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RENEWABLE ENERGY IN EUROPE

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Abstract

Renewable energy sources are potentially capable of providing a significant fraction of Europe's energy needs in the 21st century. The development of renewable energy is desirable for two main reasons. First, from the geopolitical standpoint, the future concentration of the world's oil resources in the Middle East involves the risks inherent in an increasing dependence on these resources. Secondly, there is widespread concern about the environmental effects of conventional energy consumption and in particular global warming.

Since renewable energy resources are well distributed over the whole earth, they offer the possibility of a global response to global change, unlike many other energy sources. For Europe, the most important renewable sources are biomass, wind, photovoltaics, small hydro, tidal power and solar buildings. Wave power has attracted less attention so far. Solar thermal power has an insignificant potential in Europe.

There is an important public consensus for a stronger development of renewable energies in Europe. In the industrial sector, large groups as well as small and medium-sized companies have committed themselves to development and market introduction. The single European market of 1993 will stimulate even more industrial development and competitivity.

Introduction

It is estimated that renewable energy presently contributes 6 to 7% of Europe's energy supply (Palz and Shock, 1989), i.e. approximately 4 to 5% from hydro and the rest from fuel wood. Several projections for various EC member countries anticipate an increase of these contributions up to 20% for 2010 and beyond. In view of the usual lead time for the introduction of new energies, such assumptions may be over-optimistic. However, the increasing environmental concern as well as the threatening restrictions on the conventional energy supply side, together with an increasing oil price, may make some kind of crash programme necessary to accelerate the development process. Eventually, renewable energy could, in the course of the 21st century, supply even more than 20% of Europe's overall energy consumption.

In the future, biomass, wind and photovoltaics, which are all insignificant at the present time, will have a large role to play in Europe's energy scenarios. The measures which are eventually taken to accelerate the integration of these new technologies into existing energy networks and distribution schemes will determine their future market success.

Development work in Europe is currently focusing on technologies which are relevant to Europe's own needs and future markets. It is important to note that the same technologies can be employed with no or only minor modifications in Third World countries. Hence renewable energy will play an increasing role in future in cooperation schemes between Europe and the developing countries and in export markets for European industry.

In terms of resources, biomass is the most evenly distributed energy in Europe. Solar radiation which can be converted directly into electricity by photovoltaics is available in sufficient quantities everywhere with a slight advantage in the Mediterranean countries. All EC member countries have at their disposal an exploitable wind resource. The strongest winds prevail in the United Kingdom, Denmark, Germany and France.

As regards technological development, there is a worldwide community between researchers and an intense cooperation between all countries, in particular Europe and the United States. There exist only minor differences of appreciation in Europe and the United States concerning the various resources. While Europe has some interest in the development of tidal and wave power, it is less concerned with ocean thermal energy systems or solar thermal power and similar devices requiring a concentration of the sun's radiation.

Rationale

The Brundtland report says that 'every effort should be made to develop the potential for renewable energy which could form the foundation of the global energy structure during the 21st century'. At the heart of the notion of sustainable development is the ethical imperative that the stock of environmental capital must be preserved for future generations. To a degree, of course, this ethical premise limits the role of markets. Translated into practical terms, it means the economic assessment of all forms of energy must include external costs.

The classic pollution processes are far from being overcome whilst global warming has been rediscovered as an essential additional problem. An ever increasing world population and further economic growth in the industrial as well as the developing countries will stimulate energy consumption. This has once again put energy high up on Europe's economic agenda. And this energy must be clean. Unlike most conventional energies, renewable energies are clean per se. All of them, including energy from biomass crops, produce no CO_2. The further development of renewables for the energy scenarios of the 21st century is of high priority because 'it is better to prevent pollution than to cure it'. Finally, renewable energies need not rely on the huge distribution networks for oil, gas and electricity of today. The renewables are available, decentralized and in all suitable sizes. It has been well established that the necessary land areas for harnessing the sun and the wind are comparable to those for conventional energies and are by no means prohibitive. The same is true for the energy pay-back time for renewable energy conversion systems.

Electricity can be produced from wind and photovoltaics without using water. This aspect may become more important in the future as some European countries are currently suffering from unusual droughts, in particular the United Kingdom and France. For instance, France recently had to import electricity because of a shortage of water for its hydro and nuclear power plants.

As well as environmental ethics, there is an important geopolitical reason for a much stronger development of the renewable energies for Europe's future energy supply systems (Table 1). It is clear that the world's remaining oil deposits will be progressively concentrated in the Middle East, hence the European economy will become more dependent on this region. In sharp contrast to the many risks of interruption of supplies or depletion of such a leading conventional energy as oil, renewable energies come in various forms which are complementary to each other, inexhaustible and available virtually everywhere, attractive as a domestic asset. For other geopolitical reasons, clean renewable energies have to be considered as an essential feature in future energy scenarios of the developing countries, where consumption will grow much faster than in Europe. Without an intensive North-South cooperation on renewable energies, these countries will not be able to harness these resources to meet their coming energy needs.

Vox populi

Owing to its varied nature, renewable energy is a 'democratic energy'. Because it is distributed everywhere, it is accessible to everybody. Renewable energy holds out the promise of individual responsibility and even autonomy in energy matters.

Renewable energies are socially desirable for many reasons. Solar energy utilization in houses for instance is associated with better comfort, living and working conditions. From an economic standpoint, renewable energies offer new opportunities for the development of rural areas because they provide new non-food markets for agro-forestry, thus creating new employments and favoring the establishment of small agro-industry and agro-energy enterprises.

In a recent poll of more than 11,000 people in the member countries of the European Community, which was organized in 1989 for the EC Commission in the frame of a study called 'The Europeans and Science' it emerges that among all research topics, the renewable energies were ranked in third position just after health and the environment. This is a strong confirmation that people in Europe pay great attention to this matter. This public awareness has been further confirmed by a recent vote of the European Parliament in Strasbourg, calling for a multifold increase of the R&D budget for renewable energies of the EC Commission in the period 1990-94.

Politics

The macro-economic advantages of renewable energy, i.e. the social ones mentioned above, the environmental benefits, the substitution of imported and depleting fossil resources, make renewable energy politically desirable. These advantages can be expressed in monetary terms. A study carried out by Hohmeyer (1988), taking the example of wind energy utilization in Germany (Fig.1), shows that the external cost of conventional electricity production is at least 7 US cents/kWh higher than for wind energy. If the external costs are included in market prices, the study concludes that electricity from wind turbines installed at good sites in Germany is competitive with conventional electricity.

Moreover, in connection with global warming, the introduction of a carbon tax is being discussed in many countries. At the beginning of this year, OECD proposed such a tax on all fossil sources e.g. $8 per barrel of oil. A new energy tax of this size would however be harmful to the economy because it will inevitably have an inflationary effect. An alternative political measure would be to grant specific tax reductions to renewable energy producers, equal to the external net benefits of clean energy production, thus reducing the market price of clean energy. Tax incentives could also be envisaged for the rational use of energy.

In summary, it has become clear that renewable energies are highly desirable on political grounds, because they will stimulate new economic activities and provide new tax income to society, apart from all the environmental and other social benefits. Therefore the international market for renewable energy needs political back-up and financial and institutional support.

It is interesting to note that in Europe, an association has just been created which attempts to translate people's concerns and wishes about energy matters into political action; this is the Eurosolar association chaired by H. Scheer, a member of the German Bundestag. Willy Brandt, a key figure in the North-South dialogue over the last few years, is a member of its Board of Directors.

Ultimately, the political interest in the renewable energies is not limited to Europe and the industrialized countries. Because of the global nature of the potential resources, greater attention by the United Nations seems appropriate and is being promoted there by Eurosolar.

Industry

In recent years, industrial involvement in the various renewable energies in Europe has increased considerably. Many small and medium-sized companies as well as large groups are engaged in development and market introduction (Table 2). Because markets are relatively small at this stage, the involvement of industry is very much related to the prospect of future development. Energy markets in Europe have by and large been captive markets for national industry so far, a situation which is harmful for the development of a powerful industry in an emerging sector. But already, the single European market which will be highly stimulating for further development is casting its shadow. Currently there are several large national renewable energy projects in progress (wind energy in Germany, photovoltaic plants in Italy, etc.) where products from abroad are accepted.

Renewable Energy Options

Energy from Biomass

Energy is derived from two large biomass resources, namely residues such as fuelwood, urban waste etc., and energy crops in agro-forestry. It is estimated that the EC consumes at least 20 million toe of fuelwood a year. The quantity of residues available is much larger, however. There are also huge areas of low-quality forests, 10 million ha in Italy and France alone. Long ago, before oil became generally available for heating, these forests were exploited for fuelwood.

Of even greater importance for the future is the potential of biomass energy plantations. This energy is environmentally benign since all the released CO_2 can be recycled. The potential in Europe is enormous. If only the 20 million ha of land in the E.C. on which food production should be phased out to eliminate surpluses were used for energy plantations, a sizeable fraction of the EC fuel consumption could eventually be met from biomass.

Although energy production from biomass crops must necessarily find its place among other non-food production schemes, in particular for timber, pulp and paper and renewable feedstocks for industry, it is true to say that bioenergy offers the largest market and provides an alternative line for Europe's agricultural policy.

Table 3 summarizes the two main energy crops and the utilizations which have been traditionally of interest in biomass. For petrol blending, the bioethanol option was thoroughly investigated by the EC Commission in 1987. In Europe, the best feedstock for alcohol production is wheat. Unlike Brazil and the United States, Europe makes no use of bioethanol for transport fuels. In strictly economic terms, bioethanol is not competitive today and the oil price would have to increase to the $30-40/barrel range to change the situation (Agro Développement, Parpinelli Tecnon et al. 1987). However, in the case of wheat plantations on 'set aside' agricultural land for which the European Community pays a bonus, together with a tax exemption for transport fuels, as discussed in France, bioethanol becomes marginally competitive today. Hence the Commission has recently decided to accept such a scheme under certain conditions.

For the future, there are many biomass opportunities for Europe's energy markets of the 21st century. Fig. 2 summarizes just a few of the possible options. On the left-hand side, the most important crops are woody species (short-rotation forestry) or alternatively annual or perennial grasses and other C4 plants and in particular sweet sorghum and miscanthus. C3 and C4 plants provide, generally speaking, complementary options for various types of terrain. C4 plants and particularly sorghum are suitable for intense cultivation on agricultural land, while C3 plants are more appropriate for land of lower value. The indicative cost figures given in Fig. 2 demonstrate that sorghum may have a cost advantage over short-rotation forestry because the high cultivation costs for sorghum (Belletti 1989) are more than offset by the much higher harvesting and transport costs for wood (Hummel, Palz et al. 1988). Moreover, the sugar yield per ha from sorghum can be as high as from sugar beet, thus the plantation can pay off for sugar production alone and the dry matter is a free by-product. A better approach is to divide the cost between the two products according to their potential value as energy raw materials. For convenience, we have split the cost equally between the liquid and the solid matter in Fig.2.

There are several competing technical routes for the conversion and utilization of biomass feedstocks with a view to the electricity market, as well as for heating or petrol blending. In particular, grasses and sorghum may be ground into a powder suitable for the direct feeding of high-temperature turbines in the 100-200 kW range. For the production of electricity, particularly in large power plants, charcoal and/or oils obtained by pyrolysis of lignocellulosic material are possible fuels (Mattucci, Grassi et al. 1989). Furthermore, there are good prospects to achieve lower economic costs with sweet sorghum, as compared with the currently preferred wheat, in view of the future petrol markets in Europe.

The various market prices are given on the right-hand side of Fig. 2 (EC Commission 1989). Prices include taxes which may be very high. It is interesting to note that biomass appears to be cost-competitive for all conventional energy markets today, even if the external benefits are not included. In practice however, the biomass market does not yet exist. The economic costs given in Fig. 2 are less relevant than the opportunity costs which represent the incentive for the farmer to grow energy crops, or for a utility to substitute a conventional fuel. Opportunity costs are difficult to determine in general terms. Furthermore, agricultural practices for biomass production, the necessary conversion devices, new turbines etc. are not yet ready. Hence, the schemes shown in Fig. 2 are promising rather in a medium and long-term perspective. Much further effort is required to strengthen R&D and organize implementation schemes.

Solar buildings

The rational use of solar energy in buildings by optimizing the use of solar radiation and the energy contained in the ambient air leads to very important energy gains for heating purposes. Besides the active solar systems for water heating which are quite successful in the south of Europe, there are many passive solar schemes: the direct gains through well designed windows are a notable example. More recently, new components have been introduced to this market, such as transparent insulation. Even houses built in unfavorable climates in Europe, such as in Scotland, can be heated up to 90% from solar energy when efficient passive solar components are used.

In the past, the esthetics of the active and passive solar heating components posed a problem. Architectural design and integration into the building's envelope will therefore be important requirements for the successful implementation of passive solar heating in the future. In this new field of 'solar architecture', therefore, costs and technology have to be studied in conjunction with artistic and design considerations.

Passive solar heating is by and large cost-competitive today. Because a major share of Europe's total energy consumption is used for the heating of buildings, there is a very large potential market for these technologies in Europe. Passive solar, together with energy conservation, could save more than a half of all the energy currently consumed in this sector.

Further development has become necessary, involving the use of new passive components and their optimal integration into building facades. Because the new solar components are highly efficient, there is a problem of overheating. In general, it can be said that new technologies have to be developed in solar architecture to allow for a dynamic and flexible response of the building envelope to solar radiation and the climatic variations.

Solar energy utilization in buildings is also desirable for reasons which are not strictly energy-related. Because these schemes include natural lighting and a better environment for the inhabitants, they can increase comfort and living conditions. These benefits can be expressed in economic terms through external costs.

Wind Energy

With approximately 250 MW installed, wind energy is currently less developed in Europe than in the United States, where there is a capacity of approximately 1500 MW. However, governments and utilities in several European countries such as Denmark, Germany, the Netherlands, the United Kingdom, Italy and Greece are considering the rapid introduction of wind farms in their generation networks. By the year 2000, according to current estimates, up to 3000 MW could be installed in the EC countries.

Since the end of the 70's, when wind energy development took off in Europe, the size of machines has continuously increased. In the 200-400 kW range, the production costs per kWh are currently the lowest: at present, the more or less standard new machine for grid supply purposes is rated at around 200 kW. Table 4 shows, as an example, estimated costs of electricity derived from wind with a commercial 200 kW turbine for various wind speeds (Shock and Palz, 1990). The turn-key cost of such a unit, based on construction in Germany, is at present about $1,200 per installed kW. The Table shows that electricity costs for wind energy look fairly competitive. This analysis is confirmed by large projects in Denmark : a total of 42 MW, employing machines in the range 90 to 300 kW, was recently installed there at an average total generation cost of $0.072 per kWh.

For large-scale implementation in the future, it may be desirable to develop larger machines, perhaps in the megawatt range. From the standpoint of operation and maintenance, large machines currently appear to be more suitable for utility networks than small ones. Hence much development activity in Europe is devoted currently to this goal. Table 5 lists a few of the large machines currently being developed in the European Community. For comparison, the typical weight breakdown of the commercial 200 kW machine mentioned above is also indicated.

The guiding principle taken for the development work on large machines is to minimize weight per kWh of electricity produced. The criterion of weight is relevant here since the cost of all components can be related to the per kg cost of similar market products already mass-produced. For example, the current cost of glass fibre rotors, which is approximately $10/kg, could be further reduced in the future since certain boat shells employing the same kind of technology cost 50% less per kg.

It can be shown that the commercial 200 kW turbine has a cost per kg which is very much in line with mass-produced items in industrial machinery. The costs of these machines can therefore not be expected to decrease much further in future and on Table 5 this machine is taken as a reference. The challenge for the large machines will be to beat the specific cost, i.e. to a first approximation the specific weight, of the smaller commercial ones. The relevant figures in Table 5 are the specific weight per m^2 of rotor swept area, the specific weight per unit rated power and the specific weight per kWh produced per year.

In order to decrease electricity production costs, the weight of the turbine, and in particular the mass on the tower head, must be minimized. The energy generated is proportional to the swept area, in other words to the square of the diameter. To maintain mechanical strength with increasing diameter, the weight of the machine however increases by a power greater than 2; the weight, as experienced in current projects, increases by a power of 2.4 to 2.6. This rule is not only true for the weight of the blades and the rest of the tower head, but also for the tower itself and the foundation. Thus, as a general rule the unit mass per m^2 of swept area increases with size.

The complexity of transport to, and erection on site also increases with size. On the other hand, the unit cost for grid connection and site preparation should simultaneously decrease. The most important effect which can offset the increasing weight for larger sizes is the vertical wind speed gradient, whereby the larger machines can exploit the higher wind speeds which prevail at greater hub heights. Consequently, the power specific weight (kg/kW) is more meaningful than the area specific weight (kg/m^2).

Table 5 confirms that, for all large machines, the kg/m^2 ratio is higher than for the small one. The one-bladed rotor comes closest to the reference machine but its kg/kW ratio is much less favorable and this is related to the rotor speed. For aerodynamic reasons, the efficiency of a one-bladed rotor is lower than that of the 3-bladed one because it must rotate much faster to harness the same amount of wind energy, but an upper limit is imposed by the permissible noise level and ultimately by the approach of the blade tip speed to the speed of sound.

It follows that all large machines beyond the 400 to 500 kW range are currently not competitive with the smaller machines. In terms of kg/m^2, the Howden machine installed at Richborough in England, looks attractive, in particular with an eye to the fact that it has 3 blades. It looks however less attractive in terms of power specific weight. For instance, the Italian Gamma 60 shows a much bigger improvement of the kg/kW ratio over the kg/m^2 ratio which cannot altogether be accounted for by the wind speed gradient.

In practice, the power rating of the various machines is often arbitrarily fixed and certainly not precise enough for this evaluation exercise. Hence the Table gives also some energy specific weights. Though they are possibly the most relevant, the figures given here are only indicative because for the large machines they are only estimates; moreover they are largely site-specific although a correction has been made to a given site mean wind speed. Finally it should be noted that most of the larger machines summarized in this Table are R&D or demonstration machines. Commercial machines of the same rating could, in all probability be built with lower weights.

Fig. 3 shows the Howden machine which was completed only a few months ago. Fig. 4 shows the Spanish machine together with a 200 kW Vestas machine. The Spanish and UK machines were part of the Commission's WEGA programme.

The Commission of the European Communities has currently embarked on a strategy study to define the optimum size for large machines. The result will be known only later this year but, at this stage, it is estimated that the optimal size would be in the 40 to 60 m diameter range. This is true for currently available blade materials such as glass fibre and composite materials employing wood. With carbon fibre and other more advanced materials, the optimum might move to larger diameters.

For the future implementation of wind energy, there are two main problems. Firstly, there may be a limitation on the installed capacity due to the difficulty of finding environmentally acceptable erection sites in sufficient numbers at the favorable locations i.e. those of highest wind speed, which tend to be found in coastal areas of Europe. The second problem is the accommodation of large percentages of wind generation capacity in current and future electricity grids. For instance, in Scotland and in Northern Germany, where there is a large wind potential, the installed capacity of nuclear power is already higher than 60%. Hence large amounts of additional production from wind power would have to be exported to other regions.

It has been established that sufficient sites are available in Europe to meet, if necessary, all the electricity consumption in the European Community. However, many sites are ruled out for environmental reasons; hence offshore sites are being envisaged, particularly in Denmark and Sweden. The investment costs could be at least twice as high as for onshore systems and thus the difference could only partly be offset by the higher wind speeds over the open sea.

A preliminary investigation of the implementation aspects of wind energy in the European Community, which was carried out by the Commission of the European Communities, confirms that generally, a 15% contribution of wind power to total electricity consumption in the European Community could be accepted by the current networks and produced at the available onshore sites.

Photovoltaics

The commitment of European industry to photovoltaics in Europe has recently been strongly increased. Nevertheless, European markets currently in the 10 MW per year range are still very modest. At present costs of more than $8 per watt, there are only some market niches such as telecommunication systems, power for remote houses, for islands and for special applications in developing countries, e.g. water pumping. The EC Commission is actively involved in these activities and has earmarked special programmes for R&D, demonstration, and market introduction. Moreover, a special project for more than 1200 photovoltaic water pumps in the Sahel countries is currently being decided by the Commission and will be implemented within the next 4 years.

The market for individual houses is particularly important from the social standpoint. Thousands of remote houses in Italy and Spain have recently been electrified by installing photovoltaic power systems. But also market introduction for grid-connected houses through public subsidies is currently being considered for some cities in Germany (Berlin, Hamburg, Saarbrücken). In this country, in addition to a Federal subsidy of 60% of the cost, financial support by local governments and utilities is being discussed.

The development of central photovoltaic power plants for Europe's electricity networks is being actively pursued. Power plants in the 300 to 3000 kW range are currently being built in Italy and Germany by the utilities ENEL, RWE and Bayernwerk.

It is important to note that, contrary to the long-term trend towards decreasing cost, in the very short term the cost of photovoltaic modules is likely to rise,because there is a shortage of supply in the market. Within a few years from now however, probably by 1995, crystalline silicon solar modules could become available at $1.70 per peak watt from European manufacturers as against $5 today, according to estimates of the French industry. At that price, the market would no doubt increase manyfold.

Table 6 gives an overview of kWh costs now and in 1995 for three countries in the European Community, including local availability of solar radiation (Palz and Schmid 1990). Further ahead, the French industry estimates that with crystalline silicon solar modules, a kWh price of 9 cents could be achieved by the year 2010. Industry in Germany projects a price of $1.20 per peak watt for crystalline silicon only for mass production in the GW-range.

Besides crystalline silicon, thin film solar cells and especially amorphous silicon still attract interest in Europe. However, thin film solar cells are virtually inexistant in Europe's power market. The reason is probably not so much the problem of degradation in time which has not yet been overcome, but rather the fact that the manufacturers missed the opportunity price level because they were not able to offer thin film modules at a lower price than crystalline silicon modules. In the long term, however, thin film solar cells remain interesting because they offer prospects to achieve ultimately a lower cost than with crystalline silicon and in particular considerably less than $1 per peak watt at which price crystalline silicon seems to level off.

Taking a wider view well into the next century, there are especially in Germany proponents of the development of the solar hydrogen economy whereby large solar plants would be established in Northern Africa and the energy transmitted to Central Europe directly in the form of electricity or hydrogen. There is however no development effort at present on these schemes.

Tidal and Wave Power

In Europe, a 240 MW tidal scheme currently operates at La Rance in France although particular interest in the expansion of this form of generation is focused in the United Kingdom.

Much attention has been focused on a single project across the River Severn, the most favored scheme being on a line from Cardiff to Weston-Super-Mare with a rating of some 7.2 GW and alone able to produce about 5% of the UK's electricity. The project has some environmental implications and latest cost estimates are at about $13,000 million making it one of the largest civil engineering projects ever undertaken. A consortium, the Severn Tidal Power Group, is pursuing feasibility studies, with some UK Department of Energy funding although the UK Government sees the construction of the project itself as lying within the private sector.

Apart from this one major project, studies have identified many smaller potential sites around the UK. If every reasonably practicable estuary in the UK were to be employed for tidal power, the yield would be about 53 TWh per year representing about 20% of present electricity demand in England and Wales. About nine tenths of this potential is in 8 very large estuaries, with the remainder in 34 small estuaries. It is considered that the tidal range in Scottish estuaries is too low for there to be any economic potential.

The issue of project funding is important because the cost of generated electricity is dependent on the cost of money, particularly for renewable generating technologies where most of the expenditure is "up-front" capital cost. At a 5% discount rate (currently used in the UK for public sector funds) the Severn, Mersey and 2 or 3 smaller sites could generate at $0.058-0.073 per kWh and could contribute 20 TWh/year (about 7% of UK electricity demand). With construction in the private sector, and capital discounted at say 10% per year, the cost of electricity nearly doubles and ceases to be attractive when compared with coal.

With regard to wave power, several European countries with Atlantic facing coasts have investigated the potential. Again the United Kingdom has been to the fore - with a R&D programme which has produced over 600 reports. Attention was initially focused on large scale devices moored several kilometers offshore. However, on further investigation, such devices appeared to have little chance of being able to compete economically with conventional sources and attention was switched to smaller scale units constructed at the sea shore. Other European countries are also investigating "onshore" wave power.

Outlook

In the chemical industry and for electric power production and transport, biomass will have an important role to play. Even if biomass production in Europe were limited to the 20 million ha of farm land which have to be taken out of production by the end of this century, approximately 20% of all the energy consumed in the Community could be supplied from biofuels.

Next to biomass, wind and photovoltaics are potential resources for the electricity market. Some electricity will also be derived from wave and tidal power.

Ultimately, the next century should see a reasonable mix between biomass, wind, photovoltaics and power from the sea together with the conventional energies among which natural gas is going to play an increasing role because the gas fields are easily accessible to Europe and natural gas is the least polluting of the fossil energies.

An attractive sector is energy consumed in buildings since it represents an important single item in Europe's energy budget. The application of solar technology in this sector will make it possible to gain up to 50% of Europe's current energy requirements for buildings from solar.

Based on an important home market, European industry will be able to cooperate efficiently with the developing countries, because its renewable energy products will fit particularly well with their needs.

Conclusions

Renewable energies will experience an important development in the next century. Technical and economic analysis shows that many of the renewable energies are going to become cost-competitive with the conventional energies in purely economic terms, and even more so if external costs are taken into account.

From a social and political standpoint, it is important to anticipate the wide market introduction of this emerging energy source in its various forms. Public support for R&D and market introduction is essential to achieve this goal.

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Environmental Ethics	RE are "pollution free" and produce no CO_2
Geopolitical constraints * Security of supply * North-South Dialogue	 RE are a Domestic Resource RE fit the needs of dev.countries
Social	RE can support rural development RE stimulate industrial innovat. RE increase quality of life in buildings

Table 1. Rationale for Renewable Energies (RE)

Aeritalia (I)	Wind
BP (GB)	Photovoltaics
Daimler Benz (D)	Photovoltaics
ENEL (I)	Biomass, Photovoltaics, Wind
Ferruzzi (I)	Biomass
RWE (D)	Photovoltaics
Siemens (D)	Photovoltaics
TOTAL (F)	Photovoltaics
Union Fenosa (E)	Biomass, Wind, Photovoltaics
Veba (D)	Biomass

Table 2. Selection of large industry groups involved in RE in Europe

Crop	Utilization
Forestry	Combustion
Wheat	Bioethanol

Table 3. Conventional crops for biomass production in Europe

Wind Speed at 30m height ms^{-1}	Total Generation Cost $ per kWh
5.5	0.155
6.5	0.108
7.5	0.078
8.5	0.060

Assumptions : Lifetime 15 years
Cash Discount Rate 10%
Annual O&M costs 2% of capital cost
Availability 95%
Array efficiency 90%

Table 4. Electricity production cost for commercial wind machines

	Commerc. Vestas	3-bladed EC-R&D turbines WEGA Program			2-bladed EC-Demo turbines			1-bladed turbines
	25m Ø	ELSAM Esbjerg DK	HOWDEN Richbor UK	UN.FENOSA Cabo Vill E	GAMMA 60 Alta Nurra I	NEWEC 45 Wieringer NL	HMZ 1MW Zeebrugge B	MONOPTEROS 50 Wilhelmshaven D
Rotor diam. (m)	25.0	60.0	55.0	60.0	60.0	45.0	45.0	56.0
Year of completion		1988	1989	1989	1990	1985	1990	1989
Total towerhead weight (tonne)	10.3	224.4	83.4	183.5	95.0	73.0	98.0	61.2
Tower head & tower weight (including internal systems, excluding found.)	21.3	887.4	178.0	275.5	245.1	153.0	193.0	146.2
Swept area (sq.m)	491.0	2827.0	2375.0	2827.0	2827.0	1590.0	1590.0	2463.0
kg/sq.m (*)	21.0	78.7	35.1	64.9	33.6	45.9	61.6	24.8
Rated power (kW)	200.0	2000.0	1000.0	1200.0	1500.0	1000.0	1000.0	640.0
kg/kW (*)	51.5	111.2	83.4	152.9	63.3	73.0	98.0	95.6
El.gen (kWh/m^2/y)	1000-1340	1380.0	910.0	1110.0	1075.0	1380.0	880.0	860.0
kg/kWh/year (*)	0.015-0.021	0.057	0.039	0.057	0.031	0.033	0.043	0.029
	(1)	(0.057)	(0.033)	(0.062)	(0.026)	(0.033)	(0.075)	(0.027)
		(2)	(2)	(2)	(2)	(2)	(2)	(2)

(*) ref. to tower head mass

(1) Typical range based on reported experience

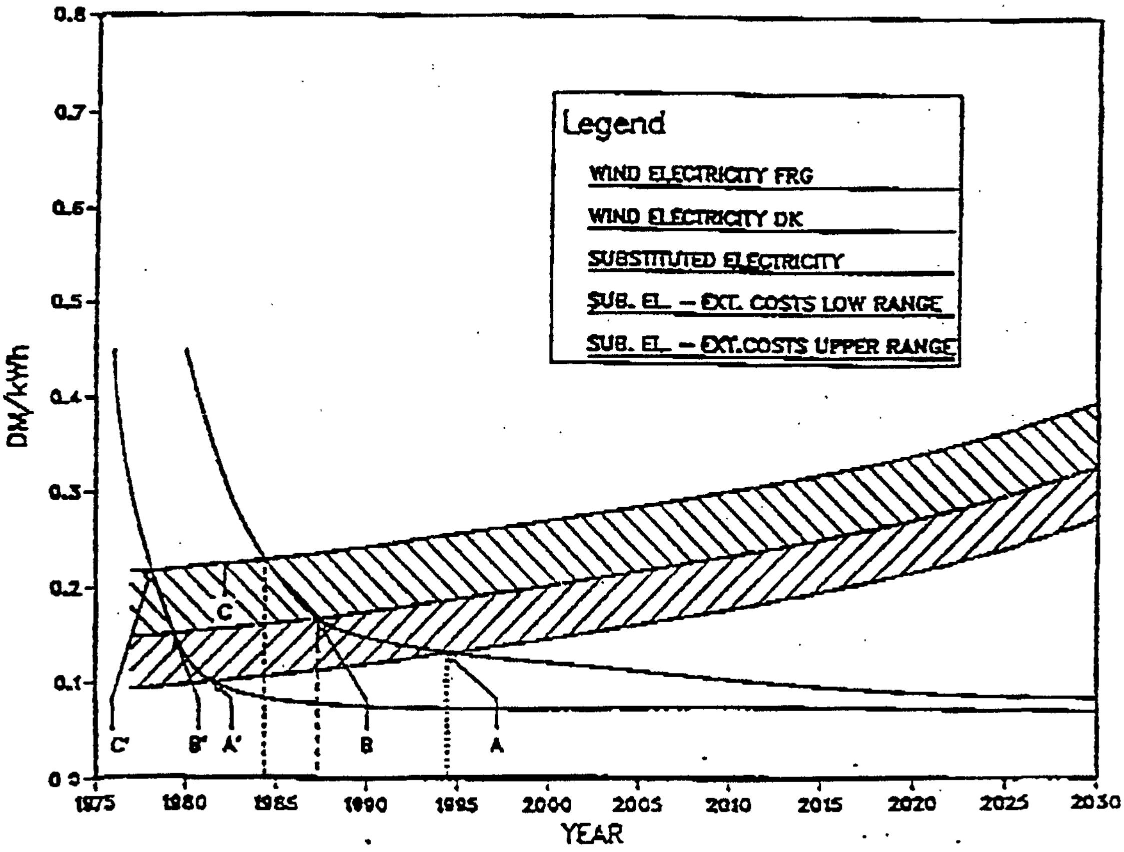
(2) Data given as - values predicted for actual site (corrected to a site of annual mean wind speed = 7.7m/s at 60 m height). Assumed availability 95%.

Table 5. Specific weight of new wind turbines in the EC.

FR Germany	
Annual Irradiation	1100-1400 kWhm^{-2}
Cost/kWh 1990	56 - 45 ¢
Cost/kWh 1995	21 - 15 ¢
France	
Annual Irradiation	1100-1900 kWhm^{-2}
Cost/kWh 1990	56 - 34 ¢
Cost/kWh 1995	21 - 12 ¢
Italy	
Annual Irradiation	1300 - 1900 kWhm^{-2}
Cost/kWh 1990	48 - 34 ¢
Cost/kWh 1995	17 - 12 ¢

Table 6. Electricity costs from small grid-connected PV systems

Fig. 1 : The influence of external effects on the cost of electricity in the FR Germany generated by wind energy systems compared with costs for substituted electricity.



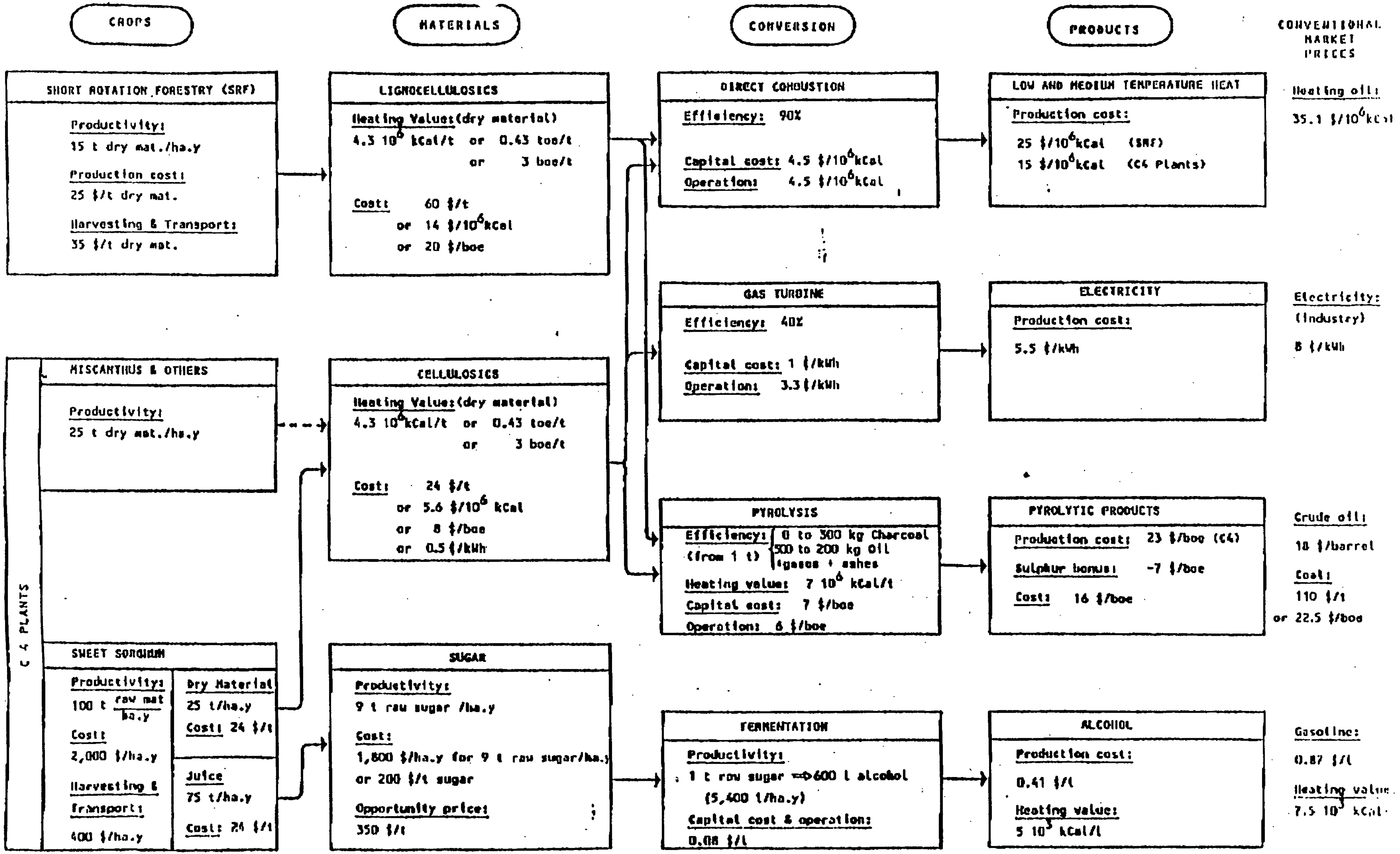


Fig. 2 : New biomass crop schemes for the future

Fig. 3 : 1 MW - wind turbine at Richborough (England)

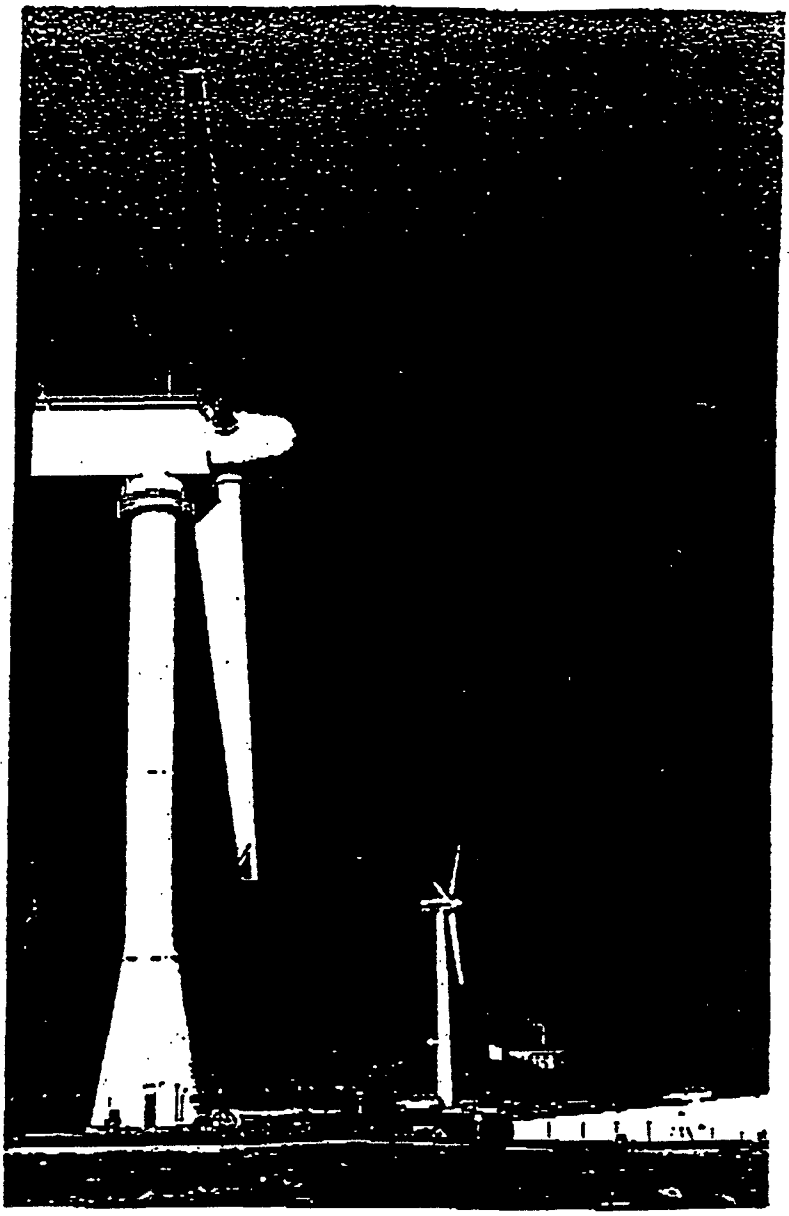


Fig. 4 : 1.2 MW - wind turbine at Cabo Villano (Galicia, Spain)
In the background a commercial 200 kW machine