person years of employment after 2030. However, while in 2030 half of the labour is needed to manufacture renewable energy equipment, in 2050 only 37% are required for the production of the equipment. The share of labour necessary for operating the new energy system rises as the use of biomass increases, especially that of energy crops.

Even the moderate extension of renewable energy technologies proposed in the Sustainable Scenario for the year 2000 requires as many as 450 000 additional person years compared to 1990.

Dividing the total number of person years required in 2050 by the cost of the energy system yields costs of 67 000 ECU/a for an average job. Compared to other economic sectors, this value does not seem high.

Finally, it has to be stressed again that the figures presented in this section have to be taken with caution. First, their calculation involved large uncertainties in terms of methodology and data. Second, they only represent additional employment necessary to build and operate the new energy sys-

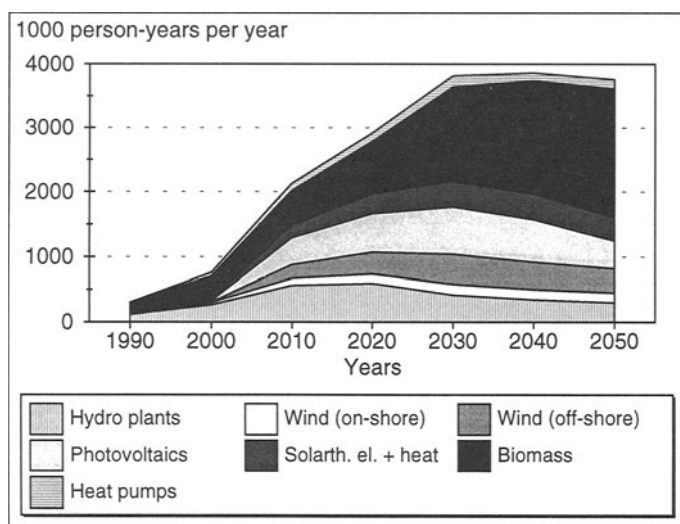


Figure 2.31 Gross development of employment due to *manufacturing and operating* renewable energy technologies in the Sustainable Scenario (labour productivity of Germany 1988).

tem and do not consider labour that might be simultaneously lost in other sectors of the economy. This problem will be tackled in the next section.

2.2.2.4 Calculation of Net Impacts on Employment in 2050

To determine the net employment effect of the Sustainable Scenario, we calculate the person years of employment created in the reference case (Sec. 2.2.1.4) in order to compare them to the person years calculated for the renewable energy based system in the previous section. Since the reference case was exclusively constructed for 2050, net employment effects can only be determined for that year. Please, keep in mind that the reference case does not include the part of the transport sector that is still fossil-fuel based in 2050. Since the same holds for the Sustainable Scenario, this effect is cancelled out anyway and does not bias the net impacts.

1.7 million person years are necessary to build and operate the conventional technologies (i.e. gas- and oil-fired boilers, combined-cycle power plants) in the reference case. This result is again obtained by feeding the respective input vectors for these technologies into the EMI model.

However, this is not the only relevant effect. To be able to compare the two cases, we have to indicate how the cost difference between the two energy systems is spent. Therefore, we assume that the respective 71 billion ECUs are spent on additional private consumption in the reference case (Garnreiter et al. 1983, 201ff). Consequently, 1.5 million person years of

employment per year are created by private consumption if the average 1990 German savings rate of 14% and the 1988 German economic structure are assumed. The figure increases to 1.7 million person years if no savings are taken into account, that is if the whole cost difference is spent on consumption. The latter assumption may be justified by the long time horizon during which all the savings would probably be spent at some point in time. If only a single national economy was considered, one would have to subtract the amount of goods imported from the goods consumed. Since most of the trading of EU member countries occurs with other member countries, this effect can be neglected here. Thus, we find a total of 3.2 to 3.4 million person years of employment per year for the reference case in 2050.

Comparing this result with the employment of 3.8 million person years generated in the Sustainable Scenario in 2050, we arrive at a net effect of 340 000 to 580 000 additional person years for the renewable energy based system (cf. Figure 2.32). When assessing this result, one has to keep in mind

- that the reason for the comparatively small difference is that the production of goods for private consumption is more labour-intensive than the energy sector.
- In addition, the assumptions for the energy supply system of the reference case are very optimistic and will therefore overestimate the cost difference to the Sustainable Scenario.
- The effects of the fundamental restructuring of the economy assumed in the Sustainable Scenario are almost identical for the renewable energy case and the reference case. More specifically, both have the same energy demand. Under business-as-usual assumptions the energy demand and costs of the reference case would be substantially higher, leaving less money for additional consumption.
- The same holds for the energy distribution networks, which are needed in both cases.

Consequently, the net figures calculated here can be viewed as conservative estimates. This explains why it is justified to feel somewhat optimistic that – in spite of the many rough estimates involved in these calculations – an economy running on renewable energies will involve more employment than one driven by conventional energies. This result is also supported by the following reflection: When introducing renewable energy technologies, capital goods produced (at least partly) within the EU are substituted for (mostly) imported fuels. Domestic labour is needed to produce these capital goods.

On the other hand, the restructuring of the energy system, which is necessary to achieve a sustainable economy, will not be the one and only solution to the current employment problem.

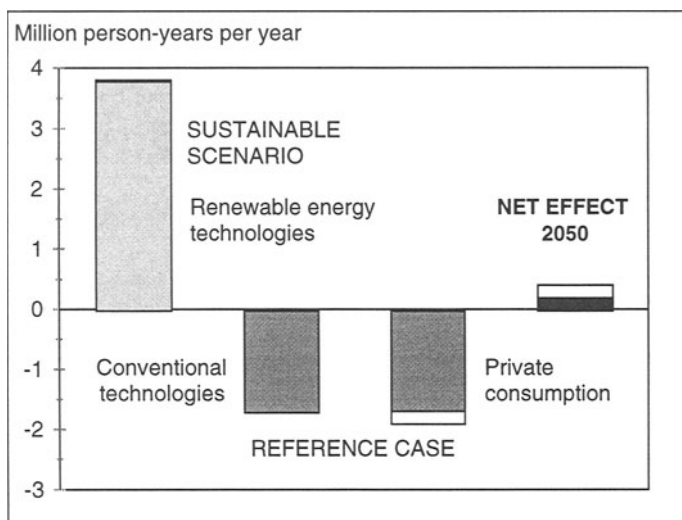


Figure 2.32 Net employment effect of the Sustainable Scenario in 2050 (savings rate 14% and 0%, respectively).

At this point it has to be stressed again, that we do not compare today's situation with the one in 2050, but we compare the impacts of different energy supply systems on a future economy. The first comparison is not possible because of the severe impacts that the development outlined in the Sustainable Scenario would have on the whole economy. For example, person years of employment might be lost in the chemical industry due to the reduced use of fertilisers. On the other hand, additional person years will be necessary to repair consumer goods due to their longer lifetime. However, assuming identical developments for both future economies considered leads to a mutual cancellation of these effects in the results presented.

2.2.3 Analysis of Environmental Impacts

The emission of pollutants in the Sustainable Scenarios is also analysed with the EMI 2.0 model. We used this approach rather than calculating direct emissions from the technologies involved to include indirect effects attributable to the manufacturing of the energy conversion technologies.

Since we only have a data base for Germany in 1988, the emissions are scaled to the EU level proportional to primary energy consumption. This approach is supported by the fact that a test run yielded 1990 CO₂ emissions which deviated by only 1% from the statistical CO₂ emissions of 3 billion tons per year given for the EU in 1990 by Andrew and Bougard (1996b).

Finally, we have to consider the production of the renewable energy technologies. In the worst case, they are produced on the basis of the current

Table 2.9 Reduction of emissions in the Sustainable Scenario – without production and operation of renewable energy technologies (Andrew and Bougard 1996b; own calculations).

Pollutant	1990 (1000 t/a)	2050 (1000 t/a)	Reduction
CO ₂	3 060 000	308 000	90 %
NO _x	10 800	4 010	63 %
SO ₂	19 800	175	99 %
CO	38 300	11 600	70 %
VOC	6 520	1 760	73 %
Particulates	2 320	215	91 %

economic structure and production technologies using fossil fuels. However, as we will demonstrate, the resulting emissions are already small compared to the remaining direct emissions. Thus, further efforts to make this calculation more precise, leading to even lower numbers, seem unnecessary.

To calculate the remaining emissions, the energy demand of the different economic sectors is reduced to the values given in the scenario descriptions for 2050 in the input matrix of the EMI 2.0 model. In addition, the emission factors are adjusted to the values appropriate for the technologies which satisfy the remaining demand. Fossil fuels are only used for transport applications. All the other (direct) emission factors of energy conversion processes are set to zero since renewable energies are used. The resulting emissions are indicated in Table 2.9.

In the Sustainable Scenario, CO₂ emissions are reduced from 3 100 million tons in 1990 to 310 million tons, that is by 90%. Thus, the objective of the LTI-Project is more than achieved. The emissions of other pollutants decrease by 63% for NO_x, 99% for SO₂, 70% for CO, 73% for VOCs, and 91% for particulates. Consequently, large additional benefits arise in addition to the mitigation of global warming.

The figures shown in Table 2.9 do not include emissions released during the production and operation of the renewable energy technologies in 2050. An upper limit for these emissions can be found using the 1988 economic structure, that is assuming that the renewable energy technologies are still produced with fossil fuels. The CO₂ emissions from constructing and operating renewable energy technologies are below 65 million tons in 2050 and would, thus, increase the emissions given in Table 2.9 by 20%. As a crude estimate for the situation in 2050, one can assume that the emissions from the production of energy technologies are reduced by the same factor that was calculated for the whole economy. In that case, only 6.5 million tons or 2% would have to be added for the construction and operation of the renewable energy equipment in 2050, an amount which in view of the uncertainties involved in all these calculations can clearly be left out of consideration.

3 A Fair-Market Scenario for the European Energy System

Stefan K. Nielsen and Bent Sørensen

3.1 Technical Description

3.1.1 Introduction

The Fair-Market Scenario represents a new development in the use of scenario techniques, an area in which the Roskilde unit has worked for over 20 years. The first scenarios constructed during the first half of the 1970'ies were aimed at demonstrating the existence of consistent energy demand and supply systems incorporating large amounts of renewable energy (Sørensen, 1975a-d). The next ten years saw several scenarios based on normative or market assumptions, the latter becoming possible as the cost of energy efficiency measures and new energy technologies became more established and the literature on market trends and prices increased (e.g. Blegaa et al., 1976; 1977; Sørensen, 1979; 1981a; 1982a; Hvelplund et al., 1983). Although the background for constructing these scenarios included environmental impacts, no detailed attempt was made to quantify them. During the 1990'ies, further emphasis on the environmental issues in scenario construction was imposed by the increased focus on global impacts such as greenhouse warming (Sørensen et al., 1994; Sørensen, 1996a; Ishitani et al., 1996), and progress was made in bringing the description of the externalities of energy conversion systems from the early qualitative level (Sørensen, 1974; 1981b) to a data-based quantitative level (e.g. Sørensen, 1993b; 1995b; European Commission DGXII, 1996; Kuemmel, Nielsen & Sørensen, 1997). The market-driven scenarios were based upon projected costs of new energy technologies (whether renewable, fossil, nuclear or related to end-use), while the more normative scenarios assumed changes in consumer attitudes. One may say that all scenarios have a normative component and the assumption that choices will be made on the basis of market prices is of course also a normative statement disproved by many historical examples.

The new component of the Fair-Market Scenario is the inclusion of externalities in the prices supposed to determine market behaviour. This can be done by politically agreed taxation and thus need not reflect the uncertainty in the scientific effort of quantifying externalities. Once the magnitude of externality adders has been fixed, the market can act on prices like it used to. Our European Fair-Market Scenario works this way, by postulating a set of externality adders (based upon our best judgement of available evaluations) and simply assuming that the market will behave rationally according to

these price tags. Due to the limited project period, we have not attempted to model consumer behaviour, which is often very complex and in plain contradiction to economically rational behaviour (e.g. purchasing the red motor car rather than the most cost-effective, energy efficient one). Instead, we simply assume that technologies will be chosen in the priority sequence given by their cost including imposed externality costs, and we further use plausible time delays based on past experience to represent lead times for the market penetration of economically viable energy technologies (for instance, due to construction times and industrial capacity building).

Because the energy system thus emerging is very different from the current one, it may be that the externalities calculated for the future scenario system will be different from those assumed in its construction. The reason is that externalities depend on the surrounding social structure as well as on the technology used. To construct a scenario dynamically following the changes in externality perception would require a self-consistent loop calculation, which we have not found possible, particularly since it would require the modelling of many other aspects of future societies besides their energy systems. We also believe that it is not necessary to do this, because the purpose of the study is to see what the implications would be of incorporating externalities as we know them today, and this is precisely what is achieved by using politically fixed externalities to define the fair market development. This is consistent with seeing scenarios as tools for current debates, not as attempts to forecast the most likely future development. A further discussion of the possible difference between the assumed politically fixed externalities and the ones that may actually emerge in the future is made in an accompanying life-cycle impact study conducted for the Danish Energy Agency (Kuemmel et al., 1997). One example is the greenhouse warming impact, which in the current study has a politically fixed value, but in reality may become zero, once the emissions of greenhouse gases globally drop to less than some 40% of the current ones. In fact, we exploit this fact in our discussion of strategies to deal with the variability of renewable energy inputs.

3.1.2 The Use of Scenario Techniques

There are many reasons for wanting to make forecasts of the future: Enterprises could make economic gains from knowing future markets or future resource requirements, governments could arrange to promote precisely the right kinds of policies, and environment groups could prove to people just how disastrous an extrapolation of current trends would be. Unfortunately, forecasting does not work, because there are too many parameters influencing our path, too many possible futures and too many unknowns. Instead, there is the option to influence the course of events by proposing new paths of development that appear attractive to our fellow human beings. This is

what politics is about, and where scenarios come in, not as predictions of the future, but as tools for influencing the direction of present policies. The scientific contribution is to test the consistency of scenarios for the future, and to identify the sequences of decisions that must be taken in order to get from the current situation to the society envisaged in a certain scenario.¹

3.1.2.1 Reasons for Using the Scenario Technique

For the purpose of assisting decision-makers regarding the upgrading of existing energy systems and planning of new, future systems, a method is required for describing a given energy system which is also suitable for systems not yet implemented. One may consider using simple forecasts of demand and supply, based on economic modelling. To this end one should keep in mind, that most economic theory deals with the past and occasionally the present structure of society. Thus it is possible to observe relations between different factors, to construct theories of causal relationship, and to test them on actual data. 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 makes it possible to produce "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 change due to abrupt changes in the 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 choice is a feature of human enterprise, including politics.

Studies such as the ones proposed here that aim at investigating the scope 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 both futures investigated in this study, therefore have no use of the conventional forecasting method, neither of status-quo nor of 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, predictions about what these should be cannot

¹ The discussion in this chapter owes to work more fully described in Kuemmel, Nielsen & Sørensen (1997). Technical details of the Fair-Market Scenario are given in Nielsen & Sørensen (1996a).

be based on studies on past or existing societies, because the whole point in human choice is that options are available that are different from past trends, 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 options cannot be reached by conventional economic methods, but must invoke a scenario construction and analysis, one way or the other (Sørensen, 1995a).

It is important to stress that scenarios are not predictions of the future. They should be presented as policy options that may only come true if a prescribed number of political actions are actually carried out. In the Fair-Market Scenario, the required action is the inclusion of prescribed externality costs in the market decisions. In democratic societies such actions can only happen if preceded by corresponding value changes affecting a sufficiently large fraction of the society. Generally speaking, the more radically the scenario differs from the present society, the larger the support of a democratically participating population has to be. Of course, not every nation in the world enjoys a democracy allowing such participation.

The actual development may comprise a combination of some reference scenarios selected for analysis, each reference scenario being a clear and perhaps extreme example of pursuing a concrete line of political preference. It is important that the scenarios selected for political consideration are based on values and preferences that are important in the society in question. The value basis should be made explicit in the scenario construction.

The scenarios presented in the present study are meant to provide a basis, upon which an informed discussion on options for greenhouse emission mitigation can be held. The scenarios proposed will be tested for technical consistency and resilience, and a number of environmental and social, as well as the basic economic impacts will be evaluated, based on recent studies in the externality field, but extrapolated to the more developed and in some cases novel technologies proposed for the mid-21st century.² The uncertainty of such an appraisal is recognised, but precisely the lack of complete knowledge is a fact that underlies the political decisions that must be taken today in order to accomplish the development of a better energy system for the future. The benefit is evident of having a thorough investigation of the scenarios and their impacts, as far as they can be discerned today,

² Externalities are included in the FMS construction as inputs. Those calculated from the final scenario are discussed in the accompanying life-cycle study (Kuemmel, Nielsen & Sørensen, 1997) for selected cases.

available for the political deliberations regarding possible actions related to greenhouse issues.

The discussion above explains why we chose the scenario method as our tool. It really does not have any meaningful competition. All analyses of long-term policy alternatives made to date are effectively scenario analyses, although they may differ in terms of the comprehensiveness with which they treat the future society. A simple analysis may make normative scenario assumptions only for the sector of society of direct interest to the study, assuming the rest to be governed by trend rules similar to those of the past. One of the scenarios in this study 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 a 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.

3.1.2.2 Methodology of Scenario Construction and Early Use

The scenario method is a decision support tool used for shaping alternative national or international policies. It basically involves choosing a small number of possible futures, selected on the basis of having spurred an interest among the population and of reflecting different values held in a particular society.

As a next step, these futures have to be modelled, with the emphasis on the issues deemed particularly 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.

Next one would 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 one would have to 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-making 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-making process on the part of the citizens of a given society, as well as on the tools used for debate,

including questions such as fairness of and access to the media. Many developed countries have a tradition of broad social debates, but even in such countries, there are also clear efforts by interest groups or sitting governments to take over the means of communication and distort the process in favour of their own preferred solutions.

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), which built on population models used in ecology (E. Odum, 1963). The basis were linear compartment models described by coupled sets of first order differential equations, originally aimed at explaining feed-back loops to students. The application of these methods to resource dynamics, promoted by the industrial magnate A. Peccei and his "Club of Rome", with D. Meadows as science writer (Meadows et al., 1972), spurred a global debate on 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 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 that came to the fore very much during the early 1970'ies: scenarios for sustainable energy systems were tied to assumptions of socially equitable and globally conscious behaviour (Eriksson, 1974; Eriksson et al., 1974; Sørensen, 1975a-d).

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 dealing with all the more subtle questions of tackling the indirect economy (i.e. precisely the externality issues).

The use of scenario techniques was again taken up by Johansson and Steen (1978), as well as by a number of other groups all over the world (see overview in Sørensen, 1981a). The attitude towards such modelling efforts has matured, and today, most modellers realise the need to model not only technical systems, but also the social context, which the technical solutions are embedded in, the environmental impacts and the implications for global strategies. In other words, scenarios are seen as more comprehensive visions of future societies, although it is still necessary to restrict the features detailed for the models to remain manageable (Sørensen, 1995a).

3.1.2.3 The Sociological and Geopolitical Basis for Current Scenarios

A model-year around 2050 is chosen for most current scenario case studies because they aim to investigate options for a future society in which most of the current equipment will have been replaced, leaving the possibility of politically influencing the choice of such new equipment. Hence the scenarios deal with systemic rather than marginal changes. Only in the case of buildings, will there be a fraction left over from the present era. Still, the purpose of constructing this kind of scenario 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, i.e. no prognosis or forecast of the future. The aim is to promote conscious policy-making in contrast to policy by inertia or default, i.e. least pressure solutions.

The attitudes characterising 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 archetypes (Sørensen, 1989):

- the concerned citizen,
- the audacious citizen

The concerned citizen is worried about the possible side-effects of human activities, whether it is pollution, genetic engineering or the degradation of social conditions. If we cannot take in and understand the consequences of introducing a new technology, then it is better to forego that technology or at least to issue a moratorium until we better understand the consequences.

In contrast to this attitude, the audacious citizen says “let us take the risk”. If something goes wrong, we will deal with it then, and it is quite likely that we shall find a solution (albeit possibly 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 lower than the cost of restraining our activities now, or we may become better at dealing with the problem, given the progress caused by all the new activities between now and then.

Audacious individuals have produced advances in the past, and they have produced quite a number of problems. Concerned persons, too, have made a contribution, although perhaps a less spectacular one: they have stimulated the development of alternative technologies, and have made social changes more humane. In any case, these two groups have existed during the last centuries in most industrialised countries, and they have roughly divided the population in two equally large parts, with predominance and political influence moving back and forth between the two groups. The debate created by

these two opposing views has probably been beneficial to the overall development.

The environmentally sustainable energy scenario of the present study is a reflection of the views of the concerned citizen. The Fair-Market Scenario described in this Chapter has a slightly more subtle motivation. 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 the 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 society is a caricature of an ultimate liberalism that 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 about realistically doing away with most of these regulations (buildings safety codes, traffic rules, etc.). The catchword "deregulation" is an argument in a much more restricted debate on whether or not to marginally increase or decrease regulation. Then what should a scenario contrasting the ecological one look like? We propose to look at the society, towards which we currently seem to be heading, i.e. an extrapolation of the directions of change that we observe today. Foremost among these is the need to incorporate environmental externalities into the costs used as a basis for decision-making. This direction is itself a compromise between the political groups of the present 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 that it may be a positive one: The current political balance between the two views might be a fair one, and the society developed as a consequence of this balance might be the best to deal with future challenges, including those posed by greenhouse warming. The question we are addressing by basing the scenario on the inclusion of externalities in energy costs is then, if this is really enough, or if a more radical change in political outlook is required which takes into account some of the considerations expressed by the concerned citizens.

In most cases even national or regional scenarios have to be complemented by at least a sketch of the global development. This includes a view on population development, the type of activities favoured globally, and correspondingly on the demand for resources and the level of international trade involving both resources and products.

In order to make, say, a reduced greenhouse warming scenario for Europe 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, at least in a strict 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 any reasons

other than greenhouse effect mitigation that could make it attractive to introduce renewable energy). In the scenarios for the European Union it is therefore loosely assumed that a similar policy is pursued all over the world, and further that the disparity between rich and poor countries is diminished, because otherwise it is difficult to see how population growth could be halted (short of a nuclear war).

The Fair-Market Scenario assumes a similar long-term global development, which, however, does not necessarily mean that similar carbon dioxide emission reductions are reached equally fast in all parts of the world; in some regions this will probably not happen within the 50 year scenario planning period. This is the reason why the emission reduction targets for the European Union proposed in the project definition of this study were set at 80%, with the hope of reaching a global average of some 60%.

One very basic fact in energy planning is that the use of primary energy may decline, while the services delivered to the end-users increase. The difference is between primary energy and end-use service, which not only counts conversion losses through the steps to the final conversion, but also reflects the actual service derived from the end-use conversion. The available end-use energy options are meant to represent the lowest possible energy required to deliver a given service, using known technology (but not necessarily technology in current use). This includes ideas for providing a given service by other means than those used today (e.g. replacing business trips by video conferencing).

3.1.3 Design of the Fair-Market Scenario for Europe

The basic assumption in the Fair-Market Scenario (FMS) is that majority values and preferences of the population change smoothly, and that current trends towards higher consideration for the environment will continue and lead to accepting the inclusion of environmental externalities into the prices of goods and services. This is what makes the market "fair". One may interpret the current situation as having a market allowed to operate freely as long as this does not lead to severe distortions of the market transactions (e.g. through the formation of monopolies), but still with a number of rules defined by society. These rules may be building codes that prevent market players from building houses below a certain standard as regards safety and as of recently also energy use. There is only a small step from building codes to considering e.g. the cost of polluting emissions from burning fossil fuels. However, there are at least two ways of dealing with such issues in a market economy:

One is by legislation and regulation, the other by incorporating externalities into prices, which typically implies adding an environmental tax. The legislative way is certain to work, and it leaves a market free to compete

under the given constraints, but may in some cases be seen as interfering too strongly with the freedom of choice. On the other hand, the taxation method makes it possible for people that are willing to pay the price to continue "bad habits", and it generally involves the subtle question of how strong price signals need to be to alter behaviour. It also assumes that the market itself will develop any necessary alternatives, as otherwise there would be no choice but to accept the higher prices. Finally, the taxation method, in contrast to the regulative method, leads to an accumulation of funds by the state, which in the European mixed economies may be seen as a good thing, whereas in straight market systems with no social security arrangements there would be no point in collecting money at state level. In the mixed economies, the notion of environmental taxation is even seen as positive compared with indiscriminate taxation, because citizens may find it easier to understand a tax that serves a clear environmental purpose. However, the need for social security should also be well understood by members of a country that chose a mixed economy (such as each of the EU member countries), and the question arises, if the revenues from an environmental tax should be used freely for any purpose, or should rather be ear-marked for speeding up the transition to a less polluting system (energy system in our case). In the latter case, the level of taxation may be lower, as it would count twice, first by influencing people's choices of energy purchase, and secondly by contributing to the development of better and cheaper low-polluting energy technology. All these issues depend rather delicately on the actual level of the fair environmental taxes, i.e. on the difficult evaluation of environmental impacts in monetary terms, which e.g. life-cycle externality calculations propose to address. It should further be stressed that conventional market theory assumes that all actors will behave "rationally", i.e. that they will understand and act upon the market signals. The FMS is based on market prices that simply include externality costs, as they would if the taxation method was used.

The Fair-Market Scenario was constructed for the 15 members of the European Union, using life-cycle analysis (LCA) and externality estimates from recent studies (European Commission DGXII, 1996; Sørensen, 1996a, 1996b, 1997; cf. the discussion in Kuemmel, Nielsen & Sørensen, 1997). A central assumption is the value of a statistical life estimated to be 2.6 MECU (a little over 3 million US\$) taken from the ExternE study of the European Commission DGXII. One should note that the externalities are calculated on the basis of e.g. greenhouse warming impacts arising for a business-as-usual scenario, distributed on each unit of fossil energy used in such a scenario. Using such externalities as fixed values in scenarios with quite different components of fossil fuels is not strictly correct, as there are known non-linearities in their dependence on total global energy use. If the sinks for CO₂ (e.g. oceans) can take care of emissions in the order of 20-40% of the

current emissions, the LCA externality associated with fossil energy use up to this level should be zero. This is precisely what happens in the Fair-Market Scenario, which leads to a 2050 fossil energy use in the 15 European Union countries of at most 20% of today's figure.

Because the externalities of the FMS are supposed to reflect a political consensus, cutting through the issues of scientific uncertainties we simply assume that the values of the greenhouse externality costs selected from literature are valid throughout and accept the possible overestimation of impacts towards the end-points of scenarios moving away from fossil fuels. Figures 3.1-3.4 give the assumed cost development for important sources of energy, including externalities during the scenario period 1990-2050, for energy derived from the main sources employed in the Fair-Market Scenario. If a global scenario were available, one could subsequently check the consistency between these input assumptions (the cost profiles driving energy use and the choice of energy sources) and the total social costs (direct costs plus externalities) that are then calculated from the actual scenario development. Because the future energy system has a structure very different from the current one, this would involve determining the full LCA costs, not only on the supply side, but all the way across the system, whether for transmission, further conversion or end-use. The FMS is based on the response to market signals that include externalities identified today, and its externalities as seen 50 years from now are likely to include other impacts than those considered at present.

For fossil and nuclear plants, several social cost studies have been conducted, albeit generally with a high level of uncertainty as regards the evaluation of the impacts of greenhouse warming and of nuclear accidents, long-term waste handling and weapons proliferation. The power production data can be used to construct externalities for other applications, because all one needs to do is to apply the correct scaling of the primary impact-causing agents: CO₂, SO₂, NO_x and particles. If greenhouse externalities are around 0.30 ECU/kWh for coal-based electricity, for natural gas-based electricity they would be about 0.18 ECU/kWh, for industrial heat around 0.10 ECU per kWh of heat, and so on (Figure 3.1). Similarly, fuel-related externalities for shipping and aviation can be approximately derived from that of ground transportation. Additional technologies contributing to the impacts include machinery and furnaces, heat pumps, appliances, light sources and transport vehicles. Sporadic studies have been made in the end-use area, but for much of the conversion equipment, no social cost estimates are available.

As regards the end-use in the transportation sector, there are several studies on externalities to draw from, and as is typical of end-use studies, they include both energy-related and infrastructure-related impacts, created by e.g. road transport (roads, filling stations, parking facilities, accident handling, etc.), cf. Sørensen (1997).

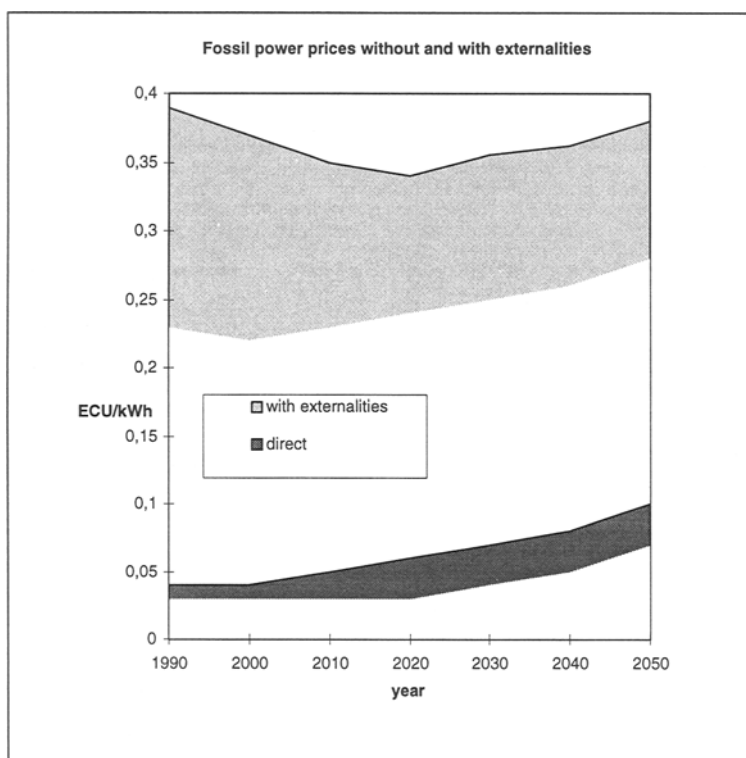


Figure 3.1 LCA costs of fossil power assumed in the Fair-Market Scenario. The higher values in the upper band are for coal-fired power stations, the lower ones for natural gas-fired stations. The most significant contribution to the externality cost is the greenhouse warming impact, but in the early period there is a contribution from SO_2 and NO_x emissions, particularly from older, existing power plants (based upon Sørensen, 1996b). Unit: ECU/kWh, 1 ECU being about 1.25 US\$.

Life-cycle impacts for current and emerging renewable energy technologies are now taken from the studies quoted and then treated as fixed externality costs attached to market prices by political decree, i.e. without uncertainty. As most of the renewable technologies are already nearly competitive and in use in some areas, the only technologies for which we found it difficult to establish a fair market price were those furthest away from the marketplace today, such as photovoltaics, where the final technology is likely to be substantially different from the current one (for reasons of necessary cost reduction), and the social costs therefore may be misrepresented by extrapolating those of the current technology. However, there are investigations available that do take the technology change into account, arguing that they

expect a parallel reduction in the use of material and material-production impacts (Sørensen, 1996b).

As for other technologies, notably the advanced biofuel technologies, the problem is that relatively few studies have been made, so that we had to rely on a fairly broad analysis, without going into detail as regards the the social and environmental costs of non-sustainable agriculture, an issue that has to be addressed in a global context and requires data not readily available at present. It should be said in this context, that a large portion of current agriculture is non-sustainable, although an evaluation of impacts will require detailed studies of a much wider nature than the energy externality studies focused upon here.

Figure 3.2 and Figure 3.3 give the assumed developments for wind and biofuel energy costs, and Figure 3.4 summarises several results and expectations for future developments of the renewable energy technologies. For wind energy, the costs (down to at least roughness class 3 sites) are lower than the fossil costs (with externalities) given above, both today and throughout the period considered. This implies that the introduction of wind energy in a Fair-Market Scenario is not governed by prices, but by problems of production capacity, infrastructure, financing etc.

We have not been able to find relevant studies of externalities for district heating lines, gas pipelines, electricity distribution systems (overhead or underground) and transmission systems (DC, AC, different voltage levels). This would matter in scenarios, where decentralisation on the one hand reduces transmission distances, but on the other hand gives rise to more frequent use of backup from more distant suppliers.

Especially ideas such as an intercontinental exchange of power call for new dimensions of transmission equipment. Data could be derived from e.g. the long-distance DC lines connecting Norway and Denmark, but alternative solutions for the future may involve other technologies, such as superconducting lines, if e.g. transmission between the Middle East or North Africa and Europe is to be part of future systems (Nielsen and Sørensen, 1996b).

The scenarios would also benefit from an analysis of social impacts connected with thermal storage, notably larger, communal seasonal storage installations connected to solar panels, district heating lines, gas storage (whether hydrogen or biogas is replacing natural gas) and liquid biofuel storage. None of these seem to exist. Some studies have been made for hydro storage (including pumped storage), but only a few for advanced batteries and other emerging storage options for energy in connection with power production and transportation.

As externalities that could not be established were omitted from the FMS costs, these may for this reason be considered to have a downward bias, whereas a discussion about the monetised European value of a statistical life used in other parts of the world indicates a possible upward bias in the fig-

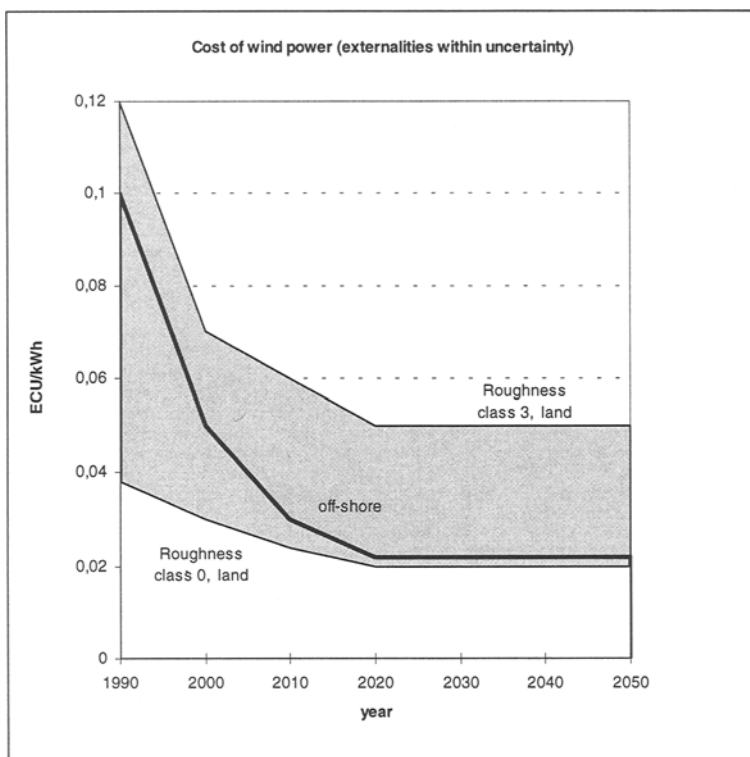


Figure 3.2 Cost of wind power as a function of time assumed in the Fair-Market Scenario. Land-based turbine costs depend on the roughness class (a smooth water surface being class 0, an open plain class 1, while increasing obstacles like trees and buildings lead to classes 2 or 3). The costs include externalities evaluated at about 10% of the total cost (Sørensen, 1996b; current costs are based on DTI, 1996). Unit: ECU/kWh, 1 ECU being about 1.25 US\$.

ures used. Again a reason to consider the values adopted in the FMS as politically agreed levels of taxation, based upon an underlying scientific knowledge, but one that (as is normal) contains many issues of uncertainty.

Photovoltaic power is in Figure 3.4 seen to become competitive with fossil power in a fair market (including externalities) after 2010, possibly earlier for South European sites. If solar-thermal competes with electric heating, as it often does at present in South European locations, it is already competitive in a fair market. When the alternatives are fossil-based boilers or district heating lines, the break-even would lie around 0.1 ECU/kWh-thermal for natural gas fired installations. Solar-thermal will overcome this barrier in the year 2000 in Southern Europe, in 2020 for Northern Europe.

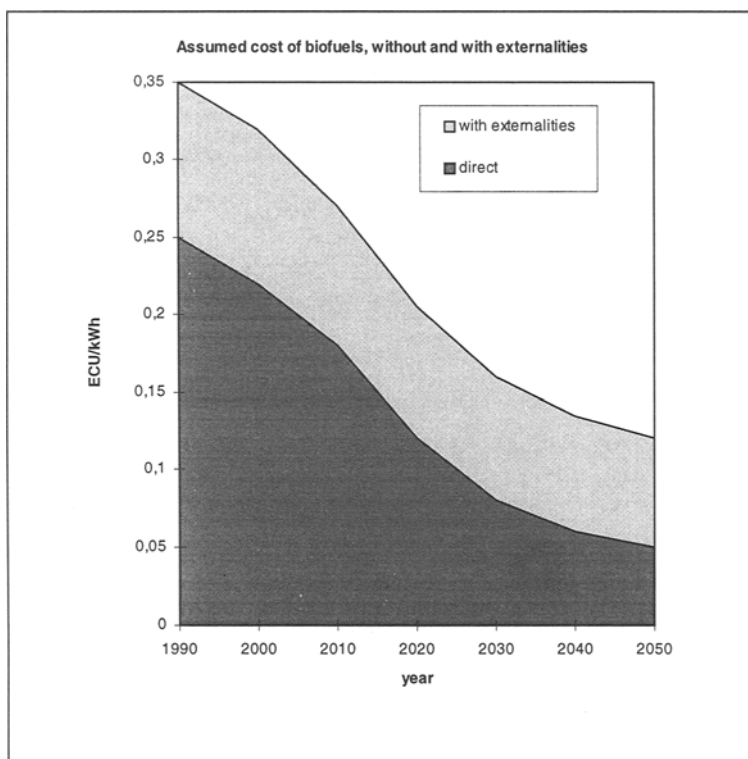


Figure 3.3 Costs assumed in the Fair-Market Scenario for biofuels such as methanol for the transportation sector. The costs are gross estimates based upon very preliminary externality estimations (Kuemmel, Nielsen & Sørensen, 1997). Unit: ECU/kWh, 1 ECU is about 1.25 US\$.

The biofuel costs shown in Figure 3.3 reflect the indirect costs of land use for bio-plantations, as well as the industrial externalities of the conversion processes leading to e.g. methanol. These estimates are uncertain and should be regarded as merely indicative. However, as the biofuels in the scenario would enter the transportation sector, the relevant fair market comparison would be with the directly fuel-related fraction of the total externality cost estimated in Sørensen (1996c) at some 0.16 ECU/kWh-fuel (air pollution and greenhouse warming only). This level is reached around 2030.

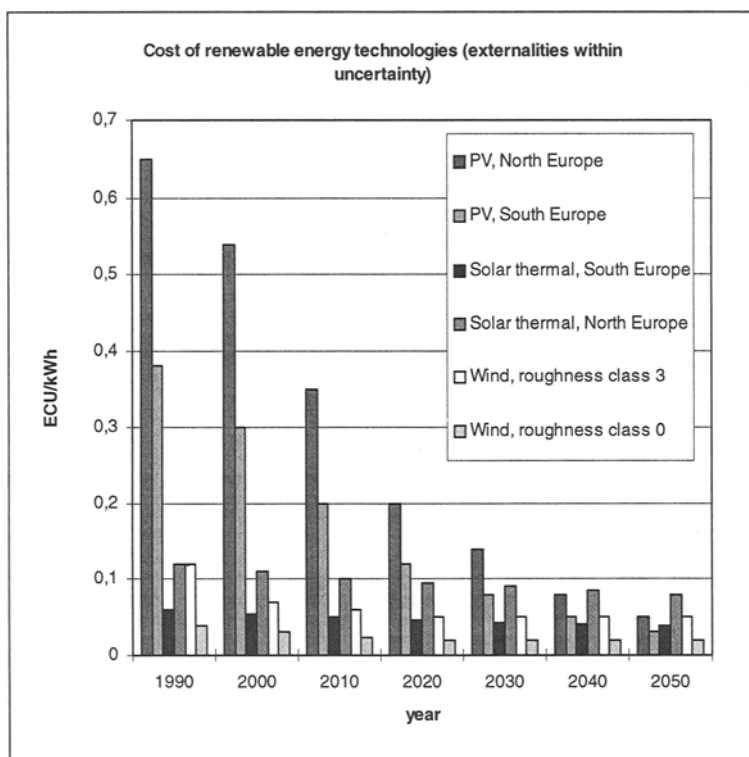


Figure 3.4 Summary of important renewable energy LCA costs used in the Fair-Market Scenario. As the externalities are modest, the trend mostly indicates an expected cost reduction due to technological progress and mass production that has been identified i.a. in the technology descriptions made as background material for the project.

The total externalities for the transportation sector are based on Scandinavian studies on passenger transport by motor vehicle (Danish Transport Council, 1993; Danish Department of Public Works, 1993; Danish Road Directorate, 1981; Danish Statistical Office, 1993; Danish Technology Council, 1993) and summarised in Figure 3.5. The annoyances traffic causes are estimated using hedonic pricing (i.e. looking at reductions in property values in areas with heavy traffic), and the greenhouse warming from emissions of greenhouse gases is evaluated in the same way as for power plants, but in this case the greenhouse related externalities are smaller than the rest (e.g. because the emission of polluting and health-impacting gases happens at breathing level, and not like in the case of power plants through high stacks and after cleaning. Sørensen, 1996b; 1996c). Of course, externalities connected to non-fuel related impacts from traffic will not be reduced by introducing alternative energy systems, such as biofuels for transportation, but

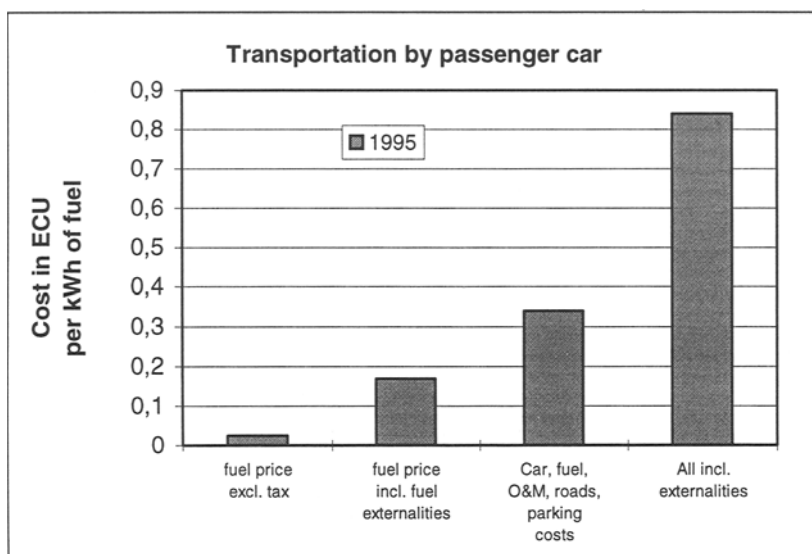


Figure 3.5 Direct and externality costs of driving a car 200000 km over 10 years at 13.5 km per litre of gasoline (Christensen, L. & Gudmundsen, H., 1993; Sørensen, 1996b; 1996c).

incorporating the full externality value will have a restricting influence on transport demand.

The costs of demand-side measures are important for the scenarios constructed, and Figure 3.6 gives an overview of the structure of these costs, as a function of efficiency measures already taken (Sørensen, 1991a, 1992; Nørgård & Viegand, 1994). The figure shows that in a Fair-Market Scenario, efficiency measures on average stay cheaper than expanding production from the current level and down to about a quarter of it, but of course with large variations between the huge number of individual measures. In other words, it is acceptable on the basis of free market behaviour to reduce the average energy intensity by roughly a factor of four by using efficiency technologies. The Fair-Market Scenario does not specify what efficiency measures are taken, and thus no detailed externality analyses were made for these measures. The question is complex as some of the efficiency measures may entail increased externalities (e.g. the use of more insulation material), while others will reduce externalities (by prolonging the lifetime of equipment, e.g. by reducing heat damage to electronics).

The examples of externality cost fixation given above allow the determination of the substitution or "cross-over" price, and hence allows us to determine when e.g. the fossil fuels presently used for particular applications will be replaced by some renewable energy technology, according to the assumed fair market rules.

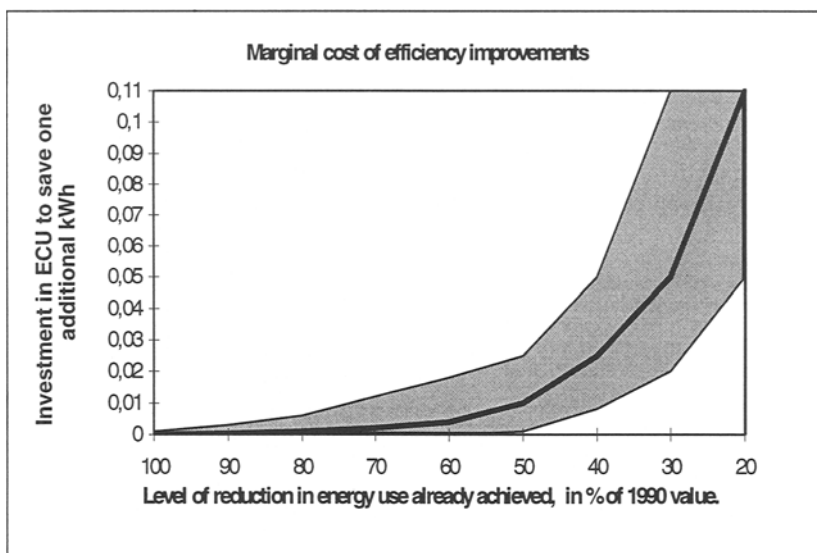


Figure 3.6 The dependence of the costs of different efficiency improvements on the level of efficiency already achieved, based on a large number of specific cases for several sectors (Sørensen, 1982b, 1991a, 1992).

3.1.3.1 Demand Development in the Fair-Market Scenario

The discussion above has primarily been about fuel and production technology substitution in the fair market. It describes how a market without distortions should be able to select the right technology for a given job, i.e. the one with the lowest fair market price. However, fair prices may also have a profound impact on the end-user in determining energy demand. This is because the entire profile of prices the consumer faces will influence the priorities and hence purchases of that consumer, including issues of substitution far beyond the technical options.

The effect of fair prices on energy demand levels may be modelled through elasticities. The elasticity E of energy demand D is defined as $E = -(dD/D) / (dP/P)$, where P is the price and (dD, dP) are changes in demand and price over an incremental period (cf. Ch. 7 in Sørensen, 1979). In other words: to what extent does demand change if prices increase or fall by a certain amount. This depends on whether the customer knows about alternative solutions and realizes that the new price will favour other technical solutions to her/his concrete demand. Since the primary demand is never for energy, but rather for the service or product obtained with the use of energy, there may be new ways of satisfying the real demand more cheaply, whenever the price of the currently selected technology increases.

Whether the customer implements such alternatives, depends on her/ his level of knowledge, and on a number of social factors. It also depends on

how easy it is to raise new capital, if the new way of satisfying demand involves a capital investment, as it most often will (e.g. putting more insulation in walls of buildings or purchasing more efficient equipment). It is therefore quite possible that the altered price relationships emerging after externalities are included in prices will not immediately (if ever) produce the most rational solutions to satisfying primary demands. Price signals are often blurred in the eyes of the consumers, e.g. in Western Europe where prices have for decades been distorted by a general taxation (i.e. not related to particular externalities) on different forms of energy. Current levels of taxation typically account for at least half the externality costs estimated above. Replacing the arbitrary taxation by an externality tax can therefore not be expected to change demand in unison. This situation may be different in those sectors of energy use, where the total externality is considerably higher than current taxation.

The issue may be illustrated by considering that the per capita rate of driving is about twice as high in the USA as in Europe, and gasoline prices are three to four times lower (due to near absence of taxation in the USA). There are other factors that contribute to a higher driving rate (travel distances, absence of public transport), but one might roughly estimate that the 4 US\$ worth of externalities per litre of gasoline implied by the LCA estimate of about 0.70\$ per kWh of fuel, made by Sørensen (1996c) and used in this study, should in itself reduce transport demand by at least a factor of two, disregarding any indirect implications of the complex mechanisms involved in the decision-making process for embarking on a particular journey. The FMS uses such considerations when constructing the demand assumptions, both for transportation and for other sectors.

Furthermore, there are issues relating to the development of energy demand that are not captured by price elasticities. The FMS estimate for future demand is based on a division of economic activity into two separate categories: One containing non-material activities usually described as information society activities (although strictly speaking, some of the activities of an information society may be energy-intensive), and another involving material processing and energy use, whether for manufacture, materials processing or leisure activities. For the market driven scenario the following method may be used to establish the relation between activity growth, price assumptions and energy demand: First, human activities are divided into those that are resource-consuming and those that are resource-free. In many cases, a given economic activity will have a number of components in each category. For a first orientation, the historical development towards a more information-based society can be used for the extrapolation of the ratio between resource-based and resource-free activities, but formulating a detailed model for future trends would involve fairly complex work. The assumption of the European Fair-Market Scenario is that about a third of the growth is in ma-

terial-intensive activities, and two thirds in non-material intensive areas, which are characterised by little or no need for energy-related activities.

In addition to questions of resource-intensity, the characterisation of the economy of a society also involves knowledge of current and future value systems upheld by groups of the population. Value systems change with time, as evidenced e.g. by the current trend to place an increasingly high value on the environment, and also by the expansion of environmental concern from the local to the regional and global levels. Changes in underlying value systems lead to changes in preferences, evidenced, for example, by current shifts in consumption patterns towards ecologically produced food. All these changes in values and preferences define a trend, which can be used as a basis for estimating changes in material production and energy use, occurring in interaction with the changes induced by shifts and increases in economic activity. The FMS actually uses such trend estimates to assess future energy demand and acceptable energy sources and conversion systems, at least indirectly through the externalities of an LCA calculation. This is based upon the fact that market theory cannot predict which products and services will be demanded, but only deal with the allocation of resources in a given market. Normative descriptions of future values and preferences are needed to derive the demands proper, and the FMS attempts to capture visible trends in demand development, and combine them with the price structures resulting from incorporating externalities into market prices.

Returning to the determination of energy demand, this will then involve not only the price of energy, but also trends in social preferences. An example are future levels of traffic, where we project that environmental considerations associated with the value system will require splitting the transportation system into an urban system that must be emission-free, and probably a different system for longer-range transport. The zero-emission urban traffic systems are likely to differ from the present not just in terms of energy conversion techniques, but also as regards vehicle size and transport infrastructure. This is a natural development when two separate systems are emerging for urban and non-urban transportation. However, one consequence is that the energy requirements are very different from what would result from the extrapolation of current trends, and further that the demand for energy cannot be deduced by extrapolating the current demand and considering only price developments. In other words, price elasticity (could its future value be guessed) is insufficient for determining the future demand for energy, and a more complex model is necessary, capturing at least the main features of the interplay between structural changes determined by shifts in values and preferences, and the predicted future prices of relevant energy forms suited for the transportation sector.

A model showing the reaction to price signals in terms of altered demand must consider that there will typically be at least three ways of coping with a

change in fuel prices. Basically, the reason for singling out fuel prices is, of course, that fuels are currently traded in the market at prices that bear little resemblance to the production costs. The costs of extracting oil from the Middle East amount to a few percent of its current market price, while e.g. North Sea oil has extraction costs accounting for perhaps 25% of the market price. To a lesser extent, such variations are also found for coal and natural gas, and the price structure is further blurred by taxes, which differ widely between regions of the world, and which in some cases constitute two thirds of the price the consumer is charged.

One possible reaction to an increase in fuel prices is, of course, to reduce the activities (or the increase in activity) associated with fuel use. However, an economically more attractive alternative may be to invest in increased energy efficiency, so that activity levels may be kept at the growth curve for unaltered prices or even above it, due to the additional activities created with the efficiency technologies (activity measures such as gross national products do not obey the principle of conservation!). At some level of efficiency gains, the cost of the next incremental increase in efficiency becomes higher than the purchase of fuels at the elevated price (cf. Figure 3.6). However, a third alternative may come into play, namely if some of the renewable energy based systems are able to produce energy at a cost lower than that of conventional systems with elevated fuel prices. Because the cost structure of renewable energy is very different from that of fossil fuel-based systems (high capital costs but low running costs and no fuel costs), it is possible and even likely that renewable energy will not suffer the same price increases as fuel-based energy. This differential in cost will determine the shift towards renewable energy sources. In other words, demand and supply adjustments are linked as responses to price signals, a fact which is hardly surprising.

The cost of marginal energy efficiency measures is currently negative, or small and positive, but increasing as the bulk efficiency of a certain energy conversion or energy service provision increases, as shown in Figure 3.6 (Sørensen, 1992). Technological considerations often lead to the price argument taking second place, because increased efficiency has non-energy benefits. For instance, the performance of electronic equipment is hampered by the heat developing in electric current channels, so that efficiency improvements have been an essential precondition for miniaturisation, irrespective of the cost of energy. The efficiency improvement made attractive through energy price increases should thus be folded with that caused by technological development. Similar effects are discernible in other sectors, although they are not as marked. For example, the increased efficiency of building insulation leads to better heat distribution in the building, which originally was the prime reason for introducing central heating. However, there are also examples of the opposite effect, e.g. the tightening of buildings, which first results in energy savings, but may later require additional

energy expenditure for active air exchange due to indoor climate quality considerations, particularly in buildings made of concrete or containing gas-emitting polymer-based furniture or equipment.

Most literature studies on energy price elasticities focus on historical behaviour of demand sectors (e.g. Barker et al., 1995; Bentzen, 1992) and are of little value for the issues focused upon here. Measured elasticities have for example been higher in the case of space heating than for transportation, which clearly reflects perceived flexibility and agent dependence rather than actual substitution options. One may say that empirical energy elasticities reflect some behavioural patterns, but rarely the technological potential of alternative ways of satisfying a given underlying demand.

Similar issues arise in attempts to relate energy use to wealth and to economic activity. In broad terms, both energy use and wealth have increased since about 1950 in several parts of the world. The ratio of growths in energy use and economic activity has historically moved from a value of two to current (European) values of substantially under one (Sørensen, 1975b; 1992). The early development reflects the low efficiency of emerging energy technologies and run-away material growth during the 1960'ies, while the recent values are the result of price hikes following the Arab oil embargo in 1973 and the associated development of more efficient technologies.

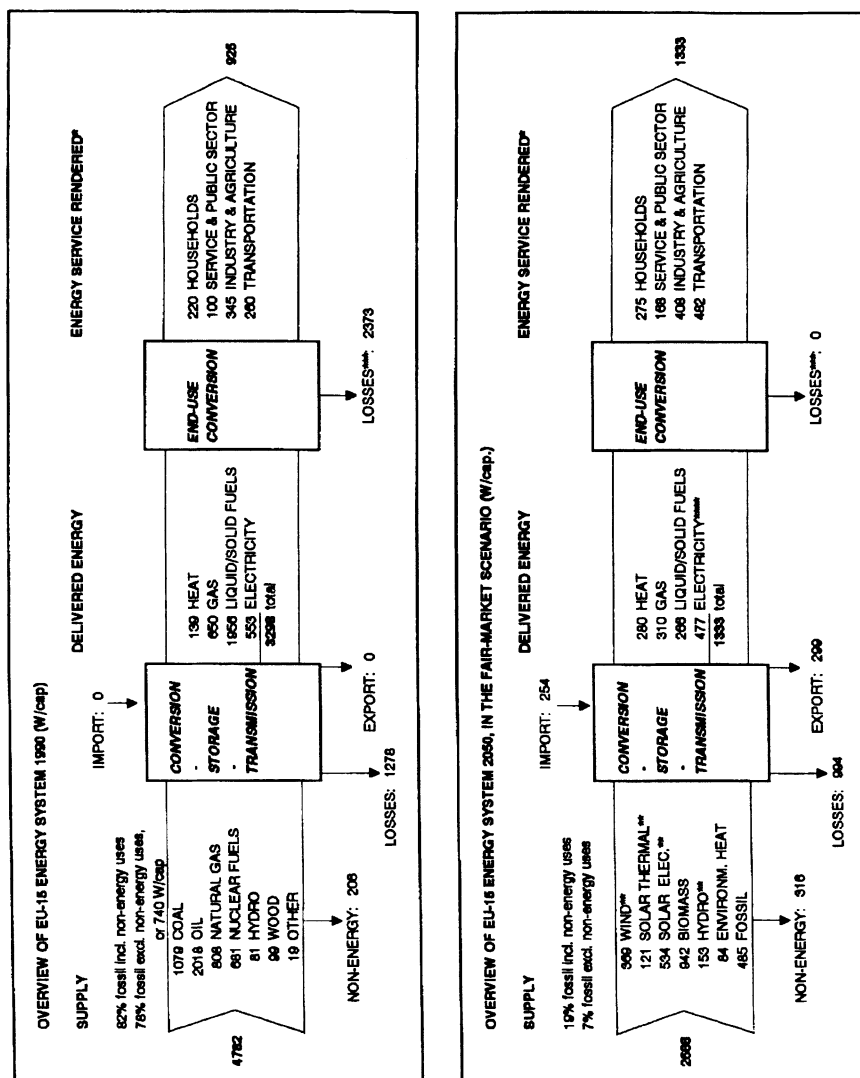
The overall growth in activity in EU member countries amounted to a factor of 5.6 during the preceding 60 years, from an average GNP of 2200 1990-US\$/cap in 1930 to 12370 1990-US\$/cap in 1990. Growth has been uneven (depression, World War II, reconstruction period, unprecedented growth period 1956-1971, and a stabilising period as of 1973), but over the entire 60 years perhaps symptomatic of the technology progress achieved during this period, which was quite exceptional in world history. Most analysts assume that 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 likely to experience a period of stabilisation. The IPCC Second Assessment (IPCC, 1996) estimates in its high-growth scenario, that growth in Western Europe will reach a GNP of 45300 1990-US\$/cap by 2050, in contrast to 69500 1990-US\$/cap, if the growth factor equals that seen in the period 1930-1990. The FMS finds a 2050 GNP level of 32000 US\$/cap for EU-15 realistic, corresponding to a development between the IPCC low and high growth scenarios. It is still growth which in absolute terms is twice as high as between 1930 and 1990 (20000 for the period 1990-2050 vs. 10000 1990-US\$/cap between 1930 and 1990).

Our assumption stated above that in the Fair-Market Scenario there will be an emerging European information society with two thirds of the growth decoupled from energy and materials use implies in simplistic terms that the growth factor for the demand for energy services should be one third of GNP growth. However as explained, the relationship between energy and

GNP is more complex and depends on how both attitudes and technology develop during the period considered. The ratio between energy and GNP growth for the period 1930-1990 first declined from 1.5 to 1.0, then rose to 2.0 during the exceptional period and turned negative after 1973. This is partly an effect of energy (and particularly oil) prices, but technology requirements also played a role by improving energy efficiency after 1975 in ways far exceeding a cost-driven transition. In short, the Fair-Market Scenario assumes an overall increase in end-use energy between 1990 and 2050 of just under 50%, which in fact may be similar to the 1930-1990 growth in delivered energy service: For specific primary energies, the increase in the 15 EU countries between 1930 and 1990 was a factor 2.7 (from 1700 to 4633 W/cap), which is less than half 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). A global model similar to the one we use for the European Union has been studied elsewhere (Sørensen, 1996a).

Energy demand in households is based on an assumed increase in heated area per person of 30%, induced among other things by emerging smaller family sizes. The 30% increase applies both to space heating and the number of energy-using appliances, although in the latter case, the rate of usage should increase less. This does not exclude that the per capita floor space in Southern Europe may approach the current Northern European level, but assumes that appropriate passive solar design will make this possible without additional heat use above the value quoted.

The activity increase in the household sector is assumed to be primarily in electrical appliances (increased penetration of known appliances and multi-media devices, plus addition of novel ones). A doubling of the demand for energy service 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 figures is precisely the difference in service rendered, and the 2050 scenario assumes that the most 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 any further efficiency improvements both before and after 2050. However, it is not known what they involve and therefore they are not included. The most likely situation in 2050 is that the energy efficiency will actually be better than assumed here, and the energy supply scenario thus easier to achieve.



- * Defined as energy delivered had the best currently known technology been used (as is assumed in 2050). This makes the 1990 and 2050 service levels directly comparable.
- ** Hydro, solar and wind energy are counted as heat or electricity produced.
- *** Losses in end-use conversion are counted relative to a given technology level (see note * above).
- **** After losses in batteries used in electric vehicles.

Figure 3.7 Overview of the EU-15 Fair-Market Scenario in 1990 and 2050. Unit of average energy flows: W/cap. Population: 367M (1990 and 2050).

In industry, our assumption that a third of the activity increase is energy related implies an increase in energy demand. However, Figure 3.7 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 currently pays substantially less per unit of energy than private individuals (due to business-stimulating tax rebates and subsidies). The overall scenario assumption of fair prices implies that subsidies for the energy European industry purchases have to be removed. For this reason and due to greater emphasis on knowledge-based products, no increase in end-use energy for industry was assumed.

For transportation, the current trend of increased leisure travel (more than one long-distance holiday trip a year per capita) was extrapolated, and leisure transport was assumed to roughly double. Work-related trips and freight transportation change less, for the reasons given above for industry, including the removal of subsidies.

The aggregated picture of the European Union (EU-15) energy system in 1990, and the similarly simplified Fair-Market Scenario picture for the year 2050, are shown in Figure 3.7. The 1990 system does not take fuel imports or exports into account, but lists all fuels as indigenous.

Having constructed an energy demand scenario for some future point in time, it must be demonstrated that a viable path leads from the present to the scenario future. A technique commonly used in scenario work is back-casting, where the introduction of new technologies and other changes are traced backwards from the scenario endpoint to the present situation. For the Fair-Market Scenario, this method cannot be used, because it would not take into account the effect of prices including externalities as a driving force for change. Since according to the considerations mentioned above it would be very difficult to construct a model for the economic behaviour of all actors, instead a plausible trajectory is constructed by assuming an entry time and a logistically shaped curve for the introduction of each new technology, based upon LCA-costs such as those indicated in Figure 3.4 and available knowledge on technical lead times for new technologies to make an impact (considering the addition of sufficient industrial capacity as well as financing issues).

Furthermore, for emerging technologies, the final cost is reached only once the technology has matured, and in some cases only after the industrial production volume has reached a certain level. It is therefore assumed that promising technologies are supported during their development, until they reach maturity, much in the same way as appropriate technologies are supported today. Because the proposed method for the realisation of the fair market consists of imposing a tax on energy prices that reflects the true social costs as seen by governments and parliaments, there will be a tax revenue that may be recycled to perform precisely the required market stimula-

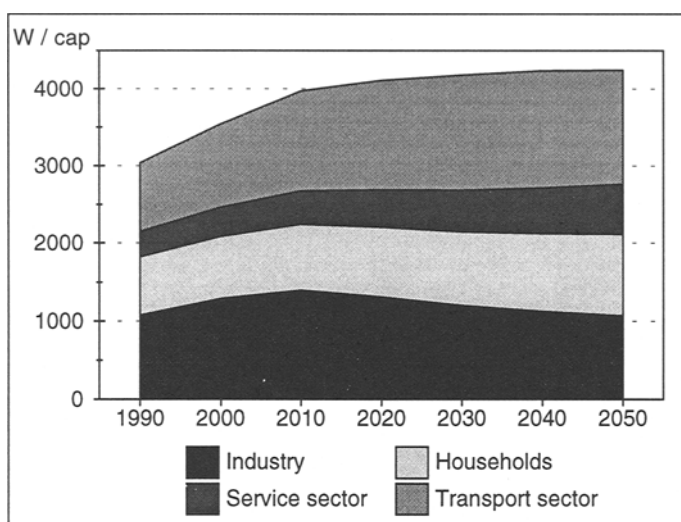


Figure 3.8 Activity growth assumed in Fair-Market Scenario for the current 15 European Union countries.

tion. Judging from the subsidies needed to achieve this, e.g. in the success story of the Danish wind industry, the social cost revenues will by far exceed the subsidies required, and we therefore assume that this function is performed, without specifying the amount of funding that has to be allocated for this purpose each year. In the case of Danish wind energy it was up to 30% of the capital cost for a period of about ten years (which corresponds to assisting the initial 3% of market penetration).

The assumed fair market development in total EU-15 energy demand is shown in Figure 3.9, and the outcome of the growth discussion above gives the activity profile of Figure 3.8. The assumptions include the following: In the transportation sector, as discussed above the large externalities (Sørensen, 1996a; 1996b) are assumed to curb demand. Getting fair prices (externality taxation replacing current taxes) in place will take some ten years, so growth in the demand for transportation energy begins to slow after 2005 and decelerates considerably after 2010, the 2050 level being about 50% over the 1990 level except for air transport, which reaches three times the 1990 level. Electricity use in the household sector grows to twice the 1990 level, due to new appliances, whereas heating and hot water needs only grow proportional to the assumed expansion in floor area and number of households. In terms of business, it is assumed that the information sector will grow and the material production sector will stagnate or decrease slightly, due to longer product life. This development is a consequence of fair pricing including social costs, because the inclusion of externalities will force the optimum product design to focus on longer product life. The

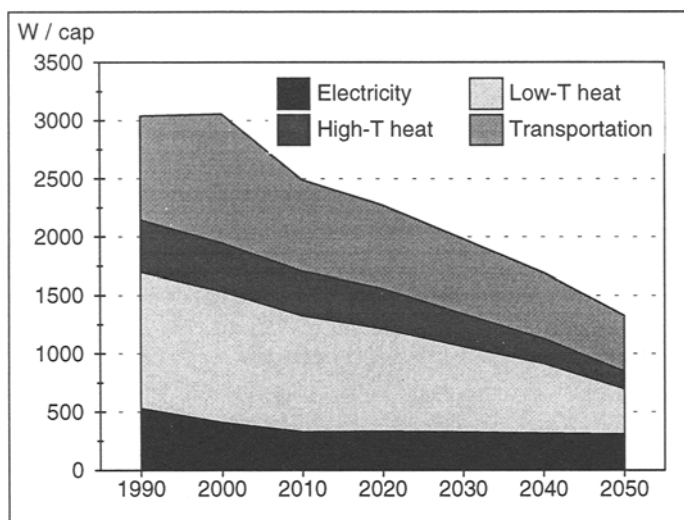


Figure 3.9 Energy demand development assumed in Fair-Market Scenario for the 15 European Union countries.

growing information sector is included by means of tripling electricity use in the service sector (in addition to the corresponding increase in the households). Service sector floor space and related energy use is assumed to grow by 43%. The demand curves in Figure 3.9 can now be determined by combining activity levels, population growth and efficiency efforts made. The total energy demand is by 2050 reduced by a factor of 0.44 relative to the 1990 level. Electricity demand constitutes an increasing fraction of the total.

In claiming that end-use reductions up to a factor of four in the energy used for obtaining a given service are LCA-economic and that many of them even are the cheapest in current direct-economy sense, the question arises why such reductions are not fully realised in the present market situation. They are in some cases: e.g. a quarter of all Danish buildings have been retrofitted to an extent that has reduced the total heating energy demand in the sector by a factor of two since 1974. So why were the remaining three quarters of the building stock not retrofitted, despite an estimated economic pay-back period for indicated energy efficiency measures of under 8 years and a physical life-time of about 50 years? There are several reasons; one of them is that in nearly 50% of all cases dwellings were rented and the owner was able to charge heating bills directly to the tenant, without any objections from the rental pricing board (a clear market distortion).

In other cases, the retrofitting would cause inconvenience to the inhabitants of a building, that they deemed a greater nuisance than the higher heating costs. Similar explanations for not taking any energy efficiency measures that are economic are found in other sectors: In non-energy inten-

sive industry, the energy bill is seen as such a small fraction of the overall production costs, that the disruption of work caused by reducing the energy requirements is considered "not worth the trouble", and in the energy-intensive industry, it is often found easier to bully the energy supplier into granting a quantity rebate, than to optimise the production line. That this is possible may again be a sign of a market distortion, provided that there are no actual cost reductions for the supplier (e.g. an electric utility) in selling large chunks of energy. This is a complex problem, among other things because bulk users exhibit individual features of importance for the "fair" price, such as constant demand (day-night, workday-weekend, seasons) and the possibility of load management (e.g. deferring loads from peak-load periods).

In a Fair-Market Scenario, it has to be assumed that energy measures that are economic are also taken, although it would seem contradictory to have to accomplish this by regulation. However, there are cases where regulation is the only fair instrument known and already systematically used (energy requirements in building codes, minimum standards for appliances, etc.). The Fair-Market Scenario assumes all energy efficiency measures that are economic today to be implemented before the year 2010. The scheme continues beyond 2010, but at a slower pace dictated by continued technology improvement. The required technology is clearly available for the strong effort before 2010, as is revealed if one considers the spread of current efficiency levels for the same technology (automobiles, appliances, light systems, computers, and so on). The above view on the efficiency options available in the present marketplace is consistent with other investigations (Nørgård, 1989; Nørgård and Viegand, 1994; Sørensen, 1991a, 1992).

3.1.3.2 Supply Development in the Fair-Market Scenario

The price of fossil fuels is currently determined by a mixture of market considerations and government taxation policies. As the accumulated use increases, the question of depletion of resources comes into play. This will first manifest itself as a trend towards the exploitation of more difficult and expensive deposits, and finally will entail steeply rising prices, but at different times for each type of fuel. Coal is expected to be the last to be affected by resource depletion, but for oil and natural gas, the finite quantity of the resources is estimated to make itself felt as early as the 21st century. Since the CO₂ release per unit of energy produced is larger for coal than for oil and particularly for natural gas, this will impact on any model with a fixed expectation regarding the reduction in greenhouse gas emission levels.

As the determination of externalities that will make the prices of fossil fuels "fair" is in some cases highly uncertain, one might be tempted to invert the problem by asking, what standard price one should introduce in order to avoid negative environmental and social impacts, for example, what price will bring about a reduction in European greenhouse gas emissions of 80%.

This question, however, can only be answered in a model revealing interactively how much can be achieved by increased energy efficiency (throughout the energy conversion system) and by introducing non fuel-based energy systems. This would be an interactive process, because the economic appeal of the alternative measures (efficiency and renewables) depends on the fuel price for the fuels that would be displaced, and vice versa. Furthermore, the non-linear behaviour associated with resource depletion introduces further instability. We therefore used the more amenable route of disregarding the externality uncertainties, using the assumption that their taxation rates are fixed by politicians anyway, and that therefore simply new, but transparent rules are created for the market.

Today, a number of renewable energy systems are competitive or near-competitive on a market-price basis without externalities relative to fossil fuel-based systems. These renewable energy systems and new ones will in the future be increasingly brought into the energy supply system as they are developed further, and also when the assumed LCA-price of competing energy options increases due to new externalities being identified. Substitution of renewable energy for fossil fuels is one of the choices facing decision-makers each time a replacement has to be made. However, renewable sources cannot contribute sustainably to any level of demand. There are natural levels of energy use densities, that should not be exceeded if the number of wind turbines is to remain acceptable, if the solar panels are to be limited to rooftops rather than requiring land, and if the production of bio-energy is to remain in harmony with food and non-energy uses of biomass, based on integrated production rather than competition among different uses of biomass. This would be reflected in steeply rising prices for renewable energy, once the "natural" capacity limits were exceeded.

The cost of renewable energy conversion systems must include costs incurred due to the possible need for energy storage, when the share of fluctuating sources increases. The FMS scenario makes use of the cheap storability of biofuels to minimise overall storage costs, keeping the total system cost below the level given by the development in fair market price. It should be mentioned, that the renewable energy costs of Figure 3.4 are only valid up to a certain level of usage. Above that, the problems of access to enough renewable energy will be reflected in higher prices. Examples are the 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 presently used for farming. As it turns out, these ceilings are not exceeded in the Fair-Market Scenario, and we thus avoid the problem of fossil fuels being in some cases cheaper than excessive use of renewables, despite externality incorporation. This simplifies the scenario construction, as the consumer reactions to steeply rising prices (reduced demand or changed priorities) discussed above need not be calculated.

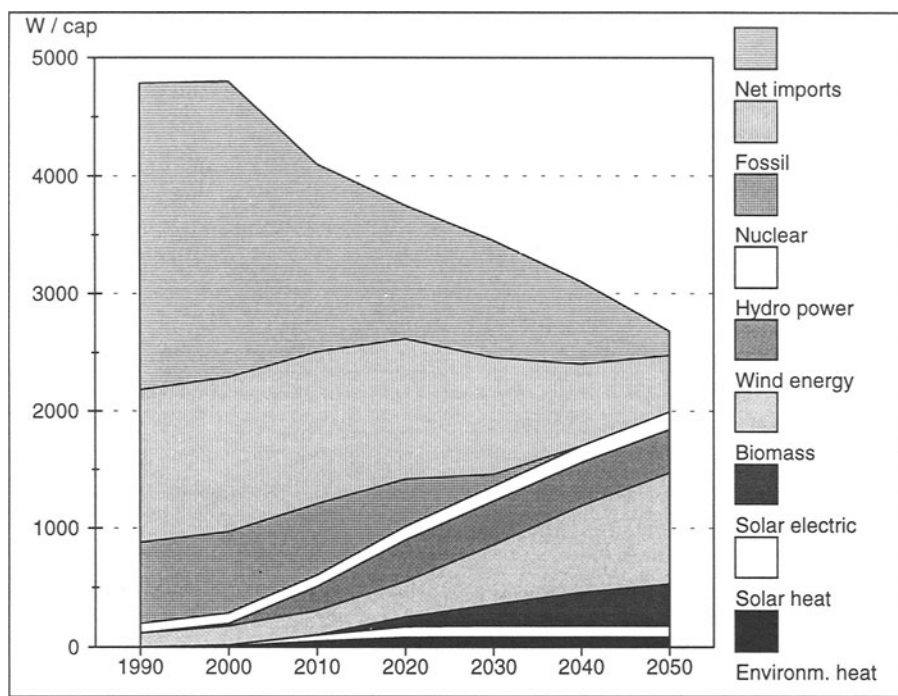


Figure 3.10 Primary energy supply of the Fair-Market Scenario for the current 15 European Union member countries.

The 2050 Fair-Market Scenario supply system is summarised in Figure 3.10. It is based on a selection of relatively few conversion technologies considered to be of high potential for the conversion of energy derived from renewable sources (see section 3.3). These are primarily 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 somewhat lower efficiency (e.g. CHP = combined heat and power plants). The actual picture is different for different European countries, and the choice of one particular set of technologies here is mainly for the sake of simplicity in illustrating the system layout, and there would be several more or less equally attractive solutions available (implying that the Fair-Market Scenario does not depend on the progress made in e.g. fuel cell technology).

Reversible fuel cells are expected to become available in a very wide range of sizes, from power plant level to larger individual buildings to perhaps mobile applications (in the case of low-temperature fuel cells). The reversibility is particularly relevant for a renewable energy system, because there will at times be an overproduction of electricity (from variable sources such as wind and photovoltaic panels). No detailed time simulation was made during the construction of the scenario to ensure the supply-demand

match, but it is assumed that less than half 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 weeks. This is consistent with calculations of the influence of storage on the capacity factor of variable sources in large electricity supply systems (Sørensen, 1979; 1991a). The need for fuel storage is diminished by including a considerable share of biofuels in the system. For the latter, production or use may be chosen to follow variations in demand minus supply of variable renewables. Heat storage, which 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 aquifers/waterways (if available). District heating systems are assumed to play a role primarily in cities in Northern Europe, the UK, Benelux and Germany. Today, only Finland and Denmark have a large coverage.

With these choices, the energy supply turns out to be amenable, using virtually no fossil fuels, except for non-fuel uses such as chemical feedstocks and lubricants, and some fossil fuel backup for dealing with renewable energy variations, as discussed below. This is gratifying, partly for reasons of greenhouse warming mitigation, and partly because the solution is then robust as regards a certain amount of change in demand, away from the level assumed in the scenario construction. Besides the possible requirement of additional storage or backup can be accommodated, despite the associated system losses. Especially for wind and solar electricity, the exploitable resources are considerably higher. In the case of wind energy, visual impact considerations led to a considerable reduction of the resource estimate. 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 more extensively for central photovoltaic plants, once again with a reversible visual impact. The present scenario only uses a modest fraction of the available marginal land for central solar power plants (photovoltaic or thermal-electric).

Biomass sources play a special role, due to their versatility as storage media and as fuels for the transportation sector (the other 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 may be operated on the basis of compressed gas. This may be compressed biogas (methane, as the CO₂ has to be removed before compression) or hydrogen. The methane comes from community-sized biogas plants fed with 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 as needed for energy is to be derived from residues. Optimised integrated food and energy production will yield much more biomass for energy purposes than today's agriculture, which is based on artificial straw-shortening, for instance, due to residues previously being considered a nuisance. The efficiency of the best operating biogas plants today is above 50%, and the same level of efficiency is possible for gasification (if pipeline gas quality is not required, the efficiency can be even higher). Methanol production from woody biomass is assumed to have an efficiency of about 50%. Energy needed internally for these processes is derived from the processes themselves, but a residue is left, which in the case of biogas is a fertiliser of particularly high value – far better than the materials that were originally removed from the farm. But gasification residues also contain all recyclable nutrients, and may be returned to the fields as they are, or in an improved physical state (e.g. granulated).

It is thus assumed that primary agricultural production is unaltered from 1990 to 2050, although the dietary balance between grain and vegetables versus meat may well change, as may the allocation of land to rotation crops, permanent crops, meadows and energy crops.

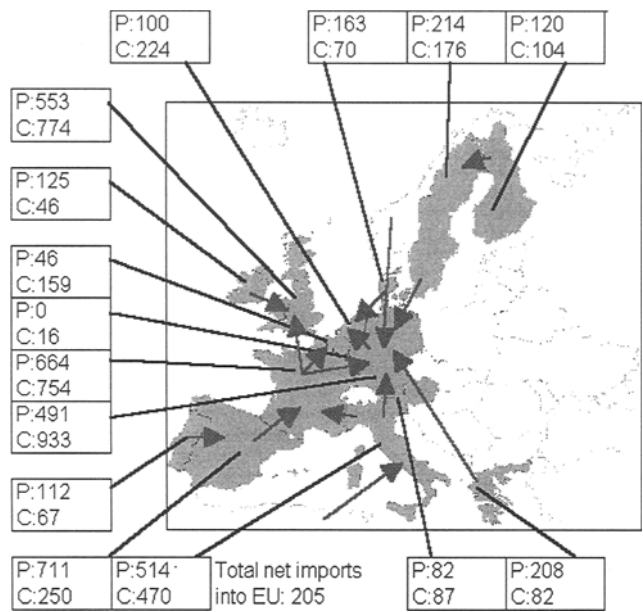
3.1.3.3 Matching Supply and Demand in the Fair-Market Scenario

Dynamic modelling of a combined model with the system components described above would exhibit loops of price-demand calculations. Starting e.g. from the activity level at a given time and the desire to expand the volume of activities, it must first be determined which fraction of the activities entails energy inputs. Once the demand for energy services has been determined, one should distribute any increment above the production of energy services through the preceding time interval among the three available options, efficiency improvements, renewable energy and increased fossil fuel use, according to the marginal price of each. Ideally, this calculation includes the feed-back of new investments in efficiency or new energy production and conversion systems into the activity levels. The outcome is the total cost of energy delivered, along with the marginal cost of the last unit of energy delivered. The ratio of incremental demand and calculated marginal cost of energy should then be compared with the price elasticity (derived from historical data when possible, but modified according to the assumed effect of value and preference changes). If it is larger the demand should be lowered by the difference and the whole model should be looped through again, assuming that this represents the next time interval. The length of the calculation intervals is an assumption on the time needed for price signals to be reflected in investment policy, which clearly has to be expressed as an average figure.

For reasons stated earlier, we did not go through such an iterative simulation, but one may reasonably guess that the assumptions regarding the price of fuels versus accumulated use, the price of efficiency improvements versus accomplished level of efficiency, and the price of renewables versus absolute rate of usage, will be the decisive parameters, and that different outcomes can result from fairly small changes in the assumptions. As a consequence, the "standard price" derived for fossil fuels in a model that succeeds in reducing greenhouse gas emissions by, say, 80%, i.e. the level of externalities that would achieve the political goal, would be a very small item in a huge calculation, and would exhibit a strong sensitivity to the range of important assumptions listed above. This indirect way of assessing the problem is thus likely to be inefficient, and the Fair-Market Scenario is therefore based upon an intuitive sketch of at least one possible development, respecting current trends and general estimates of future supply and demand prices.

Figure 3.11 gives a more detailed picture of the way supply and demand are matched in the overall Fair-Market Scenario for the year 2050, corresponding to the summary of Figure 3.7. The model depicted in Figure 3.11 for all the 15 EU countries is a summary of models for each country (depicted below); the overall differences in supply and demand between EU member countries are outlined in Figure 3.12, along with imports and exports. It is seen that considerable trade takes place among the EU countries, as well as with countries outside the EU, notably Norway, the Middle East and North Africa. The option of substantial trade in energy among the European countries has had a profound influence on the set-up of renewable energy systems in the different countries. Countries with good solar conditions (Portugal, Spain, Italy, Southern France and Greece) produce more photovoltaic power than they are able to use by themselves, and countries located in areas with good wind conditions (Denmark, UK etc.) similarly increase their production of wind power in the interest of neighbouring countries with smaller renewable energy assets. Biomass surpluses (plantations of residues) that may be used for energy purposes are found in agricultural export countries such as France, Denmark, and possibly more Mediterranean countries that are currently characterised by fairly low photosynthesis efficiency.

Each new renewable energy device makes a transition from marginal importance towards its final 2050 level, starting the year that the fair price gets below that of the appropriate alternative (cf. Figures 3.1-3.4). From that point, growth is essentially linear until it levels off at the maximum assumed penetration. The slope considers replacement to happen when other equipment reaches retiring age, and takes into account production capacity and life time of the new devices introduced (typically rising from 10-15 years for new technologies to above 25 for fully mature technologies).



OVERVIEW OF 2050 FAIR MARKET SCENARIO FOR EU15
Net production (P) and end-use consumption (C) in TWh/y

Figure 3.12 Energy production and consumption in the 2050 Fair-Market Scenario for EU-15, and indications of major imports and exports between EU countries and energy trade with countries outside the European Union (Nielsen and Sørensen, 1996b).

Current wind power growth is used as a template. Wind power is fully introduced by 2020. Until then, biomass continues to be used for combustion as it is today, although there is an additional introduction of biogas plants, too. After 2020, the gasification and production of liquid biofuels become economic in the transportation sector, and they expand over the subsequent decades. Solar-thermal is immediately competitive in Southern Europe for space heating, and becomes so after 2020 in Northern Europe, under the fair price assumption. On the basis of these assumptions solar electricity is forecast to become competitive with coal-based power from around 2020, and from 2030 also with natural-gas based power.

The indigenous European fossil fuel reserves are declining towards the end of the scenario period, but more slowly than they would be at the current rate of use. This makes it possible to reduce imports of fuels from outside the 15 European countries, but towards the end of the scenario period, fossil and nuclear fuel imports have been replaced by small amounts of solar electricity imports, notably from the Middle East or North Africa. Some hydro

electricity imports from Norway (with its seasonal reservoirs and associated active storage displacement) are also included. The option of hydrogen imports/exports is left open, but they turn out to balance, when the country-by-country renewable energy-based hydrogen production of the scenario is allocated on the basis of the resource assumptions.

In evaluating the investment costs for the scenario trajectory, it should be kept in mind that no new capacity for conventional power plants, oil refineries or gas treatment plants is required (although some installations will be old towards the end of the period, they will not be any older than some plants in operation today). Existing refinery or gas treatment sites may gradually be converted to biomass gasification and liquefaction installations.

The calculation of investments needed during the transition to the 2050 Fair-Market Scenario requires knowledge of the cost of all system components (corresponding in part to Figures 3.1-3.4, but including the costs of end-use equipment and certain storage and transmission devices). Not only are the externality costs unknown in some cases, but even the direct capital costs for some of the components are hardly known. It is therefore only possible to gain a rough overview of the needed investments through extrapolations such as the ones needed for photovoltaics. We only included technologies in the scenario which according to our estimate will become economic during the transition period under the externality assumptions made, and there remains considerable uncertainty about when exactly they will start being competitive. This is particularly true for components such as reversible fuel cells, photovoltaic panels, liquid biofuels and new forms of energy storage. Because of the long period considered, the physical life times of the components also matter, but the scenario is not very sensitive to the physical lifetime, as long as it is longer than the assumed economic depreciation period.

When accepting these uncertainties, in order to calculate investment profiles one has to adapt standard depreciation methods to the new types of technology. Conventional concepts such as capacity factors take on a somewhat different meaning, because of the peculiarities of renewable energy systems. For example, a wind turbine of a given size may be equipped with a generator with rated power twice as high as that of a standard one, at an extra expense of a few percent of the capital cost, and with a modest increase in energy production. The capital cost expressed as ECU/kW, however, will be roughly halved by this measure, exposing the fragility of the rated-kW cost as a basis for investment calculations. Similar qualifications have to be made for several conventional concepts:

- Availability: is very high (over 98%) for solar and wind power plants.
- Load factor: depends on system set-up, due to the local mismatch between fluctuating energy sources and demand (that, however, may be

smoothed in large systems, or deferred by load-managing systems expected to play a larger role in the future).

- Capacity factor: currently about 25% for wind turbines. Expected to rise to around 35%. Around 10% for a photovoltaic installation in Denmark, under 10% for current solar-thermal systems, when evaluated on an annual basis.
- Reserve power: could be greatly reduced from currently 15-20%, because of the modular nature of dispersed energy systems, that need reserve power only corresponding to their non-availability.
- Electric transmission losses: Expected to be reduced from currently 5-6% (in Denmark, somewhat higher in Southern Europe) to 2-3% for dispersed renewable energy systems, because at least 50% of the power will be delivered from local systems, and because present lines will have been replaced at least once before 2050, and presumably with better technology. On the other hand, backup power may have to be transmitted from further away than in the present system. If the year 2050 we assumed a 2% local distribution loss and a 4% loss for each long-distance (typically international) transmission.

Renewable energy systems such as wind turbines or solar panels have large investments up-front, but very short lead times as regards construction. These factors must be taken into account when calculating the financing costs. However, the modular nature of many renewable energy systems makes it unnecessary to look at optimum times for adding new capacity, as the capacity build-up can be made gradually without penalty. Questions of hourly supply-demand matching and need for storage or back-up are addressed by Novator in the LTI-Project report (LTI 1996), based upon principles described in Sørensen (1997b).

3.1.4 Details of Fair-Market Scenario Results

In this section, the main FMS scenario construction is presented. The data assumptions for the demand and supply sides were described in Sec. 3.1.3.1 and 3.1.3.2. Sections 3.1.4.1 and 3.1.4.2 give the main data used in the scenario.

3.1.4.1 *Renewable Energy Resources in the 15 European Union Countries, and Other Supply Side Data*

Renewable energy sources are assumed not to have penetrated the transportation sector fully by 2050, so some fossil fuels are used for aviation and waterway transportation. All non-energy uses (such as feedstocks for the chemical industry) are still assumed to be of fossil origin.

The energy finally assumed in the FMS to be derived from renewable energy in EU15 by 2050 is shown on the left-hand side of Figure 3.12, and for each country in Figures 6.1-6.15 in the Appendix. In 2050, primary energy production from renewable energy is about 6 PWh per year (cf. the left-hand column in the summary in Figure 3.11). This is high compared to the 1990 renewable production of about 600 TWh, of which 260 TWh was generated by hydropower plants and only 33 TWh came from geothermal, solar and wind sources (IEA/OECD, 1993). Actually, the renewable production in 2050 amounts to around 40% of the total primary energy use in 1990. A very high share of this renewable production is in the form of electricity. More than 2300 TWh is primary electricity generated by wind turbines on land or off-shore, hydropower plants, large scale centralised solar-thermal electricity plants and decentralised façadephotovoltaic systems integrated in roofs and façades. This primary renewable energy electricity production exceeds the total final electricity consumption in 1990 by more than 600 TWh.

3.1.4.2 Energy Demand 1990-2050

The energy demand in 1990 was taken from IEA/OECD (1993). The data for 1990 energy use in industry is supplemented by data from the German ISI-project contributed to the this project (these data are given in the technical report, Nielsen & Sørensen, 1996a). Estimates of the future energy demand draw on work by Nørgård & Viegand, 1994, for several European countries, Sørensen et al., 1994, for Denmark, and the ISI report for Germany; the last two sources mentioned allow some extrapolation for other countries. Energy categories considered are electricity, fuels (for process heat), space and water heating, cooling and transportation subdivided according to mode (road, rail, waterway, air).

Energy demand in industry

The ISI report estimates the potential for improving energy efficiency of eight main industrial sectors in Europe (iron & steel, chemical & petrochemical, non-ferrous metals, non-metallic materials, food & tobacco, paper & pulp & printing, textile & leather, and other industry). These estimates are primarily based on a study on the German industrial sector. ISI's assumption is that the efficiency gains possible in the German industrial sectors are representative of the same industrial sectors in the other EU15 countries.

ISI's assessment gives estimates for both 2020 and 2050 for two different scenarios, reflecting different views in industry on the importance of efficiency investments. For the future energy prices of the FMS which include externality costs, it is expected that the ISI high-efficiency scenario is the proper one to use. We thus adapted ISI's estimates for the possible future intensity indices in different industrial sectors to the sectors of the FMS sce-

nario. Of course, the ISI data did not originate from the same externality assumptions as the FMS and thus may constitute an underestimation of the industrial efficiency options at the appropriate price level. By 2050 the efficiency measures lead to intensities (energy use per unit of industrial output) that range from 25% to 50% of the present figure, for the different industrial sectors.

In particular, for the category of industry called "other industries" in the ISI database (comprising the emerging knowledge-based industries, assumed in the FMS to gain importance), our expectations for future improvements in efficiency exceed the estimates in the ISI-database. For this category of industry we have used an intensity of 25% relative to 1990, based on Danish experience (cf. Sørensen et al., 1994, and references therein). The Danish situation is assumed to be indicative of a future "information society", because of the preponderance of small companies without material production, and the near absence of heavy industry.

The intensity changes have to be folded with changes in activity and in the industry mix. The expected growth is in the share taken up by "other industries", their share in the energy use of industry as a whole is assumed to be 1.5 times larger in 2020 and 2.5 times larger in 2050 than in 1990. This uniform scaling implies that countries with at present large "other industry" sectors will continue to lead in this respect. The increased share of the information industry is offset by a uniform reduction in other sectors. Total industry activity (defined as activity in energy use) increases by 30% up to the year 2010 and then drops back to the current level (time, country and sectorial distributions are given in Nielsen and Sørensen, 1996a). Of course the activity measure as an economic entity will continue to increase throughout the transition to a more information-based industry.

Space heating in industry is estimated separately for each industrial sector, as it depends more on the building area than on industrial output. The energy quality issue involved is fairly important for a renewable energy scenario where space heating and hot water heating may be supplied by low temperature solar heating or heat pumps while high-temperature heat can only be obtained by using electricity, gas, or fuels. However, national and OECD statistics do not provide much information on what the energy delivered to the consumers is used for, but only state how much is delivered as fuel or electricity. To get a more realistic picture of the energy quality the consumer needs, we used the information in the ISI database to estimate how much energy industry actually needed for space heating in 1990. Similar estimates have been made for Denmark (Sørensen et al., 1994).

Future energy demand for other sectors

Our model for the realised efficiency improvements is in all sectors based on presently identified efficiency measures that will be economic under the

FMS energy cost assumptions. The energy demands are based upon intensities that are 25% of the 1990 values for the household and service sectors, as well as 25% for road transport, but only 50% for rail and air transportation, and 75% for sea transport.

Provided the activity level and the population figure remained unchanged implementing the assumed efficiency measures would reduce the EU-15 energy use by a factor of three by 2050. The effects of increases in activity without efficiency improvements were shown in Figure 3.8.

However, the scenario must include expected changes in the activity level associated with the changes in society inherent in the FMS development. We assume that end-users will react to the price signals provided in the FMS, based on the choices provided by the range of technological solutions offered in the scenario (which will, of course, be supplemented by other solutions not foreseen in the scenario). While historical examples of strong price signals (e.g. 1973 and 1980 oil prices) at least led to temporary reductions in consumption, their long-term effect is not clear. In each case they appear to have influenced people's behaviour only for a period of less than five years, but as the development in the absence of these price changes is not known, the only indicator is the ratio of gross national product and energy use or the ratio of changes in these two entities. Neither of these indicators has gone back to the value it had before 1973. If correct pricing does not lead to the rational behaviour indicated by the price relations, then the market mechanism has failed, and other methods such as legislation based upon basic principles of sustainability should replace the market theory.

We assume that activities involving energy use increase as much during the period 1990 to 2050 as they have in the past 50 years. The increase is highest for electricity use in households and the service sector, and for transportation by air (a factor of three is assumed, based on the emergence of many new products requiring electricity, and a trend towards more intercontinental leisure travel). Factors of about 1.5 are assumed for all other sectors, except those associated with personal hygiene and cooking, which are considered constant on a per capita basis, and space heating, which only increases by 30% even if the increase in floor area is larger (in view of the effects of passive designs that avoid active heating and cooling in many buildings in Southern Europe).

The assumed future population development is based on the World Bank's long-term population projection for the population in all 15 European countries included in this project. The European Union population is expected to grow by less than 1% from 1990 to 2050. This assumes that immigration continues to be controlled approximately as it is today.

The final results for the expected future energy demand were shown in Figure 3.9 and may for each country be read off Figures 3.13-3.28 (right-hand side).

3.1.4.3 Energy Conversion Systems for the 15 European Union Countries

The next step in constructing the FMS scenario is to match supply and demand through feasible energy conversion systems which can generate and deliver the energy needed at the end-use level.

Energy technologies used

The technologies used for energy conversion, storage and transmission in 2050 appear in Figure 3.11 and Figures 3.13-3.28. The assumed efficiencies are as follows (Jensen & Sørensen, 1984; Sørensen, 1979; IPCC, 1996):

- Heat pumps, COP=4 (one unit of electricity gives 4 units of heat).
- Hot water solar thermal systems, storage losses 20% in Southern Europe (GR, IT, AT, ES, PT, FR), 30% in Northern Europe (rest).
- Solar-thermal systems for space heating, storage losses 25% in Southern Europe, 50% in Northern Europe.
- Biogas production from biomass, 50% efficiency.
- Hydrogen production from biomass, 50% efficiency.
- Methanol production from biomass, 44% efficiency.
- Combined heat and power (CHP) plant using biogas, 30% electricity and 50% heat.
- Electric cars, 50% efficiency, due to battery losses.
- Gas production through reversible fuel cells, 90% efficiency.
- Power and heat production through reversible fuel cells, 62% electricity and 28% heat.
- Transmission of electricity, average 2050 local losses 2%, long-distance (international) losses 4%.
- Gas pipeline and storage losses, 15%, for international transmission an additional 10% loss.
- District heating lines and heat stores, average losses 25%.
- Efficiency of non-energy uses of fossil fuels, 50% higher in 2050 compared to 1990.

Individual country 2050 FMS system layout

Figures 3.13-3.28 show the 2050 FMS construction of the energy system in each country. It is clear that there is considerable room for using different technologies to match demand with supply. We picked one example using known technologies, but several others would be possible at very similar overall efficiency and cost. The scenario thus does not depend heavily on, for example, whether or not the assumed reversible fuel cell technology is sufficiently developed at the time it is supposed to be introduced. Other CHP technologies could do the job. Most likely, technology will advance over the long period considered, so that better and cheaper technologies will

come into play than the ones we can envisage now. However, by using technologies that are already available, but in some cases need to be developed further, we prove that the proposed scenario is at least possible, although better technologies may materialize over the fifty-year period modelled.

Conversion, distribution and storage components in the system

Because biomass plays a specially important role in the scenario, a few comments are here made regarding the technologies used: Biogas is produced on the basis of agricultural and municipal waste, then distributed through pipelines and storage systems currently used for natural gas, with an average energy loss of 15%.

Biomass residues from the agricultural sector and the primary crops from energy plantations are converted to hydrogen and methanol with average losses of 50% and 56% respectively. The methanol produced is used for road transportation and the hydrogen goes into the hydrogen store and pipeline system where we have assumed an average loss of 15%, before being delivered directly to the combined heat and power plant, the fuel cell system, to final use in the industrial sector or distribution via a pipeline system and export to other countries. Hydrogen is storable and helps smooth the variations in renewable energy supply.

The high share of primary electricity from intermittent renewable energy sources requires additional storage and back-up systems. The scenario assumes extensive use of gas storage in connection with reversible fuel cell technology. Excess electric power is used to produce a gas (such as hydrogen or methane) that can be stored and later returned to the fuel cells to produce electricity and heat. In the FMS scenario, an average 50% of all primary electricity go through this storage cycle, where fuel cells convert electricity to hydrogen with a 10% loss of energy. After the conversion, hydrogen is distributed by pipeline for direct use or storage in a hydrogen store (possible aquifer or salt dome sites have been identified throughout Europe). The average loss of the total hydrogen and storage system is assumed to be 15% of the energy content. Additionally, some of the primary electricity generated by hydropower plants can be stored (e.g. using pumped hydro), and battery storage may be operated in vehicles by the end-users.

The remaining 50% of the intermittent primary electricity generated by renewable energy technologies is distributed directly to the grid. Fuel for air and sea transportation is assumed to be fossil. The same holds for non-energy feedstocks.

Combined heat and power production plays a major role in some EU countries. The main fuel for CHP plants is hydrogen, producing on average 30% electricity and 50% heat, relative to the hydrogen energy input. For the reversible fuel cell systems, a mix of 62% electricity and 28% heat is assumed, corresponding to expectations for larger systems (Sørensen, 1984).

The heat produced by combined heat and power plants and fuel cell systems is distributed in a district heat pipeline with an average loss of 25% of the energy content.

The change assumed to take place in the road transportation sector over the 50 year scenario period is such that in the future all transport activities in cities will have to be carried out without any emission of pollutants. Therefore half of the total road transportation is assumed to involve electric vehicles. The latter entail an assumed 50% energy loss penalty by having to go through a battery storage cycle. The other half of the fuels, for road transportation outside urban areas, is provided by biogas and methanol. This implies that at least half of all fuels for road transportation is derived from biomass. All rail transportation is assumed to be electrified. For air and sea transportation we conservatively assume that the fuel delivered will still be fossil in 2050.

The industrial sector will derive low-temperature heat from either heat pumps or district heating. The demand for high-temperature heat for processes as well as any other energy use is covered by either hydrogen or electricity.

Low-temperature energy for households and the service sector is delivered by solar heat systems, district heating systems and heat pump systems. The specific electricity needs for appliances, electronic equipment and electrical cooking, etc. is delivered from the grid. Heat pumps and solar heat are not assumed to be used very widely in Northern European countries, where district heating with communal heat stores is used, but in Southern European countries, where the overall need for heating is lower, solar heating and heat pumps are considered the best solution.

Import and export in the Fair-Market Scenario

As can be seen from Figure 3.12 and Figures 3.13-3.28, some countries are exporters of gas or/and electricity while others are importers of these commodities, depending on the amount of natural renewable energy sources and fossil fuels available. When electricity is exported we assume an additional average loss of 4% due to transport, on top of the 2% assumed for national distribution in both the exporting and the importing country. These losses are smaller than current ones, but consistent with the best technology in use today. For gas exports we assume an average loss of 2% for transport and 15% when going into the national hydrogen storage and pipeline system, in addition to a similar 15% already lost in the national storage and pipeline system of the country where the hydrogen was produced.

Figure 3.12 shows how the 15 European countries export energy to each other, and gives the total production and consumption in each country. The way we constructed it, the scenario suffers from a minor shortage of electricity; the missing electricity is to be imported from outside of the European

Union. If this is not an acceptable solution in the future, the 15 member countries have the potential to exploit more wind and solar energy. There is an especially large additional potential for the installation of façade-photovoltaic systems integrated in roofs and façades in Central and Northern Europe, large scale centralised solar-thermal electricity plants or photovoltaic plants in Spain, Greece, Italy and Portugal, and off-shore wind turbines in several European waters. The 201 TWh of power imported could come from Northern Africa, where the exploitation of solar energy has considerable potential. If photovoltaics and solar-thermal power are cost-effective in Europe, they will be even more so in Northern Africa, which has higher average radiation and plenty of low-cost desert land; the additional cost of transmission to Europe could then be sustained without altering the consumer electricity price. Therefore we feel that such imports might be realistic within a rigid fair market society.

3.1.5 Concluding Remarks

The construction of a scenario based on the fair market principles did not lead to any complications in the sense that the available energy resources were able to satisfy the projected demand without entering the regime of high and uncertain prices expected if the use of renewable energy exceeds certain natural ceilings, and if non-renewable resources have to be used at rates involving near-term resource depletion issues.

The externality costs assumed to drive this development were fixed according to evaluations based upon the current situation. Because both the energy system and the society which it is embedded in will be different at the end of the fifty-year transition period, an evaluation of externalities made at that time may turn out differently, for instance due to new knowledge emerging as regards environmental side effects of energy use. Since these cannot be predicted, the only test that can be done is to evaluate the overall externality costs of the constructed scenario and see if these are consistent with the assumed costs. In a project for the Danish Energy Agency we did that for Denmark (Kuemmel, Nielsen & Sørensen, 1997), and found total externalities of the FMS amounting to 25 GECU/y compared to 40 GECU/y for the present system. However, the externality costs associated with greenhouse warming and air pollution had become nearly zero, and the remaining externality costs were almost entirely due to traffic infrastructure (accidents, noise, visual impacts, etc.).

The transportation externalities are higher than today, because transport volume is larger in the 2050 FMS than the current one. This is despite the introduction of zero-emission urban transport systems and generally reflects the absence of alternatives to the present type of traffic infrastructure that might offer a choice to consumers on the basis of fair prices. We would ex-

pect that the high transportation externalities will be seen as a problem, and that resources will be spent on developing alternative solutions, although it does appear difficult due to the size of the system that would have to be replaced.

Another sector that may have similar problems is agriculture. Here we have not tried to estimate the externality cost associated with monoculture-type farming and changes in the landscape. If these were viewed as alterations of a natural environment associated with an externality cost just as the highway systems, a fair market might spur changes, first in the direction of sustainable agricultural practices, presumably based on ecological farming, and perhaps later a switch to multicultures grown with the help of techniques still being explored on an experimental basis today. It is in our view important to point out these issues, because they indicate the limitations of any scenario construction for the future, and in particular point to the likely change in ingredients that will be included in “fair” prices in the future.

A further fundamental limitation to using market-based approaches is the fact that reality rarely fulfils the basic assumptions of economic theory as used in the development of market models. In particular, assumptions regarding “rational” behaviour of consumers have never historically been fully justified, due to market distortions present in all existing markets, regarding size distribution of players, access to knowledge and willingness to follow price signals. However, it should be noted that the purpose of scenario constructions is not to predict the behaviour of consumers, but to provide tools useful for political decision-making that should take place now and not at some future scenario date. In this respect, the Fair-Market Scenario gives an important input by stating that the market can be made to behave in a way that the greenhouse warming problem is avoided, provided there is the political will to set the rules correctly and to follow up on whether they are adhered to or not.

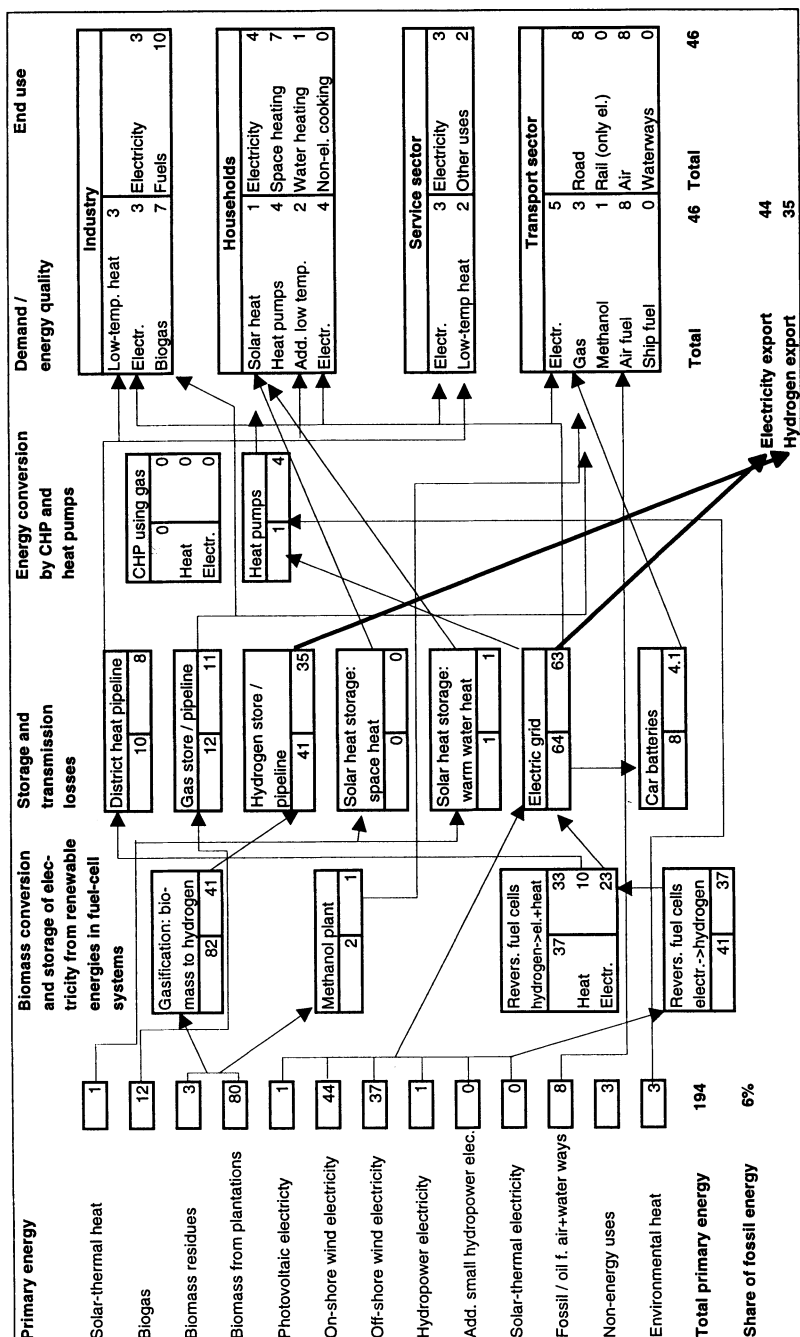


Figure 3.13 Irish energy system in the Fair-Market Scenario in 2050 (in TWh/a).

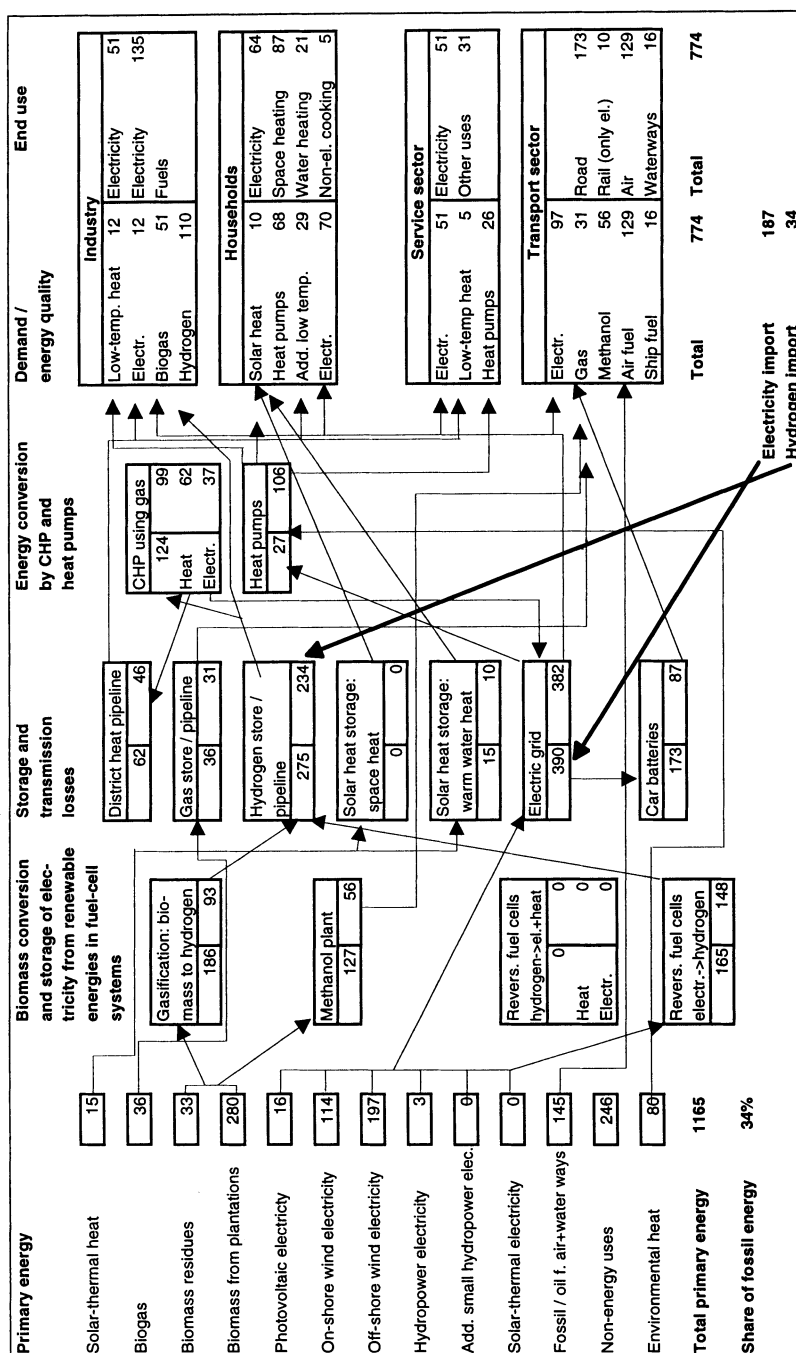


Figure 3.14 U.K. energy system in the Fair-Market Scenario in 2050 (in TWh/a).

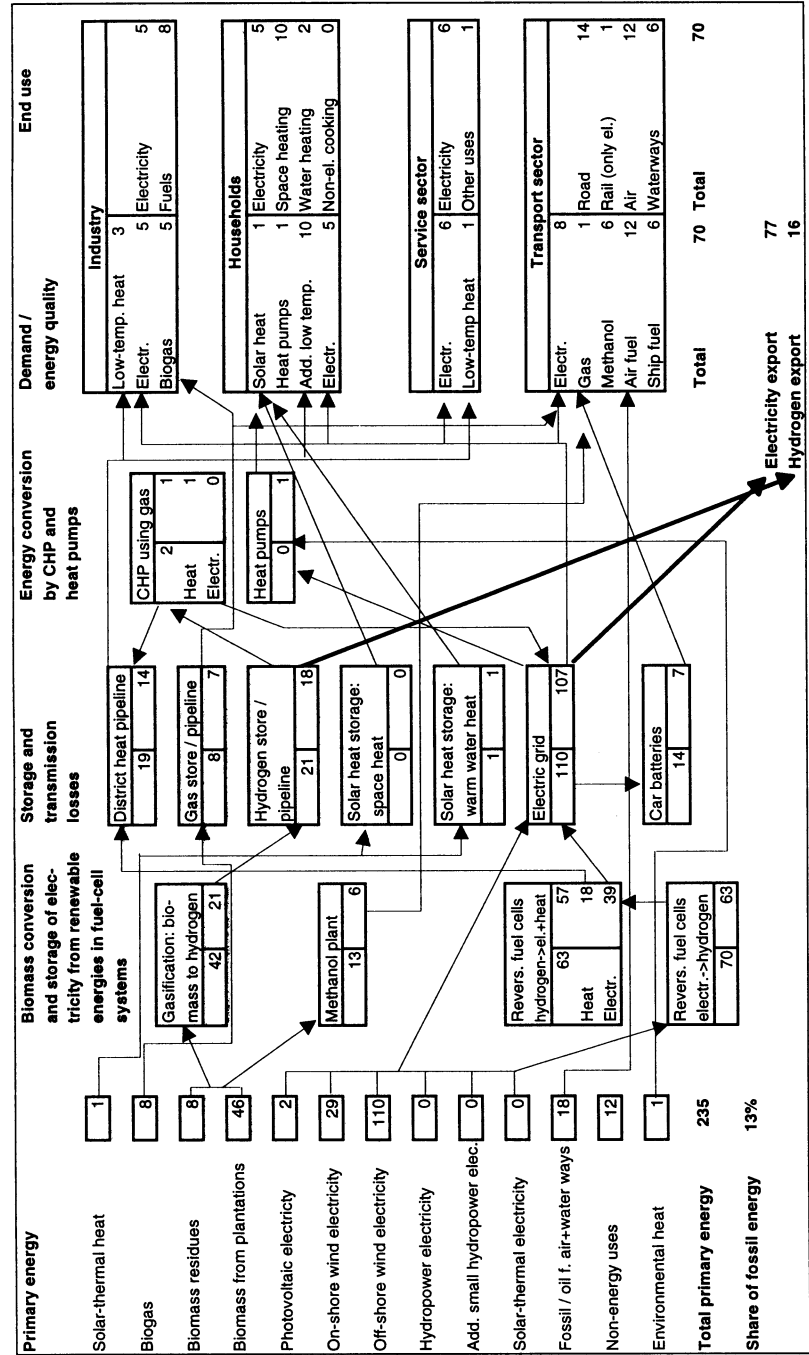


Figure 3.15 Danish energy system in the Fair-Market Scenario in 2050 (in TWh/a).

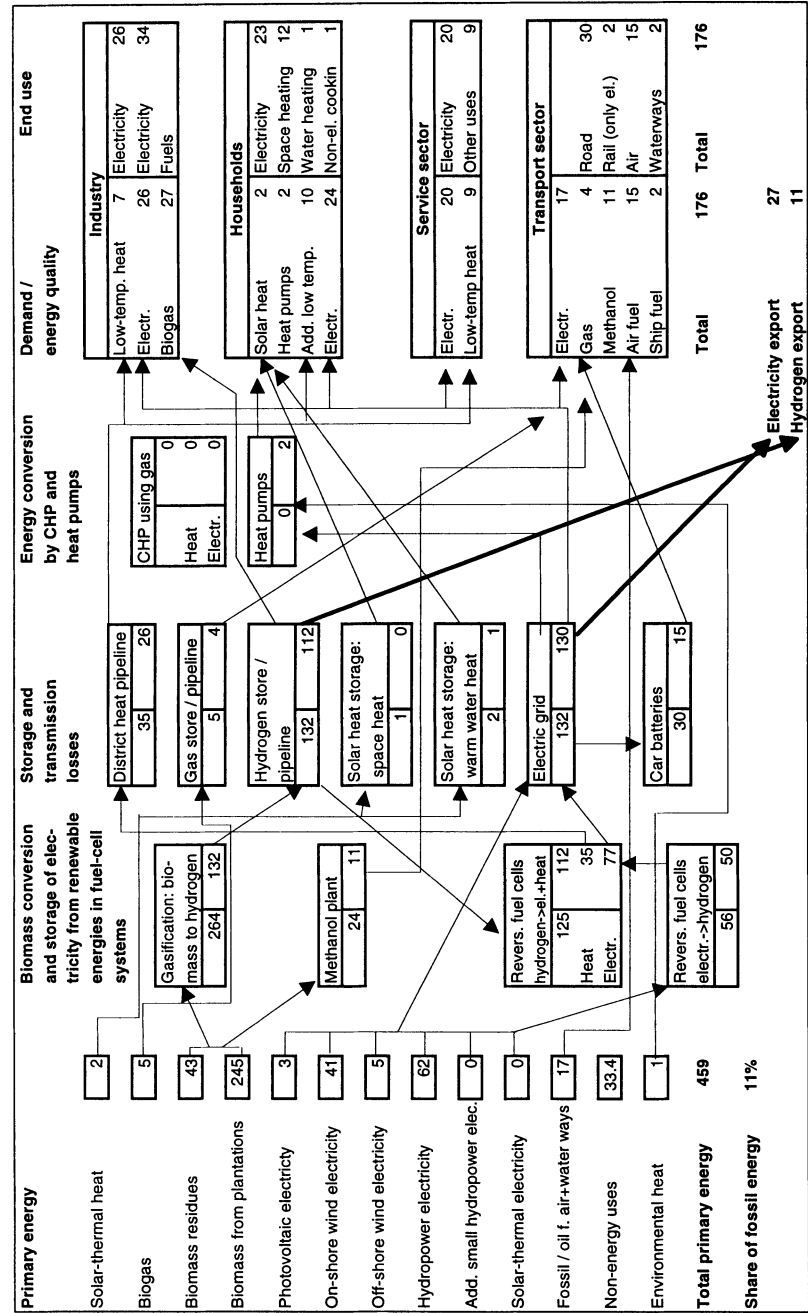


Figure 3.16 Swedish energy system in the Fair-Market Scenario 2050 (in TWh/a).

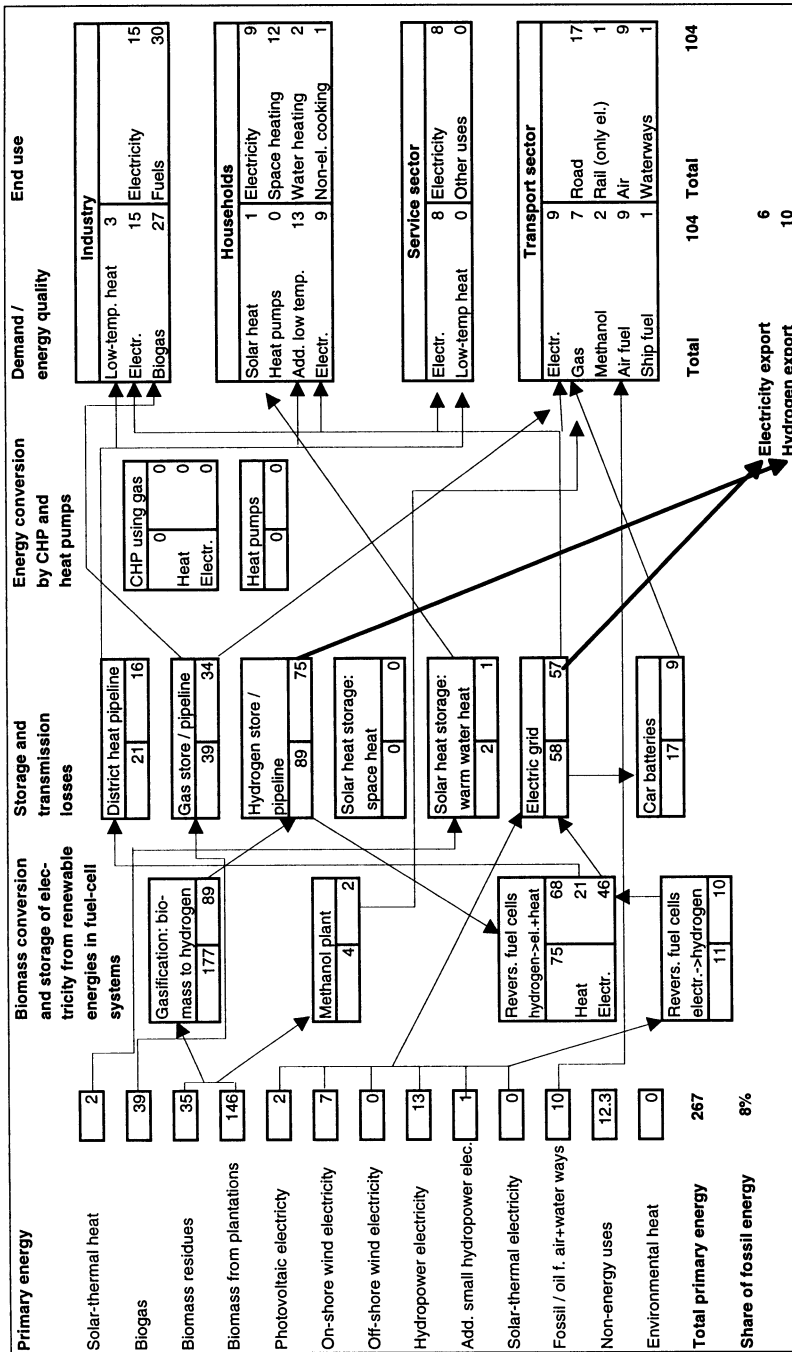


Figure 3.17 Finnish energy system in the Fair-Market Scenario in 2050 (in TWh/a).

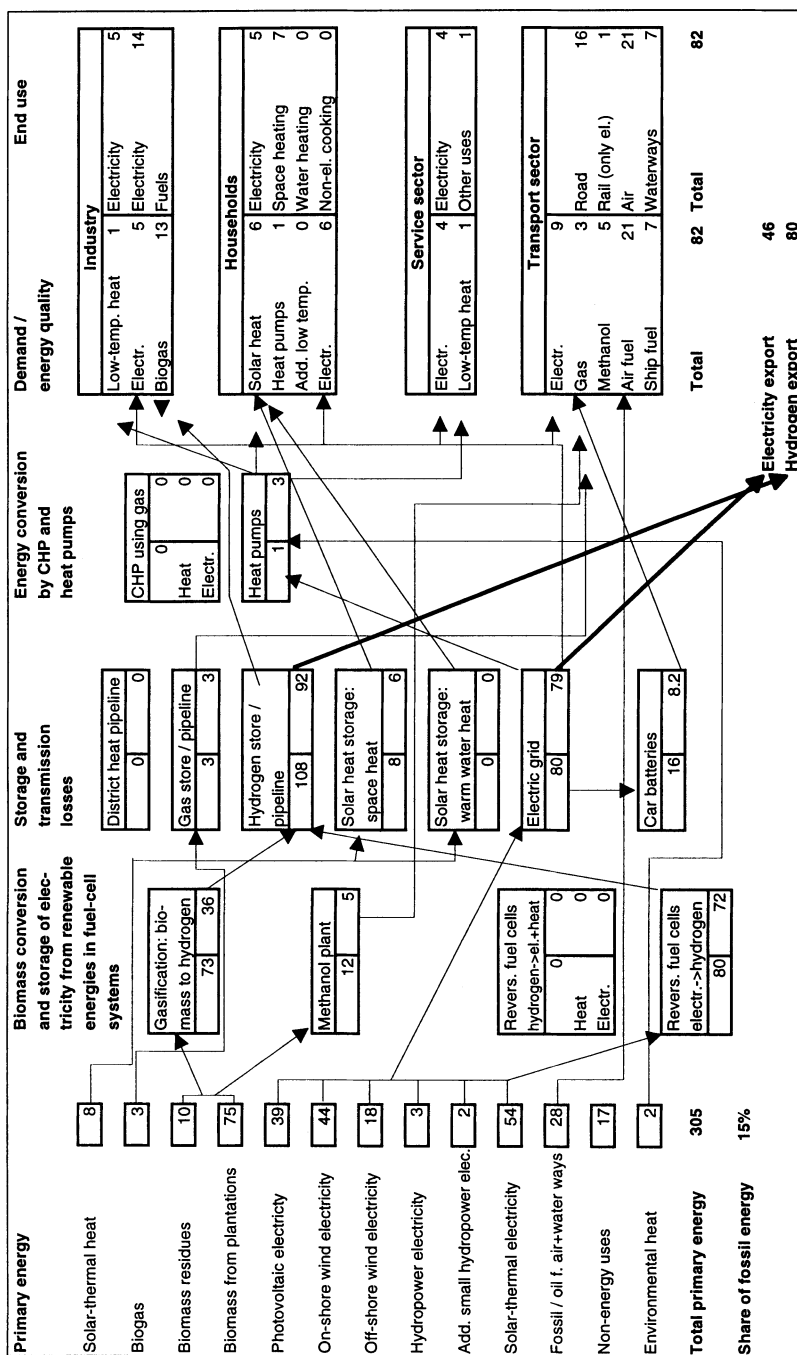


Figure 3.18 Greek energy system in the Fair-Market Scenario in 2050 (in TWh/a).

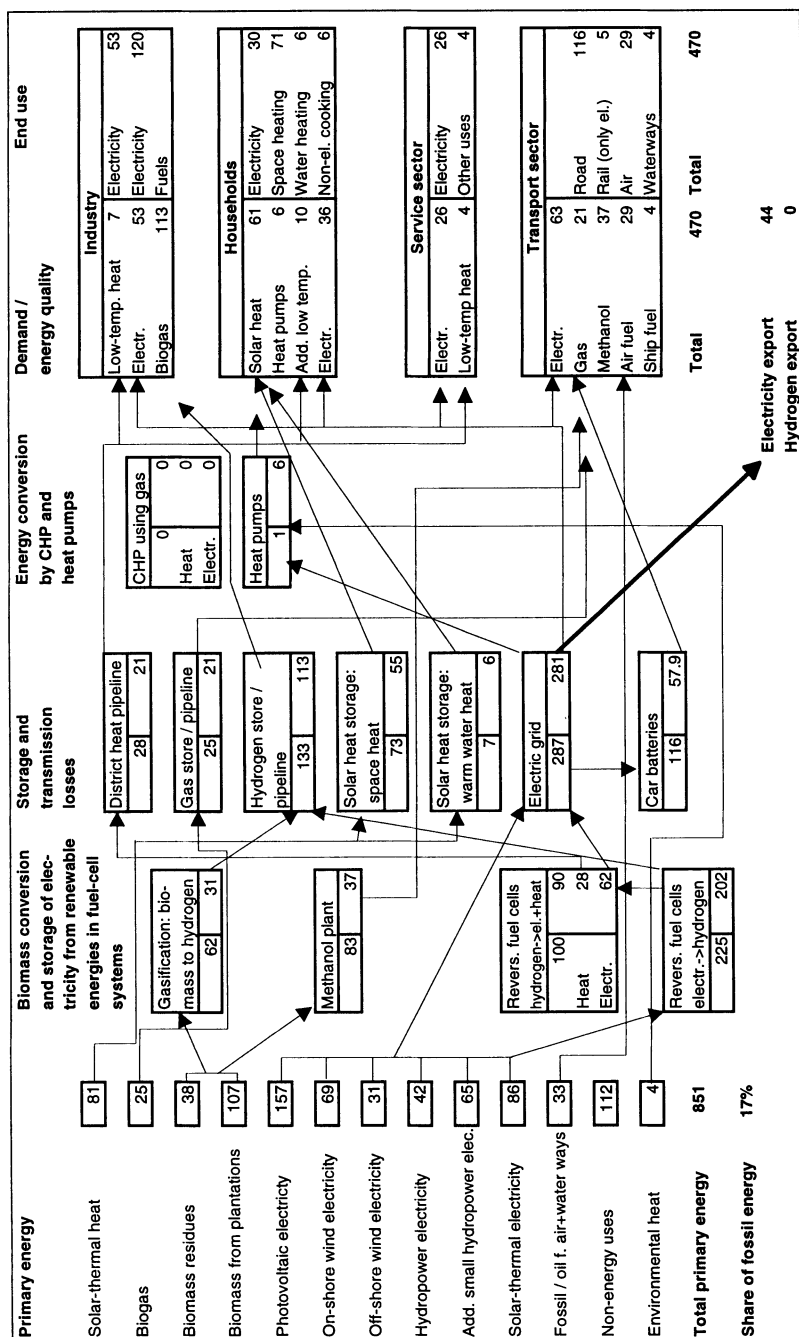


Figure 3.19 Italian energy system in the Fair-Market Scenario in 2050 (in TWh/a).

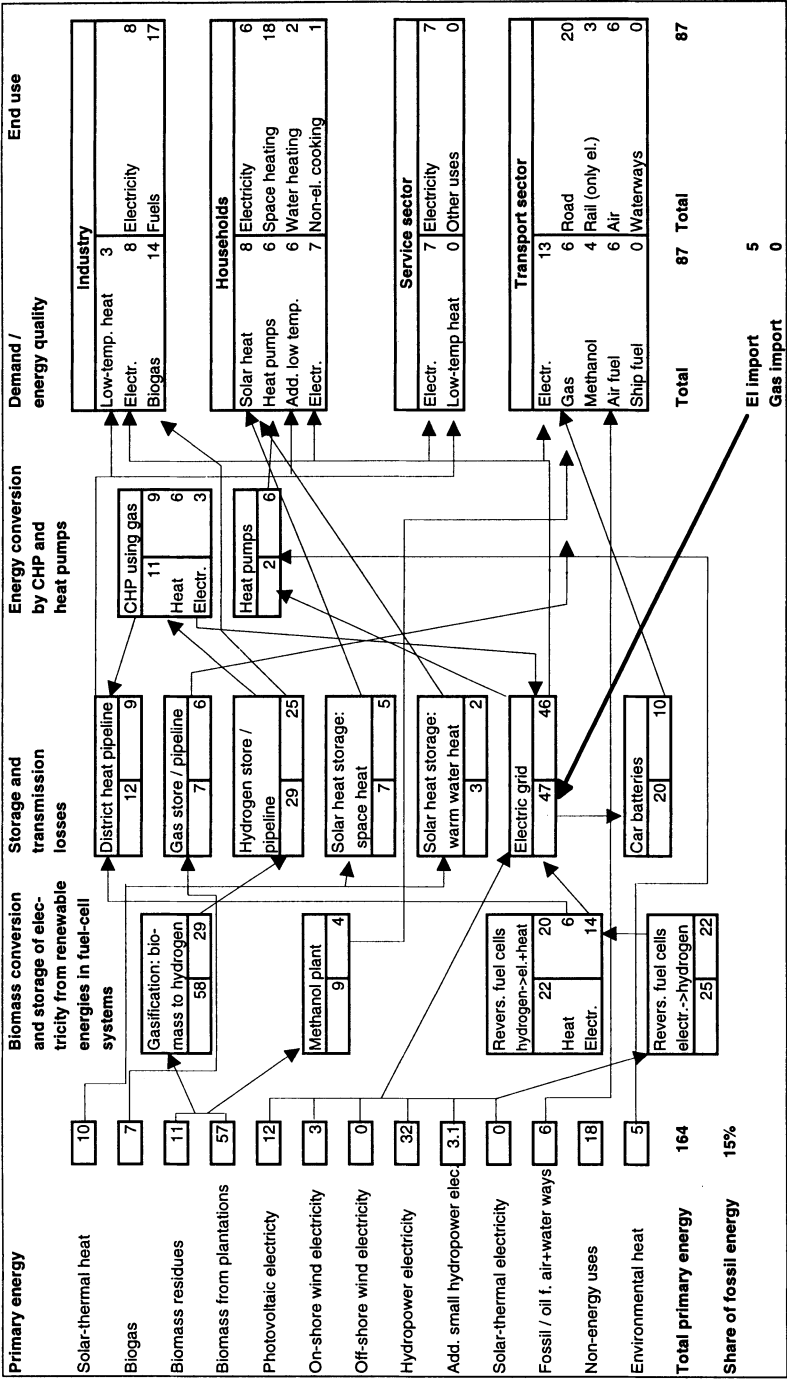


Figure 3.20 Austrian energy system in the Fair-Market Scenario 2050 (in TWh/a).

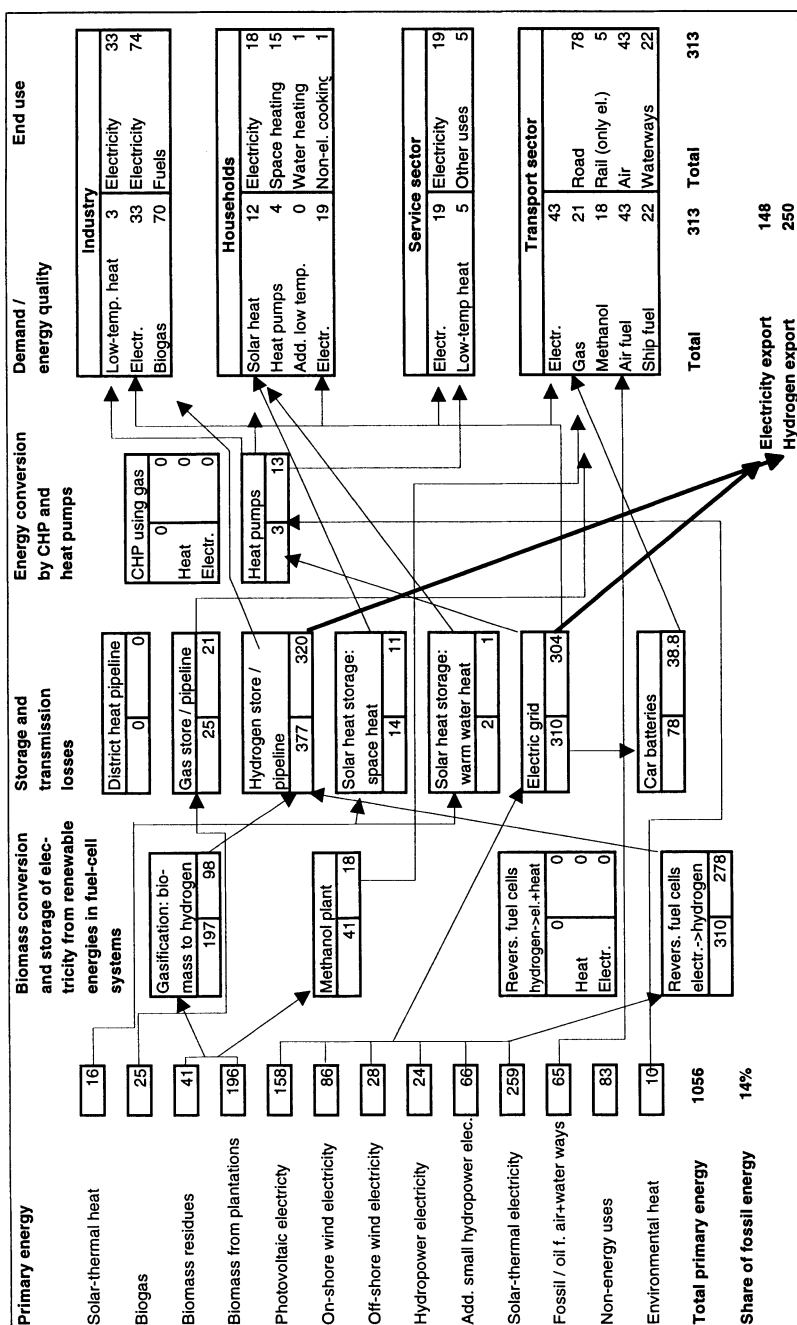


Figure 3.21 Spanish energy system in the Fair-Market Scenario in 2050 (in TWh/a).

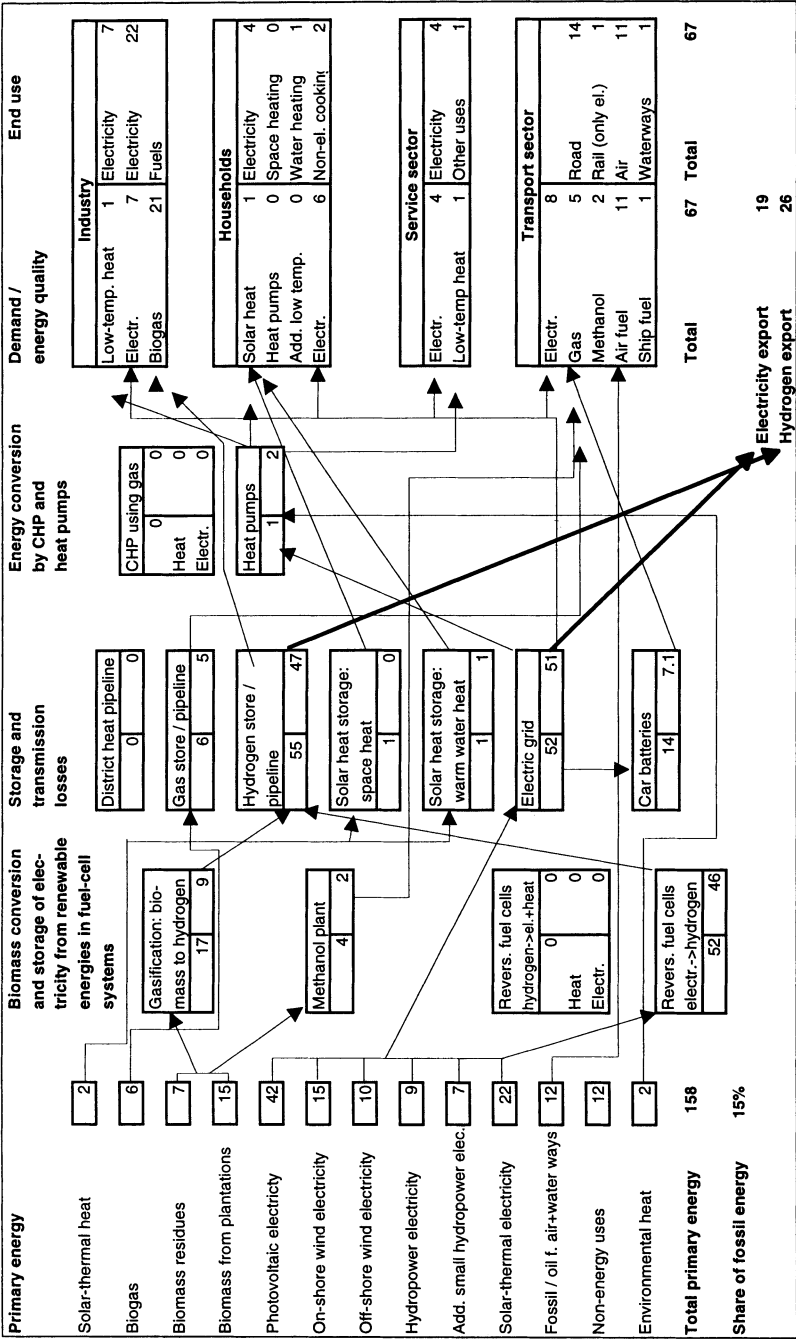


Figure 3.22 Portuguese energy system in the Fair-Market Scenario 2050 (TWh/a).

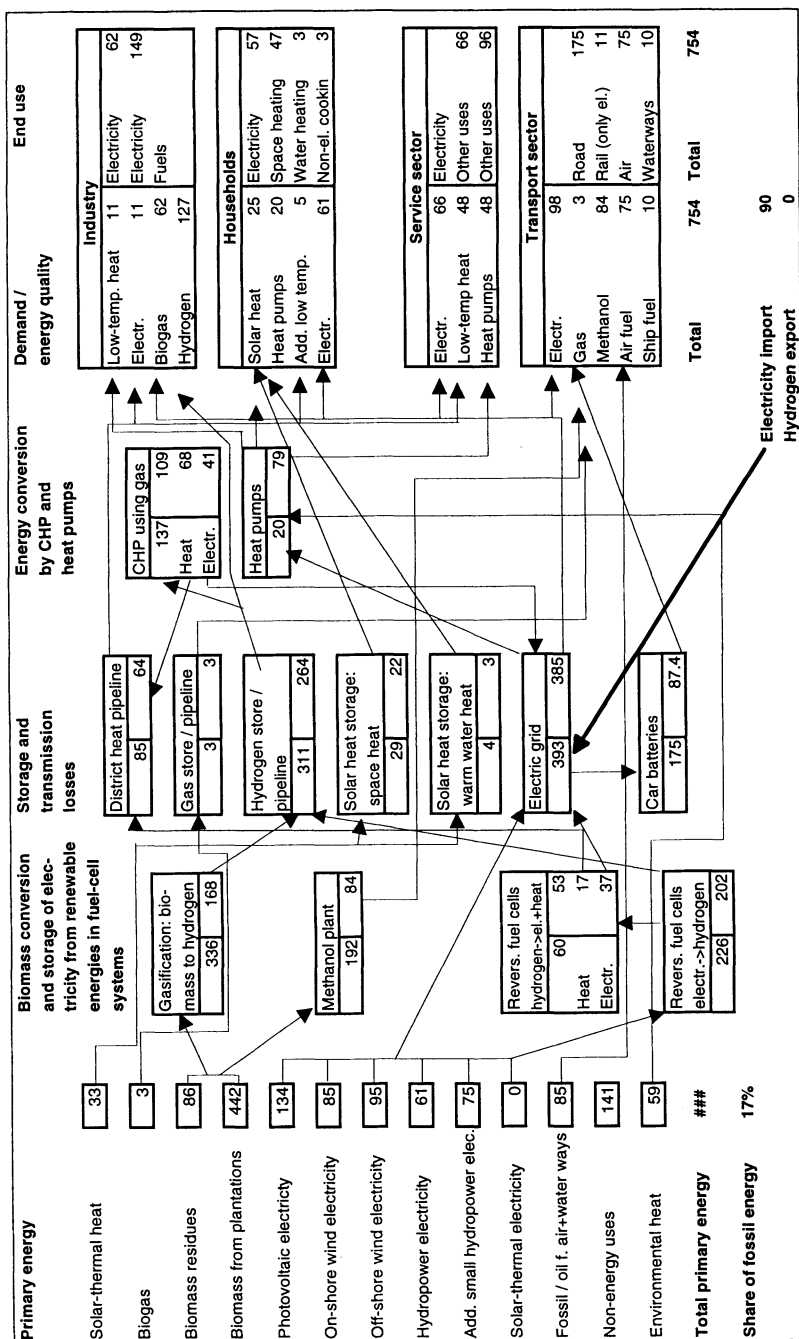


Figure 3.23 French energy system in the Fair-Market Scenario 2050 (in TWh/a).

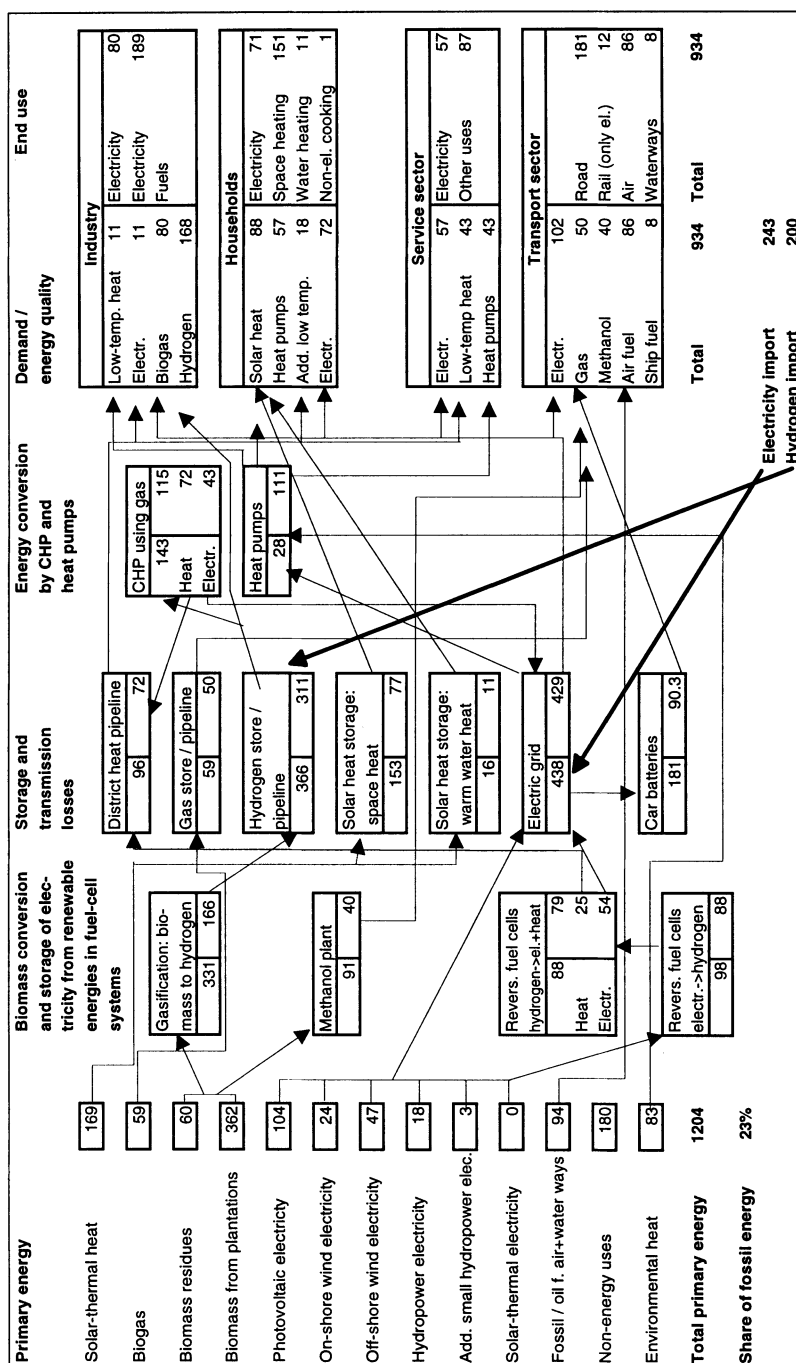


Figure 3.24 German energy system in the Fair-Market Scenario 2050 (in TWh/a).

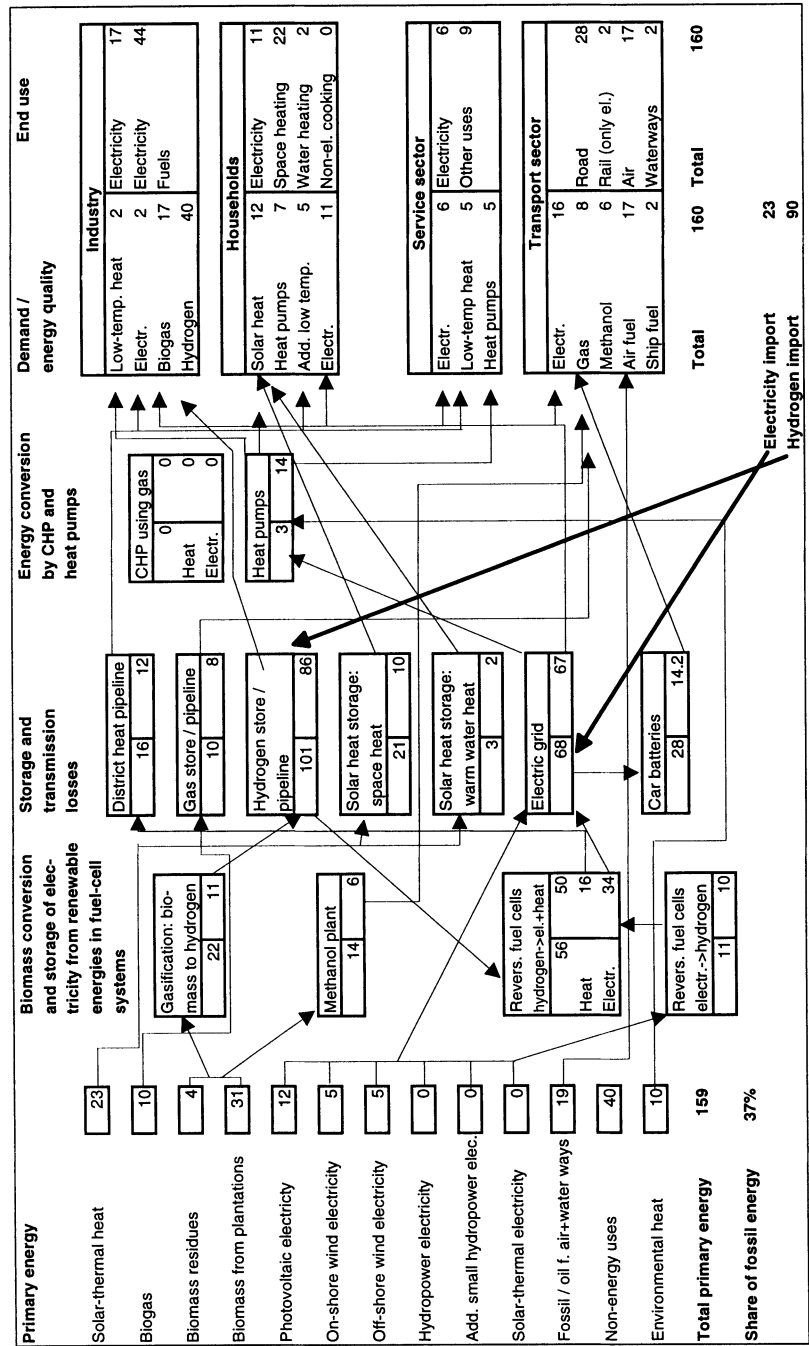


Figure 3.25 Belgian energy system in the Fair-Market Scenario 2050 (in TWh/a).

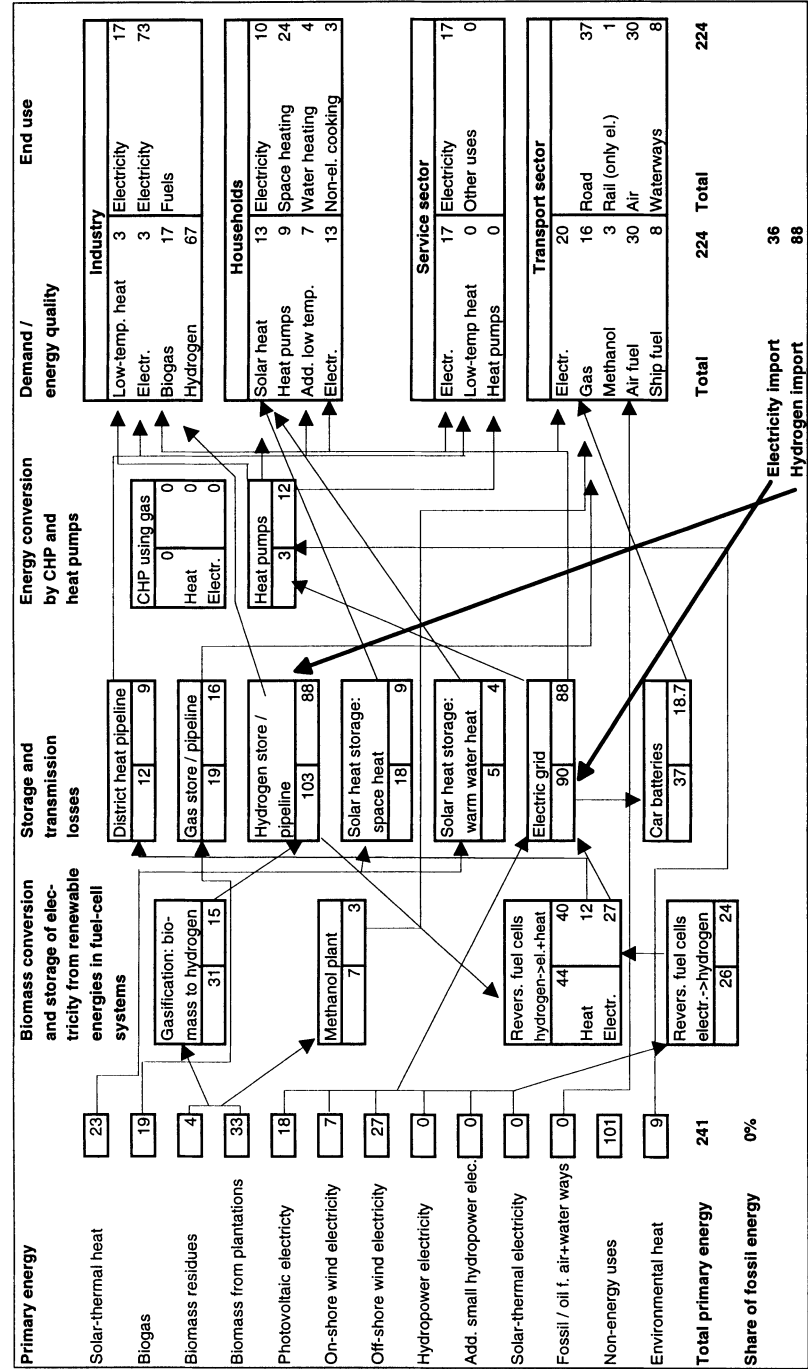


Figure 3.26 Dutch energy system in the Fair-Market Scenario 2050 (in TWh/a).

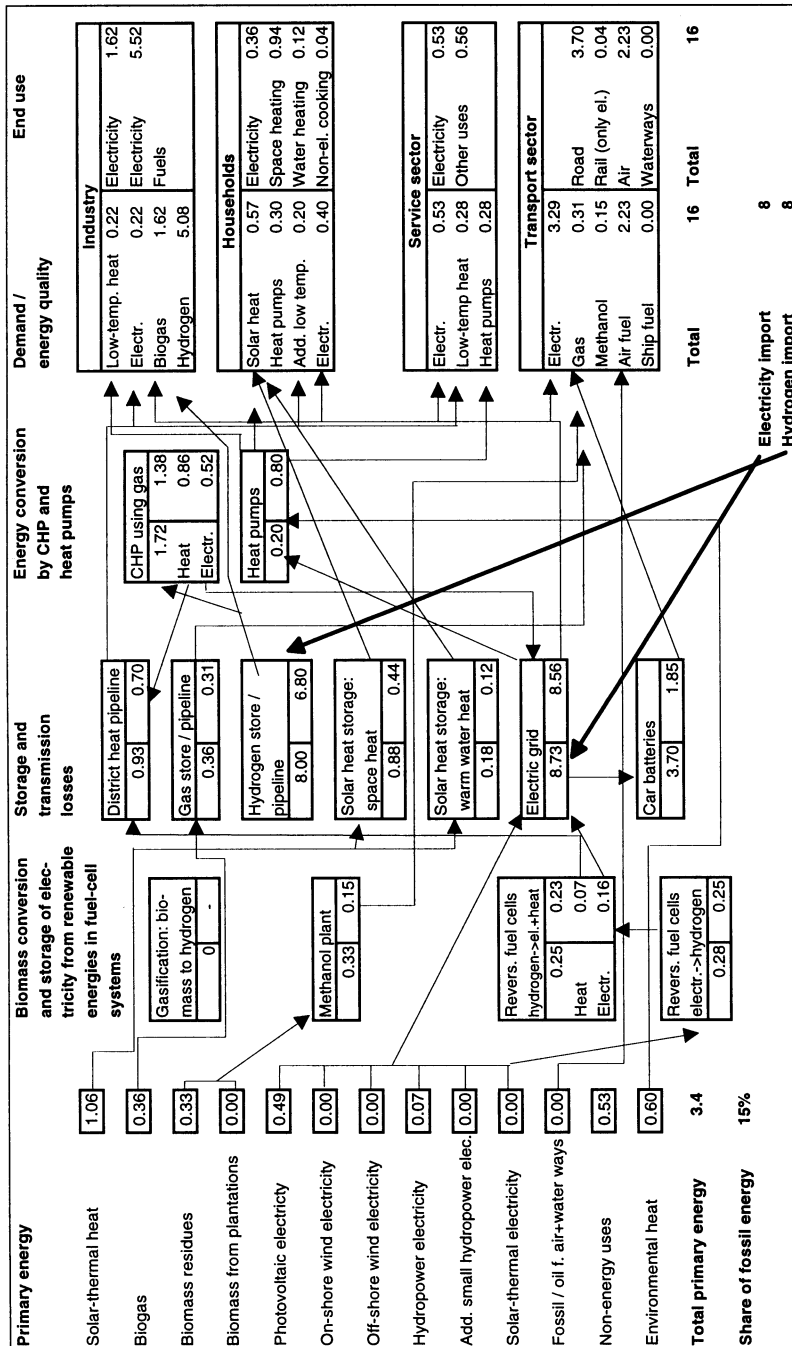


Figure 3.27 Luxembourgian energy system, Fair-Market Scenario, 2050 (TWh/a).

3.2 Economic and Environmental Impacts

Sigurd Weinreich

3.2.1 Economic Impacts

The economic impacts of the Fair-Market Scenario were obtained in the same way as those of the Sustainable Scenario described in Sec. 2.2. The cost figures, in particular, derived in that section are also used in this section.

In the Fair-Market Scenario, the total capacity of renewable energy technologies for all energy forms increases from 159 GW_p in 1990 to 2 340 GW_p in 2050. The total annual costs of these technologies, including investments and operation, rise from 42 billion ECU (1990) to 374 billion ECU in 2050 (cf. Figure 3.28), the largest contributions coming from biomass and wind energy. While capacities increase by a factor of 15, total costs rise by a factor of 9 within the time horizon considered. The aggregated cost of the Fair-Market Scenario between 1990 and 2050 is 11 600 billion ECU.

The amount of energy supplied is nearly the same as in the Sustainable Scenario – annual costs, however, are much higher. This is because much more biomass is used, which is assumed to be specifically more expensive than other technologies and which is the only technology for which rising costs are expected. In addition, the share of the transport energy demand is higher and the assumptions on technical efficiencies and the underlying full-

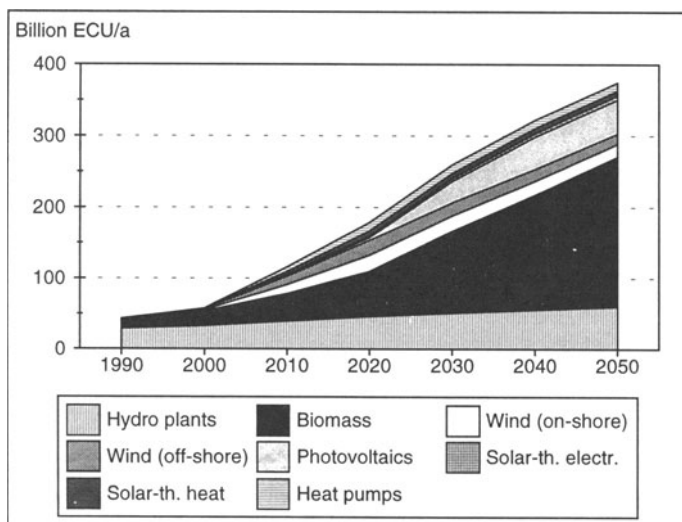


Figure 3.28 Development of the total annual costs of renewable energy technologies in the Fair-Market Scenario.

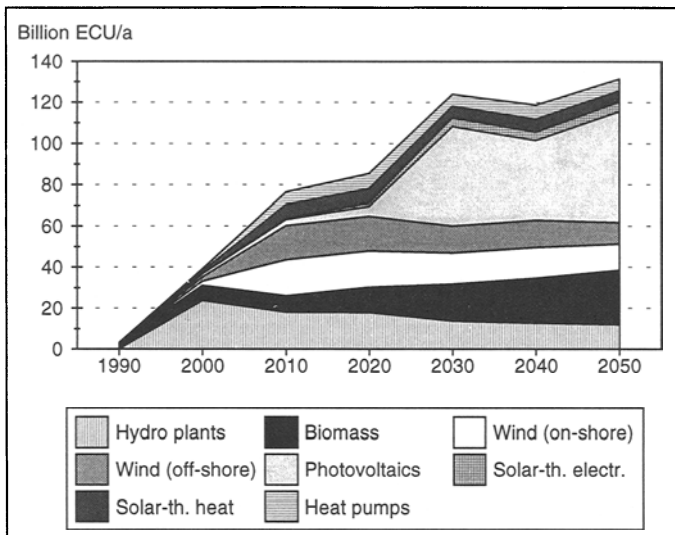


Figure 3.29 Development of the annual investments in renewable energy technologies in the Fair-Market Scenario.

load hours are less optimistic than in the Sustainable Scenario.

The largest additional capacity has to be built in 2050 while the highest annual capital requirement occurs in 2025 (cf. Figure 3.29). This development is caused by the trajectories introducing the individual technologies and the assumptions on the development of specific costs.

As in the Sustainable Scenario, the conventional energy system declines steadily in the Fair-Market Scenario after the year 2000. Following an increase from 504 to 525 billion ECU between 1990 and 2000, costs decrease steeply to 392 billion ECU in 2010 due to the cost-efficient energy savings assumed. Afterwards, the costs of the conventional energy system fall more slowly as more and more renewable energies enter the markets until they finally reach 113 billion ECU in 2050. Figure 3.30 shows this development together with the increase in the costs of renewable energies. In contrast to the Sustainable Scenario, total annual costs will decrease only slightly. Thus, they still amount to 487 billion ECU in 2050, which is only 11% less than in 1990. These figures do not include the costs of energy savings on the demand side. Compared to the Sustainable Scenario, fewer financial resources are set free which can be used to finance energy efficiency measures. Nevertheless, it seems reasonable to assume that the costs for energy services will not be much higher than today, since the efficiency improvements were assumed to be very cost-efficient.

The reference case of the Fair-Market Scenario includes the same conventional technologies as the Sustainable Scenario (gas turbines, gas- and oil-fired boilers), but is based on its respective energy demand. The resulting

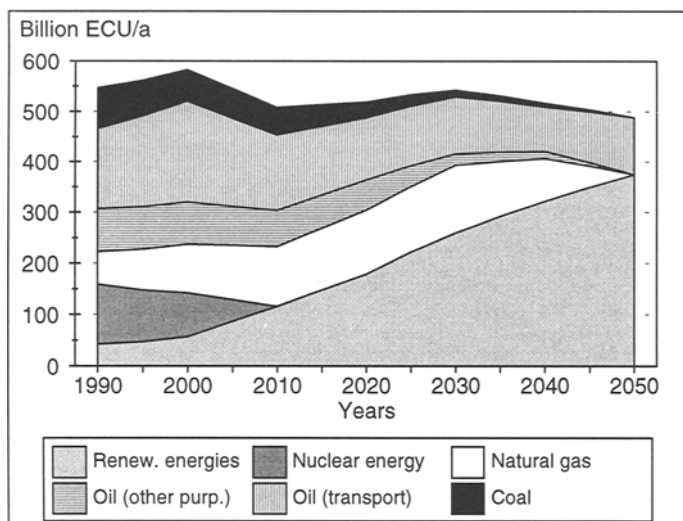


Figure 3.30 Annual costs of the conventional and renewable energy parts of the energy system in the Fair-Market Scenario.

costs are 164 billion ECU per year in 2050. It is, thus, 211 billion ECU cheaper than the renewable energy based system. In both cases, 113 billion ECU have to be added for fossil-fuel driven transport activities which were calculated separately.

The cost figures stated so far do not include any social costs, which are fundamental for the Fair-Market Scenario. If the social costs determined in the European Commission's ExternE project, which do not include global warming, are taken into consideration the costs of the reference case increase by as little as 8%. However, if the social costs assumed in the Fair-Market Scenario are taken into account, which is largely justified by the negative impacts of global warming, the total costs of the reference case rise to 1 015 billion ECU/a, which is more than twice the costs of the Fair-Market Scenario.

The 374 billion ECU per year needed to exploit renewable energy sources in the Fair-Market Scenario amount to only 7% of the EU's 1990 GDP. In the scenario, substantial economic growth is assumed which will decrease this share. The average spending for construction and operation of renewable energy technologies is in the order of 1000 ECU per capita in 2050.

The input-output model calculations yield 6.4 million person years of employment in 2050, 2.3 million of which are required to manufacture and 4.1 million to operate renewable energy technologies (cf. Figure 3.31). More than half of this employment is contributed by biomass technologies alone, especially by the production of biofuels. Here, like in the reference case be-

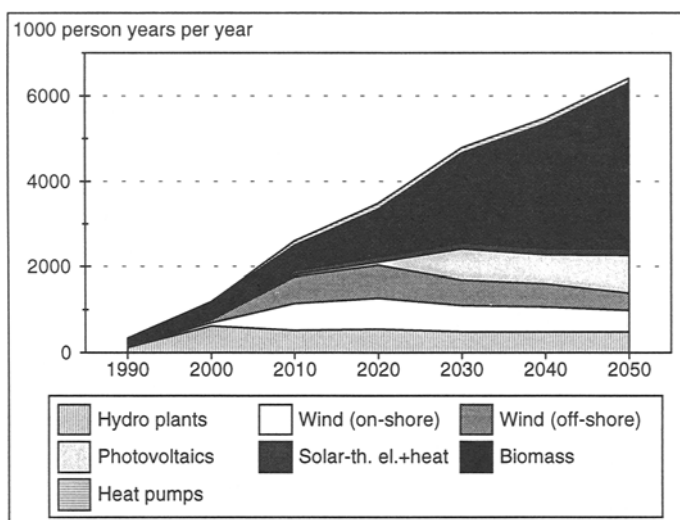


Figure 3.31 Estimated gross employment effect of the construction and operation of renewable energy technologies in the Fair-Market Scenario.

low, the part of the transport systems that still runs on fossil fuels in 2050 is not taken into account.

Dividing the cost of the energy system by the number of person years needed leads to costs of about 59 000 ECU₁₉₉₀ per person year in 2050. This is less than the cost for an average industrial person year today and is related to the high share of biofuel production in the overall employment effects.

1.4 million person years per year are necessary to build and operate the conventional technologies of the respective reference case. Again, we assume that the cost difference of 211 billion ECU is spent on private consumption. Consequently, 4.4 to 5.2 million person years (for a 14% and 0% savings rate, respectively) are needed to produce consumer goods (based on the economic structure in Germany in 1998). Thus, we have a total of 5.8 to 6.6 million person years for the reference case. These figures are much higher than in the Sustainable Scenario due to the larger cost difference between the two cases considered.

Comparing the employment effects of the Fair-Market Scenario and its reference case, we get a net effect of -200 000 to +520 000 person years. In this calculation, the positive structural effects of substituting imported fuels and using domestic agricultural labour are offset by the effects of the massive reductions in consumption caused by the increased energy bill. This, however, is not the whole story. It has to be stressed again that using the 1988 economic structure of Germany for the consumer sector while assuming large improvements in energy technologies leads to the results being

biased. Second, the very large amounts of gas used in the reference case may lead to scarcity signals being reflected in energy prices which are not included in the moderate price increases assumed so far. And finally, one has to keep in mind that the cost advantage of the fossil fuel based reference case only exists as long as the external costs of global warming are not taken into account. This is even more important, since internalising these external costs was a fundamental assumption in the Fair-Market Scenario.

3.2.2 Environmental Impacts

The emissions of pollutants in the Fair-Market Scenario are calculated in the same way as for the Sustainable Scenario. The results are shown in Table 3.1. CO₂ emissions are reduced from 3 100 million tons in 1990 to 223 million tons in 2050, that is by 93%. Thus, the objective of the LTI-Project is again more than achieved.

An upper limit for the CO₂ emissions arising from the construction and operation of renewable energy technologies can be calculated, assuming that the technologies are produced with fossil fuels. It yields 110 million tons of CO₂ or an additional 50% with respect to the value given in Table 3.1. Reducing the emissions from the production of renewable energy technologies by the factor calculated for the whole economy, decreases the additional CO₂ emissions to 7.7 million tons or 3.5%.

Table 3.1 Reduction of emissions in the Fair-Market Scenario (without the production and operation of renewable energy technologies).

Pollutant	1990 ([million t/a)	2050 (million t/a)	Reduction
CO ₂	3060	223	93 %
NO _x	10.8	1.15	89 %
SO ₂	19.8	0.35	98 %
CO	38.3	5.61	85 %
VOC	6.52	0.66	90 %
Particulates	2.32	0.62	73 %

4 Bottlenecks and Obstacles – Success Stories and Measures

Olav Hohmeyer, Wolfgang Bräuer, and Helmuth-M. Groscurth

4.1 Bottlenecks and Obstacles

In the preceding chapters, we saw that by the year 2050 it is quite possible to build a sustainable European energy system around the rational use of energy and the massive use of renewable energy sources achieving two ambitious targets at the same time: the reduction of CO₂ emissions from energy conversion processes to a level of 20% of the emissions of 1990 and the reduction of nuclear power to zero. Thus, climate protection and the protection against the risks of a major nuclear accident can be attained simultaneously. It has been demonstrated that the resulting energy system can meet all energy demands even though intermittent energy sources play a central role in the new supply structure.

If this is possible the question remaining is: Why are we progressing so slowly towards such a sustainable energy future? The answer is that there are many obstacles and bottlenecks in the way. They need to be removed or widened through decisive political action if we want to secure a sustainable energy future. In the following, the most prominent obstacles and bottlenecks are briefly described as the basis for actions to overcome at least the most important hindrances. Based on this description, a number of important measures are sketched which can help to remove these obstacles.

Obstacles are interpreted as structural, legal, social or technological hindrances which prevent users and suppliers from promoting renewable energies. Due to their characteristics, obstacles can only be removed as a whole. *Bottlenecks* are hindrances to the development of renewable energies which are caused by a lack of technological, personal and financial resources or by a lack of knowledge. They vary in terms of their impact and strength and can be removed continuously. *Measures* are actions taken to overcome bottlenecks and obstacles. They have to be defined with respect to the key-players involved.

The analysis of bottlenecks and obstacles draws upon a number of major sources, as these problems have been discussed at length before. The first source is the report to the LTI-Project by Christophe de Gouvello and his co-workers from CIRED (Gouvello et al. 1996), which looked at institutional bottlenecks limiting the diffusion of renewable energies. This source is supplemented by the results of a study on an ambitious introduction of renewable energy sources in Germany up to the year 2010 (Altner et al. 1995), which treats all the obstacles and bottlenecks seen in the German context

very systematically. Furthermore, the discussion draws upon the results of the German Enquete Commission Report outlining possible energy policies to massively reduce German greenhouse gas emissions till 2005 and 2050. Here, renewable energy sources play a major role. Thus, a thorough discussion of possible hindrances and measures to overcome them is given in the report (Enquete Commission, 1991). In addition, Danish experiences with the introduction of small decentralised heat and power plants were included on the basis of a case study for the LTI-Project conducted by Frede Hvelplund from the University of Aalborg (Hvelplund 1996).

As the different sources show, the number of hindrances which can be enumerated easily reaches fifty and more. Thus, a certain focus seems to be advisable in order not to confuse the reader too much and to allow decisive action to be taken against the most important obstacles and bottlenecks. Table 4.1 gives an overview of the most important obstacles relating to the massive introduction of renewable energies. They do not all apply to the different renewable energies in the same way. Thus, the applicability to the different renewable energy technologies is marked on the right-hand part of Table 4.1.

The obstacles and bottlenecks can be subdivided according to a number of different criteria. For the purpose of this book, we have grouped them into eight categories, each concerning a rather different aspect of the introduction of renewable energies and requiring different measures to overcome the obstacles and bottlenecks belonging to each category. The following categories were defined:

- A. Hindrances stemming from internal properties of the technologies to be used.
- B. Hindrances in the field of research and development (R&D) of renewable energies.
- C. Adverse market conditions and political forces actively opposing renewable energies.
- D. Legal and institutional barriers.
- E. Problems relating to financing renewable energies.
- F. Problems stemming from a lack of knowledge and training or a lack of awareness of the positive aspects of renewable energies.
- G. Necessary adjustments of the management of and the access to the electricity system.
- H. Necessary changes in lifestyle for the Sustainable Scenario.

The letters A to H are also used in Table 4.1 to identify the different categories of obstacles and bottlenecks.

Table 4.1 List of obstacles and bottlenecks for the large scale introduction of renewable energy resources into the European energy system

Code number	Obstacle or bottleneck	Photovoltaics γ				
		Solar-thermal heat γ		Solar-thermal electricity γ		Biomass γ
		Wind energy γ				
A	Internal properties of the technologies to be used					
A.1	Low price level for conventional energy	x	x	x	x	x
A.2	Internal energy costs		x	x	x	x
A.3	Uncertainty of future energy price developments	x	x	x	x	x
A.4	Technical development / efficiency		x	x		x
A.5	Security of supply / Production of expected amount of energy per year		x	x		x
A.6	Reliability of the technology		x			x
A.7	Intermittent production / back-up	x		x	x	x
A.8	Low production numbers prohibit cost reduction due to scale effects / lack of mass production		x	x		x
B	Hindrances in the field of R&D					
B.1	Low R&D budgets for renewable energies	x	x	x	x	
B.2	Lack of steady R&D budgets for renewable energy technologies	x	x	x	x	
B.3	High mandatory share of small and medium enterprises (SME) in research funding (50%)		x	x	x	x
B.4	Excessive formalities in acquisition of public R&D funding	x	x	x	x	x
C	Adverse market conditions and political forces					
C.1	Insufficient reflection of external costs in energy prices	x	x	x	x	x
C.2	Unfair purchase price of electricity	x	x	x		x
C.3	Penetration into existing structures	x	x	x		x
C.4	Existing conventional over-capacities	x	x			
C.5	Existing centralised supply structures	x	x			x
C.6	Highly centralised and monopolistic markets	x	x	x		x
C.7	Vested interests of large utilities	x	x	x		x
C.8	Political resistance by vested interests	x	x			
C.9	Preferential conditions for conventional energy sources / tax privileges	x	x	x		x
C.10	Subsidies for conventional energy sources	x	x	x		x
C.11	Biased advertising for conventional energy sources	x	x	x	x	x
C.12	Insufficient recognition by economic policies	x	x	x	x	

Table 4.1 continued

D	Legal and institutional barriers				
D.1	Legal obstacles to renewable energies	x	x		x
D.2	Institutional barriers	x	x		
E	Problems relating to financing				
E.1	Shortage of capital		x	x	x
E.2	Lack of fair financing		x	x	x
E.3	Lack of tailor-made financing models		x	x	x
E.4	Unknown economic risk for investor		x	x	x
E.5	Investor-user gap / pay-back gap				x
F	Lack of knowledge and training or of awareness of the positive aspects of renewable energies				
F.1	Adverse patterns of thought on the part of engineers	x	x	x	x
F.2	Lack of knowledge on the part of policy makers	x	x	x	x
F.3	Lack of knowledge on the part of installers / lack of training		x	x	x
F.4	Lack of trained maintenance personnel		x	x	x
F.5	Lack of knowledge on the part of investors		x	x	x
F.6	Lack of knowledge of public funding sources on the part of investors		x	x	x
F.7	Lack of public awareness of environmental and energy problems	x	x	x	x
F.8	Lack of organisational infrastructure (professional organisations and installation networks)		x	x	
F.9	Difficult to organise many diverse actors		x	x	x
F.10	Insufficient credit for structural, technological and employment benefits	x	x	x	x
F.11	Public acceptance of renewable energies	x	x		
G	Necessary adjustments of the management of and the access to the electricity system				
G.1	Agreements between major players on assumptions				
G.2	New standards and management practices of grid management necessary	x	x	x	x
G.3	New access protocols necessary	x	x	x	x
G.4	Lack of integrated energy planning	x	x	x	x
G.5	Infrastructure for large scale grid integration lacking in important areas	x		x	
H	Necessary changes in lifestyle for the Sustainable Scenario				
H.1	Changes in lifestyle for sufficiency revolution		x		x

4.1.1 Hindrances Due to Internal Properties of Renewable Energies

The first problem associated with a large scale introduction of renewable energies into the European energy system is that either their costs are too high or the cost for conventional energy sources are too low. This problem is partly due to the technological stage of development of some of the renewable energy technologies like photovoltaic installations or solar-thermal electricity generation, which are substantially more expensive than conventional electricity. Although this is only true for grid-connected installations, it is an obstacle to a large scale introduction of these technologies, as the market volume for remote stand alone electricity generation in Europe is rather limited. For these technologies, it is obviously necessary to improve their technical performance and to reduce their production costs quite drastically to make them viable options for the grid-connected production of substantial amounts of electricity.

Even in the case of renewable energy technologies much closer to the market like wind energy or the use of biomass the energy produced is still not competitive in entirely unregulated markets. At least in the case of wind energy, which has matured as a technology and is produced almost at an industrial scale, we find that undercutting the internal costs of the cheapest sources of conventional electricity will hardly be possible even in the long run. Although we can expect the cost of renewable energy sources to be reduced in the future through both technological improvements and a scaling up to industrial mass production, they will only be competitive in niche markets if exclusively based on the current internal costs.

Besides this fundamental cost problem there are a number of secondary problems making an investment in renewable energy technologies risky for potential investors even under favourable conditions. First, it is difficult to estimate the future prices for conventional energy which renewable energies will have to compete with. This is due to the situation on the international oil and gas markets as well as to the liberalisation of electricity markets in Europe. If real prices for conventional energy fall in the future, the economics of today's investment in renewable energy technologies deteriorates even further. Second, with all renewable energy sources it is very difficult to predict the actual amount of energy delivered by an installation in a given year, as the weather conditions may differ substantially making for variations of up to 50% compared to a long-term average on which the investment decision was based. We have seen such developments in the use of wind energy in Germany during the last years. Third, the reliability of the technology used can have a great impact on the energy produced. Even if a good installation could be economical under the given circumstances, component failures and bad maintenance can lead to far lower energy output than predicted. That is what happened in the early days of wind energy as well as in the case of photovoltaic systems.

Finally, the intermittent nature of wind and direct solar energy can increase the system costs of energy due to the need for substantial back-up capacities. This problem becomes the more pronounced the larger the overall share of intermittent energy sources in the system. Fortunately, biomass energy can be stored seasonally without huge extra costs. Thus, in an integrated European energy system based mostly on renewable energy sources, biomass can play the part of back-up energy source. A factor reducing the necessary volume of back-up capacity in the overall European system is the sheer number of decentralised production units spread out all across Europe. Thus, on calm days in Northern Europe wind may be blowing on the Spanish or Portuguese coast or during the summer months with generally light winds, sunshine may be especially intense, making up for the lack of wind energy.

We find that there are still substantial bottlenecks due to internal structures of technologies for the use renewable energy sources. Some can be overcome by technical developments, some by improved maintenance and others need to be compensated for by market adjustments.

4.1.2 Hindrances in the Field of Research and Development

Although technologies for the use of renewable energy sources have come a long way in their technical development mostly due to private initiative and public research and development (R&D) spending, there are still a number of bottlenecks relating to public R&D policies for renewable energies.

First of all, overall public R&D spending for renewable energies seems to be far too low compared to the necessary role they have to play in a sustainable future European energy-supply system. This is true at the national as well as at the European level. In general, the R&D budgets spent on all the different renewable energy sources combined are smaller than the budgets for nuclear fusion or nuclear fission alone, neither of which will play a role as beneficial and as important to sustainable development as renewable energy sources.

What is more, R&D budgets for renewable energy sources seriously lack long-term stability, which is necessary for a continuous development of these technologies from the laboratory to mature proven technologies to be used in the field for the generation of a substantial share of our energy supplies. The observer is left with the impression that in many countries R&D budgets for renewable energies are only increased when a disaster involving conventional energy supplies happens. Such a case can be traced in Germany, for example, in the mid 80ies before and after the nuclear accident at Chernobyl. Before the accident, the German R&D budget for renewable energies, which had been increased after the oil-price shocks in the 70ies,

was scaled down quite drastically by 1986. After the Chernobyl accident, the budget was instantly raised again more or less to show that the government was not idle. Government officials toured research institutes and industry trying to find multi-million dollar projects to visibly increase the R&D spending on renewable energies as fast as possible. In such a situation neither research institutes based largely on contract research funding nor companies developing and producing technologies for the use of renewable energy sources can develop a mid-term perspective on possible technology developments for the use of renewable energy sources.

Even under the existing public R&D programs, participation is made rather difficult. As the German Enquete Commission (1991, 225) put it *"The reason for this must be sought ... in the excessively high portion of funds that companies are required to provide from their own resources and to some extent – at least where smaller companies are concerned – also in the excessively complicated and time-consuming procedures for approval of government grants."*

Thus, substantial improvements in public R&D policies for renewable energies are a mandatory precondition for substantial technical advances and most likely for necessary further cost reductions as well. One obstacle relating to the R&D programs of the European Union is the fact that all research institutes with full cost accounting are only eligible for 50% project funding just like companies. Yet, these institutes have no other source of funding for technology developments relevant for the advancement of renewable energies. This leads to a situation where in particular the most professional institutes, like the Solar Energy Research Institute of the German Fraunhofer Society (ISE), can only do very little research under these circumstances. This inadequate form of research financing creates a serious obstacle for the advancement of renewable energies and needs to be removed as fast as possible.

4.1.3 Adverse Market Conditions and Political Forces Actively Opposing Renewable Energy Sources

The most important bottlenecks and obstacles for the market introduction and large scale use of renewable energies are in the field of adverse market conditions and political forces fighting against the large scale use of renewable energies. The central obstacle is the lack of internalisation of external costs of conventional energy sources. As the German Enquete Commission (1991, 225) put it *"... the crucial factor inhibiting greater use of renewable energy sources must be seen in the present low prices of conventional fuels, which are also likely to persist in the foreseeable future, at least as long as they do not absorb the external costs incurred."* This fact is widely acknowledged in political circles as well as in the literature, nevertheless, it

seems to be a long road until the internalisation of at least the most important parts of the external costs of conventional energy sources, like health or environmental damage, is accomplished. Once substantial external costs are internalised, a number of renewable energy sources will become quite competitive, like wind energy, energy from biomass or solar-thermal energy in Southern Europe. In some countries, this hindrance is even more pronounced as not even a fair price based on the avoided internal costs is paid for renewable energies, like in the case of France (Gouvello et al. 1996, 28).

Another central set of hindrances relates to the fact that *"renewable energy sources must penetrate into an existing energy system that is characterised (partly for historical reasons) by lack of knowledge about the new technologies, traditional behaviour and investment patterns, and inhibiting laws and guidelines"* (Enquete Commission 1991, 223). What is more, the electricity sector of the existing energy system in most European countries has accumulated large over-capacities where each new electricity producer will make the economics of the existing installations even worse. Thus, the existing utility companies see their interests threatened by any large scale introduction of renewable energies. As the electric utilities (regional or national producers) are rather large companies, they exert great political influence and have large resources available to fight against any newcomer threatening their interests. Just how such influence and power are used against renewable energies can be seen in the case of wind energy in Germany, which is booming due to a law improving buy-back rates for electricity from renewable energies fed into the public grid. Public utilities have tried to ignore the law and to avoid paying the mandatory prices, to contest the law in the courts and after failing with these attempts are trying to exert their influence on the European Commission and the German Government for the law to be changed in their favour. This effort is undertaken in a situation where the production capacity of wind energy has not even reached two per cent of the overall electricity generation capacity in Germany. We can imagine the resistance a full scale development of renewable energies as suggested in our scenarios will meet.

Additional obstacles to renewable energies are preferential conditions and tax privileges for conventional energy sources, which have developed historically and need to be removed in order to create a level playing field ensuring renewable energies have a fair and even chance. Another source of discrimination against renewable energies can be found in biased advertising in favour of conventional energy sources paid for by the large companies engaged in conventional energy markets (Altner et al. 1995, 128). No countervailing advertising in favour of renewable energies can be found as the promoters of these technologies have far fewer financial resources at hand than their counterparts. In most cases, the entire turnover of a producer of a

renewable energy technology is less than or only a small share of the advertising budget of the major players in conventional energy markets.

Due to the relatively weak political influence of the 'renewable energy lobby' the Enquete Commission of the German Bundestag (1991, 225) found that *"renewable energy sources also suffer from the insufficient recognition accorded to them by economic policy and the lack of promotion that goes with it."* This prevents a full scale introduction of renewable energies as the necessary political back-up is lacking.

4.1.4 Legal and Institutional Barriers

Due to the historical development of the existing energy systems in the different European countries there are legal and institutional settings which are tailor-made for the major conventional energy sources used (cf. Gouvello et al. 1996). As renewable energy sources have totally different technical structures (small, dispersed and decentralised sources compared to huge centralised power plants and installations), they hardly fit into the existing legal and institutional frameworks. Altner et al. (1995, 129) list eight major legal obstacles to renewable energies in Germany alone. As the legal and institutional setting is quite different in each member country of the European Union, a separate analysis of these obstacles is necessary to assure an adequate treatment of the problems. Thus, we will not deal with these obstacles in detail here. Let us simply point out that in the case of Germany the problems range from the basic energy law (Energiewirtschaftsgesetz) and its provisions to ordinances for chimney sweepers, with many laws and ordinances in between, all containing adverse provisions against the introduction of renewable energies.

4.1.5 Problems Relating to the Financing of Renewable Energy Sources

Another category of bottlenecks for the large scale introduction of renewable energies is the present shortage of available capital and a lack of adequate financing measures. Looking at the sheer volume of financing necessary for the large scale introduction of renewable energies as envisioned in our scenarios, substantial amounts of capital will be necessary as annual investments. The need for capital will be greater than for conventional energy supply systems as the technologies for the use of renewable energy sources are more capital intensive with only low operation and maintenance costs – with the exception of biomass –, and as the total internal energy costs will be higher than for most conventional alternatives. This will create a higher demand for capital by the energy supply sector, which may lead to at least slightly increasing costs of financing. Although it can be foreseen

that there will be no long-term shortage of capital for the large scale introduction of renewable energies, the present situation for most of the technologies is different. Specifically for those technologies with still relatively high specific energy costs little capital is commercially available as these technologies are considered high-risk investments.

It can be seen that in a positive general setting for renewable energies this bottleneck can be overcome quite fast as demonstrated by the availability of investment capital for wind energy in Germany and in the UK, where preferential buy-back rates and reserved market shares under the Non Fossil Fuel Obligation (NFFO), respectively, have made these technologies economically viable and good investments. As soon as a potential private investor sees that the technology is reliable and economically viable, private capital can be mobilised in large amounts. Thus, the best policy to reduce the financial bottlenecks for renewable energies is to make them reliable technologies and to improve the general situation for them in order to make them viable economic options. In this context, economically viable means profitable for the investor, but it need not necessarily mean cheaper than other supply options. Even without governmental action, there may well be customers who are willing and able to pay premium rates for an environmentally benign energy supply.

To mobilise renewable energies to their full potential, financing conditions similar to those for conventional energy systems need to be made available. Conventional energy systems enjoy, by comparison, preferential interest rates and financing conditions not yet available to renewable energies.

For solar-thermal heating systems built on apartment houses, there is a special problem due to the so-called investor-user gap. While the owner of the house has to finance the investment, the tenant enjoys the specific benefits. Like in the case of technologies for the rational use of energy, this often prevents such investments from being made although they are economically viable. In this case, forms of shared investment or preferential tax deduction need to be developed.

4.1.6 Problems Stemming from a Lack of Knowledge and Training or Awareness of the Positive Aspects of Renewable Energy Sources

A large area of different bottlenecks is due to a lack of knowledge and training as well as to a lack of awareness of the specific advantages of renewable energies. One hindrance to the use of renewable energies by utilities or to architects giving them adequate consideration are the adverse patterns of thought of engineers and architects. With electrical engineers considering a 100 kW plant insignificant or temperature spreads of 5 °C being considered negligible by a designer of a conventional heating system (En-

quete 1991, 224), renewable energies just do not fit into these patterns of thought. As long as architects, engineers and planners do not change these patterns of thought, renewable energies stand little chance of being considered in the planning process of energy systems or new houses.

For many renewable energies a lack of trained installers and maintenance personnel is a short-term bottleneck. Specifically for solar-thermal and photovoltaic installations in private homes, this can prove to be a real bottleneck as many households willing to invest in renewable energies will get little or wrong advice by local plumbers and other craftsmen. Nevertheless, as soon as a technology starts to be economically viable, we find that an infrastructure of trained personnel develops like in the case of wind energy in Denmark, Germany or the UK. Removing this bottleneck relatively early through education programs for all crafts involved can help to speed up the early introduction of renewable energy technologies. What is more, it can help to avoid failures caused by poor installation due to untrained personnel. As inadequate installations can give renewable energies a bad reputation in a local community, it is very important to systematically avoid such adverse publicity.

Like most other bottlenecks and obstacles, this one is also relevant for the efficient use of energy. Its removal is extremely important, since improving the energy efficiency of buildings is a cornerstone of the Sustainable Scenario.

Whenever failures of installed renewable energy technologies occur, it is extremely important to analyse the reasons for the failures and to compile all the information about the failures in order to speed up the learning process so as to reach a status of high reliability as soon as possible. What is more, all experiences should be exchanged through networks of operators and installers of renewable energy technologies as fast and as thoroughly as possible like in the case of wind energy in Denmark, where the most important things that had to be learnt for the fast scale up of wind turbines came from such systematic networking.

Potential investors seem to know rather little about the possibilities of renewable energies and the availability of supplementary public financing. But we find that this bottleneck seems to disappear as soon as renewable energies start to produce good returns on investment. Neither in Denmark, nor in Germany or the UK do we find a shortage of investors for wind energy (cf. Sec. 4.2). We find that the financing of the installations has created its own markets and that specialised companies have been started to collect investment capital.

Another important lack of knowledge about renewable energies concerns the general level of knowledge and awareness of policy makers. Many of them neither know the actual potential and importance of renewable energies for a sustainable energy future, and still think of renewable energies as

niche technologies, nor do they appreciate the great advantages of renewable energies in the field of environmental impacts or national and local employment benefits. Without this knowledge, the political support for renewable energies from most policy makers is still rather weak.

In some cases, like in the case of the large scale introduction of wind energy in the UK, we find that some parts of the local public are not quite aware of the environmental and local employment benefits of renewable energy technologies. This has led to a situation where some local groups oppose wind converters on the basis of potential visual intrusion and a general 'NIMBY' (Not In My Back Yard) attitude. In cases where local public involvement in the development of wind farms had been secured quite early in the planning process, practically all resistance was overcome. If the original plan was to site a wind park very close to residential buildings, such involvement can lead to finding a better site for the park with considerably lower impacts on the locals and far better acceptance. In general, public acceptance of all renewable energy developments is a crucial factor today and will be even more important for any large scale development of renewable energies as a major part of a sustainable European energy system.

4.1.7 Necessary Adjustments of the Management of and the Access to the Electricity System

Another category of hindrances to the large scale introduction of renewable energy sources are all kinds of obstacles connected to the management of and the access to the electricity grid. Presently, electricity is produced by a few large utilities mainly in large central power stations. The dispatch of these power stations is easily managed, as only a few actors are involved and because the power plants are based on storable fuels so that they can be brought on line whenever necessary. Electricity from renewable energy sources will be mostly produced by a vast number of independent power producers. Furthermore, except for electricity from biomass the electricity produced needs to be fed into the grid whenever the wind is blowing or the sun is shining. The management of such dispersed intermittent power sources is far more complicated than the present dispatch management system. As the shares of renewable energies on the grid increase, this problem becomes even more important. Thus, new dispatch and reserve strategies and models for the prediction of intermittent power from renewable energies based on weather forecasts need to be developed. First positive experiences have been gained with the integration of substantial amounts of wind energy in Denmark and Northern Germany. These experiences should be built upon to improve grid management and power plant dispatch practice.

One level above the actual grid management, integrated energy planning seems to be necessary to ensure the best possible use of renewable energies

in co-ordination with the rational use of energy. If no integrated planning takes place, over-capacities on the supply side will result as more and more energy will be saved on the demand side by better appliances and by using energy more intelligently. Without integrated planning the necessary back-up for a large scale integration of intermittent renewable energy sources, especially into the electricity grid, may not be made available on time creating a serious bottleneck for the expansion of the share of renewable energies.

If we envisage large scale use of renewable energies in the European energy system, we find that in the case of electricity generation high-voltage grid infrastructure is lacking in the areas with the best renewable energy resources. This holds for off-shore high-voltage cables for off-shore wind parks or high-voltage power lines in the desert areas of Southern Spain or other Mediterranean countries with superb solar resources for solar-thermal power generation. These bottlenecks can be overcome with the help of an integrated European energy masterplan earmarking certain areas with prime renewable energy resources for infrastructure reinforcement.

In some European countries grid access for electricity produced from renewable energy sources is still not guaranteed by law. Whenever this is the case, this obstacle has to be removed immediately. In other cases utility companies try to make access to the grid quite expensive for independent power producers by charging rather high fees for a link to the grid or by allowing access only at substations. In the latter case, the operator of a wind turbine, for example, may have to build and finance a power line of more than ten kilometres to the next substation while he may only be a few hundred meters away from the next suitable power line. Such obstacles rooted in the resistance of utility companies to independent power producers have to be removed through appropriate laws and ordinances as fast as possible.

4.1.8 Necessary Changes in Lifestyle for the Sustainable Scenario

If the large scale integration of renewable energy sources into the European energy system is to be achieved in the context of the Sustainable Scenario outlined in Ch. 2 above, major changes in our lifestyle will be necessary starting with adjustments in our daily diet, and changes in the way we use our cars and public transportation, all the way to major changes in the way we spend our annual vacations. The change in diet seems to be necessary to reduce agricultural production of food to free substantial acreage for the production of energy biomass. The changes in the mode of transportation are necessary to reduce our consumption of automotive fuels to such a level that we are able to cover the remaining demand with biomass and some residual fossil fuels which we are still allowed to burn under the 80% reduction target for CO₂ emissions. Changes in the average holiday destinations

are necessary to shift from energy-intensive long-distance air travel to short-distance destinations which can be reached consuming far less energy. Needless to say, weekend air trips to shop in New York or similar destinations cannot be part of any sustainable energy future if we take the 80% CO₂ reduction target seriously.

Although the necessary lifestyle changes on the road to a sustainable energy future will be serious bottlenecks, it needs to be said that many of these changes are not only necessary to reduce our energy consumption or to make renewable energies viable energy options, but also to secure a sustainable development of mankind. Thus, these bottlenecks will have to be removed for far more fundamental reasons than just for the sake of a sustainable energy future. Therefore, we assume that these bottlenecks will be removed by the time they would be crucial for the further introduction of renewable energies. What is more, the targeted reductions in energy consumption necessary as preconditions for the large scale introduction of renewable energies can just as well be achieved by drastic price increases for energy just as well. Thus, voluntary changes in lifestyle are no crucial precondition for a sustainable energy future.

4.2 The Success Story of Wind Energy in Denmark, Germany and Wales

Whenever grid access is secured and fair prices are paid for renewable energies to make them economically viable, their introduction and large scale diffusion will follow, as can be seen from the development of wind energy in Denmark, Germany, and Wales (cf. Figure 4.1). How these success stories came about is discussed in the next section to give an idea of how renewable energies can be turned into impressive success stories.

The three countries are at different stages in their wind power development and this in itself provides a useful indication of the route to success. Denmark has the oldest and most mature industry, with 835 MW of installed wind turbines in 1996, while Germany has about 1500 MW (1996) and Wales 75 MW (1995; UK: 265 MW in 1996). The targets set by the respective governments and the mechanisms used to support wind power are different for each country, as are the constraints that have affected the industries' growth. The various factors responsible for the respective developments were analysed in a European research project, the results of which are summarised in this section (Bean et al. 1996). After briefly describing the general conditions for wind energy in the three countries, we will concentrate on the decisive financial mechanisms.

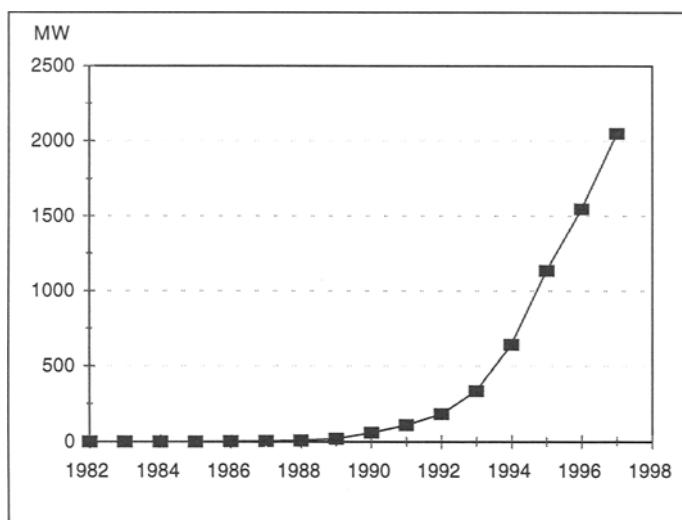


Figure 4.1 Development of the installed wind energy capacity in Germany (DEWI 1997; value for 1997: own estimate).

4.2.1 General Requirements

The first requirement for any renewable energy use is, of course, the existence of a suitable resource. All three countries under consideration have a significant wind potential both on and off shore, though wind speeds across Germany are lower than those across Denmark and Wales. There is some form of wind resource assessment in each country which considers not only the theoretical potential, but also constraints such as the existing local grid infrastructure and habitation as well as areas of high natural and scenic value. Due to the different financing mechanisms in Wales and Germany, the wind speeds or resource considered to be economically viable are quite different. In Wales wind speeds need to be around 6.5 m/s at 10 m height or more to make them competitive within the NFFO (Non-Fossil Fuel Obligation) bidding process. However, in Germany sites with wind speeds of 4 m/s are exploited due to the substantial buy-back requirements contained in the Electricity Feed Law (EFL) whereby the utilities have to pay 90% of their proceeds per kilowatt-hour to wind farm operators. Thus, lower wind speeds and a smaller resource have been used to establish a successful and growing industry. The reviews have shown the importance of mapping the theoretical wind resource in a co-ordinated way, and of identifying any constraints such as the distance to the existing electricity grid, the existence of infrastructure and habitation and the location of valued natural areas such as national parks and nature reserves. Even in places where a country has an excellent resource, these constraints can reduce the potential significantly.

Wind energy is known for its benefits for the global environment in terms of the reduction in gaseous emissions produced by traditional fossil fuelled power stations. It is also, however, a decentralised technology, and therefore local environmental issues are an important consideration. Public perception of these environmental issues has been very influential in speeding up growth and acceptance of the wind power generating industry in all three countries. It is the support of the local community that is paramount for the development of renewable energies, which due to their decentralised nature will always impact on local communities whilst supplying sustainable and clean energy at a national level. In all three countries, the most critical local issues have been the visual and noise impacts of wind power generation. Other impacts such as effects on ecological, ornithological and archaeological interests, and electromagnetic interference, are generally recognised to be less controversial and easier to overcome. Up to a certain degree, visual and noise impacts can be reduced through technical and planning measures. More important, it has been proven that the willingness of the local population to bear the remaining impacts crucially depends on their involvement in the planning process and the benefits they derive.

In all three countries the implementation of wind energy generation raised local and land use planning issues and made it necessary to develop regional and local planning policies. It is the aim of every planning system to provide a mechanism for the development of sustainable national industries while maintaining high local environmental standards. Planning procedures are a necessary form of land use control and should be used carefully for planning developments such as renewable energy schemes. The country reports pointed out that over-bureaucratic systems can hinder the development of a new industry such as wind power, but on the other hand, so can lack of guidance. Clear guidance is essential at a national level, and also at regional and local levels, and plans should be drafted with the input of a wide range of professionals from both within and outside the industry. Local scrutiny and acceptance of these plans is also essential.

Wind power plants must be connected to the local electricity distribution system and the associated technical and economic constraints can reduce the size of the available resource (cf. Sec. 4.1.7).

4.2.2 Financial Mechanisms

One of the most important aspects of this study is to understand the different legislative and fiscal measures that have been used in the three countries and to find out which have been most successful in encouraging the commercialisation of the technology at the lowest cost for the State. The discussion will include buy-back rates, subsidies, special credit conditions and tax credits.

Buy-Back Rates

The buy-back rate for wind energy in Wales is determined by the Non-Fossil Fuel Obligation (NFFO) scheme, which is a biennial bidding process. The average bid in NFFO3 was 55.7 mECU/kWh for large wind farm projects (> 1.6 MW) and 68.2 mECU/kWh for projects under 1.6 MW. Approved projects receive the respective buy-back rate over a 15 year period, which is a reliable basis for the investor. However, the wind farm developer and the manufacturers who depend on that market do not face a continuous market. Consequently, they are forced to consider shorter pay-back times, which leads to higher costs compared to manufacturers and developers who act at an international level. This might be a reason why the UK has not yet developed a sizeable wind industry. The NFFO fund is fed by the electricity consumer i.e. it is supported on a broad basis without creating special burdens for any actor in society.

The situation in Germany is different. According to the Electricity Feed Law (EFL), utilities have to pay 90% of their average revenues per kWh to the wind farm operators, i.e. approximately 90 mECU/kWh in 1995. Consequently, utilities vigorously oppose the EFL. In contrast to the UK, there is a considerable political risk, although all political parties in Germany still support the EFL on a broad basis. The German scheme guarantees access to the market (grid) at any time, as the utilities are obliged to buy renewable electricity except in special cases of hardship. In consequence, developers, consultants and manufacturers face a steady and fairly transparent demand-side of the market, which facilitates their business in this market.

The Danish buy-back rate forces the electric utilities to pay 85% of the electricity price non-bulk consumers are charged to private wind farm owners. The Danish and German mechanisms depend on the cost development of conventional fuels, which in Denmark decreased by 11% between 1991 and 1995. Accordingly, the buy-back mechanism in Germany and Denmark is a competitive scheme inducing competition between wind energy and other fuels. This is different from the UK scheme where competition is induced between wind farm developers regardless of the conventional electricity market.

Subsidies

It is only for Welsh wind farm projects, that EU-funding has played a considerable role in wind energy subsidisation. Under the THERMIE programme, grant funding of up to 50% of a project's capital cost is available.

German wind farm developers may apply for a variety of subsidy programmes. Subsidies are granted by both the federal government and state governments. Often, programmes can be accumulated. Grant funding is possible as well as revenue support. However, nobody has a right to obtain subsidies, and subsidy applications must be approved. Under the (now de-

funct) 250 MW Wind Energy Programme, it was possible to receive revenue support of approximately 30 mECU/kWh in addition to the buy-back rate. Without the buy-back rate, a revenue of more than 40 mECU/kWh could be applied for. Revenue support in Germany has proved to be very successful, whereas grant funding has only been important in some cases, because credit institutions consider the subsidy to be equivalent to equity funding.

Subsidies from the Danish government for wind turbine installations started in 1979. They remained at 30% up to 1982 and then constantly decreased until their elimination in 1989. Since 1992 a "subsidy" of 37 mECU/kWh has been used to repay energy taxes (as a result of external cost considerations) to guilds and private owners of wind turbines.

Obviously, subsidy programmes in Denmark and Germany were established to induce a steady market development in favour of the wind industry. These mechanisms may be one reason for the smaller wind industry in the UK.

Credit Conditions

The Welsh financing scheme follows the general market terms of financing. There are basically two ways of financing wind projects in Wales, namely balance sheet financing and project financing. Balance sheet financing is done by the developing company with all the conditions that have to be taken into account in normal trading (cash-flow etc.), whereas project financing is based on a separate company. It requires a certain equity ratio on behalf of the major lenders, which provide most of the project funding. The ratio usually ranges between 20 and 30%, meaning that the wind farm investor bears a considerable risk.

In Denmark, wind project funding is possible through guild-owned turbines and usually does not require any equity at all. Credit worthiness, however, must be proved for each guild member. Privately owned turbines usually require an equity ratio of 60%. There are special loans by the credit association that cover 60% of the value of the wind turbine and offer special interest rates. However, the investor has to meet certain requirements, e.g. the certification of the wind turbine.

In Germany, publicly subsidised loans for environmental projects are provided by the Deutsche Ausgleichsbank (DtA). These loans cover up to 75% of the eligible investment and offer interest rates which are 1 to 2% lower compared to market conditions. Approximately 80% of the German wind energy projects have been funded by these loans. In addition, there are various forms of business organisation with the same variety of advantages and disadvantages as in normal trading. Banks often do not require any equity. In some cases, investment subsidies were accepted as equity and in other cases the wind turbine itself was considered to be equity, despite very few turbines having achieved 10 years of operational experience. German

credit institutions accepted the technical maturity of wind turbines in the early 1990's partly due to the 250 MW Wind Energy Programme, which assumed a lifetime of 10 years.

The financing of renewable energy technologies is often considered to be a bottleneck. However, Germany has implemented a publicly subsidised environmental programme that offers low interest loans to environmental projects such as wind farm installation. In Denmark, a large number of wind turbines are utility owned. These utilities basically have two favourable ways of refunding. Firstly, utilities are allowed to include additional costs due to wind farms in their electricity prices. Secondly, utilities enjoy favourable credit terms, i.e. low interest rates. Although German utilities can use the same mechanisms, utility involvement in wind energy development seems to be rather modest compared to Denmark. In contrast, wind energy in Wales has to face normal trading conditions, benefiting developers with good credit standing.

In each of the three countries, utilities enjoy better credit conditions than small private investors.

Other financial issues

For private investors in Germany, it was important that financial authorities accepted electricity production from wind energy as a mature business. Consequently, it was possible to invest profits from other businesses (e.g. lawyers, dentists, farmers etc.) in wind energy effecting considerable savings in income taxes. Such investors are able to make money even from sites with comparatively low wind speeds.

Denmark and Wales established a financial scheme that supports the revenue of wind energy projects. These schemes have proved to be a key measure to overcome the barrier of finance. In Denmark, the wind industry and the utilities negotiate the buy-back rates for wind energy.

The Wind Energy Industry

The existence of a sizeable home market was the precondition for wind industry development in all three countries. Whereas the Welsh market is dominated by large scale wind farms, the German and Danish market are a mixture of single turbine sites/ small wind farms and large wind farm projects. The domestic markets were created through various support mechanisms.

In Denmark, substantial governmental involvement existed only at the beginning of wind energy development. However, the successful Danish development was based on private individual's initiative. Today, the Danish wind industry negotiates buy-back rates with the public utilities and there is an additional subsidy for wind energy due to the comparatively low social costs of this technology. The German government provided substantial and

steady support to wind energy in the past six years. Thus, German manufacturers had a chance to catch up with world's leading Danish manufacturers. The NFFO system in the UK is designed in a way to make sure that wind energy is as cheap as possible. Accordingly, it was very difficult for manufacturers in Wales (and the UK, respectively) to come into the business.

In Denmark and Germany, a sizeable wind turbine industry has developed with presently 7 large producers in Denmark and 3 in Germany. The number of employees in these countries ranges in the same order of magnitude with 8 500 employees in Denmark and 4 500 people working in the German wind industry. Wales, however, employs approximately 50 (UK: 1 300) people in the wind industry. The low employment in Wales is due to the lack of large wind turbine producers in the country and jobs have only been created in component manufacturing, consultancy, project development, and wind farm operation.

According to the three country studies, a sustainable internal wind energy development seems to require a local or regional wind industry in order to induce a self-supporting development. If a country or region wants to develop a sizeable wind industry with modern workplaces and export opportunities, there are several possible approaches.

There are different ways and means to establish an industry, however, the creation of a market for the respective renewable energy technology is the prime task and a precondition for industrial policy activities.

4.3 Measures to Overcome the Most Important Obstacles and Bottlenecks

It has been demonstrated that the conversion of the European energy system towards a sustainable use of energy within the next 60 years is *technically feasible* and *economically affordable*. In the medium- and long-term, the revised energy system will not be more expensive than the current one and it will create more jobs than are lost in the conventional energy system. Additional investments will be necessary in an early phase to trigger off the desired development. Even though we did not come across any principle infeasibilities, we have to conclude that the *economic, legal, and institutional conditions for the energy-supply systems have to be changed substantially and that this change has to be effected soon*.

In the following we will not list dozens of measures to tackle each of the obstacles or bottlenecks listed above. We will rather concentrate on a list of eleven prime measures which seem to be the most important steps to take in the near future to remove the most severe obstacles and to widen the most immediate bottlenecks for a successful large scale introduction of renewable energies.

From our analysis, the following measures seem to be the most important ones (the list follows the sequence of Sec. 4.1 and the measures are not in order of importance):

1. Decrease the internal costs of renewable energies through technological improvements, mass production, and increased reliability.
2. Increase public R&D budgets substantially and give them greater long-term stability.
3. Drop the 50% financing clause of the European Union for research projects.
4. Internalise the external costs of conventional energy.
5. Overcome and if necessary break the resistance of utility companies to renewable energies.
6. End all privileges for conventional energy systems and fuels.
7. First analyse and then remove all legal and institutional barriers to the large scale use of renewable energies.
8. Improve the general level of information about renewable energies and the training of engineers, architects and craftsmen possibly dealing with renewable energies.
9. Improve the grid access for renewable energies and reinforce the high voltage grid in areas of prime renewable energy resources.
10. Develop a long-term European energy master plan outlining the future role of all the different sources of energy and the necessary steps for a transition to a sustainable energy future.
11. Set stringent standards for the energy use in new and existing buildings.

These measures will not be elaborated upon in detail, as most of such an elaboration would repeat the discussion in Sec. 4.1 from which the measures were deducted.

Finally, the support of the population for the necessary restructuring of the energy system has to be enlisted. Decision-making processes have to be transparent and the people affected should be involved as early as possible.

Above all, the development towards sustainable energy use in Europe will only take place if a broad consensus is found and the resulting policies are actively pursued by the governments involved and the respective societies. A start should be made as soon as possible, since each year which passes without decisive action will create further bottlenecks due to additional money being invested in long-lasting conventional equipment.

5 Appendix I: Bottlenecks and Obstacles – Elements of a Methodology for National Diagnosis

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5.1 General Typology for a Study on Bottlenecks

There are various types of obstacles and bottlenecks to renewable energy penetration. Each of these bottlenecks has to be treated at its own level. The following typology is a first attempt to give an account of the different types of bottlenecks. This typology derives its principles from the Economics of Conventions. Boltansky and Thévenot suggest differentiating between different "cities"; "cities" are ideal places characterised by their own scale of values, which guide the behaviour and guarantee the legitimacy of agents and permits co-ordination processes. Each city produces its own rules, conventions and institutions. In the real world, people belong to various cities at the same time, and the creation of real rules, norms, institutions and institutional mechanisms (like public service tariffs) result from mitigating various co-ordination processes. The authors distinguish between the city of market, the city of industry, the city of citizenship, the "inspired city", and the "domestic city" etc. The detailed categories of bottlenecks are in a way related to the different cities (Boltansky and Thévenot 1987; Thévenot and Lafaye 1993).

The different categories of bottlenecks can be classified in two main groups: the first one includes bottlenecks active at a general level (valid for any energy plant at a global level), the second includes bottlenecks which are context dependent (local, regional or national).

5.1.1 External Bottlenecks and General Economic Conditions

External bottlenecks correspond to purely external and objective economic conditions prevailing for New and Renewable Energies (NRE) regardless of the local socio-economic context. Among these conditions are, first of all, the costs and prices of conventional forms of energy as perceived by the various economic players. These costs and prices are based in part on extraction techniques and on the geopolitical conditions of access to the extraction fields. For example, one has to remember that the oil crisis in the early seventies boosted (though only for a short time) renewable energies and energy management.

It should be noted that prices and cost are affected by high taxes or subsidies applied to these supply costs. These taxes or subsidies might correspond to some bottlenecks or help to diffuse renewable energy, but they are of a much more conventional (i.e. less external and objective) nature. These taxes and subsidies are dependent on local conditions and therefore belong to the "procedural bottlenecks" discussed in Sec. 5.1.4.

If a general tax, related to the externalities generated by fossil fuels at a global level was to be introduced, it would obviously belong to the general economic conditions for renewable energy. The absence of such a tax, if the climatic effect of carbon burning was to be confirmed, could be certainly considered an "external bottleneck". External bottlenecks mainly belong to the "industrial city" of the Boltansky and Thévenot model.

5.1.2 Technical Bottlenecks

New technologies can initially be hindered by obstacles of a technical nature that are surmountable, but nevertheless not easily eliminated. In the case of NRE, there is a brake on diffusion due to a particular characteristic of the equipment involved in collecting and using renewable forms of energy.

While the collection of NRE requires competitive components comparable to those of the industrial revolution (solar collectors, solar cells, wind turbines etc.), these components are connected in "systems" whose configuration must be adapted to the characteristics of each site (local geographic and climatic conditions, and energy demand). This implies a need for specific integration work very different from that of the usual industrial products. Thus, it seems that behind the technical problem there is a problem of organisation. With regard to the industrial production of components, a specific knowledge of local system integration must be acquired. A new type of engineering know-how must be developed.

5.1.3 Internal Bottlenecks in the Renewable Energies' Supply Sector

Internal bottlenecks correspond to obstacles of an organisational nature which prevent a high-performance and competitive and dependable offering of products, equipment for taking full advantage of NRE, or energy services based on NRE. These bottlenecks played a considerable role in certain failures in the past, but could now be eliminated through appropriate policies.

The development of NRE was disappointing in the 1970s and 80s, despite the favourable circumstances arising from the oil shock. There is reason to believe that this was largely due to an absence of structures (professional organisations and installation networks) which would have made it possible to supply equipment and services to satisfy requirements. One of

the recent successes of NRE showed that such an obstacle exists by removing it. We are referring to the successful introduction of solar water heaters in Greece, Turkey and Israel. It happened in an energy context far less favourable than that of the 1970s. This breakthrough occurred in the absence of any major incentive from governments and without decisive technical innovations. It seems that good co-ordination among players whose functions are complementary (component producers, system designers, fitters, contractors, agents and installation managers, suppliers of various maintenance services, etc.) is indispensable to a competitive and economic supply of services, equipment and energy projects. This co-ordination is especially important in order to ensure the adequate and dependable maintenance of the equipment required for the collection of renewable resources.

5.1.4 Procedural Bottlenecks and the Establishment of a System of Agreements Among the Players Involved

In a social context, relationships between agents are not only determined by objective economic conditions (price mechanisms, tax systems, purchase prices, etc.) and established institutional structures (companies, installation networks, public administrations, etc.), but also by the definition of procedures which economic agents will use to define their actions and to interact. These systems of rules and agreements, in particular those on which investment and pricing choices are based, have a decisive effect on the diffusion of certain technologies.

More specifically, choices are made relative to different energy forms based on economic calculation agreements (for example, the choice of discount rate and cost-benefit analysis methods). Furthermore, the collective appraisal of risks and of future scenarios, so important for factoring in the positive external effects of NRE, results from procedures for legitimising information. The information is used to identify and collectively appraise the risk associated with the accessibility and use of different sources of fossil fuels in the future.

Players in the energy sector must agree or converge on visions of the future so that long-term decisions can be taken. The absence of a consensus, or even disagreement on visions of the future is a fundamental obstacle to decision-making. If a strong political consensus is established at the European level concerning the greenhouse effect, this will enable normative goals and incentives for reducing emissions to be instituted. These could take the form of transferable permits, for example, or taxes which help to improve the relative competitiveness of NRE vis-à-vis fossil fuels.

The diversity of NRE and of the technologies for taking full advantage of them place them in an unstable position relative to several statutory bodies established much earlier. One example is the case of statutes relative to

building permits (protection of sites, obligation to build "in the country's style", etc.). The construction of wind turbines and solar power stations, and the introduction of NRE, for example solar energy, in the habitat could be hindered or even prevented by such restrictions (like "Not In My Backyard" behaviour based on a strict interpretation of some regulation at a local level).

5.2 Identifying Bottlenecks According to Categories of NRE Projects

5.2.1 The Different Structures of Renewable Energy Projects

There are varied concepts, in reality complementary, of NRE development and gathering. The goal of these different concepts, which we will delineate following two distinct lines of analysis, is to reveal a typology of project strategies relative to making the most of renewable energies.

- The first line of analysis examines NRE use from a geographic perspective: Is the energy collected used locally or distributed through the grid?
- The second line of analysis relates to the institutional nature of the project, to the connection between the owner and manager of the energy production equipment and the user of this energy: Are energy consumers buyers of energy products, energy services or self-producing equipment?

5.2.1.1 *Typology of Projects Based on Territorial Correspondence Between Production and Consumption Sites*

Two extreme configurations are possible:

- local production for local needs (like that of earlier societies using renewable energy),
- energy production entirely unrelated to local needs and destined to be distributed through the grid (as has become the norm since the industrial revolution with the development of fossil fuels).

The first concept has some technical justifications (difficulty of transporting energy, particular in thermal form) and political justifications (energy self-sufficiency of a territory, thereby ensuring independence from uncertainties in the energy market). The technical argument as to the difficulty of distribution is especially relevant to solar-thermal energy in low temperatures, which is therefore confined to local use.

Biomass, wind energy, solar energy and in general most NRE can, however, equally be turned into intermediate products, and, like fossil fuels, be transported for use some distance away from the production site. In this second concept, one can imagine constructing NRE production plants in Europe which make the most of local, industrial-sized resources (agricultural biomass production, wind turbine fields, thermo-solar power stations in sunny

desert zones). At first glance, this second concept seems to limit institutional and technical problems. All that is needed is for large energy producers to accept new sources which should be integrated into the large circuits for the production and distribution of energy. For example, energy produced from biomass plantations is transformed into fuel distributed by pre-existing distribution channels (gas networks and engine-fuel distribution). Another example: wind and solar power stations have just become integrated into electric grids, which distribute the energy produced. In this case, easily stored products (gas, synthetic fuel) could complement more ephemeral products (not easily stored, such as electricity) and vice versa. This complementary solution could be less expensive and more dependable than installing decentralised autonomous equipment, which would imply either large and burdensome reserves or accepting uncertain availability due to the natural rhythms and risks which characterise the natural flow of renewable energies.

5.2.1.2 Typology of Products Based on the Degree of Centralisation of Equipment Management

The second line of analysis is related to the institutional structure of renewable energy projects. Two such configurations can be envisaged:

- Energy users are equipment buyers to gather natural energy.
- Energy users limit themselves to buying energy products or services.

In the first case, energy consumers are producers of energy, that is they must buy energy systems to produce the energy they consume. They are therefore sensitive to the price of equipment and to the terms and conditions for financing the purchase of this equipment. They can benefit from assistance for purchasing certain equipment and from tax reductions, they can also eventually sell any extra energy produced. Energy consumers are thus self-producers and are the only ones responsible for making sure that production meets their needs.

In the second case, energy consumers are only buyers of energy products or services. They are consumers of several types of energy (biofuels, electricity, etc.) and/ or energy services (lighting, heating grids, public transportation, etc.). Here, consumers are relieved of all responsibility relative to energy production. They do not have to make any investments to set up this system. Energy production and distribution are carried out in the framework of programs defined by specialised operators who propose a varied supply. From an economic point of view, the consumers make their choices depending on the tariffs charged (notably their temporal and spatial structures) and the utility that they derive from these different energies or energy services.

5.2.1.3 *The Main Categories of Renewable Energy Projects*

If we cut across the preceding geographic and institutional categories, we can define four main configurations for projects to integrate renewable energies. Each of these project categories calls for specific measures to promote it and eliminate its specific obstacles.

5.2.1.4 *Configuration No.1 – Local Production for Local Needs by Producers-Consumers*

In the past, this form of capitalising on renewable energies was the principal way of using these energies in developed countries. However, it has remained marginal despite the great hopes it raised. Its model is that of an actor (individual, company) who partially frees himself from the conventional network by installing collecting equipment for renewable energies. This actor thus takes on all tasks connected with the energy system that he has set up. He chooses among various types of equipment which are proposed to him based on his own criteria. He chooses the way of doing economic calculations best-suited to his needs, and makes implicit or explicit assumptions about the future price of energy, etc. He oversees the construction of the installation and co-ordinates the different associations involved or sub-contracts this co-ordination. Afterwards he is the manager of the installation and handles its maintenance and renovation with the help of the manufacturer.

This situation showed its advantages and disadvantages in the past. While the actor concerned is able to choose the project which is best for him (for example, aesthetically), he is relatively isolated starting with the planning phase, then while negotiating the price of the installation and, finally, doing the maintenance work. In the start-up phase, the pioneers in the matter had to cope with all the initial problems. A small energy project can sometimes be as complex as a big project. Setting up a project is often crippling, as much at the technical level (the planning) as at the financial level (combining multiple forms of assistance). Regarding upkeep, it is important that there are well-established networks of installers and maintenance technicians. So far, these have been in short supply.

Regarding the supply of energy, working out the required dimensions of such systems is a complex task. In order to ensure a steady supply of energy, systems are frequently too large and therefore more expensive. This is because smaller systems do not guarantee the required amount of energy in certain limiting weather conditions. It is thus necessary to provide for assistance (supplementary or back-up support from fossil energies, connection to electricity grids, stocks of combustibles), the cost of which may hurt the economics of the overall project.

These different problems have prompted many actors to give up on renewable energies and switch back to centralised production.

5.2.1.5 Configuration No.2 – Centralised Production Distributed as Energy Products Via Specialised Networks

This form of capitalising on renewable energies is well-established historically. It was even at the root of the formation of large electricity producing companies and their use of hydro-electric potential. In those days such companies focused on fossil energies. After this first centralised use of the most accessible renewable resource, some of these companies attempted to diversify into other renewable resources such as wind and tidal energy, etc. These diversifications have remained marginal relative to fossil fuels and to the emergence of nuclear energy. For several years, it has looked as though this institutional formula could be repeated, as much for wind energy as for solar energy.

The advantages of this form of capitalising on renewable energies are obvious: projects conceived in a very professional manner, opportunities to negotiate for components in bulk, possible economies of scale and standardisation effects, and the injection of the energy produced in the grid in the framework of an elaborate temporal management of energy. Everything that historically worked in favour of hydro-electricity should work in favour of other renewable energies.

5.2.1.6 Configuration No.3 – Local Production for Local Needs Assured by Large Operators Selling Energy Services

The institutional principle of such a form of capitalising on NRE is as follows: energy production and distribution companies assure the planning, installation, management and maintenance of apparatus for decentralised energy production. Such production, by means of integrated energy systems, is geared to selling energy services (heating, lighting etc.) rather than energy vectors. This institutional solution aims to bring to the fore a complementarity – managed by the major energy operators – between centralised and decentralised production. On this basis, energy producers seek to protect themselves from the high cost of distributing small quantities of energy in the peripheral parts of the grid. It is possible that planning the means of distribution by setting up a local source of energy services using equipment that capitalises on renewable energy is a situation that is preferable for the big operators to a daily confrontation with individual NRE projects or reinforcements of small sections of the grid.

Such a solution could prove economical for big operators in the energy market able to find in it a means to optimise the spatial/ temporal management of energy (points at the periphery of the grid ...) and for users who find

competitive services are being offered that do not entail the difficulties and limits of planning one's own energy production equipment. The producers involved can set up small local grids, which will enable them to make the most out of local energy resources.

Economies of scale effects, mass markets, upkeep network, good adaptation to energy demand and local renewable energy potential as well as integrated energy management are the major advantages and the principal determinants that could lead to this solution being chosen.

On the other hand, "distance costs" may soar again, this time, however, not in connection with investment in the infrastructure, which is necessary for a small number of dispersed subscribers, but with variable maintenance costs. It is also clear that management of numerous small pieces of equipment, all or part of which are mobile (and not immobile like electric grids), involves new kinds of problems, which presumes finding innovative legal/organisational arrangements.

5.2.1.7 Configuration No.4 – Centralised Production Assured by Local Producers

This is the case of large consumers/ producers who have surpluses over and above their requirements which they can re-inject into the grid. One can also imagine small speculative industrial producers of energy interested in attractive purchase tariffs at peak hours.

5.2.2 Using a Matrix to Identify Bottlenecks which Limit the Multiplication of Each Type of NRE Project

Using two types of bottlenecks and NRE projects, it is possible to specify the different categories of bottlenecks and obstacles for each of the preceding four major categories of energy projects. A summary presentation could consist in filling in the boxes of the matrix shown in Table 5.1.

Presented below is a summary of the main bottlenecks for each of the categories of NRE projects.

Configuration No.1 – Individual projects that stand alone and are managed locally

External bottlenecks: Projects in competition with large conventional units based on fossil and nuclear fuels whose production costs do not include their external effects.

Internal bottlenecks: This type of project cannot spread without a structured supply side, notably with networks of agents and distributors. For these agents and distributors to be viable, a critical threshold of demand is

Table 5.1 Matrix identifying bottlenecks which limit the multiplication of NRE projects.

Project types		Types of Bottlenecks			
		External	Technical	Internal	Procedural
Individual systems	Stand-alone and locally managed				
	Centralised management/ sale of energy services based on individual equipment				
Production systems connected to the grid	NRE plants connected to the grid				
	Autoproduction projects with sale of excess production				

necessary. This creates a vicious circle which blocks the expansion of this type of project.

Procedural bottlenecks: 1) The user must make an investment, as opposed to when the user opts for conventional energy, in which case he only has the tariff to pay. In the second case, he benefits from the implicit subsidy created by standardised tariffs and therefore from lower distribution charges if he is not located in a city. 2) It is difficult to make this type of decentralised production competitive compared to conventional energy when the comparison is based on micro-economic criteria which, over the years, have been "made-to-measure" according to technical-economic characteristics of conventional energy technologies (principally the marginal development cost by kW or kWh and rate of actualisation).

Technical bottlenecks: Problems linked with setting up the different components of NRE technology at reduced cost; problems during periods of extreme climatic conditions, which result in a lack of energy supply.

Configuration No.2 – Renewable energy plants connected to the grid projects managed by utilities

External bottlenecks: Projects in competition with large conventional units based on fossil and nuclear fuels whose production costs do not include their external effects.

Internal bottlenecks: In order to be attractive and benefit from a high level of industrialisation of projects and suppliers, this type of project requires large equipment, in particular to benefit from positive scale effects regarding components and their development, and from greater dependability of installations.

Procedural bottlenecks: Inertia in the decision-making structures of the conventional energy sector; environmentalists' opposition in order to protect the sites.

Technical bottlenecks: Problems of timing when managing energy in order to maintain the same guaranteed level of supply to consumers.

Configuration No.3 – Centralised management sale of energy services based on individual equipment

External bottlenecks: Selling prices of fossil fuels which permit decentralised production (mini diesels...) and whose production costs do not take account of external effects.

Internal bottlenecks: As with configuration no.1, this type of project cannot spread without a structured supply side, notably with networks of agents and distributors. For these agents and distributors to be viable, a critical threshold of demand is necessary. This creates a vicious circle which blocks the expansion of this type of projects, unless the utility accepts paying an additional cost which corresponds to the learning period.

Procedural bottlenecks: 1) Differences in price for equal service to the user if the utility refuses to extend cost equalisation to costs other than those related to distance. 2) Creation of new funding possibilities, or extension of those which already exist for reinforcing and extending the network; reluctance on the part of utilities to absorb explicitly the difference in price compared with the average cost of conventional energy due to standardised tariffs; question of who owns the equipment and what contractual arrangements control its use; high transaction costs; difficulties regarding tariffs for energy services (lighting...) as opposed to energy products; the nature of the contracts and guarantees as to the lack of production during extreme climatic conditions.

Technical bottlenecks: Difficulties in guaranteeing service and the stocks which are thus required.

Configuration No.4 – Industrial projects "Autoproduction-speculative production"

External bottlenecks: Projects are less profitable when purchase prices are negotiated based on sales tariffs which include provisions for avoided costs which are difficult to quantify. Faced with this difficulty, estimates of prices are made to the disadvantage of NRE projects, since the differences in external effects when compared with fossil fuels are not taken account of in the purchase prices.

Internal bottlenecks: This requires good co-ordination of independent producers, for example through associations capable of negotiating good purchasing conditions; necessity of expertise in order to select good projects.

Procedural bottlenecks: Controversy over the setting of purchase prices and conditions for accessing the network; strategies which feature inertia from those in charge of the conventional energy sector.

Technical bottlenecks: Technical regularisation and normalisation (frequency, etc.) of small independent production.

This twofold typology of bottlenecks was used to develop our analysis in two directions:

- the diagnosis of market distortions unfavourable to NRE resulting from the institutional structure inherited from the history of conventional energy,
- the proposal for institutional innovations to help to achieve the normative scenario for emissions reductions.

5.3 Reducing Distortions of an Institutional Nature Unfavourable to NRE

When examining

- institutional conditions that would help the development of New and Renewable Energies,
- legislative measures which could be taken in their favour,
- financial support that they could benefit from and the means of tapping corresponding resources between producers, operators, consumers, and the Treasury,
- public or private sector-based institutions and the functions that they could assume,
- regulations and standards that should be elaborated;

and when, using a word borrowed from conventional economics, we seek to sketch out the forms of future co-ordination between players in the NRE

sector, we should keep in mind that the forms now governing the sector of conventional forms of energy were not built in a day.

Forms of energy now referred to as conventional emerged with the industrial revolution and gradually replaced the same renewable forms of energy that are now presented as new: biomass, wind, hydropower, etc.

When new institutional measures for guaranteeing the large scale distribution of NRE are envisaged, the ultimate goal is to redo what was done nearly fifty years ago for conventional forms of energy. Once aware of this historical perspective, it seems entirely legitimate to construct new institutional frameworks to make this large scale exploitation of NRE possible. Such is the goal of the next part of this study. At the same time, the consolidated framework now in place cannot be ignored, even if this framework is being debated again today as part of the vast deregulation movement which has been underway in the sector for some years. An analysis of how this framework should be adapted to the new distribution needs to be done.

Historical analysis of the way the current institutional framework governing the energy sector was formed turns out to be a powerful methodological principle for explaining how the framework (i) has been specifically adapted to conventional energies, and (ii) currently distorts competition in favour of the latter at the expense of NRE.

We propose here a methodological principle for identifying bottlenecks in each energy sub-sector. This involves a historical analysis of the birth and consolidation of institutional structures around dominant technological choices. This approach must be pursued in each country, because of the particular history which has influenced the players and legislation.

5.3.1 Standardisation and Institutionalisation Supporting the Diffusion of Conventional Forms of Energy

Since the industrial revolution, considerable scientific and technological ingenuity was expended to concentrate natural energy resources before using them in the form of intermediate industrial products, i.e. energy products. Coal/ steam came first, then petroleum fuels, gasoline as well as electricity derived from hydropower and fossil and nuclear fuels.

Around these products, first a market and then an energy industry were structured. The quest for increased productivity in this industry resulted mainly in ever greater economies of scale and scope in terms of production (a restricted number of increasingly standardised energy products for a greater number of uses and consumers). Parallel to the spatial concentration of production, was the necessity of developing distribution grids to bring these energy products close to the users. Some of these grids are concrete, such as gas and electric grids; others are logistic storage bases, such as liquid fuel distribution grids, bottled LPG distribution grids, etc. These distribution

grids were centralised both in terms of production units and major consumption centres, to which the energy produced was transferred en masse. It was only later that efforts were made to extend these grids from cities to the country.

Before the industrial revolution, the mill was driven by the river. Today, the mill's motor is powered by electricity; such electricity is produced industrially by a power plant and then transported over several dozen kilometres by the electric grid before reaching the mill.

Today this model is particularly evident in the case of commercial energy known as conventional energy, i.e. derivative petroleum products for energy uses (gas oil, fuel, gasoline LPG, kerosene) and electricity.

These intermediate products, the form and processing of which are selected to be both convenient to use and economic to produce, thus definitely constitute an organisational and logistical choice which meets the requirements of the Industrial Society.

The adequacy of supply relative to demand implies the planning and realisation of investments, and therefore decision-making processes. The different specifics of energy product markets, some of which can be analysed inductively using the theory of natural and contestable monopolies, have anchored the investment decision-making process in the sphere of public control, giving rise to the definition of specific institutional programmes.

Thus, for energy forms which require the construction of costly distribution networks (electricity, gas), competition could not be completely free without an important loss of efficiency. It is unthinkable that two companies develop two grids at the same time to fight for the same customers. Often competition is limited to awarding a licensing contract of a predetermined length for a given territory within which the operator is guaranteed a monopoly. This is a very structured form of co-ordination, closely linked to the nature of the technical solution (centralised production distributed via a network). In certain cases, public companies are created.

5.3.2 Consequences for Project Selection and Redistributive Equity Mechanisms

In the same way, this choice of spatial organisation of production and distribution defines arbitrarily what is far away and/ or costly to serve. A mountain village, located far from large production centres preferably located near major cities, necessitates a greater transport distance and is therefore more costly to serve than a small village on the periphery of a town. This would not be the case in a scenario of "Distributed Utilities" (decentralised production). The centralisation of production consequently leads to heavy spatial costs depending on the global costs of the energy service area. Of course this burden is much greater in the case of energy forms requiring

specific transport grids than in those cases where energy is transported by road. However, the burden is still significant in the latter case.

As a result, the search for an equitable treatment of users vis-à-vis access to a good considered essential (historically, electric lighting) has led to a system that corrects the discrimination arbitrarily introduced through a technical choice: the standardised tariff.

It is in the electricity sector that the standardised tariff is generally most common. Satisfying certain individual or collective needs regarded as having priority (historically, electric lighting) depends directly on consumers having access to energy products: then comes the question of equity.

Matching supply with demand under equitable terms often requires very costly investment choices and tariffs that have not been calculated to maximise profit. Thus, this partly falls in the sphere of public decision-making, notably with the creation of the Public Electricity Service.

Two principles guide the Public Service's mission:

- *Economic efficiency*, which from the outset is embodied in the technical choice of a centralised grid. The industrial nature of the activity of public electric companies has led them to adopt methods of selecting and planning projects which stem from the industrial economy and are based primarily on neo-classic micro-economic calculations. These methods are all the more refined, since a technical choice has been maintained for several decades, i.e. that of the electric distribution grid with huge centralised production units. A particularly representative illustration of this micro-economic logic of calculation is the marginalist calculation of the cost of the service applied to pricing and planning; the first projects retained are those which present the marginal cost discounted by the kW of installed power or the lowest kWh delivered.
- *Equity*, which must guide grid developments in order to respect the right of all citizens to access the Public Service under the same terms, since electric lighting is considered so important.

To guarantee this equity, a regulatory measure, decided on after the technical choice had been made, was thus implemented: the standardised tariff. By standardising tariffs, urban consumers are billed slightly more than their actual costs in order to help finance rural lines, which cost more because of the lower population density. This is done to guarantee the same tariffs for rural consumers.

The formalisation of the equity principle, the definition of the Public Service's mission, the allocation of the roles to the public and private domains, and notably the creation of public entities such as utilities are all elements in the institutional structure which has been in place for nearly a century. This structure formalised various co-ordinating systems, entire sections of which had been crafted based on specific constraints which came

from having chosen (a technical choice) a grid-based service with large centralised production centres.

Compared with the very elaborate institutional frameworks which structure and govern the markets for conventional forms of energy, NRE seem to have very little today.

5.3.3 The Inherited Institutional Structure Checking the Development of NRE

It is important, however, to emphasise that despite the NRE's extreme need for an institutional structure, NRE are also suffering from being excluded from niches which would be natural for them from the standpoint of simple considerations of economic efficiency. They are excluded by the nearly automatic play of institutional measures surrounding conventional forms of energy. While these measures were set up to implement the principle of equitable treatment of users (standardised tariffs), it now seems that conventional forms of energy benefit from serious market distortions vis-à-vis new types of energy.

Although in general these distortions are ultimately based on principles which are relatively easy to explain, they must be detected through a laborious analysis of the relevant historical process and a combination of often complex administrative, legal and fiscal measures.

This *in situ* detection, i.e. by country and by sub-sector, is absolutely necessary and a prerequisite for any proposal to correct the situation by changing the institutional structure (administrative institutions, regulations, taxes, sectoral funding and financing, etc.). Without this change, it is impossible to translate the political will to restore competitive conditions to the decision-making process into concrete operating measure and thus reflect the reality of costs to the general public.

But, in order to illustrate these distortions in this synthetical methodological presentation, we will detail three perfect examples of configurations which penalise NRE development, relating to

- access to the conventional energy distribution grid for back-up production,
- competition between NRE and conventional energy for non-specific uses,
- substitution of distributed utilities for the centralised production/ distribution system.

5.3.4 Three Configurations Which Penalise NRE Relative to Conventional Electricity Supply

5.3.4.1 Decentralised Production Connected to the Grid

Lastly, although the grid first resulted in the centralisation of conventional production at very large plants, the presence of a dense grid connecting the various production and consumption sites constitutes an essential element in the development of NRE. This is because the back-up principle (dumping surplus production onto the grid) considerably reduces the handicap posed by the temporary drop in availability of energy which is intrinsic to NRE investments (i.e. variability of wind and sunshine, seasonality of biomass production). Since a dense secondary energy transport grid (generally for electricity) already exists, the low additional cost of developing this grid locally will make it possible to absorb all energy produced for basic consumption, even the energy that was previously wasted. Overall supply will be matched with overall demand through adjustments to the planning of particularly costly peak production resources.

Often, however, the initiative for NRE production comes from investors independent of the large conventional operators in the energy sector, notably those who control the grids (utilities, in the case of electricity). This causes very significant inefficiency in the co-ordination between, on the one hand, a structure with strong monopolistic tendencies and, on the other hand, independent production units with unique characteristics. This leads to the still open and controversial question of the terms of access to the grid for independent NRE production.

For monopolies, purchase prices paid to independent producers should be calculated based on selling prices to consumers minus inevitable costs from the utility's point of view. This is particularly the case in France. Inevitable costs include costs of the distribution grid used by the independent producer. In the case of France, the utility estimates this to amount to 50% of the grid's total cost (which represents a reduction of 12.5% of the fixed purchase premium).

Today, the bulk of independent electricity producers that sell on the grid are factories located in industrial districts on the outskirts of urban centres which sell their surplus production.

Since the factories are located in generally dense grid zones, the standardised tariffs fully reflect the real cost of the grid to which they are connected.

However, independent producers of electricity using NRE, currently a very small minority, are and will be in most cases located in rural areas, i.e. in low-density zones where the real distribution costs are high. In these areas, the standardised selling prices are therefore well below real costs, because the latter include the additional cost of distribution. Now, the utility applies the same discounts to NRE producers as to other independent pro-

ducers. In this case, the inevitable distribution costs are deducted twice from the purchase price proposed to NRE producers:

- once because the standardised tariffs do not account for the cost of the semi-individualised grid,
- a second time because the utility calculates the purchase price by deducting the cost of the grid from the standardised selling price.

It is thus clear that the present pricing system penalises decentralised electricity production derived from NRE relative to conventional production. It is essential to change this system, so that NRE producers can access the grid without such a handicap.

In Table 5.2, Finon and Poppe (1996) summarised the main institutional initiatives that European countries have taken to improve the attractiveness of independent production of electricity from NRE.

5.3.4.2 *The Area of Private Heating Equipment*

Furthermore, there is significant development potential for private NRE (heating water with solar energy, wood-fired heaters, etc.) in zones where the grid already exists, as soon as minimum real cost conditions are restored when choosing among the various alternatives.

Indeed, regarding thermal use of electricity which is not electricity-specific (electric water heater, electric heating, etc.), electricity distributed by the grid, benefits

- from a hidden subsidy in competing NRE sources' natural niches of development. Through standardised tariffs, the electricity consumed for thermal purposes is billed to the user at below its real cost. Our study on France shows that the difference between the tariff and the cost for the general public (marginal cost of growth) can reach 40%, and frequently exceeds 25% for nearly 30% of French consumers at low voltage;
- from the fact that the user who resorts to electricity does not need to make an investment, whereas he must do so if he opts for an NRE alternative.

The pricing system which has come into general use over several decades consists of calculating the price the consumer needs to pay by averaging all discounted costs of investment and operation over all kWh and kW made available to consumers over the course of the useful life span of the equipment. In fact, this very traditional system effectively transfers investment costs to current expenditure (tarification), which spares the user from bearing the full cost of the investment (as well as the ensuing financial charges). Today, however, unless compensatory mechanisms are implemented, the user who would like to implement an NRE-type solution must bear the full cost of investment himself (by borrowing). He faces relatively unfavourable financing terms given the dispersal of investment resulting from the indi-

Table 5.2 Different types of incentives for electricity production from NRE (Finon and Poppe 1996).

	Germany	Denmark	Spain	Italy	Netherlands	United Kingdom
Reserved market	No	No*	No*	Yes (Niches)	No	Yes* (Niches)
Way of defining standard prices	Reference to average sales prices over all territory · 90% for PV · 75% for wind biogas · 65% for mini-hydro.	Reference to domestic prices for wind and co-generation biomass: 85% of the tariff if all is sold · Premium for wind and biomass by allocating VAT and energy tax receipts	· Reference to sales prices · Taking account of external effects · Price incentives for NRE since 1995	· Reference to CCGT cost of 300 MW plus premium	· No standard price · BT purchase at 90% of sales prices · Premium on the price of purchase by certain distributors	· Prices set by bidding specific to each type of technology, then setting prices based on the project decided on (NFFO2) (Competitive bidding) · Currently offered price of each candidate
Guarantee of durability	Implicit	Agreement reached between electric companies and productions associations	At least 5-year contracts	8-year contracts	Implicit	8- then 15- year contracts
Competitive bidding	No	No	No	No	No	Yes
Selection procedure	No	No**	No	Yes	No**	Yes
Other means	· Subsidies by diverse ministries or Länder for: PV, wind, biogas · Fiscal incentives	Previously, subsidies for investment. Currently abolished for wind; Subsidies for moving to biomass co-generation	Large subsidies using public funds (at least 30%); Setting up special financing schemes	No subsidies; Payment of half the cost of connection to the system for certain projects	Subsidies by distributors with funds received from a 2% tax and from NOVEM Special financing schemes	Possible subsidies by European programmes (ALTENER, etc.)

* Quantified objectives in Spain, the UK and Denmark (Biomass and wind)

** No need for authorisation to construct up to 50 MW in Denmark, up to 5 MW in the Netherlands

vidualisation of the equipment. In addition to this extra initial cost, someone who chooses an NRE solution will have a reduced borrowing capacity which could require making choices in relation to other equipment he requires.

Therefore, without calling into question the importance of the grid for electricity-specific uses, it is possible to extend the benefits of standardised pricing to NRE, so as to restore fair market conditions and make it possible for NRE to develop in its natural niches. These niches are far from negligible, as shown by the case of Greece. More than 400,000 solar collectors

have been installed, saving more than 160,000 tonnes of oil equivalents per year, and creating 3,000 jobs selling and maintaining the collectors.

Standardised selling tariffs do not reflect the diversity of distribution costs. Purchase tariffs are therefore calculated on the same statistical basis as selling tariffs.

5.3.4.3 The Potential of Isolated Sites

It is generally thought that the electric grid spans the full territory of European countries, and that there is very little residual space for small systems of local energy production: mountain cottages, forest refuges, small islands, etc. Moreover, this is generally what specialised NRE promoters independent of utilities have observed. In the French example, one finds instead that when local managers of conventional rural electrification have the possibility of balancing the conventional grid and decentralised solutions, a much larger potential emerges than expected for local energy projects. There are two reasons for this.

First, local rural-electrification operators (EDF centres and agencies, rural electrification associations) have, over time, listed a large number of sites as "waiting" for connections, rather than officially considering them "non-connectable". This would be politically unacceptable given the obligation of a public service to serve everyone. Moreover, it is very tedious to identify such sites independently, since they are dispersed across the country. There are no reports from people stating their actual characteristics, and often local operators themselves are not fully aware of the extent of the phenomenon, since this type of site can be lost among the requests for more common connections such as new constructions (second homes, housing estates, etc.).

Second, the reduced cost of small decentralised systems is leading to a review of technical choices whenever it is necessary to replace old lines. These lines were constructed at a time when there was no alternative, and when the grid's technical standards were less demanding and therefore far cheaper. Moreover, they generally have relatively low feeding capacity, which has limited the development of demand. When looking to replace them, local conventional operators acknowledge ever more readily that the cost of building an equivalent line incorporating modern technical specifications is exorbitant compared with the demand on the part of consumers, which sometimes remains very modest. It thus becomes possible for them to remove the line and replace it with a local production system such as NRE, or even to complement the low residual capacity of the line, if it is still functional, with local NRE production. However, if such a proposition came "from outside", it could be seen as a real provocation if it deprived clients of resources traditionally allocated to their grid.

In the French case, the 1995 setting-up of a specific line of financing within the conventional system of financing rural electrification (FACE) in

just one year revealed as many as 450 isolated sites which could potentially be served by autonomous electricity production systems based on NRE.

5.4 Beyond the Reform of Incentive Systems – Organising the Co-ordination of Actors in Europe

It is true that the generally local and contingent character of renewable energy resources requires treatment and operating systems adjusted to local conditions. However, the above analysis of internal bottlenecks shows that for NRE to become a true energy alternative with the goal of attaining the most ambitious objectives for reducing emissions, close co-ordination of the actors involved in their development at the national and European level will be required. As a result, the classic incentives through pricing (taxes, purchase prices, selling prices, investment subsidies, transfers through time of investment using a posteriori amortised financing based on consumption during the life of the equipment, etc.) will certainly not be enough to generate the necessary co-ordination between the actors involved in setting up NRE projects on a large scale. We propose institutional initiatives to encourage this co-ordination.

5.4.1 A Catalogue of Typical Projects for Pairing Renewable Energy Technologies and Conventional Energy Technologies

Today, the complementarity between centralised and decentralised production using NRE suffers from a lack of information on the possibilities of effective pairing from a technological and economic point of view. The Danish case of cogeneration shows that an important step consists in making official information available about the realistic technological and economic potential. In view of the inertia of conventional institutional structures at a national level, it would be useful to produce this information at a European level, for example in the form of a catalogue of examples of pairing the two types of production at different territorial levels of energy planning. These examples would be taken from real configurations found in EU countries and would be described according to their technical specifications and existing economic conditions in the different EU countries.

Admitting that most of the NRE technology is still only at the beginning of the “production cycle” (Vernon 1966), capitalising on successful experiences and failures, and the learning effect which can lead to their spread are likely to boost the competitiveness and quality of supply, and reduce transaction costs (project planning, selection of the equipment, project presentation, choice of interacting parties, management of installations, etc.). It is therefore desirable to organise the capitalisation and diffusion of examples of experiences. This could also be done through a European initiative.

Among the objectives of such an education initiative, a special place is granted to new technical measures which enable the “installation of the system” of diverse renewable energy equipment. This principally refers to modelling and simulation techniques which are developing rapidly.

5.4.2 Norms and Certification of Systems

In order to obtain dependability levels which allow these projects to be extended, it is vital that NRE systems (collection equipment together with storage components and/or connection to the network, controlling equipment and efficient equipment for end use) become standardised and certified. This is required by the preceding simulation operations. The operations for setting up NRE should be as predictable as other energy operations. It is therefore desirable to go from certifying components to certifying systems.

5.4.3 Negotiating Large Quantities, Economies of Scale, and Public Tenders

To increase the competitiveness of alternative energies based on NRE, the development of economies of scale is important.

Public decision-makers in the energy sector should be encouraged to avoid numerous small calls for tender, and to regroup these into larger unified calls for tender instead. The maximum size of these calls for tender is, however, limited by the size of operators present on the market. Imposing excessively large calls for tender too rapidly would create serious industrial risks and weaken competition too much.

From this point of view, it would be interesting to set up an observation station whose function would be partly to detect and consolidate information on the sources and size of markets, and partly to follow the evolution of the sector's structure in order to recommend the most propitious sizes of calls for tender to maximise economies of scale without generating any serious industrial risks. Public dissemination of this information would also allow industrials to predict the size of future markets more accurately, and thus to adjust their investment strategies.

5.4.4 A European NRE Agency as a Vehicle for Helping to Coordinate Actors

Evidently there is a need for a European Agency to develop decentralised NRE production projects which would unite different initiatives. In addition to the three principles we presented above (database on typical projects, norms and certification, negotiation of large quantities), the following actions could be part of such an agency's responsibilities:

- **Teaching agents and professional groups:** A large number of professional groups will be involved in demand-side management (DSM) and the propagation of NRE. These include energy engineers in industry, architects, plumbers, electricians. Training all these different professional groups to use varied technologies will be difficult. A DSM measure or promotion of NRE in general requires knowledge of a large number of scientific and technical areas (thermodynamics of industrial processes and buildings, electrical engineering, process control). Therefore one must conceive and establish broad actions to deal with the question of training these different professional groups throughout Europe.
- **Insurance and maintenance:** In order for a technology to spread, it has to have a good reputation. Producers and individuals who have chosen it should not be penalised relative to others. Installation must not take longer than expected, anticipated performance levels must be attained and maintenance must not be more expensive than predicted. Therefore, it is important to develop insurance and guarantees which would contribute to these objectives.
- **Financing terms:** An analysis of the 1970-80 period shows that one of the obstacles to renewable energies' penetration was the difficulty for private agents (individuals or producers) to find financing on terms as advantageous as those for large energy operators. Note the disparity between financial terms granted to a large operator to construct an electric plant and those offered to a private individual to insulate his house or to install a solar water heater. Therefore one can imagine the financing circuits which the large operators of energy renovation through DSM and NRE found when negotiating conditions as advantageous as those of the major energy operators for significant groups of energy projects.

5.5 Conclusions

We saw how the development of fossil energies gave rise to a sector divided into primary energy producers, secondary energy transformers, distributors and end users. Basically, we showed how national energy sectors were built at the same time as very complex institutional systems.

One long-term reason for hope for the emergence of renewables came from the expectation that users would be progressively "disconnected" from centralised energy production and distribution systems. For technical as well as institutional reasons, some people felt that energy consumers should become more autonomous by becoming producers themselves. This idea remains alive in certain European ecological movements. We saw how attempts in this direction failed in the 1970s.

Those who believe in this idea think that there should be a shift from a regime with a very integrated supply of energy to one where a system of

individual collectors would be set up. Thus, the business of energy suppliers would consist in installing equipment for collecting natural energy, which in the end would be a market just like the markets for other industrial or domestic equipment. Institutionally, they hoped to see an increasingly large number of autoproducers of energy, loosely linked through complementary networks.

Opposing this concept are certain ideas which we developed in this study and which we will try to synthesise here.

NRE penetration increases through gains in dependability and competitiveness. Concerning competitiveness, our analysis shows that the institutional framework, notably that which determines tariffs, financial circuits and technological choices, should be adapted so as to reduce the distortion in favour of conventional solutions. Where this does not happen, collective choices having led to exchanged subsidies, especially through standardisation of tariffs, the system should be reformed so as to include NRE technology each time it is preferable from a technical, economic or environmental point of view.

However, there is a real complementarity between the "fatal" rhythms of NRE production and the production rhythms of fossil energies, whose programming is much more flexible. Connecting NRE production to very dense distribution networks already set up for conventional energy production would enable the variations in natural rhythms to be evened out without any extra costs for storage or overcapacity.

Economies of scale should be sought through large unified calls for tender whose size would be adjusted to the evolution of the sector so as to avoid generating serious industrial risks or weakening competition.

Improvements in dependability should be increased by capitalising on experience – success or failure – and maximising learning effects for operators in the sector. Promotion of learning should be accompanied by the development of a certification policy for systems, going beyond a simple certification of components.

Thus, in spite of the generally local and contingent character of renewable energy resources, their arrival as true energy alternatives worthy of being included in energy plans will require good co-ordination of the actors involved in their development.

We underlined the importance of today's institutional measures, which are inadequate to develop NRE and which result from the history of the conventional energy sector. The first of these is the incentive system. It is clear that one of the essential conditions for change will be the evolution of a group of conventions which today predetermine technological energy choices in favour of conventional solutions. This evolution would lead to:

- improved methods of comparing alternatives and determining purchase prices and selling prices of energy products or energy services,

- taking the impact of different energies on the environment into account, as well as technologies for exploiting these energies,
- officially legitimising alternative energies so that they benefit from true expertise when their potential is determined and technologies are identified, and so that they are taken into account in energy planning exercises,
- the carrying out of collective choices based on other considerations besides the technical-economic optimisation of the sector. This principally concerns exchanged subsidies and measures for financing and investment, today too rigidly associated with conventional energy technology.

To systematically diagnose the dysfunctions in current institutional systems which curtail penetration of NRE in naturally competitive niches (principle of the Fair-Market Scenario), we created a method for analysis which we applied to the French case to show how it works. Taking into account the contingent nature of national institutional systems inherited from several decades of history affected by specific local requirements, it would of course be a good idea to apply this method to each of the EU member countries. This is a particularly rich future research area.

To continue beyond that (to the normative Sustainable Scenario), we created a twofold typology of NRE projects and internal organisational bottlenecks in the NRE sector which have to be overcome if one wants to see these energies rapidly take over from conventional energy.

In this way, the classic incentives through pricing (taxes, purchase prices, selling prices, investment subsidies, transfers through time of investment by using a posteriori amortised financing based on consumption realised during the life of equipment, etc.) will certainly not be enough to generate the necessary co-ordination between the actors involved in setting up NRE projects on a large scale. In this sense, the initiatives could be taken by the government, notably at the European level. We proposed a preliminary list of these initiatives, which include the potential responsibilities of a European NRE agency.

Taking the intrinsic inertia of old, inflexible institutional measures into account, political bodies play an important role in questioning these sectoral systems, which are too restrictive where technical choices are concerned.

In fact, it is precisely a political mobilisation which has lately led several countries to set normative objectives for reducing emission levels. Massive recourse to NRE could contribute in a decisive manner to realising these objectives.

Therefore, it is important today to make this political mobilisation concrete in order to remove the different bottlenecks identified in this study, which risk keeping renewable energies from contributing to the collective goal of reducing emissions.

6 Appendix II: Additional Data and Figures

Table 6.1 Assumptions of the Sustainable Scenario for nutrition in 2050 in gram per capita and day [g/(cap·d)].

Foodstuffs	Current	Recommendations for 2050		
	demand in the EU*	Northern Europe	Central Europe	Southern Europe
Cereals	231	271	249	305
Potatoes	220	298	312	215
Pulses	-	50	50	50
Vegetables	320	236	223	366
Fruits	253	200	365	210
Dairy products	275	340	210	200
Cheese	41	50	50	50
Meat	253	51	58	53
Fish	-	38	28	30
Oil and fats	-	40	40	40

* Gross consumption of food in EU12 in 1989.

Table 6.2 Development of the industrial energy demand in EU15 in the Sustainable Scenario in watt per capita (W/cap).

Year	1990	2000	2010	2020	2030	2040	2050
Energy form							
Heat <100 °C	242	242	184	160	160	136	128
Heat >100 °C	595	595	539	386	288	193	155
Electricity	223	223	208	169	149	125	119
<i>Total</i>	<i>1060</i>	<i>1060</i>	<i>931</i>	<i>715</i>	<i>597</i>	<i>454</i>	<i>402</i>

Table 6.3 Development of the domestic energy demand in EU15 in the Sustainable Scenario (in W/cap).

Year	1990*	1990*	2000	2010	2020	2030	2040	2050
Energy form	Stat.	Model						
Heat <100°C	633	668	663	594	494	407	321	236
Heat >100°C	46	46	45	39	31	27	24	23
Electricity	165	130	126	107	75	64	44	37
<i>Total</i>	<i>844</i>	<i>844</i>	<i>834</i>	<i>740</i>	<i>600</i>	<i>498</i>	<i>389</i>	<i>296</i>

* The difference between statistical and model data is due to the fact that in the model, electricity for space and water heating is counted as heat below 100 °C.

Table 6.4 Development of the energy demand in the service sector of EU15 in the Sustainable Scenario (in W/cap).

Year	1990	2000	2010	2020	2030	2040	2050
Energy form							
Heat <100°C	153	151	179	197	193	180	178
Heat >100°C	41	41	49	57	63	58	58
Electricity	135	136	157	173	188	154	153
<i>Total</i>	<i>329</i>	<i>331</i>	<i>385</i>	<i>427</i>	<i>444</i>	<i>392</i>	<i>389</i>

Table 6.5 Development of the energy demand in the agricultural sector of EU15 in the Sustainable Scenario (in W/cap).

Year	1990	2000	2010	2020	2030	2040	2050
Energy form							
Heat >100°C	57	57	52	46	39	34	34
Electricity	10	10	9	8	6	5	5
<i>Total</i>	<i>67</i>	<i>67</i>	<i>61</i>	<i>54</i>	<i>45</i>	<i>39</i>	<i>39</i>

Table 6.6 Development of the energy demand in the transport sector of EU15 in the Sustainable Scenario (in W/cap).

Year	1990	2000	2010	2020	2030	2040	2050
Energy form							
Fuels	897	971	654	413	255	160	102
Kerosene	99	142	113	82	54	32	17
Electricity	37	34	41	41	38	31	25
<i>Total</i>	<i>1033</i>	<i>1147</i>	<i>808</i>	<i>536</i>	<i>347</i>	<i>223</i>	<i>144</i>

Table 6.7 Development of the total energy demand of all sectors for EU15 in the Sustainable Scenario (in W/cap).

Year	1990	2000	2010	2020	2030	2040	2050
Sector							
Industry	1060	1060	931	715	597	454	402
Households	844	834	740	600	498	389	296
Tertiary	329	331	385	427	444	392	389
Agriculture	67	67	61	54	45	39	39
Transport	1033	1147	808	536	347	223	144
<i>Total</i>	<i>3333</i>	<i>3439</i>	<i>2925</i>	<i>2332</i>	<i>1931</i>	<i>1497</i>	<i>1270</i>

Table 6.8 Technical potential of residues for energy purposes and energy crops (in W/cap) as well as installed capacities of biomass plants (in GW) in the Sustainable Scenario.

Year	1990	2000	2010	2020	2030	2040	2050
Source							
Industrial	–	64	70	94	129	160	186
Forestry and agriculture	–	96	160	108	63	37	34
<i>Total residues</i>	<i>94</i>	<i>160</i>	<i>230</i>	<i>202</i>	<i>192</i>	<i>197</i>	<i>220</i>
Energy crops	0	0	12	69	174	264	280
<i>Total biomass</i>	<i>94</i>	<i>160</i>	<i>234</i>	<i>271</i>	<i>366</i>	<i>461</i>	<i>500</i>
Capacity (GW)	–	88	129	150	202	251	267

Table 6.9 Development of electrical energy produced, capacity installed, and areas used for photovoltaic modules in the Sustainable Scenario.

Year	1990	2000	2010	2020	2030	2040	2050
Electricity (W/cap)	0	0	23	60	103	138	153
Capacity (GW)	0	0	62	164	280	370	405
Total area used (km ²)	0	6	560	1 400	2 220	2 700	2 770

Table 6.10 Development of heat energy produced and capacity installed of solar collectors in the Sustainable Scenario.

Year	1990*	2000	2010	2020	2030	2040	2050
Heat produced (W/cap)	0	0	68	160	260	308	326
Capacity installed (GW)	n.b.	2	189	466	735	891	906
Total area used (km ²)	3	5	446	1 137	1 782	2 164	2 200

Table 6.11 Development of the electrical energy produced and the capacity installed of solar-thermal power plants in the Sustainable Scenario.

Year	1990	2000	2010	2020	2030	2040	2050
Electricity produced (W/cap)	0	0	35	86	138	171	177
Capacity installed (GW)	0	0	32	79	127	155	158

Table 6.12 Development of electrical energy produced and capacity installed of wind energy in the Sustainable Scenario.

Year	1990	2000	2010	2020	2030	2040	2050
Electricity on-shore (W/cap)	0	4	16	32	41	47	51
Electricity off-shore (W/cap)	0	0	32	78	126	156	161
<i>Electricity total (W/cap)</i>	<i>0</i>	<i>4</i>	<i>47</i>	<i>110</i>	<i>167</i>	<i>203</i>	<i>212</i>
Capacity on-shore (GW)	0	7	27	54	68	77	82
Capacity off-shore (GW)	0	0	30	74	119	146	149
<i>Total capacity (GW)</i>	<i>0</i>	<i>7</i>	<i>57</i>	<i>128</i>	<i>187</i>	<i>223</i>	<i>231</i>

Table 6.13 Development of electrical energy produced and capacity installed of hydropower installations in the Sustainable Scenario.

Year	1990	2000	2010	2020	2030	2040	2050
Electricity produced (W/cap)	84	85	97	115	125	132	137
Electricity stored (W/cap)	4	4	5	7	8	8	9
Capacity installed (GW)	94	98	117	144	158	166	171

Table 6.14 Development of heat pumps in the Sustainable Scenario.

Year	1990	2000	2010	2020	2030	2040	2050
Environmental heat (W/cap)	0	7	40	59	78	73	67
Electricity used (W/cap)	0	2	13	18	22	20	19
<i>Heat supplied (W/cap)</i>	<i>0</i>	<i>9</i>	<i>53</i>	<i>77</i>	<i>100</i>	<i>93</i>	<i>86</i>
Capacity (GW)	0	9	57	79	97	88	84

Table 6.15 Development of the demand for conventional fuels in the Sustainable Scenario.

Year	1990	2000	2010	2020	2030	2040	2050
Nuclear (W/cap)	677	516	0	0	0	0	0
Natural gas (W/cap)	781	962	1048	799	549	275	0
Oil (W/cap)	1 971	2 132	1 680	1 117	553	318	82
Coal (W/cap)	875	698	621	371	120	60	0
<i>Sum (W/cap)</i>	<i>4 304</i>	<i>4 308</i>	<i>3 349</i>	<i>2 286</i>	<i>1 222</i>	<i>652</i>	<i>82</i>

Table 6.16 Assumed specific investment in renewable energy systems in ECU per kilowatt of peak capacity installed (ECU/ kW_p).

	1990	2000	2010	2030	2050
Small hydropower plants	8 720	8 720	8 720	8 720	8 720
Wind turbines, on-shore	1 410	1 300	1 200	1 060	932
Wind turbines, off-shore	2 350	2 120	1 900	1 540	1 250
Photovoltaic installations	6 210	5 630	4 310	2 480	1 450
Solar-thermal electricity	2 990	2 370	1 870	1 130	673
Solar-thermal heat	1 140	935	615	461	413
Biomass	1 170	1 100	1 110	1 090	1 036
Heat pumps	731	731	731	731	731

Table 6.17 Assumed specific production costs of renewable energy systems in milli-ECU per kilowatt-hour (mECU/kWh).

	1990	2000	2010	2030	2050
Small hydropower plants	73	73	73	73	73
Wind turbines, on-shore	48	43	39	32	26
Wind turbines, off-shore	63	57	51	41	33
Photovoltaic installations	378	268	190	96	48
Solar-thermal electricity	211	152	109	56	29
Solar-thermal heat	107	86	58	39	32
Biomass	41	39	41	62	65
Heat pumps	72	66	66	76	93

Table 6.18 Development of the annual costs of the energy supply system of EU15 in the Sustainable Scenario (in billion ECU/a), including capacities currently installed.

	1990	2010	2030	2050
Small hydropower plants	29.5	36.8	49.7	53.9
Wind turbines, on-shore	0.0	2.1	4.9	5.1
Wind turbines, off-shore	0.0	3.8	12.2	12.3
Photovoltaic installations	0.0	15.3	39.9	33.6
Solar-thermal electricity	0.0	3.8	9.1	6.7
Solar-thermal heat	0.0	7.8	22.8	25.2
Biomass	12.3	33.6	75.7	105.0
Heat pumps	0.0	7.4	14.0	11.7
<i>All technologies</i>	<i>41.8</i>	<i>110.6</i>	<i>228.1</i>	<i>253.6</i>

Table 6.19 Development of the annual capital requirements of the energy system of EU15 in the Sustainable Scenario.

	1990	2010	2030	2050
Small hydropower plants	0.0	20.2	10.8	4.0
Wind turbines, on-shore	0.0	3.2	4.2	4.1
Wind turbines, off-shore	0.0	5.6	11.4	9.6
Photovoltaic installations	0.0	28.1	45.2	22.2
Solar-thermal electricity	0.0	5.5	8.4	5.0
Solar-thermal heat	0.0	11.5	21.0	19.4
Biomass	2.9	7.9	15.4	15.8
Heat pumps	0.0	6.5	9.9	8.7
<i>All technologies</i>	<i>2.9</i>	<i>88.7</i>	<i>126.3</i>	<i>88.8</i>

Table 6.20 Shares of the different renewable energy technologies in the Sustainable Scenario.

Technology	Energy supplied	Capacity installed	Annual costs
Biomass	31.8 %	12.0 %	41.4 %
Solar-thermal heat	20.5 %	40.8 %	9.9 %
Wind energy	13.6 %	10.4 %	6.9 %
Solar-thermal electricity	11.3 %	7.1 %	2.6 %
Photovoltaics	9.8 %	18.2 %	13.3 %
Hydropower	8.8 %	7.7 %	21.2 %
Environmental heat	4.3 %	3.8 %	4.6 %

Table 6.21 Assumed development of specific capital costs of conventional energy technologies.

mECU/kWh	Fuels	1990	2000	2010	2020	2030	2040	2050
Electricity	Nuclear	50.1	50.1	50.1	-	-	-	-
	Gas	9.3	10.6	11.9	11.9	11.9	11.9	11.9
	Coal	19.0	20.7	22.3	22.3	22.3	22.3	22.3
Low temp. Heat	Gas	11.3	11.3	11.3	11.3	11.3	11.3	11.3
	Oil	11.9	11.9	11.9	11.9	11.9	11.9	11.9
High temp. Heat	Gas	8.8	8.8	8.8	8.8	8.8	8.8	8.8
	Oil	10.5	10.5	10.5	10.5	10.5	10.5	10.5

All values are averages of existing plants. Due to the uncertainties involved, we do not assume future cost changes. Nuclear cost includes fuel cost. (Energieversorgung Schwaben 1989; CIRED 1996b; Groscurth 1996; Voss et al. 1990)

Table 6.22 Gross development of employment due to the manufacturing of renewable energy technologies in the Sustainable Scenario (in 1000 person-years per year).

	1990	2010	2030	2050
Small hydropower plants	0	413	220	83
Wind turbines, on-shore	0*	85	112	110
Wind turbines, off-shore	0	139	281	237
Photovoltaic installations	0	341	550	270
Solar-thermal electricity and heat	0	129	222	184
Biomass	74	199	388	396
Heat pumps	0	83	125	110
<i>All technologies</i>	<i>74</i>	<i>1389</i>	<i>1897</i>	<i>1390</i>

* For methodological reasons, it was necessary to set this figure to zero, even though it does not represent the historical development correctly.

Table 6.23 Gross development of employment due to operating renewable energy technologies in the Sustainable Scenario (in 1000 person-years per year).

	1990	2010	2030	2050
Small hydropower plants	116	145	196	213
Wind turbines, on-shore	0*	26	49	41
Wind turbines, off-shore	0	70	180	137
Photovoltaic installations	0	67	175	148
Solar-thermal electricity and heat	0	65	179	179
Biomass	113	340	1090	1614
Heat pumps	0	25	48	40
<i>All technologies</i>	<i>230</i>	<i>738</i>	<i>1917</i>	<i>2371</i>

* For methodological reasons, it was necessary to set this figure to zero, even though it does not represent the historical development correctly.

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