Renewable Energy in Europe

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I. Introduction

There are different, partly complementary reasons to foster the growth of renewable energy sources (RES) in Europe. Reducing the environmental impact of energy supply on the local (e.g. emissions of pollutants) and the global level (reduction of green house gases) has been a major incentive for RES policies in the last two decades. In some countries, concerns about the safety of nuclear power generation has motivated the search for RES as an alternative. Considering Europe's growing dependency on foreign energy sources, the security of energy supply by replacing foreign fossil and nuclear fuels by domestic RES is another motivation gaining more and more attention In 1999, half of EU-15's energy demand was covered by imported energy and this share is expected to increase to 70 % within the next two to three decades. Social and economic benefits of RES like creating new industries with good export prospects, positive structural effects on regional economies or job creation are further areas of motivation to support RES. The characteristics of RES lead to public benefits in all of these areas.

Additionally, the growing integration of Europe is influencing the importance and the future development of RES. At the moment national goals and political measures still determine substantially the actual growth of RES. But besides national targets for the extension of RES, the EU–parliament and the EU–commission also have defined precise yet indicative targets for the contribution of RES in 2010. The existing European long-term energy scenarios up to 2030/2050 also deal with RES and show in part significantly high shares of RES in future energy systems. In addition, the EU affects the national RES promotion conditions of RES within the given legal framework. The commission is anxious to harmonize the national promotion instruments which currently vary greatly. A further fact is that the markets of the different RES-technologies establish themselves increasingly European-wide. This holds particularly for the dynamically growing wind power industry. Therefore it is foreseeable that a uniform strategy will be developed within this decade for the further promotion and the implementation of mid and long-term goals of RES-technologies in Europe. This process is presently supported by the growing awareness to increase the growth of RES worldwide, which was an essential point on the agenda of the Johannesburg World Summit for Sustainable Development. In summary there is a growing number of indications that Western Europe will strengthen its position as the worlds leading region in utilization and commercialization of RES in the next years.

II. The present use of renewable energy sources in Europe

a) Use by energy sources

In Europe, modern RES technologies have been explored thoroughly for the first time after the oil price crisis of 1973. Notably market introduction started about 1985, but only during the last decade it developed a remarkable vitality. Accordingly, the systematic statistical compilation of relevant RES data did not start before that time. Presently there exist reliable

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and harmonized statistical data for all countries of the European Union (EU - 15) and for Western Europe (EU – 15 including Switzerland, Norway and Iceland), beginning in 1989. Earlier data are fragmentary and less reliable because of inconsistent acquisition in the different European countries. Regarding the energy sources most data are available up to 2001, the country specific data are compiled up to 1999/2000. Only few RES data sources are available from eastern European countries; but their RES-contribution today is still very small.

The present utilization of RES in Europe - as well as in the other continents – is dominated by hydropower and the traditional use of firewood for heating purposes. Both energy sources were the main basis of human energy supply before industrialization. But even after fossil and nuclear energies emerged, both retained a certain importance. In 1970 hydropower met 30 % of the European electricity demand, which was a noticeably higher fraction than in 2000 with 17 %. Because of the already high exploitation today, the contribution of these two energy sources cannot be increased considerably in the future. The primary energy production of RES in Europe is rising continuously since 1990 (**Fig. 1**; data for EU-15). Within the last decade it increased by 40 %, accounting for 6,4 % of total primary energy production in 2001. The current RES production of 3 850 PJ/yr is provided mainly by biomass with 62 % and by hydropower with 31 %. Geothermal energy with 4 % and wind energy with 3 % follow by far distance. The useable final energy from RES amounts to 3 350 PJ/yr corresponding to 8,5 % of the total final energy consumption of EU-15. Vehicle fuels with only 30 PJ/yr are negligible yet, useful RES heat with 1 880 PJ/yr meets 9,5 % of total heat demand and RES electricity with 1 460 PJ/yr (resp. 406 TWh/a) 15 % of total electricity generation (**Fig. 2**). About 80 % of this electricity comes from hydropower. The use of biomass (10 %) is predominantly in the form of wood fed power plants (60 %), although biogas and sewage gas (10 %) and municipal waste (30 %) also contribute significantly. The contribution of wind energy has grown considerably to 6,6 %, while geothermal energy covers 1,2 %; solar electricity is yet insignificant with presently 0,1 %. Highly visible is the dominance of biomass in heat production. Individual firewood heating contributes about 60%, another 20 % comes from wood and waste fired district heating systems, industrial wood firing provides 18 % and biogas contributes 2 %. Solar and geothermal energy contribute only small amounts each with a percentage of 1 %

b) Use by countries

RES contributes very differently to energy supply in the individual energy consumption of the EU Member States (**Fig. 3 and 4**). This is not astonishing, because the actual RES share is determined by a number of different parameters::

- the country-specific potentials of the different RES,
- the existence of other cheap and abundant domestic energy resources (e.g. coal, natural gas)
- structural boundary conditions like population density, structure of settlements, ratio of rural to urban areas, extension of electricity grids and district heating networks
- economical conditions like national energy prices and taxes
- level of economic wealth and of energy consumption
- conditions of energy policy like promoting instruments for RES, targets of national energy policy.

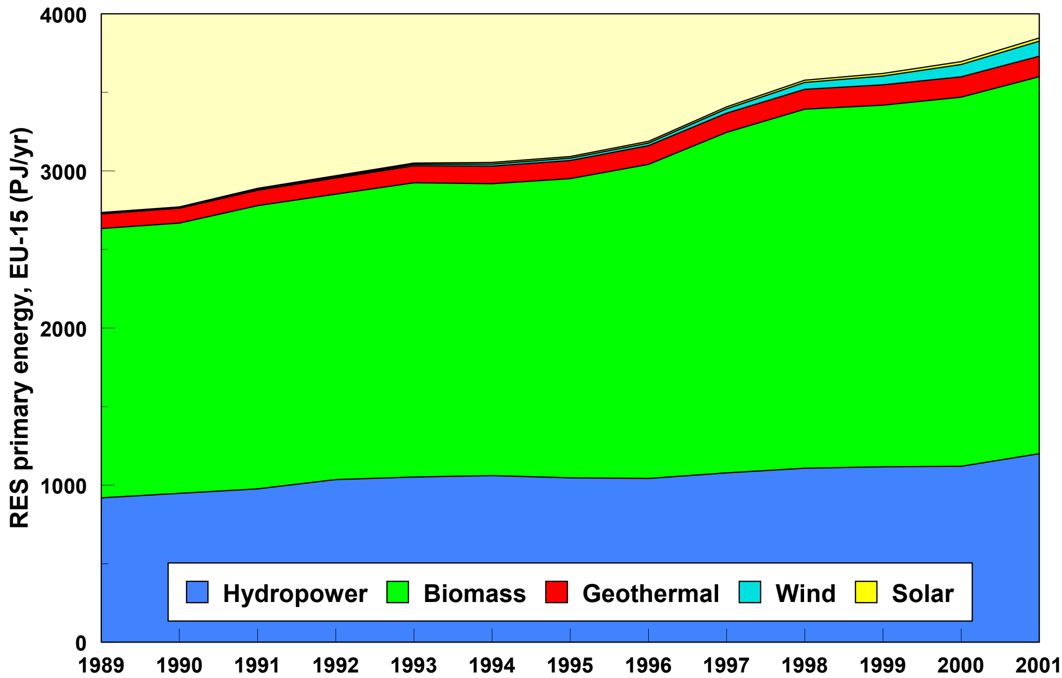

Figure 1: Development of RES primary energy production by energy sources since 1989 in the member countries of the European Union (EU-15)

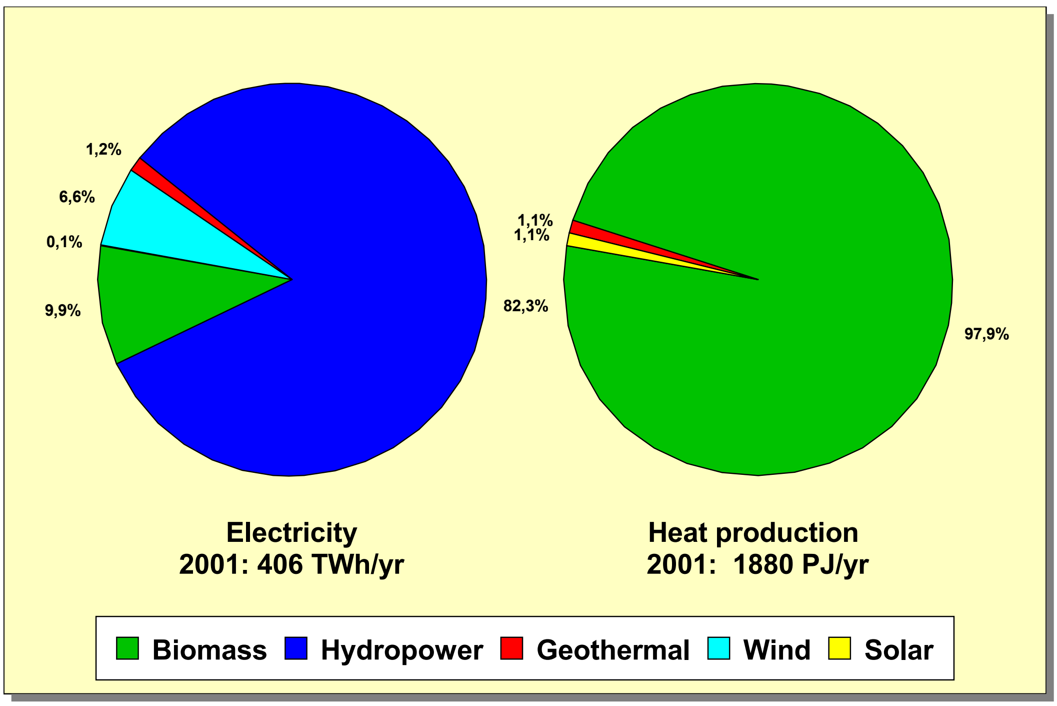

Figure 2: Contribution of energy sources to final energy production from RES (electricity left, heat right) in EU-15 for the year 2001.

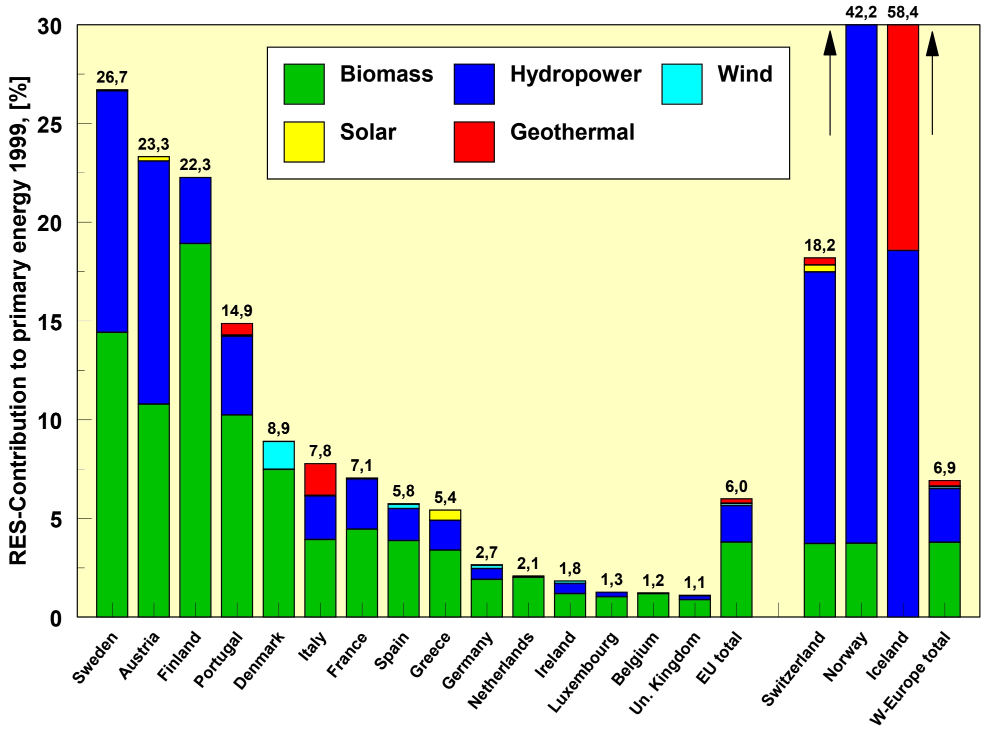

Figure 3: Contribution of RES to primary energy consumption of the EU member countries and Switzerland, Norway, Iceland in 1999.

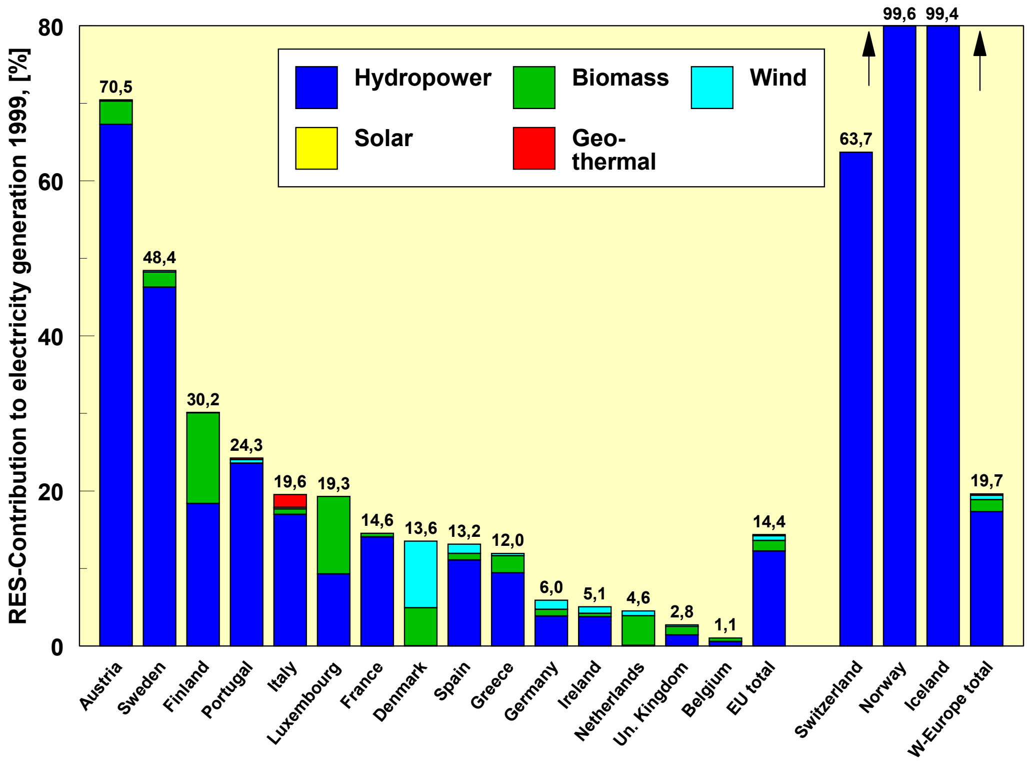

Figure 4: Contribution of RES to electricity generation of the EU member countries and Switzerland, Norway, Iceland in 1999.

Countries with large land areas, correspondingly low population density and at the same time abundant hydropower have a relatively high contribution of RES. This applies to Sweden, Finland and Austria with more than 20 % share in primary energy consumption and electricity generation. In densely populated countries RES account for less than 10 % contribution, down to 2,7 % in Germany, 2,1 % in the Netherlands and only 1,1 % in the United Kingdom. On the other hand there are strong disparities among countries with similar RES- potentials and comparable infrastructure. The example of Denmark with 9 % RES on primary energy consumption and 14 % RES on electricity generation shows the importance of well-defined political targets and ambitious promotion measures. This affects mainly the development of the “new” RES technologies (wind energy in Denmark). In contrast RES markets have made little progress in the United Kingdom.

The contribution of hydropower and geothermal energy increases considerably when Switzerland, Norway and Iceland are included, which are geographically, economically and culturally part of Western Europe (Fig. 3, 4 right side). Norway and Iceland provide about 50 % of their primary consumption and 100 % of their electricity by RES, Switzerland 18 % and 64% ,respectively. Thus RES accounted for 7 % of primary energy consumption and 20 % of electricity generation in 1999 in Western Europe. It may be 0.5 percentage points more in 2001. The five states with the highest amount of RES primary energy are France, Italy, Sweden, Norway and Germany with together 62 % of total RES primary energy production. The highest amount of RES electricity is generated in Norway, followed by France, Sweden, Italy and Austria; these five countries sum up to 68% of total RES electricity production.

c) Use by technologies

Especially the development of the “new” wind and solar technologies is of great importance for the future contribution of RES to energy supply. Although their present contribution of 0,4% to total primary energy consumption is still very small, their growth has been considerable in the last 6 to 8 years. Today they provide ten times the energy of 10 years ago. Wind energy shows the most remarkable growth dynamics, its contribution is now reaching energetically relevant dimensions **(Fig. 5)**. Since 1992 the average growth rate is 35 %/yr . At the end of 2001 the installed capacity in Western Europe reached 17 250 MW, about 70 % of the total global wind power. 1 % of the Western European electricity demand is generated in this way. With 8 750 MW, Germany alone accounts for 50 % of the installed capacity, Spain with 3 300 MW follows with rapidly increasing wind installations. It has surpassed the pioneering wind country Denmark where growth decreased strongly because of a recent change in energy policy priorities. Yet, with 9%, Denmark still has the highest share of wind power on total electricity generation.

Photovoltaics also showed similar high growth rates in the last eight years **(Fig. 6)**. But with an installed power of 300 MW in Western Europe (280 MW in EU-15), its contribution to electricity generation with 0,01 % is still negligible. Even more noticeable than in the case of wind energy the growth rate of photovoltaics is dominated by the development in Germany, which accounts for 60 % of the total installed power in Europe. This fact is the result of the very favorable promotion conditions in the frame of the German Renewable Energy Resources Act and the additional “100 000 PV-installations” program. A considerable growth also occurred in the Netherlands, which have reached the power level of Italy with 20 MW. Nevertheless, related to population, Switzerland has the highest density of photovoltaic installations with 2 W/capita.

Solar thermal collectors showed a permanent increase in installed collector area too, but not as rapid as wind or photovoltaics. In Western Europe 12,8 Mill. m² (EU-15 = 11,9 Mill. m²) deliver actually 0,01% of the total heat demand **(Fig. 7)**. The areas of installed solar thermal collectors are surprisingly high in Germany, Austria and Switzerland where climatic conditions are far less favorable than in southern European countries. Favorable promotion conditions are the basic reason for that development. In addition higher ranking of nature conservation and protection of resources in policy and public opinion in these countries is responsible for this favorable development. This may also be the reason, that - besides Greece – the contribution of solar thermal collectors is currently very low in Southern European countries despite the high technical potential. Another reason is that in Greece solar collectors for water heating are cost competitive against electrical water heaters.

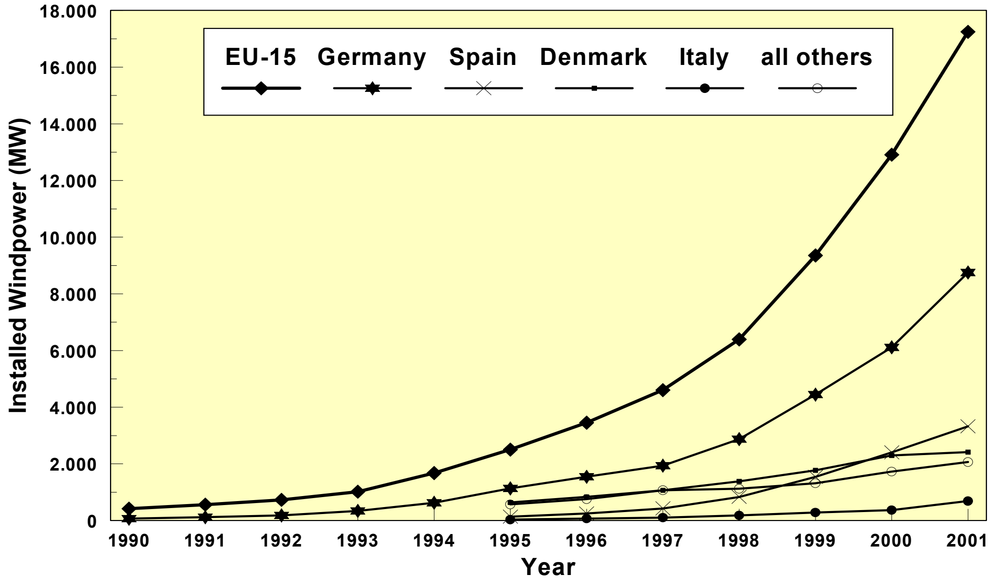

Figure 5: Growth of installed wind power in selected EU member countries and EU-15 from 1990 to 2001.

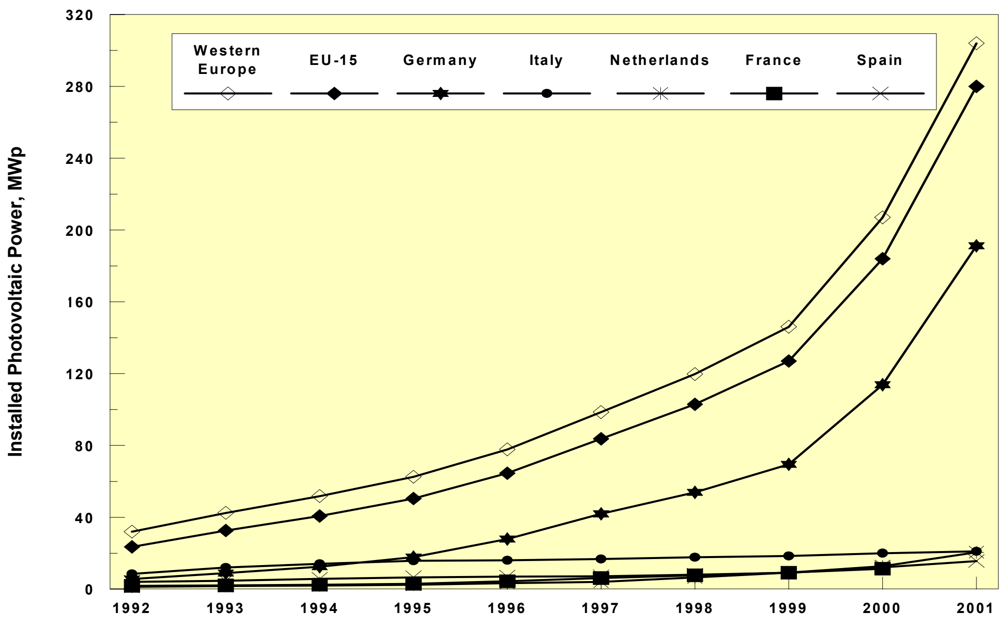

Figure 6: Growth of installed photovoltaic power in selected EU member countries, EU-15 and Western Europe.

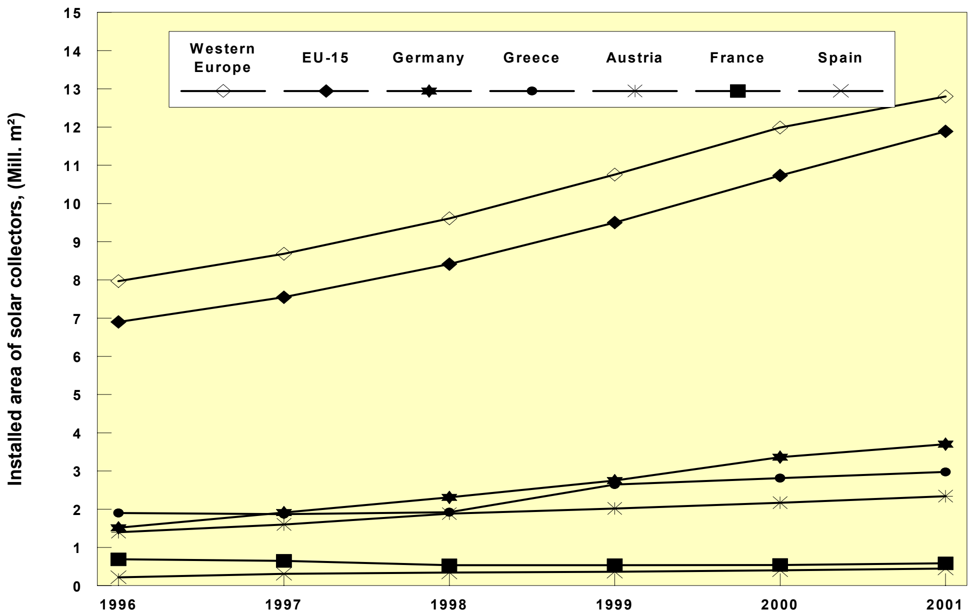

Figure 7: Growth of solar thermal collector area in selected EU member countries, EU-15 and Western Europe.

III. Policies to foster renewable energies in Europe

Setting definite targets in the form of a certain share of RES in total energy supply at a certain time provides an important guideline for a well-coordinated RES policy strategy. Thereby, certainty is signaled to investors hence allowing them to recover their initial investment. Attracting private investments is particularly crucial for RES since an accelerated deployment of RES will require considerable funds which will exceed public budgets. Different elements are needed to support deployment of RES. A comprehensive strategy with a set of different instruments rather than a single instrument are required to addressing the various users of different RES in a range of applications. Moreover, a RES policy needs not only to tackle sufficiently the cost gap between RES and conventional energy carriers, but should also address non-economic barriers and R&D needs. Overcoming the cost gap of RES to conventional energy sources is a central building block of any RES policy. For this purpose, energy or emission taxes on conventional energy carriers can be raised reflecting the external costs of such fuels. The costs of RES to the user can be reduced by providing grants, soft loans or tax benefits. The cost gap can also be overcome by creating a demand for RES through obliging certain entities like house-owners or electricity suppliers to apply RES (the latter is called renewable portfolio standard). The voluntary purchase of green electricity i.e. electricity from RES, although widely discussed has not met expectations in Europe so far and can only supplement but not substitute public support policies.

Establishing RES in the political and regulatory structures is a further important element for a successful RES policy. Over the past two centuries the present energy supply system and the political and regulatory framework conditions have evolved in a mutual adaptation process. The “late-comer” RES with their different characteristics like decentralized dispersed application is disadvantaged in many cases by the present framework conditions. A successful RES policy needs to address such non-economic barriers for RES. This includes a fair access to the electricity grid, adapted building permission procedures for wind power plants or consideration of solar thermal collectors in building codes. Workmen, tradesmen and engineers need to be educated comprehensively about RES technologies and their applications. Thus schools and universities need to incorporate RES subjects in their curricula. Last but not least there is an ongoing demand for R&D to exploit the cost reduction potential through technical progress.

Energy policy happens on different levels within the EU: Policy on the level of the European Union with its institutions European Parliament, European Commission and European Council is gaining more and more importance for the promotion of RES. On the one hand, the general framework conditions for European energy markets are very much targeted on creating a common market for energy with equal conditions for all market players across the EU. As an example, the EU directive: "Common Rules for the Internal Market in Electricity" has created a fairer access to the electricity grid for independent power producers with RES and green electricity suppliers. The European Community Guidelines on State Aid for Environmental protection allow member states to grant operating support to new RES power plants of up to 5 cent/kWh referring thereby to the amount of external costs of conventional fuelled power plants. At the same time, the European Union is also an active player to promote RES directly. In 1997 the White Paper on "Energy for the future - renewable sources of energy" was issued setting a target of doubling the share of RES on primary energy supply by 2010 and describing scenarios and policy strategies to reach this goal. As a follow-up a "Campaign to Take Off" has been launched in 1998. The EU's own financial means allocated to this campaign are rather limited with 74 million US-$ over 5 years compared to the total required investment of 20 billion US-$. However the campaign aimed to levy a multiple of this amount of national support means. The European Directive 'On the Promotion of Electricity produced from RES in the Internal Electricity Market' sets indicative targets to the EU member states regarding the share of RES for electricity production by 2010. Albeit the Directive failed to establish a common European instrument to foster RES for electricity generation it has created some momentum to establish support policies on the national level like recently in the UK and in Sweden. A political review of all national RES policies is scheduled for the end of 2005 creating a basis for a common European support instrument for electricity from RES.

National support mechanisms remain the most important means to foster the deployment of RES. To name only a few: National minimum price standards also referred to as fixed feed-in tariffs have in particular brought forward wind power in Denmark, Germany and Spain. Favorable conditions have been created for biomass fuelled districting heating in Sweden by high taxes on conventional energy carriers and a CO_2 tax refund. Soft loans and direct investment grants have caused the demand for solar collectors to sky-rook in Germany. Examples for regional and municipal RES policies are the solar ordinance in Barcelona requiring real estate developers to install solar water heaters and the green power purchase of some Dutch municipalities.

Generally, RES policies have been focused on the electricity sector rather than on transport or heating purposes mainly because there is a long tradition of state intervention in the electricity sector. Minimum price standards, bidding schemes and renewable portfolio standards, also referred to as RES quotas or green certificates have been the major way to support electricity generation from RES on the national level. Minimum price standards require the grid operator or the default electricity supplier to purchase electricity form RES generators at fixed premium prices. It should be noted that a minimum price standard does not only regulate the price but also grid access and power purchase. Within bidding schemes RES capacity is publicly tendered periodically and power purchase contracts are awarded to the winning bids. With renewable portfolio standards, electricity suppliers are obliged to cover a certain share of their electricity supply with RES. The engaged parties comply with the obligation by presenting tradable ‘green certificates’ certifying the generation of a certain amount of electricity. Thus these certificates have an economic value generating an extra income to RES-electricity producers.

Countries with minimum price standards (e.g. Germany since 1991, France since 2001, Spain since 2000, Denmark until 2000) have seen the largest growth of RES electricity. This particularly applies to wind power. At the same time, a viable RES manufacturing industry has been established in these countries. To organize political support and create local acceptance it has been proven successful to spread ownership among many, preferably local people. Even though it is not appropriate to attribute the success in RES deployment solely to a single policy instrument it becomes clear that a well-designed minimum price standard together with supplementing policies like simplified building permission procedures seems to be the most effective way to support the introduction of RES electricity. Nevertheless, a proper design of a specific support instrument is even more crucial than the type of instrument as indicated by experiences in different countries. There, RES electricity has grown only insignificantly due to insufficient levels of premium tariffs.

England and Wales introduced a bidding scheme called Non-Fossil-Fuel obligation in 1990. In five rounds between 1990 and 1998, developers of RES plants could bid in different technology slots (e.g. wind power, waste to power, hydro power). The winners with the lowest bided generation costs were awarded with a 15 year power purchase agreement. The bid prices sank between 45 % (hydro power) and 70 % (wind power) between the first and the last round. Yet, due to different conditions in the bidding procedure and the awarded power purchase agreements as well, the bids are not directly comparable to each other. More over, up to now (October 2002) no large wind project of the last bid round in 1998 has been commissioned at the low average bid price of 4,5 cent/kWh. Supposably, these bided prices are economically not feasible. While the UK has the largest wind power potential in Europe, the NFFO failed to foster wind and other RES electricity in the expected way due to inherent weaknesses of the NFFO itself but also due to a lack of appropriate building permission procedures. It was therefore abandoned.

Renewable portfolio standards have recently been discussed widely and have been introduced in Austria, Belgium, Italy, Sweden and the United Kingdom. While such mechanisms are promising in theory, practical experience has been limited and rather mixed in Europe. Larger providers are more ready to take the risk of selling electricity and certificates under uncertain conditions than small generators. Instead of a wide range of different RES technologies only the most cost effective technology will be supported at a given time. Long-term contracts rather than spot markets will govern transactions between RES providers and the obliged parties, thus undermining competition. The different design of the national renewable portfolio standards hinder rather than enable the free trade of certificates between different countries.

Increasing prices for conventional fuels have been an effective method to deploy biomass and other RES in the heating sector in Northern Europe. The widespread district heating grids support the application of RES in these countries. Solar collectors have been successfully promoted in household applications by tax benefits and direct investment grants. Building regulations allowing only a certain maximum fossil based heat demand for new building are another effective way. Austria has been extremely successful in deploying solar collectors via grass-rooted do-it-yourself construction groups. In some countries, the RES use in the transportation sector is supported by exempting car fuels based on biomass from tax. For instance this has led to a sudden growth of demand in Germany since 2001.

An overview of promotional systems for RES in EU-15 is given in **Table 1**. It is apparent that most countries are using either the feed-in tariff model (respectively minimum price standards) or the certificate trading model (respectively the quota model). Bidding schemes, originally introduced in UK, are used in Ireland only. The feed-in model turned out to be the most successful instrument in terms of installed RES-capacity, but an increasing number of countries are considering the certificate trading model as the future winner. Possibly a mixture of both will be used in the future because “green” certificates also can be combined with feed-in models.

Table 1: Overview of promotional systems for RES in the countries of EU-15 by 2002

	AU	BE	DK	FI	FR	GE	GR	IR	IT	LU	NL	PO	SP	SW	UK
FIT	X		(X)		X	X	X			X		X	X		
BID								X							
SUB			(X)	X		(X)	(X)	(X)		(X)	X			(X)	
CTM	(X)	X	Xp						X		(X)			Xp	X

FIT = Feed-in tariffs; BID = Bidding System; SUB = Subsidies, Tax reliefs; CTM = Certificate trading model; X = Main instrument; (X) = Additional instrument or combination with main instrument; p = proposed.

IV. Potentials, costs and environmental characteristics of representative technologies

a) Technical potentials

The ambient energy flows in terms of radiation, wind and water flows, annual increase of biomass and geothermal flows have to be transformed in useable forms of energy like electricity, process heat or fuels by means of technical installations in order to provide benefits for men. Determining these “technical” potentials, a great number of physical, technical and structural restrictions have to be considered to assure that the calculated figures are meaningful enough. In order to achieve a realistic picture of the possible fields of application in energy supply, it is necessary to add further boundary conditions, mainly economically and ecologically ones, for the practical use of RES. In view of the huge amounts of the ambient energy flows – e.g. the solar radiation reaching the earth’s surface within three hours corresponds physically to the total annual global energy consumption – it is sufficient to produce energy carriers only in per mill shares, in maximum percent shares, from the ambient energy flows to meet mankind’s future energy demand.

Numerous investigations available on RES potentials today provide a detailed and sophisticated insight in extent and structure of the technical potentials of RES. **Table 2** presents these figures for Western Europe. The values are explicitly down sized according to specifications of infrastructure and ecological restrictions. The comments in the table point out the most important assumptions in this respect. It can be assumed therefore that these potentials can be tapped completely and that they are socially accepted. The figures in table 1 exceed the present electricity generation of Western Europe twice and are able to meet 75 % of the present heat demand. Altogether 62 % of the present primary energy consumption could be met by these proven technical potentials of RES. Today they are exploited very unequally. The hydropower potential is exploited already to a large extent, if the construction of new plants on non-regulated rivers is excluded. Also, the use of biomass residues takes place already to a large extent. All other RES potentials are only exploited to a very small degree so far. Altogether it can be shown, that with the proven technical RES potential alone, ten times the present amount of energy can be provided from RES in Western Europe.

Table 2: Assured technical potentials of renewable energy sources in Western Europe

Renewable Sources	Electricity generation TWh/yr	Heat production PJ/yr	Primary energy PJ/yr	Used in 2001 %	Remarks
Hydropower	640		2 270	79	New plants only on regulated rivers; contains reactivation and modernization of existing plants
Wind energy	1 580		5 680	1,8	Restricted potentials onshore 630 TWh/yr., offshore 950 TWh/yr. considering acceptance as high and ecological interaction as low as possible
Photovoltaics	585		2 105	0,03	2 300 km² module area assumed = 25% of suitable roofs and 100% of suitable facades (1000 km²)
Biomass residues	185	2 350	3 350	52	Residues from forestry, agriculture and organic fraction of municipal waste; for energy plantations present excess agricultural area in EU-15 (9 Mill. ha) assumed; 50% use in cogeneration plants, 50% direct heat production, no fuel production assumed
Energy crops and short rotation forestry	85	1 050	1 500		
Thermal collectors		6 570	7 300	0,2	4 000 km² collector area assumed = 75% of suitable roofs; contains also large collector fields with seasonal heat storage
Geothermal energy	350	5 000	9 155	1,4	only known resources (lowest value of a variety of estimates)
Solar thermal power plants	2 000		7 200	0	suitable sites for 100-200 MW solar thermal power plants in Southern Europe (Spain, Italy, Greece, including Mediterranean islands)
Total RES-potential	**5 415**	**14 970**	**38 560**	**12**	
Consumption 2001	2 800	20 000	62 500		
Share of RES-potential (%)	**193**	**75**	**62**		

In the long-term far more energy carriers from RES can be made accessible, if all RES technologies are established in the energy market to a certain extent. Some examples from Western Europe's point of view are:

- a extended application of offshore wind converters at the European coasts with an additional electricity generation potential of about 2 000 TWh/yr;
- cultivation of energy plants on additional excess agricultural areas in connection with the planned enlargement of the EU to Eastern European countries, with an additional 30 mill. ha, i.e. 3 500 PJ/yr primary energy equivalent;

- exploitation of further geothermal resources with an additional electricity generation up to 1 700 TWh/yr;
- import of electricity from solar thermal power plants in North Africa to Western European countries by means of an Euro-Mediterranean electricity grid, which allows in principle the additional mobilization of some 10 000 TWh/yr of electricity.

It is obvious that these additional RES potentials are available mainly as electricity. There is no sense in exploiting further potentials of RES heat, because heat supply at low temperature (up to 150 °C) has to be adjusted to the demand for space heating, warm water and low temperature process heat. In contrast, surplus RES electricity can be transformed to hydrogen by electrolysis, which can be used as a fuel for transportation as well as for high temperature process heat in industry. The above-mentioned additional technical RES potentials add up to more than 80 000 PJ/yr of primary energy. Thus, even a further growing energy demand in Western Europe can be met in principle in the long term solely by RES.

Concentrating solar thermal power plants (CSP) – a representative for new innovative RES technologies with large potentials.

CSP are able to supply very large amounts of electricity and process heat in the earth's sun belt. Like any conventional power plant, their integration into the grid does not require any new measures for backup capacities. On the contrary, they allow for a smooth transition from today's fossil based power technology to a future energy economy based essentially on renewables. The history of the "Solar Electricity Generating Systems (SEGS)" in California shows impressive results. Steam cycle plants with up to 80 MW capacity using parabolic trough collectors have been in commercial operation for more than fifteen years. Nine plants with a total of 354 MW of installed power are feeding the Californian electric grid with 800 GWh/yr. The plants have proven a maximum efficiency of 21% for the conversion of direct solar radiation into grid electricity. Considerable cost reductions have been achieved up to now, with electricity costs ranging today between 10 and 15 ct/kWh in solar only mode. Advanced technologies, mass production, economies of scale and improved operation will allow to reduce the solar electricity costs to a competitive level within the next 10 to 15 years or as soon as a world wide capacity of 5 000 MW is achieved. Hybrid solar and fossil fuel plants, making use of special financial schemes, can already today deliver competitively priced electricity today at favorable sites,

In sunbelt countries, CSP is able to reduce the consumption of fossil energy resources and the need for energy imports. The power supply will be diversified with a resource that is accessible by many countries. Moreover process heat from combined generation can be used for seawater desalination and help to address the challenge of a growing water scarcity in many arid regions. In the medium term large electricity grids such as a Euro-Mediterranean Power Pool via High Voltage Direct Current Transmission will allow for an intercontinental transport of RES-electricity **(Fig. 8)** thus interconnecting sites with large renewable electricity resources in Europe (wind, hydro, geothermal) and North Africa (solar) . This concept could be of outstanding importance for Europeans' energy future, because it can help to stabilize the political and economic relations between the countries of an enlarging European Union as well as between the EU and the North African countries. Furthermore it can help contributing to a considerable reduction of the growing dependence on Middle East oil and gas resources. As a main result CSP, in combination with other powerful RES-technologies, will effectively reduce the risk of conflicts related to energy and water scarcity and to climate change.

b) Cost of RES-technologies

In order to evaluate the chances of a significant commercial RES utilization in the medium term, the costs of energy production respectively the cost difference to conventional energy supply, are of outstanding importance. This defines which fraction of the technical potentials are economically exploitable under the existing circumstances, and which measures are required to achieve cost competitiveness in a given time frame. It can be assumed, that the cost differences between RES and conventional energies decrease continuously because of further technical development and growing production rates of RES technologies, and due to an increase in prices of conventional energy carriers in the medium term. Thus a growing share of the technical potentials can be exploited economically and the "economic" RES-potential converges to the assured technical potential. By promoting investments in RES for a certain time or influencing the price of energy by taxes or comparable instruments, this process can be accelerated. If future shortage of oil and natural gas or CO_2-separation from

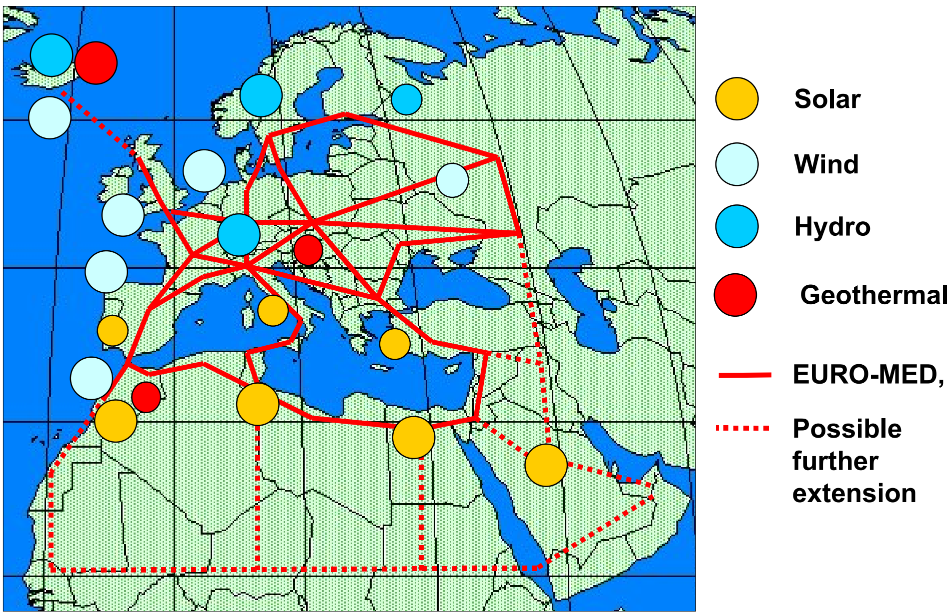

Figure 8: Planned extension of European high voltage electricity grids to an European – Mediterranean Pool (EURO-MED) and possible future extension in order to use RES widely.

coal will substantially raise energy price levels, RES energy carriers can achieve even lower prices than energy from fossil sources.

A survey of energy generation costs of typical RES technologies useable in Western European countries which represent the present status and the probably achievable cost reductions in the future shows a very large spread **(Fig. 9, 10)**. This results from the great variety of energy sources and their regional differences, the broad spectrum of conversion technologies, the very large range of capacity from about 1 kW to some 100 MW as well as different prices for biofuels and for credits in the case of cogeneration plants.

Excluding photovoltaics, whose actual costs are typically 70 cent/kWh in Central Europe and 40 cent/kWh in Southern Europe, the representative cost of RES under Western European conditions reach from 2,5 to 15 cent/kWh (Fig. 9). Only few RES-technologies generate competitive electricity today, e.g. older depreciated hydro power plants or cogeneration plants using cheap biomass residues. For that reason the potentials of these sources are already exploited widely. A large fraction of RES technologies offer electricity in the range of 7 to 8 cent/kWh, among others wind in coastal regions, hybrid solar thermal power plants, biogas and biomass gasification plants in cogeneration mode. Hence, they require further financial subsidies for a certain time. If market growth of RES takes place on a large scale, the electricity generation costs of most RES-technologies will decline to 4 to 5 cent/kWh. At this time new fossil power plants may have arrived the same cost range because of increasing fuel prizes or – in the case of coal – because of costly measures for CO_2-separation. Under these conditions the largest part of technical RES potentials could be exploited economically. Solely photovoltaics with then 13 cent/kWh (Southern Europe) and 20 cent/kWh (Central Europe) will still be too expensive to be used to a large extent in the general electricity supply. The cost situation of biomass technologies will strongly depend on the prize of the available biomass. Cost reductions by means of technological development or mass production will be small, because of growing emission standards. If energy plants will be used to a larger extent, the cost level of electricity will not decline below a level of about 7 to 8 cent/kWh. Therefore it is proposed to use them preferably for the production of transportation fuels, although they are more expensive than gasoline or diesel in the foreseeable future. Because of relatively high taxes on fossil fuel in Western Europe, biofuels with production costs of about 2,5 to 3 cent/MJ are competitive, if they are not taxed themselves. This approach is pursued in Germany since 2001 and has resulted in a substantial increase in sales.

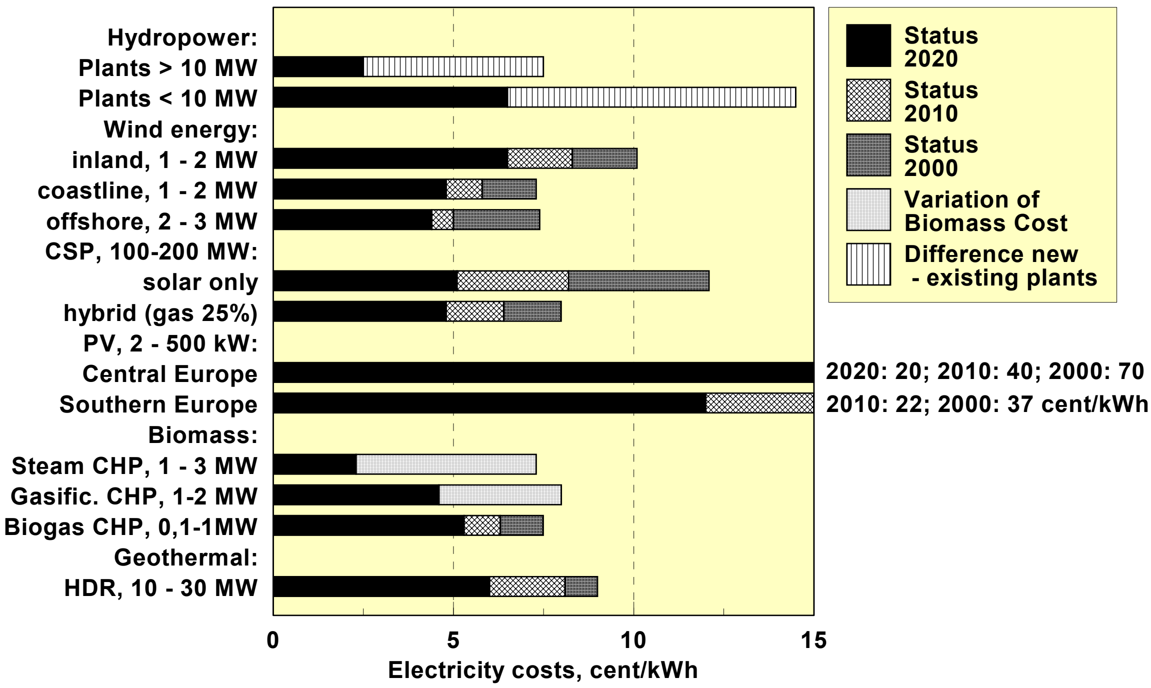

Figure 9: Survey of current electricity generation costs of representative RES-technologies (total length of bars) and possible cost reduction until 2010 and 2020, (CSP = concentrating solar power; CHP = combined heat power; HDR = hot dry rock)

Costs of RES technologies for heat production can be assessed similarly. RES can provided heat with stand alone systems (e.g. wood fired boilers, small solar thermal collectors) and by means of district heating networks. The latter ones are of outstanding importance for RES to achieve a break-through in the heat market. In most cases, only district heating allows the use of RES e.g. geothermal heat plants, large solar collector fields for space heating and biomass fired cogeneration plants. Costs of heat distribution in typical Western European settlements are in the range of 2 to 3 cent/kWh. Medium sized heating plants and large collector fields require lower specific investments than small boilers or small collectors. Therefore heating costs for the end user of both configurations are comparable (Fig. 10). RES heating costs show large differences. Water heated by typical solar collectors costs about 20 cent/kWh in Central Europe, larger collector fields are able to reduce the costs to 15 cent/kWh, but this is still four times the prize of warm water from an oil or gas fired boiler with actual cost of 5 to 6,5 cent/kWh. Only biomass heating is competitive today, if wood is available at very low cost. Warm water solar collectors in Southern Europe are less expensive with 10 to 12 cent/kWh making them competitive to electrical boilers. Future collector systems are able to reduce heat costs considerably. Particularly large collector fields with some 100 to more than 1000 m² will allow future costs of about 7 cent/kWh. The direct use of geothermal energy will result in future costs of about 6 cent/kWh. In view of rising prizes of fuel oil and natural gas in the future, mainly biomass plants, but also geothermal and solar collector systems will be able to supply end users with competitive thermal energy.

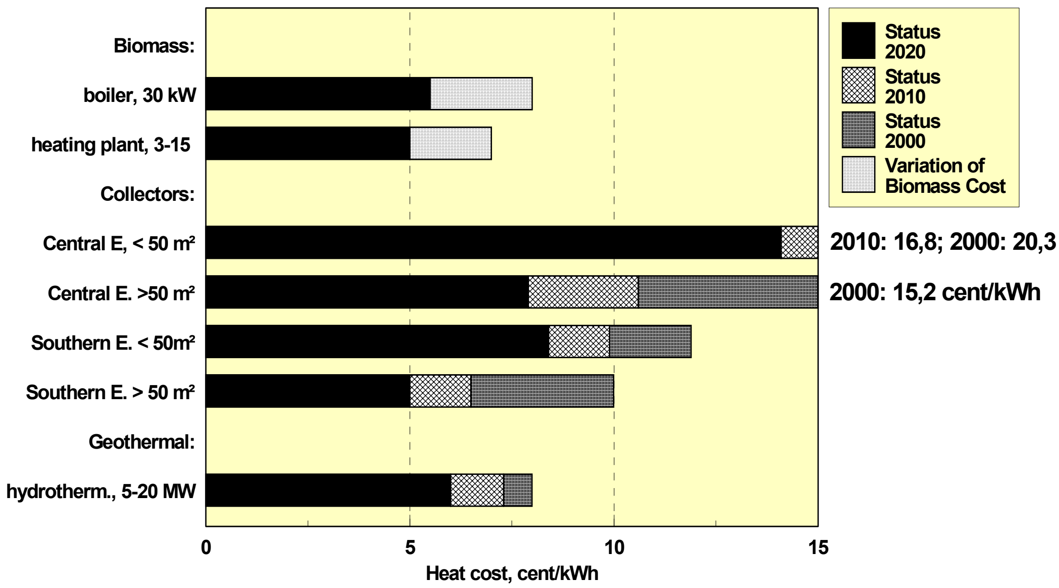

Figure 10: Survey of current heat production costs of representative RES-technologies (total length of bars) and possible cost reduction until 2010 and 2020.

c) Environmental characteristics of selected RES-technologies

The environmental problems arising from the use of fossil and nuclear energy sources are well acknowledged today: global climate change, acidification of ecosystems, risks from nuclear accidents, long term storage of radioactive waste, and public health effects from air pollution. As RES technologies largely rely on natural energy and material flow cycles, they can help to significantly reduce the environmental impact of energy supply. Although for most of the RES the energy conversion process is practically emission free, environmental impacts might result from the provision of materials and the manufacturing of components. The following environmental characterisation of current RES technologies for electricity generation and their comparison against a modern natural gas fired combined cycle (CC) power plant is thus based on a life cycle perspective, taking into account emissions from all the up- and downstream processes related to energy conversion **(Fig. 11).**

It is obvious that for most of the RES technologies both the consumption of non-renewable energy resources and the emissions of greenhouse gases is more than an order of magnitude lower than for the highly efficient gas fired power plant – and the difference is even considerable larger compared to less efficient coal fired power plants. This fact underlines the important role of RES for climate protection and the security of energy supply. Electricity generation from hydropower, wind and solar thermal power plants ranks particularly high on these two categories. For geothermal energy, the combined production of heat and electricity is required to achieve similar values. The harvesting and processing of biomass fuels requires substantial combustion of fossil fuels, so that biomass ranks slightly worse than the non-combustion processes. Despite significant improvements in recent years, the manufacturing of PV-cells still requires a quite high material and energy input, leading to relatively high life cycle emissions, which in the case of SO_2 are even in the same order of magnitude as those from the gas fired power plants.

The example of iron ore indicates that for the RES-technologies the demand of non-energy resources is higher than for the fossil options, a fact which is sometimes considered as a critical drawback of renewable energy sources. The expected increase in recycling rates, which in most cases goes along with a further reduction of environmental impacts compared to the extraction of primary raw materials, will however lead to a significant reduction of primary resource consumption in the future.

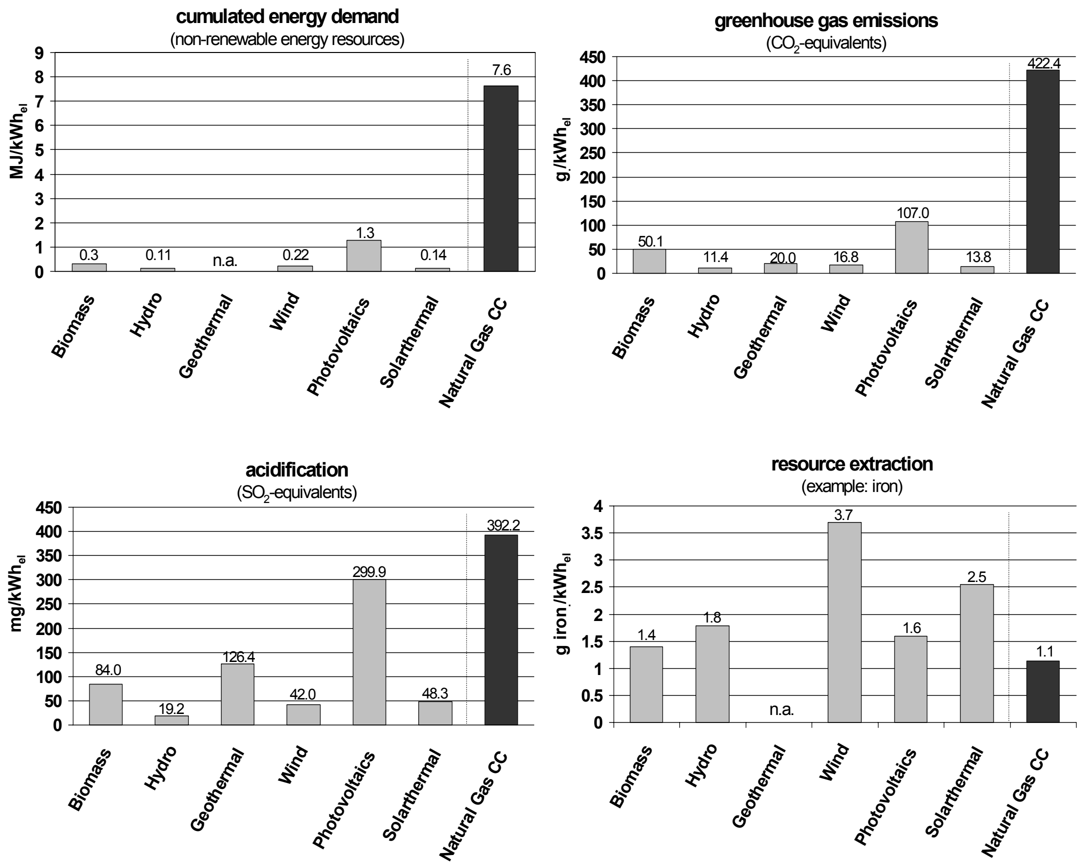

Figure 11: Environmental characteristics (cumulated energy demand, greenhouse gas emissions, acidification, resource extraction) of RES-technologies for electricity generation (Biomass: forest residuals, 20 MW steam turbine; Hydro: 3 MW run-of-river plant; Geothermal: 900 kW organic rankine cycle (ORC) cogeneration plant; Wind: 1,5 MW on-shore; PV: 3 kW p-Si roof application, Central Europe; Solar thermal: parabolic trough 80 MW (Southern Europe); Natural Gas CC: natural gas combined cycle, 58 % efficiency).

The environmental impacts of RES technologies are dominated by emissions from energy conversion in upstream processes like component manufacturing or transportation. The data thus primarily characterise the resource efficiency of the underlying economy rather than the performance of a specific energy conversion technology. Changes in the national energy mix for instance have a direct impact on the life cycle emissions of RES technologies. The evaluation of emerging technologies should thus be based on conditions that are representative for the time of their market entry, rather than associating them with the environmental load from technologies that they are expected to replace. **Fig. 12** illustrates the large potential for the reduction of life cycle CO_2-emissions from a PV-roof application due to key technological developments (use of solar-grade silicon, increase in recycling rates, electricity generation with a high share of RES).

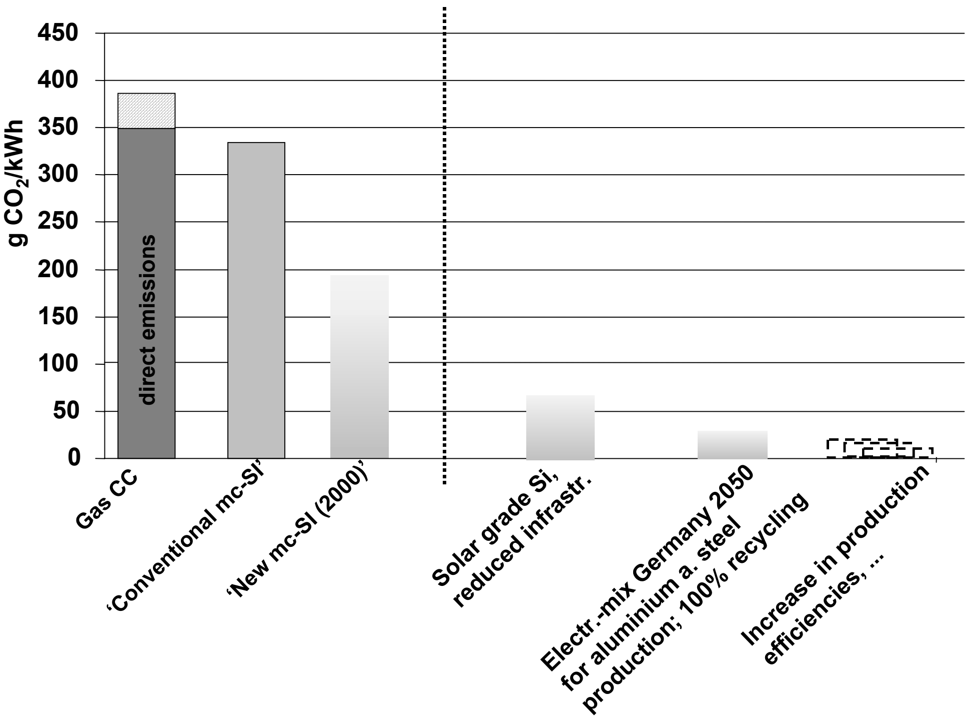

Figure 12: Life cycle emissions of CO_2 from a 3 kW p-Si roof application as a function of technological development and change in the energy mix of an economy.

Environmental impacts from energy generation, leading to public health effects, yield losses of crops, material damage, etc., pose a significant economic burden on society which is not reflected in current energy prices (external costs). The popular claim for 'getting prices right' asks for a supplement to the energy price that accounts for environmental damage costs from power plant emissions. Although the quantification of environmental impacts and the subsequent monetary valuation is extremely complex and a matter of great uncertainties, the European Commission decided based on a thorough research effort to allow Member States to grant operating aid to new plants producing renewable energy of up to 5 cent./kWh on the basis of external costs avoided. This measure for internalising environmental damage costs underlines the environmental advantages of RES and helps to further increase the competitiveness of RES technologies based on environmental considerations.

V. Prospects of RES in Europe

Several indicative targets have been set in the last five years on the European level to increase the use of RES:

- In December 1997, the European Commission adopted the White Paper for a "Community Strategy and Action Plan, Energy for the Future: Renewable Sources of Energy". The objective is to increase RES to an amount equal to 12% of the EU gross inland energy consumption by 2010. In 2001 this action plan was supplemented by a directive of the European Parliament on the promotion of electricity from RES. The target is to increase the share of RES electricity generation to 22% of total consumption in 2010. The directive holds specific targets for the individual share of RES electricity per EU member state.
- In 1999 the European Commission started a campaign for Take-Off (CTO) with the intention to start the implementation strategy set out in the White Paper with indicative targets for the period 1999 – 2003. In 2001 an additional draft directive on biofuels was proposed. The aim is to increase the consumption of biofuels to 2% of the consumption of diesel and gasoline in 2005.

In fact, the growth of RES has accelerated clearly since 1995. Between 1990 and 1995 the average growth rate of RES primary energy production in EU-15 was 2,2 %/yr, in the following five years period it rose already to 3,6 %/yr and the current growth rate amounts to 4 %/yr The average growth rate of the last decade was 2,9 %/yr However the targets defined in the White Paper demand an average growth rate of 7,3 %/yr until 2010, according to 2,5 times the value of the past decade (**Fig. 13**); a somewhat lower increase is necessary for electricity generation. **(Fig 14).**

A recent investigation, which monitors the progress of RES, states that the aspired targets will not be reached with the present policy instruments and measures. The data indicated with "Active Policy" in Fig. 13 and 14 for the year 2010 point out that only an estimated two third of the target values will be achieved in time. Here all approved policy instruments that have passed the parliaments in the different EU Member States before September 1, 2001 have been considered. Assuming that currently existing incentives will be active in a foreseeable time – marked with "Continued Policy" in Fig. 13 and 14 - probably 80 to 85 % of the target value could be achieved. Only the target value for wind energy will be exceeded clearly with 60 GW installed power in 2010 (White Paper 40 GW), all other RES stay behind the original objectives. The most severe discrepancies are expected with photovoltaics with only 20 % achievement and electricity generation with biomass with 35 % achievement of objectives.

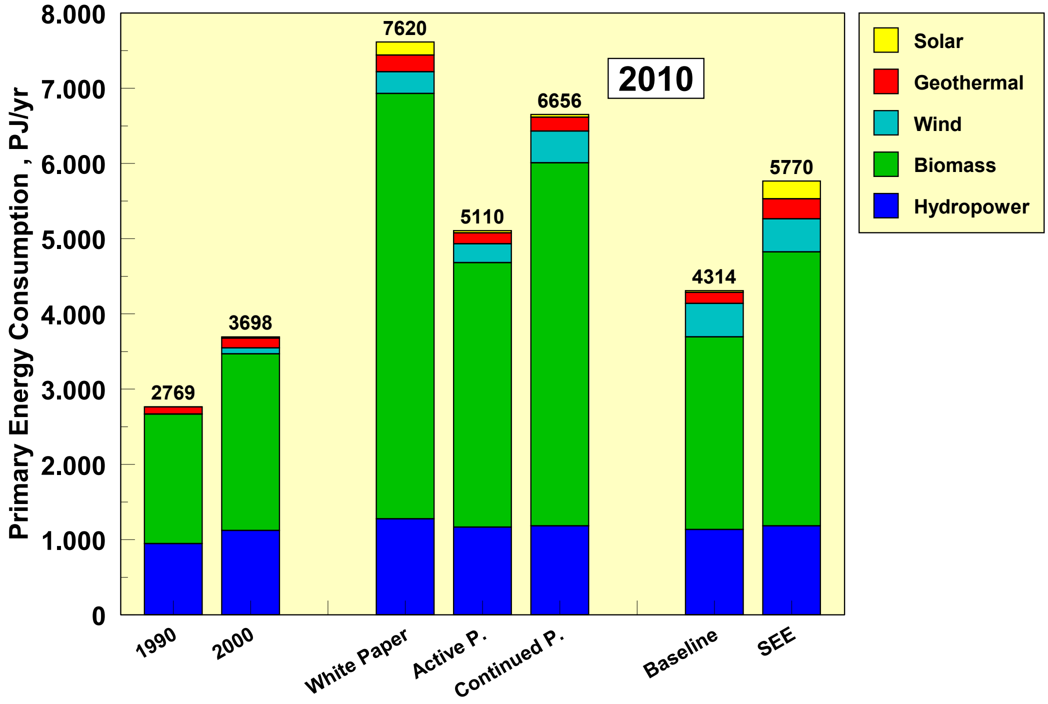

Figure 13: Contribution of RES to primary energy consumption of EU-15 in the past (1990, 2000), target for 2010 (White Paper) and possible contributions in 2010 for different scenarios.

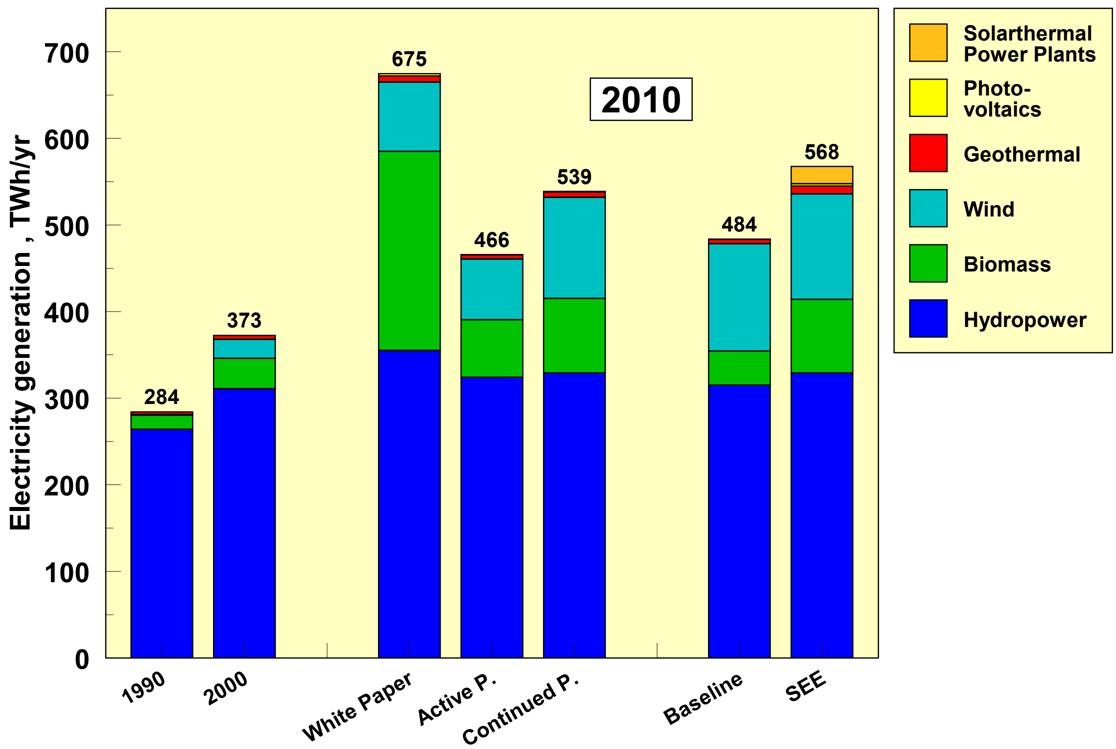

Figure 14: Contribution of RES to electricity generation of EU-15 in the past (1990, 2000), target for 2010 (White Paper) and possible contributions in 2010 for different scenarios.

Substantial structural changes in an energy supply system always require long time periods. Therefore it is of crucial importance to take into account long-term considerations concerning the transformation of EU' s energy supply structure in order to describe the prospects of RES appropriately. The Green Paper of the EU-commission "Towards a European strategy to the security of energy supply" from November 2000 is based on a projection of the European energy system up to 2030. Hence it can be used as a guideline for the investigation of the future role of RES in Europe. The reference scenario "Baseline" uses a business as usual development of the demographic and macroeconomic assumptions and is based on the EU energy policies currently in place. The gross domestic product of the EU will be 80 % higher in 2030, population will rise only modestly by 12 million people until 2010 and will be stable thereafter on a level of 384 million people. Price increase for energy is assumed to be moderate until 2030 which can be shown exemplary by the crude oil price of 30 US-$/bbl in 2030. Policy decisions to nuclear energy remain unchanged throughout the projection period. This results in a decrease of the contribution of nuclear energy to half of the present value until 2030. These basic conditions lead to an increase of primary energy demand of 11 %, to a growing dependence on energy imports from presently 49 % to 70 %, and – because of growing coal consumption – to an increase of CO_2- emissions of 22 % compared to the reference value of 1990 with 3 068 Mt/yr.

Apparently the described assumptions also cause a weak growth of RES. Until 2010 it roughly corresponds to the figures derived in "Active Policy". Considering the current dynamics of wind energy growth, only the electricity generation is somewhat higher (Fig. 14 "Baseline"), but the growth of primary energy contribution of biomass is estimated to be clearly below the value in "active policy", (Fig. 13 "Baseline").

Against this background it has become clear, that the targets of the White Paper for RES – contribution in 2010 cannot be met in time if only the present energy policy instruments – described in section III – are taken into consideration. Also after 2010 the growth of RES will not gain substantial momentum. Hence the European energy policy has to take further supporting activities in the next years to accelerate the market penetration of RES technologies. From a present point of view the scenario "Solar Energy Economy (SEE)" gives a realistic assessment of the RES contributions that can be mobilized within the next eight years. With the strategy "continued policy" as a starting point, it is assumed that the existing energy policy instruments of the EU member states as well as current incentives will be strengthened and harmonized until 2005 in order to take effect on the accelerated growth of RES before 2010. In this way almost all targets of the White paper can be reached until 2010 except for the very high electricity generation from biomass assumed in the White Paper in 2010 (230 TWh/yr compared to 35 TWh/yr in 2000) and a somewhat lower growth of solar thermal collectors. As a complement electricity generation by concentrating solar thermal power plants in Southern European countries is added in the scenario SEE, which was not considered in any other scenario up to now. It is assumed that they will generate 20 TWh/yr electricity in 2010, corresponding to 5 000 MW installed power. With that the improved conditions due to the Spanish electricity feed in law are taken into consideration, which allows economically feasible operation of such power plants by means of a guaranteed payment of 16 cent/kWh. Several projects are in preparation now. In scenario SEE total electricity generation by RES will sum up to 568 TWh/yr in 2010, a share of 20 % (Fig. 14). The contribution to gross primary energy demand grows to 5 770 PJ/yr which is equivalent to 9,5 %, (Fig. 13).

The long-term development potential of RES and their significance for a future energy supply system depends decisively on the status and the growth dynamics they have reached by 2010. Comparing different long-term scenarios for the energy supply of the EU, this is quite obvious. It is noteworthy that the already discussed reference scenario "baseline" shows only a small growth of RES over several decades (**Fig. 15** and **16**). The share of RES on electricity generation obtains the 2010-target of the White Paper in 2030, the growth in the heat and fuel market almost stagnates, so that the RES contribution to gross primary energy consumption rises only marginally. Extrapolating this scenario to 2050, RES will reach at best a share of 10 % on primary energy consumption with 6 400 PJ/yr and would remain for that reason a nearly negligible energy source. Such "business as usual" development would offer no chance for RES to contribute significantly to climate change mitigation or prolongation of oil and gas resources.

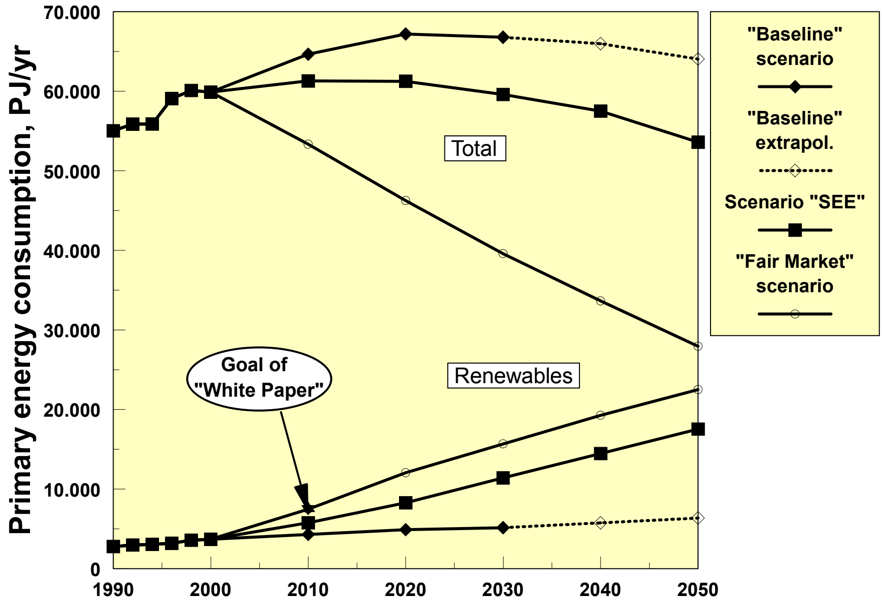

Figure 15: Future primary energy consumption of EU-15 until 2050 and possible contribution of RES for different scenarios

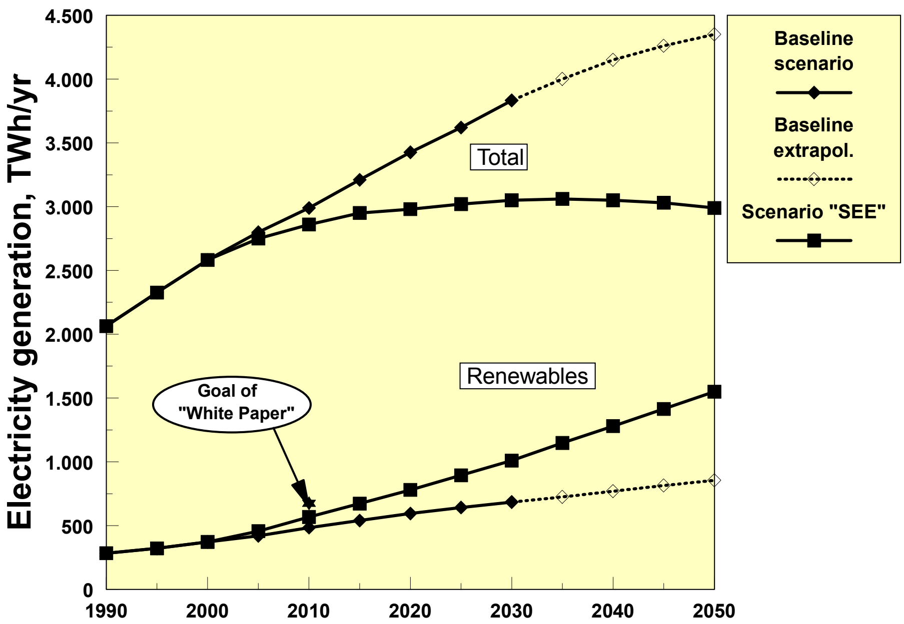

Figure 16. Future electricity generation of EU-15 until 2050 and possible contributions of RES for different scenarios.

A totally changed perspective is offered by the scenario "Fair Market", that was carried out by a consortium of five research teams from Germany, France, Belgium and Denmark in 1997. The main approach of this scenario is the inclusion of externalities of energy consumption in energy prices to determine market behavior. Once the magnitude of external costs has been fixed e.g. by politically agreed taxation, the market can act on prices like it used to. Adding the known externalities to market prices of energy leads to considerably strong increases and results in price levels which are twice to three times as high as the energy prices used in the scenario “Baseline”. In parallel learning curves have been used to calculate the decreasing future cost of RES technologies. With these conditions a strong market growth of RES as well as of energy saving technologies can be expected. The transformation of the energy system will be determined mainly by structural limits, e.g. the decommissioning of power plants and boilers for heating, the reconstruction of buildings, the construction of new production sites for RES technologies or necessary changes of infrastructure for new fuels. These very favorable conditions for RES technologies result in average growth rates for all technologies of 4,5 %/yr during the next three decades starting with about 7 %/yr in the next ten years. Growth is assumed to continue until 2050 with slowly declining rates, resulting in a RES contribution of 22 400 PJ/yr in 2050 to primary energy consumption (Fig.15), which corresponds to six times the present value. Energy demand is declining simultaneously because many energy saving technologies are cost-effective at the assumed prices. The “Fair Market” scenario shows, that in 2050 the demand for energy services of EU-15 can be met by half of the present energy amount. Therefore RES are able to contribute 80 % of the remaining primary energy consumption. As a result CO_2-emissions are negligible compared to the present value, the dependency on external energy resources is diminished to 15 % of the actual imports of crude oil and natural gas. This scenario describes a development of the European energy system which could occur under very favorable political conditions. It would considerably reduce the deficits of the current energy system with respect to sustainability. In fact this scenario is rather unlikely from a present point of view. But it shows in principle the unused potentials of RES and rational use of energy modern economies are able to exploit.

The third scenario “SEE” tries to balance the challenges of reaching sustainability in energy supply and the well-know slowness in removing the numerous barriers and restraints, which are opposed to accelerated structural changes in the European energy system. It outlines the chances towards a more independent, secure and environmentally sound energy system in Europe with “careful optimism”. This includes an efficient and quick advancement and harmonization of support mechanism for RES (and for saving energy) in the EU, but on the other side no excessive demands on society and economy. Starting from the interim values for 2010 shown in Figs. 13 and 14, the contribution of RES grows continuously and meets in 2050 one third of total primary energy consumption with 17 500 PJ/yr. Also the reinforced efforts of saving energy show an impact, resulting in a total energy productivity in 2050 of twice the present value. In particular it is assumed that the steadily growing electricity demand will be slowed down by adequate energy saving efforts. In combination with the growing RES electricity generation about 50% of electricity demand in 2050 can be met by RES (Fig. 16). RES contributions to the heat and fuel market are growing somewhat slower.

To achieve an economically attractive growth of RES a well-balanced and timed mobilization of all RES technologies is of paramount importance. This mobilization depends on their technical potentials, their actual costs, their cost reduction potentials and their technological maturity. In **Fig 17** this is demonstrated with the RES electricity generation of scenario SEE. Until 2010 cost-effective hydropower, biomass power plants and wind energy converters are the main contributors to RES growth. Hydropower and biomass will then reach their limits (the latter one is increasingly used for fuel production). After 2010 the continuously growing use of wind energy is complemented by electricity from solar thermal power plants and from geothermal energy. Relevant contributions from photovoltaics will emerge not until 2030 because of its relatively high cost.

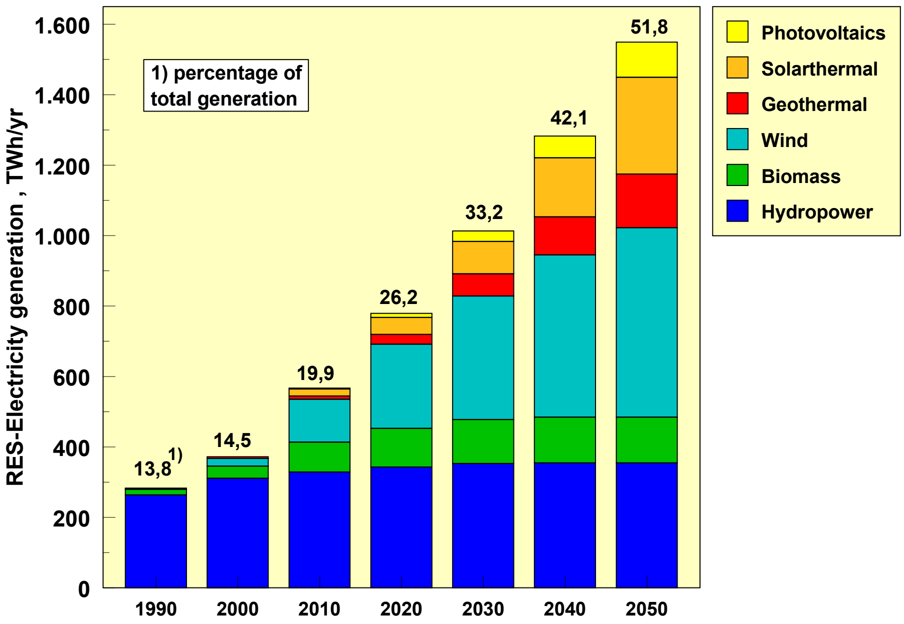

Figure 17: Growth of RES electricity generation in the scenario SEE for EU-15 until 2050 by individual sources.

The described activities within the scenario SEE correspond widely to the minimum level of technically feasible changes. CO_2-emissions in 2050 are reduced to 2 100 Mt/yr, or 67 % of the current value. This is only a first approach to an effective CO_2 abatement policy. Also the dependency on imports of crude oil and natural gas with 65 % of the present value is still too high. Altogether the scenario represents the minimum requirements from European energy policy, if a relevant role of RES in future energy supply is one of their substantial goals.

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