TRANS-CSP

Trans-Mediterranean Interconnection for Concentrating Solar Power

Final Report

by

German Aerospace Center (DLR)
Institute of Technical Thermodynamics
Section Systems Analysis and Technology Assessment

Study commissioned by

Federal Ministry for the Environment,
Nature Conservation and Nuclear Safety
Germany

The Federal Ministry
for the Environment,
Nature Conservation
and Nuclear Safety

DLR

The full **TRANS-CSP Study Report** can be found at the website:
http://www.dlr.de/tt/trans-csp

Contents:

Introduction and Summary

Chapter 1: Solar Electricity Transfer from MENA to Europe

Chapter 2: A Scenario for Sustainable Electricity

Chapter 3: Policies and Finance

Chapter 4: Socio-Economic Impacts

Chapter 5: Environmental Impacts

Annex (Individual Country Data)

Project Responsible:

Dr. Franz Trieb
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
Institute of Technical Thermodynamics
Systems Analysis and Technology Assessment
Pfaffenwaldring 38-40
D-70569 Stuttgart
Germany
Tel.: ++49-711 / 6862-423
Fax: ++49-711 / 6862-783
Email: franz.trieb@dlr.de
http://www.dlr.de/tt/system

Stuttgart, June 2006

TRANS-CSP Team

German Aerospace Center (DLR)
Dr. Franz Trieb, Dr. Christoph Schillings, Stefan Kronshage, Dr. Peter Viebahn, Nadine May, Christian Paul, Stuttgart, Germany

National Energy Research Center (NERC)
Eng. Malek Kabariti (Director), Khaled M. Daoud, Amman, Jordan

Prof. Dr. Abdelaziz Bennouna, Rabat, Morocco

Nokraschy Engineering GmbH (NE)
Dr. Ing. Hani El Nokraschy, Holm, Germany

New and Renewable Energy Authority (NREA)
Samir Hassan (Director), Laila Georgy Yussef, Cairo, Egypt

New Energy Algeria (NEAL)
Tewfik Hasni (Director), Alger, Algeria

Internationales Forschungszentrum für Erneuerbare Energien e.V. (IFEED)
Dr. Nasir El Bassam (Director), Braunschweig, Germany

Hamburg Institute of International Economics (HWWA)
Honorat Satoguina, Hamburg, Germany

Acknowledgements:

The TRANS-CSP team thanks the German Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) for sponsoring this project, Ralf Christmann from BMU and Ludger Lorych from VDI/VDE/IT for their efficient project management, Bernhard Lehner from WWF-US and Lukas Menzel from USF Kassel for the data for the hydropower resource map based on the model WaterGap 2.1, to BESTEC GmbH for providing a geothermal resource map, Manfred Hafner from OME for providing excellent information on the Mediterranean Ring, the Trans-Mediterranean Renewable Energy Cooperation (TREC) and especially Gerhard Knies for providing a very useful discussion forum, our colleagues at DLR and to everybody else who helped in making this project a success.

Index of the TRANS-CSP Report

Introduction and Summary **1**

1 Solar Electricity Transfer from MENA to Europe **13**
  1.1 Present Electricity Transfer Capacities in EU-MENA
  1.2 High Voltage Alternate Current Transmission (HVAC)
  1.3 High Voltage Direct Current Transmission (HVDC)
  1.4 Performance, Economy and Impacts of High Voltage Transmission Lines
  1.5 The Vision of EU-MENA Electricity Highways
2 A Scenario for Sustainable Electricity **29**
  2.1 Outlook of Electricity Demand in Europe
  2.2 Renewable Electricity Potentials in Europe
  2.3 Outlook for Electricity Supply in Europe
  2.4 Market Potential for Solar Import Electricity
  2.5 Solar Power for Europe – Water and Development for MENA
3 Policies and Finance **87**
  3.1 Discrepancy of Awareness and Action
  3.2 Concepts of Financing Renewable Energies
  3.3 Necessary Political Framesets
  3.4 Policies and Finance for Solar Electricity Imports
  3.5 General Conclusions for Policy and Finance
4 Socio-Economic Impacts **105**
  4.1 Wealth Creation
  4.2 Reduced Subsidies and External Costs
  4.3 Improved Diversity and Security of Supply
5 Environmental Impacts **119**
  5.1 Environmental Impacts of the TRANS-CSP Scenario
  5.2 Environmental Impacts of Overhead Lines
  5.3 Environmental Impacts of ground Cables
  5.4 Environmental Impacts of Submarine Cables
  5.5 Low Impact Solar Electricity Links
  5.6 Eco-Balance of Solar Electricity Imports

Bibliography **145**

Annex

A 1 Individual Country Data A-1
A 2 Abbreviations A-31
A 3 Solar Import Electricity by Countries A-33

“The sun-belt and the technology belt can become very powerful when they begin to understand themselves as a community: a community of energy, water and climate security; a community for their common future.”

H.R.H. Prince El Hassan Bin Talal

President of the Club of Rome

Address for World Energy Dialogue,

Hannover Messe, April 2006

Introduction

Competitiveness, compatibility with society and the environment, security of supply and international cooperation are considered main pillars for sustainability in the energy sector. For each of the 30 countries[1] shown in Figure 1, electricity scenarios from the year 2000 to 2050 were developed that show a consistent transition to a sustainable supply that is inexpensive, compatible with the environment and based on diversified, secure resources.

Sustainable power in Europe (EU) can be based to a great extent on renewable generation including solar electricity import from the Middle East and North Africa (MENA). A well balanced mix of renewable energy sources with fossil fuel backup can provide affordable power capacity on demand.

The transfer of solar electricity from MENA to Europe can initiate an understanding of a common EUMENA region, starting with a partnership and free trade area for renewable energy, and culminating in what H.R.H. Prince El Hassan Bin Talal, President of the Club of Rome, called a "Community for Energy, Water and Climate Security" at the World Energy Dialogue at the Hannover Technology Fair in April 2006.

The TRANS-CSP study comprises a comprehensive data base on the present and expected demand for electricity and firm power capacity, quantifies the available renewable energy resources and their applicability for power, provides scenarios of the electricity supply system until 2050, and evaluates the resulting socio-economic and environmental impacts for each of the analysed countries. The executive summary at hand gives the aggregated results for Europe as a whole, while individual country data is given in the annex of the full study report.

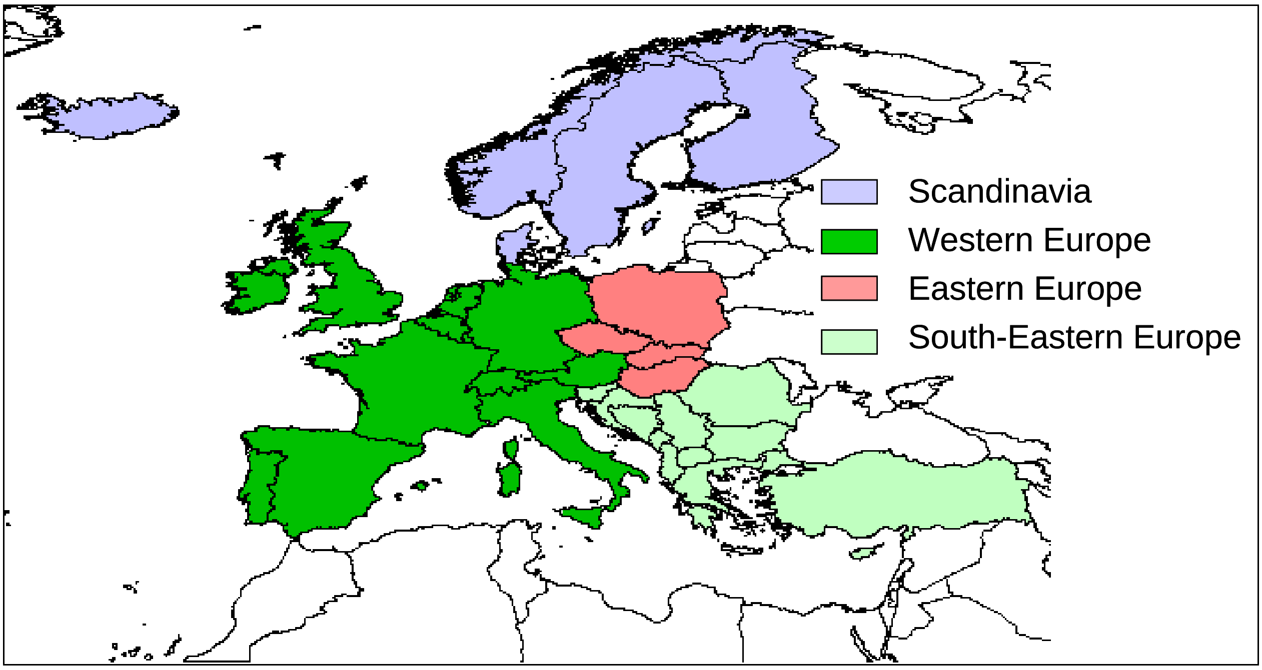


Figure 1: A total of 30 countries in Europe were analysed in the TRANS-CSP study

---

[1] TRANS-CSP covers: Iceland, Norway, Sweden, Finland, Denmark, Ireland, United Kingdom, Portugal, Spain, France, Belgium, Netherlands, Luxembourg, Germany, Austria, Switzerland, Italy, Poland, Czech Republic, Hungary, Slovakia, Slovenia, Croatia, Bosnia-Herzegovina, Serbia-Montenegro, Macedonia, Greece, Romania, Bulgaria, Turkey, www.dlr.de/tt/trans-csp. The MENA countries and some Southern European countries were analysed within the MED-CSP study, www.dlr.de/tt/med-csp, quantifying the opportunities of the Mediterranean region.

Main Results of the TRANS-CSP Study

The TRANS-CSP study analyses the renewable electricity potentials in Europe and their capability to provide firm power capacity on demand. The concept includes an interconnection of the electricity grids of Europe, the Middle East and North Africa (EUMENA) and evaluates the potential and benefits of solar power imports from the South. The conventional electricity grid is not capable of transferring large amounts of electricity over long distances. Therefore, a combination of the conventional Alternate Current (AC) grid and High Voltage Direct Current (HVDC) transmission technology will be used in a Trans-European electricity scheme based mainly on renewable energy sources with fossil fuel backup. The results of the TRANS-CSP study can be summarized in the following statements:

- A well balanced mix of renewable energy sources backed by fossil fuels can provide sustainable, competitive and secure electricity for Europe. For the total region, our scenario starts with a reported share of 20 % renewable electricity in the year 2000 and reaches 80 % in 2050. An efficient backup infrastructure will be necessary to complement the renewable electricity mix, providing firm capacity on demand by quickly reacting, natural gas fired peaking plants, and by an efficient grid infrastructure to distribute renewable electricity from the best centres of production to the main centres of demand.

- If initiated now, the change to a sustainable energy mix leads to less expensive power generation than a business as usual strategy in a time span of about 15 years. Imported fuels with escalating cost will be increasingly substituted by renewable, mostly domestic energy sources. The negative socio-economic impacts of fossil fuel price escalation can be reversed by 2020 if an adequate political and legal framework is established at time. Feed-in tariffs like the German or Spanish Renewable Energy Acts are very effective instruments for the market introduction of renewables. If tariff additions are subsequently reduced to zero, they can be considered a public investment rather than a subsidy.

- Solar electricity generated by concentrating solar thermal power stations in MENA and transferred to Europe via high voltage direct current transmission can provide firm capacity for base load, intermediate and peaking power, effectively complementing European electricity sources. Starting between 2020 and 2025 with a transfer of 60 TWh/y, solar electricity imports could subsequently be extended to 700 TWh/y in 2050. High solar irradiance in MENA and low transmission losses of 10-15 % will yield a competitive import solar electricity cost of around 0.05 €/kWh.

- Carbon emissions can be reduced to 25 % compared to the year 2000. 1 % of the European land will be required for the power mix, which is equivalent to the land used at present for transport and mobility.

- European support for MENA for the market introduction of renewables can attenuate the growing pressure on fossil fuel resources that would otherwise result from the economic growth of this region, thus helping indirectly to secure fossil fuel supply also in Europe. The necessary political process could be initiated by a renewable energy partnership and a common free trade area for renewable energies in EUMENA and culminate in a Community for Energy, Water and Climate Security.

The TRANS-CSP study provides a first information base for the design of a political framework that is required to initiate and realise such a scheme.

Chapter 1 (Solar Electricity Transfer) describes the technical options of transferring solar electricity from MENA to Europe via hydrogen, through the conventional alternating current (AC) grid and by a possible future high voltage direct current (HVDC) infrastructure.

The transport of solar energy via hydrogen over a distance of e.g. 3000 km would in principle be possible, but 75 % of the generated renewable electricity would be lost by the involved conversion, transport and storage processes. Consequently, this option was disregarded.

The transfer capacities of the conventional AC grid are rather limited, and even considering that the MENA countries would empower their regional electricity grid to Central European standards and would create additional interconnections all around the Mediterranean Sea, the transfer would still be limited to about 3.5 % of the European electricity demand. Over a distance of 3000 km, about 45 % of the generated solar electricity would be lost by such a transfer.

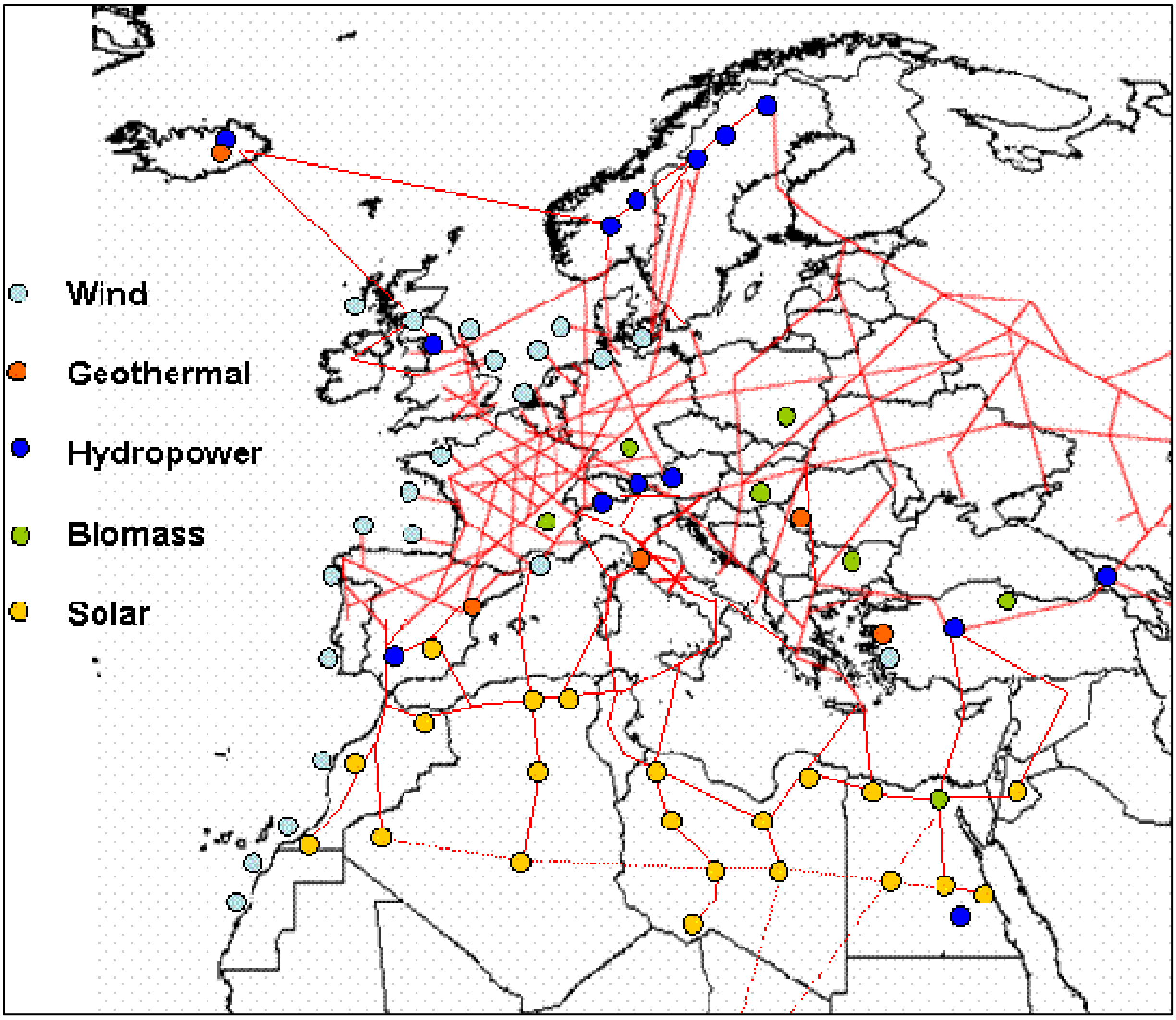


Figure 2: Vision of an EUMENA backbone grid using HVDC power transmission technology as "Electricity Highways" to complement the conventional AC electricity grid.

HVDC technology is becoming increasingly important for the stabilisation of large electricity grids, especially if more and more fluctuating resources are incorporated. HVDC over long distances contributes considerably to increase the compensational effects between distant and local energy sources and allows to compensate blackouts of large power stations through distant backup capacity. It can be expected that in the long term, a HVDC backbone will be established to support the conventional European electricity grid and increase the redundancy and stability of the future power supply system.

As a spin-off effect of this development, the import of solar electricity from MENA will become an attractive diversification of the European power generation portfolio. Solar and wind energy, hydropower, geothermal power and biomass will be generated in regions of best performance and abundance, distributed all over Europe and MENA through a highly efficient HVDC grid on the upper voltage level, and finally delivered to the consumers by the conventional interconnected AC grid on the lower voltage level (Figure 2). Analogue to the network of interstate highways, a future HVDC grid will have a low number of inlets and outlets to the conventional AC system as it will primarily serve long distance transfer, while the AC grid will have a function analogue to country roads and city streets.

Only 10 % of the generated electricity will be lost by HVDC transmission from MENA to Europe over 3000 km distance. In 2050, twenty power lines with 5000 MW capacity each could provide about 15 % of the European electricity demand by solar imports, motivated by their low cost of around 5 €-cent/kWh (not accounting for further cost reduction by carbon credits) and their high flexibility for base-, intermediate- and peak load operation.

Year		2020	2030	2040	2050
Transfer Capacity GW		2 x 5	8 x 5	14 x 5	20 x 5
Electricity Transfer TWh/y		60	230	470	700
Capacity Factor		0.60	0.67	0.75	0.80
Turnover Billion €/y		3.8	12.5	24	35
Land Area	CSP	15 x 15	30 x 30	40 x 40	50 x 50
km x km	HVDC	3100 x 0.1	3600 x 0.4	3600 x 0.7	3600 x 1.0
Investment	CSP	42	143	245	350
Billion €	HVDC	5	20	31	45
Elec. Cost	CSP	0.050	0.045	0.040	0.040
€/kWh	HVDC	0.014	0.010	0.010	0.010

Table 1: Main indicators of the total EUMENA High Voltage Direct Current (HVDC) interconnection and Concentrating Solar Power (CSP) plants from 2020 – 2050 according to the TRANS-CSP scenario. In the final stage in 2050, lines with a capacity of 5 GW each will transmit about 700 TWh/y of electricity from 20 different locations in the Middle East and North Africa (MENA) to the main centres of demand in Europe.

Chapter 2 (Scenario for Sustainable Electricity) demonstrates the capability of a well balanced mix of renewable and fossil energy sources to provide secure, inexpensive and sustainable electricity for the supply of each of the European countries. Renewable energy can provide the necessary amount of clean energy to achieve the targets for climate stabilisation and reduce the consumption of fossil fuels to the rare times when renewable energy supply and electricity demand do not coincide. The strategy of reducing fossil energy use to peaking power allows for firm capacity on demand and at the same time reduces the consumption of fossil fuels that are a very valuable, ideally stored form of energy that should be exclusively used for that purpose.

Europe has plenty renewable energy sources for power generation (Figure 3). Their total economic potential amounts to about 145 % of the expected future electricity demand. This suggests that the coverage of the demand by 100 % should be achievable within a time span of 50 years. However, 60 % of this potential comes from wind and solar energy, both fluctuating resources that can provide electricity, but almost no firm power capacity on demand (Table 2). Moreover, the potentials are not distributed uniformly, but are concentrated in typical regions, e.g. hydropower in Scandinavia and the south central mountains, solar energy in the south, wind energy at the northern coasts and geothermal energy in South and Eastern Europe. Therefore, only 80 % of the power mix of the year 2050 will be derived from renewable sources.

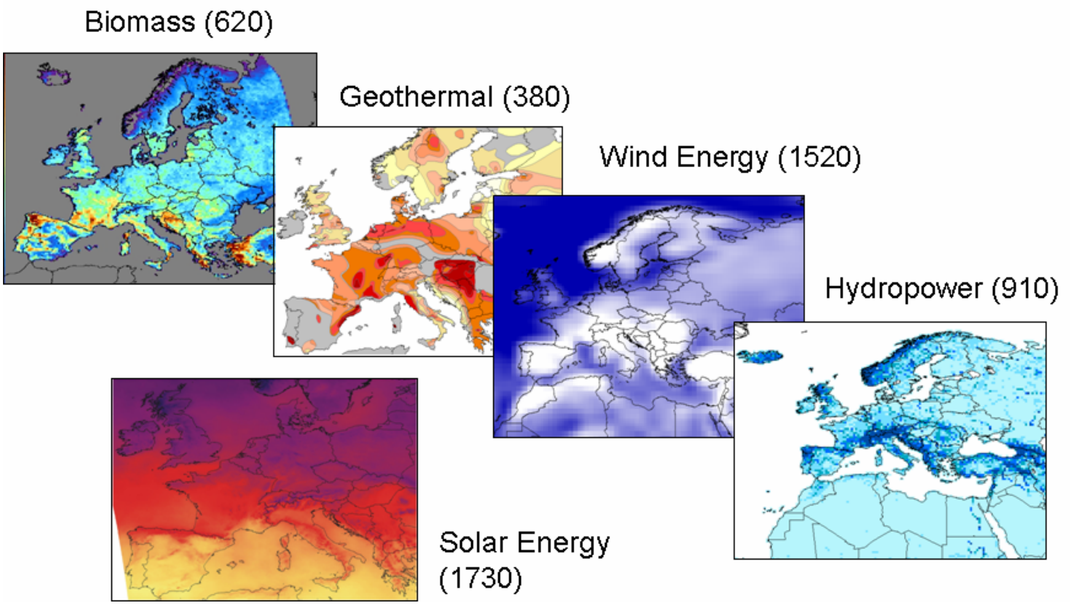


Figure 3: Renewable energy resource maps for the European region. Please refer to the main report for the colour code and references. The numbers give the economic electricity potential in TWh/y. Solar energy includes both CSP and PV potentials within the analysed European countries. All renewables sum up to 5160 TWh/y. The total future electricity demand of the analysed countries amounts to about 4000 TWh per year.

An efficient backup infrastructure will be necessary to complement the renewable electricity mix, on one side to provide firm capacity on demand by quickly reacting, natural gas fired peaking plants, and on the other side by an efficient grid infrastructure that allows to distribute renewable electricity from the best centres of production to the main centres of demand. The best solution is a combination of HVDC electricity highways and the conventional AC grid. On the lower voltage level, decentralised structures will also gain importance, combining e.g. PV, wind and micro-turbines operating together just like one, virtual power plant. Such a grid infrastructure will not be motivated by the use of renewables alone. In fact, its construction will probably take place anyway, with the purpose to stabilize the growing Pan-European grid, to provide higher security of supply, and to foster competition. Using fossil energies exclusively for backup purposes will reduce their consumption to a sustainable level and will reduce the quickly escalating cost of power generation. Fossil fuels will be used to provide firm capacity, while renewables will serve to reduce fossil fuel consumption.

	Unit Capacity	Capacity Credit *	Capacity Factor **	Resource	Applications	Comment
Wind Power	1 kW – 5 MW	0 – 30 %	15 – 50 %	kinetic energy of the wind	electricity	fluctuating, supply defined by resource
Photovoltaic	1 W – 5 MW	0 %	5 – 25 %	direct and diffuse irradiance on a tilted surface	electricity	fluctuating, supply defined by resource
Biomass	1 kW – 25 MW	50 - 90 %	40 – 60 %	biogas from the decomposition of organic residues, solid residues and wood	electricity and heat	seasonal fluctuations but good storability, power on demand
Geothermal (Hot Dry Rock)	25 – 50 MW	90 %	40 – 90 %	heat of hot dry rocks in several 1000 meters depth	electricity and heat	no fluctuations, power on demand
Hydropower	1 kW – 1000 MW	50 - 90 %	10 – 90 %	kinetic energy and pressure of water streams	electricity	seasonal fluctuation, good storability in dams, used also as pump storage for other sources
Solar Updraft	100 – 200 MW	10 to 70 % depending on storage	20 to 70 %	direct and diffuse irradiance on a horizontal surface	electricity	seasonal fluctuations, good storability, base load power
Concentrating Solar Thermal Power	10 kW – 200 MW	0 to 90 % depending on storage and hybridisation	20 to 90 %	direct irradiance on a surface tracking the sun	electricity and heat	fluctuations are compensated by thermal storage and (bio)fuel, power on demand
Gas Turbine	0.5 – 100 MW	90 %	10 – 90 %	natural gas, fuel oil	electricity and heat	power on demand
Steam Cycle	5 – 500 MW	90 %	40 – 90 %	coal, lignite, fuel oil, natural gas	electricity and heat	power on demand
Nuclear	> 500 MW	90 %	90 %	uranium	electricity and heat	base load power

Table 2: Some characteristics of contemporary power technologies. * Contribution to firm power and reserve capacity. ** Average annual utilisation.

Several renewable power technologies can also operate as base load and peaking plants: geothermal (hot dry rock) systems that are today still in a phase of research and development, hydropower plants with large storage dams available in Norway, Iceland and the Alps, most biomass plants and concentrating solar power plants in MENA, using the high annual solar irradiance of that region, the possibility of solar thermal energy storage for overnight operation and the option of backup firing with fuels. CSP in Europe is bound to significant seasonal fluctuations, and firm peaking power can only be provided with a considerable fossil fuel share. Due to a higher solar irradiance, the cost of CSP is usually lower in MENA than in Europe. Therefore, there will be a significant market for CSP imports to complement the European sources and provide firm power capacity at competitive cost (Figure 4).

A requisite of the electricity mix is to provide firm capacity and a reserve of about 25 % in addition to the expected peaking load (Figure 5). Before significant CSP imports start in the year 2020, this can only be provided extending the capacity and fuel consumption of natural gas fired peaking plants. In our scenario, the consumption of natural gas doubles with respect to the starting year 2000, but is then brought back to the initial level, after introducing in 2020 increasing shares of import CSP, geothermal power and hydropower from Scandinavia by HVDC interconnections. As shown in Figure 3, the European renewable energy sources that could provide firm capacity are rather limited from the point of view of their potentials. Therefore, CSP imports will be useful to reduce both the installed capacity and the fuel consumption of gas fired peaking plants and to provide firm renewable power capacity.

Except for wind power that is already booming today, and hydropower that is already introduced, renewable energy will hardly become visible in the electricity mix before 2020. At the same time, the fade out of nuclear power in many European countries and a stagnating use of coal and lignite due to climate protection will imply increasing pressure on natural gas resources, increasing their consumption as well as their installed capacity. As described above renewables will primarily reduce fuel consumption until 2020, but hardly substitute power capacities. Therefore, the total installed capacity will grow faster than the peaking load (Figure 5). Due to the growth of consumption and the substitution of nuclear power, fossil fuel consumption for power generation in Europe cannot be reduced before 2020. Fuel oil for electricity will fade out in 2030, nuclear power will follow after 2040. The consumption of gas and coal will be reduced by 2050 to a compatible and affordable level.

The electricity mix of the year 2000 depends mainly on five resources, most of them limited and imported, while the mix of 2050 will be based on ten energy sources, most of them domestic and renewable (Figure 4). Thus, the TRANS-CSP scenario responds to the European Strategy for Sustainable, Competitive and Secure Energy declared by the European Commission in the corresponding Green Paper and Background Document, aiming at higher diversification and security of the European energy supply.

Chapter 3 (Policies and Finance) discusses the political and financial issues of a strategy following the TRANS-CSP scenario. Industry and private investors need a reliable political and legal framework to introduce and expand renewables in the power market. It can be stated that many countries are already on that track, with a large portfolio of instruments to foster renewable energy market introduction in many countries. The present share of renewables on global power investment of 25 % and industrial production growth rates of up to 60 % per year speak a clear language. Most successful instruments seem to be the feed-in tariffs like the German and Spanish Renewable Energy Acts that provide a fixed premium or revenue for renewable electricity that is individually adapted to the requirements of each technology and granted for the total economic lifetime of the plants.

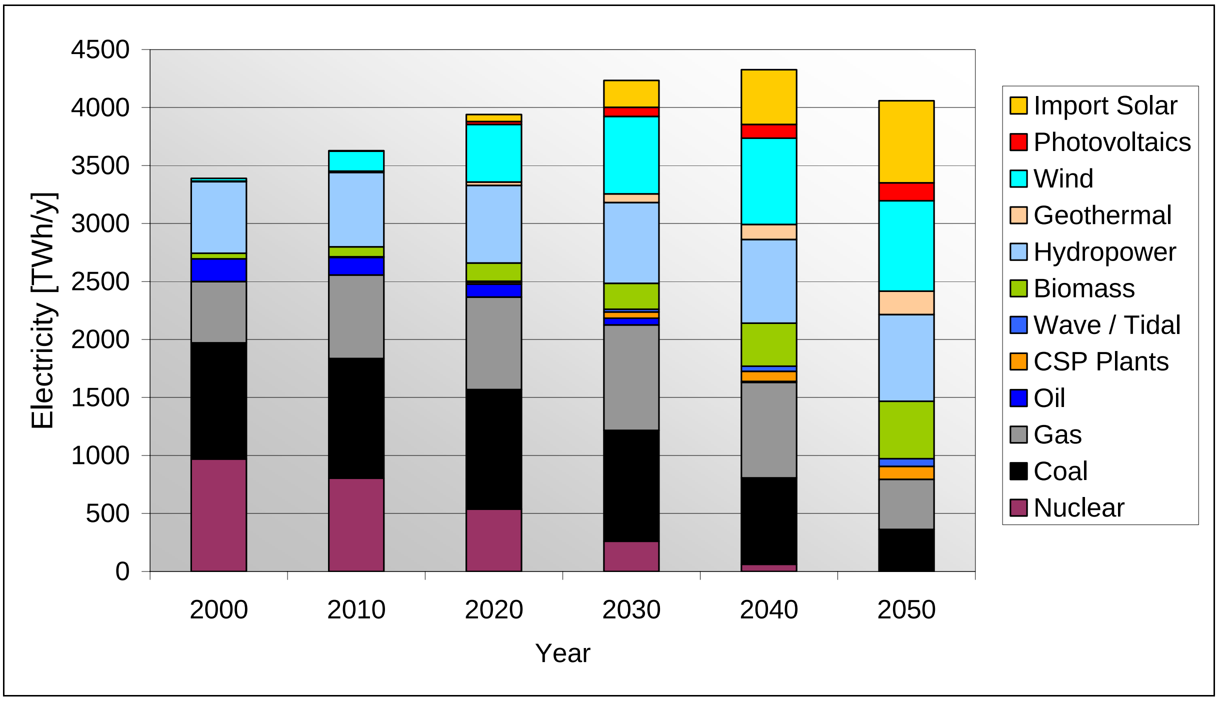


Figure 4: TRANS-CSP scenario of gross electricity production and import for the analysed European countries until 2050. The import of other than solar electricity to the region is negligible.

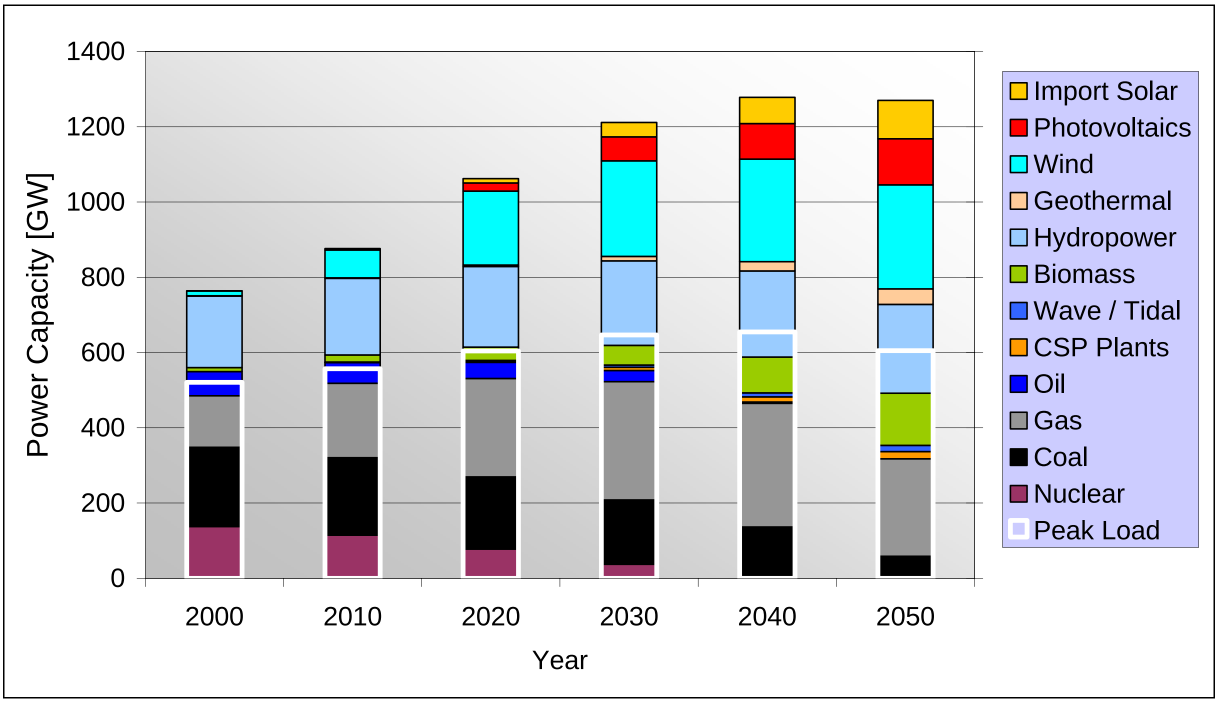


Figure 5: TRANS-CSP scenario for the total installed power capacities and peak load for the analysed European countries until 2050.

Renewable energy feed-in laws provide long term, guaranteed power purchase agreements with local utilities. Private investments under such a scheme are usually provided at interest rates that are 50 % lower than those in the conventional power sector, thus effectively reducing the cost of market introduction of renewables. Feed-in tariffs (for new plants) are subsequently reduced year by year, thus motivating intensive research and development for cost reduction. Although such instruments are already effective in some European countries, adequate policies have been adapted only by a few, and there is still a long although promising way to achieve a European standard.

The situation is quite different in public research, development and demonstration policies (RD&D). In this sector, there is a strong contradiction between the allocation of funds and the awareness of the necessities of a sustainable energy future. More than 50 % of the energy RD&D budget supports the existing nuclear / fossil energy mix, while poorly 8 % are dedicated to the different forms of renewable energy. Present energy subsidies give a similar picture: 90 % are granted to fossil and nuclear energy, while only 10 % are dedicated to the total renewable energy portfolio. Moreover, there is a fundamental difference between public funding of renewables and the subsidization of fossil or nuclear energy: the first supports new technologies in the phase of market introduction that still require public investment to achieve further cost reduction, while the second artificially prolongs the life of a supply scheme that is clearly beyond its economic summit. Table 3 compares a renewable with a fossil-nuclear strategy for energy security. Looking at those facts, it is difficult to find any reason at all for persisting in the present fossil-nuclear energy strategy of many European countries. A third option, the combination of renewables with nuclear plants must be disregarded too, due to the simple fact that nuclear plants can only operate economically if they run at constant power.

Electricity Mix dominated by Renewable Energy with Fossil Fuel Backup	**Electricity Mix dominated by Nuclear Power and Fossil Fuels**
Power on demand by a well balanced mix of renewable and fossil energy sources	Power on demand by using ideally stored forms of energy like uranium, coal, oil and gas
Supply based on many, mostly unlimited resources	Supply based on few, mostly limited resources
Domestic sources dominate the electricity mix	Energy imports dominate the electricity mix
Low vulnerability of decentralised generation	High vulnerability of large central generation units
Low hazardous waste, recyclable materials	Disposal of nuclear waste and CO_2 unsolved
Low risk of contamination or major accidents	Risks of plutonium proliferation and nuclear accidents
Requires public investment over limited time span	Requires long-term continuous subsidisation
Low environmental impact	Climate change, pollution and nuclear radiation
Intrinsic trend to lower cost and less price volatility	Intrinsic trend to higher cost and price volatility
Requires a change of structures and thinking	Fits to present structures and thinking
Based on proven and demonstrated technologies	Requires major technological breakthroughs: o Safe fission and breeder technology o Commercial fusion reactor o Carbon capture and sequestration (CCS)
=> Low risk strategy	**=> High risk strategy**

Table 3: Comparison of a renewable power strategy in Europe with a nuclear – fossil energy mix

Chapter 4 (Socio-Economic Impacts) analyses the societal consequences of our scenario, especially in terms of wealth creation, energy economy and security of supply. The TRANS-CSP concept addresses those issues in a unique way. As described before, the diversification of resources and empowering of the electricity grid will increase the European security of power supply. Import dependency will be reduced through the improved use of domestic renewable energy (Figure 6). A growing pressure on natural gas resources will be avoided.

In contrast to the common belief that for every wind park a backup power plant must be installed, the analysis shows that the need of peaking plants is relatively constant although the share of fluctuating sources (PV and wind) increases. Fact is that the necessary peaking capacity is already there, with the purpose to cover the fluctuations of demand. No extra capacities are needed as long as the fluctuating renewable energy share is smaller than the existing peaking capacity, which is the case in our scenario. Wind and PV plants cannot considerably reduce the required installed capacity of conventional power plants, but they will reduce their consumption of fossil fuels. Establishing a well balanced mix of technologies and sources, fossil peaking capacities will remain, while fossil and nuclear base load plants will be subsequently replaced.

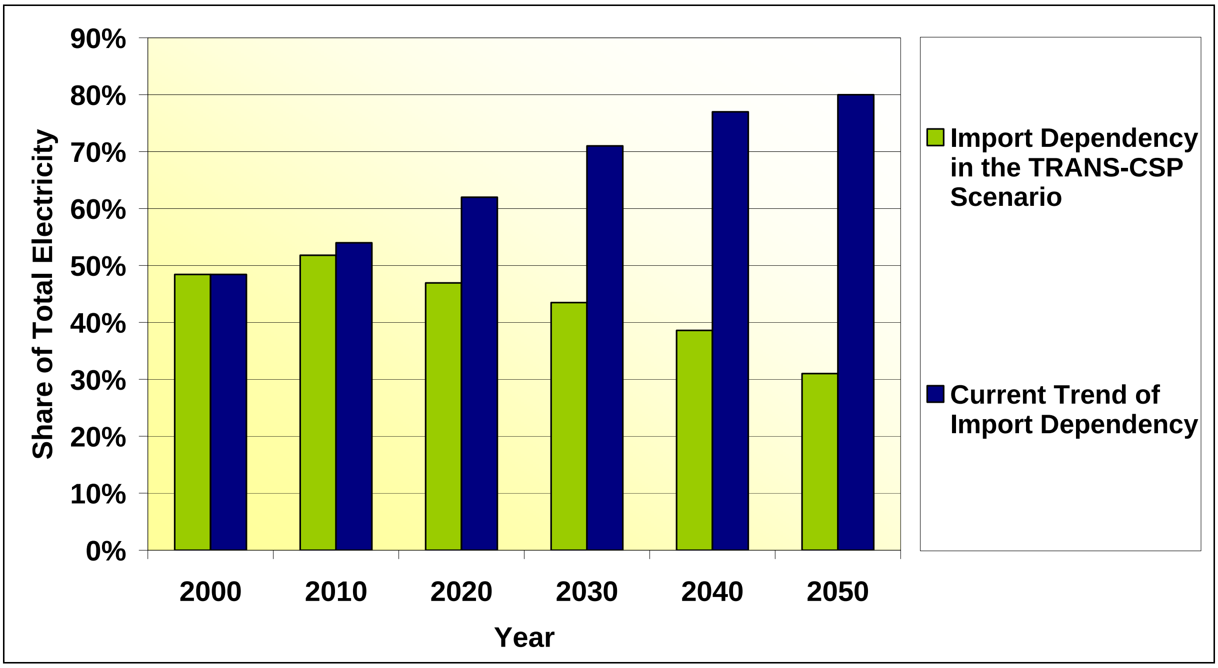


Figure 6: Import dependency inclusive CSP import in the TRANS-CSP scenario compared to the current trend of import dependency in the EU.

The International Energy Agency has calculated a reduction of 0.5 % of the Gross Domestic Income, an inflation of 0.6 % and a loss of 400,000 jobs in the OECD for a rise of the oil price of 10 $/barrel. However, the oil price escalated from 25 $/barrel in 2000 to over 60 $/barrel today, and all other primary fuels including uranium followed this trend, causing a proportionally stronger socio-economic impact. A further rise to 120 $/barrel within the next twenty years is not outside the range of expert expectations. On the other hand, the development of renewables has created over 150,000 new jobs in Germany alone, and its stabilising effect on the electricity cost was recently confirmed by one of the major German utilities.

As shown in Figure 7 for the example of Spain, the introduction of renewables will also add to the average cost of power generation, and thus to the negative impacts of electricity cost escalation. However, during the first twenty years, this impact is relatively small, because the share of renewables is small, too. Most of the cost escalation is due to fuel prices and to new power plant capacity investments. By 2020 most renewables will be cheaper than conventional power, and from that point, the renewable energy shares and their stabilising impact on the electricity cost will become much more noticeable. This demonstrates the danger of policy decisions based on short term scenarios that simply overlook the unique chance of abandoning the present trend of cost escalation, not in the short term – because the necessary investments must still be done – but in the medium and long term. Individual cost learning curves for the different power technologies are shown in Figure 8. To become effective in time, they will require an adequate political and legal framework that allows for the implementation of the necessary power capacities to achieve the related economies of scale.

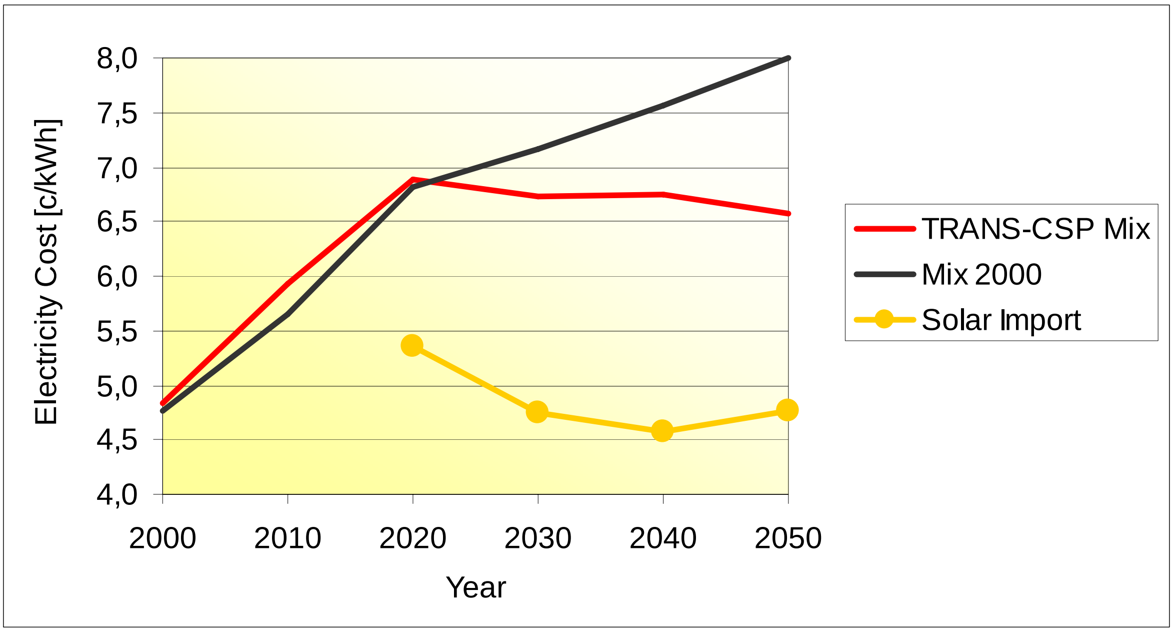


Figure 7: Average cost of electricity from new plants within the TRANS-CSP scenario and within a conservative scenario based on the electricity mix of the year 2000, in comparison to the cost of electricity imports from MENA for the example of Spain. For other countries please refer to the annex of the report.

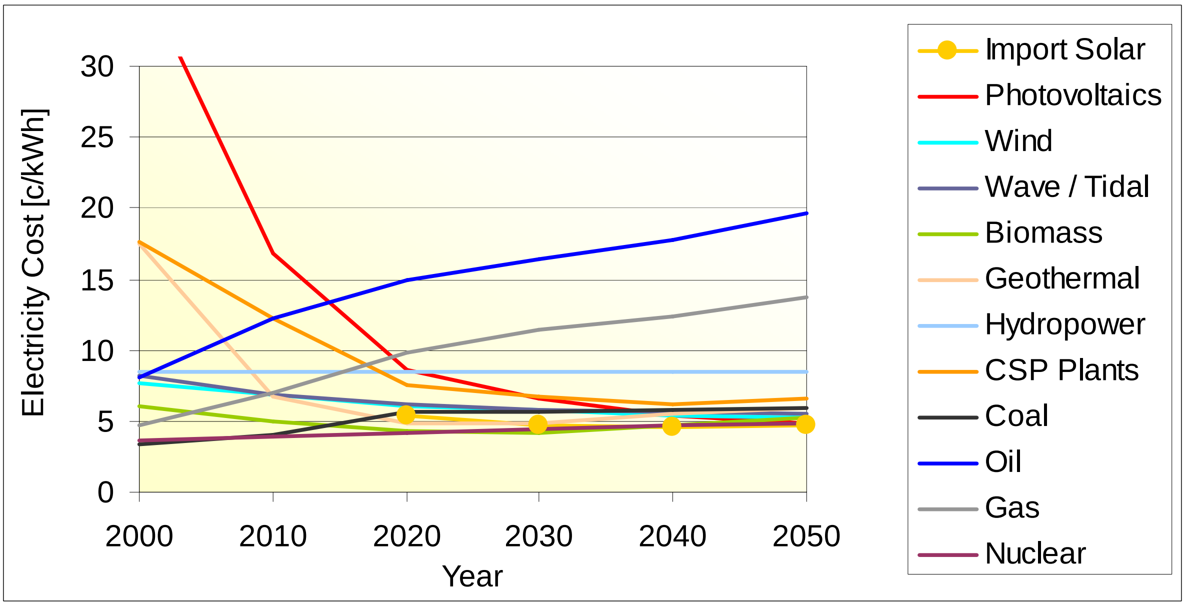


Figure 8: Electricity generation cost of new power plants. In the medium term, renewables are the least cost option for power. The curve "Import Solar" starts in 2020.

Chapter 5 (Environmental Impacts) looks at the emission of carbon dioxide and other pollutants, the energy amortisation time, land use and visibility of the renewable energy mix, and to the specific impacts of the scheduled HVDC overhead lines and submarine cables on the environment and biosphere.

Carbon emissions are effectively reduced to values that are considered as compatible with the goal of stabilising the CO_2 content of the atmosphere at 450 parts per million, as stated by the International Panel on Climate Change. Starting with 1400 million tons of carbon dioxide per year in the year 2000, the emissions are reduced to 350 Mt/y in 2050, instead of growing to 2350 Mt/y in a business as usual case. The final per capita emissions of 0.59 tons/cap/y are acceptable in terms of a maximum total emission of 1-1.5 tons/cap/y that has been recommended by the German Scientific Council on Global Environmental Change (WBGU).

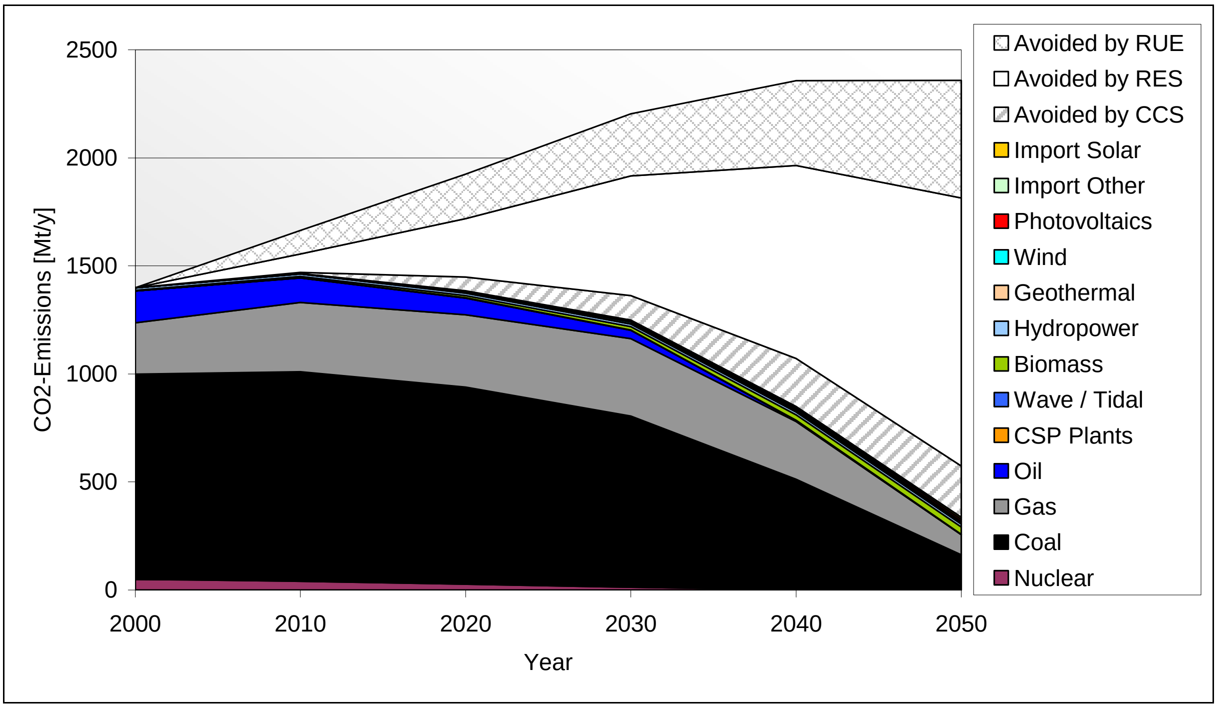


Figure 9: CO_2-emissions from electricity generation in million tons per year for all countries of the TRANS-CSP scenario and emissions avoided by Rational Use of Energy (RUE 22 %), Renewable Energy Source (RES 66 %) and by Carbon Capture and Sequestration (CCS 12 %) with respect to an electricity mix equivalent to that of the year 2000. For single countries please refer to the Annex.

The land used for the renewable energy infrastructure scheduled for 2050 amounts to roughly 1 % of the total land area, which is comparable to the land presently used for the transport and mobility infrastructure in Europe.

Using a geographic information system (GIS) three exemplary HVDC lines were analysed connecting very good sites for CSP generation in MENA with three major European centres of demand. The GIS was programmed to minimize cost, environmental impacts and visibility of the power lines, and we found that the resulting impacts are in an acceptable range. In general, the environmental impacts of HVDC lines are much lower than those of comparable AC overhead lines using conventional technology. Altogether, the TRANS-CSP scenario shows a way to reduce significantly the negative environmental impacts of power generation in Europe, and could also serve as a model for global application.

1 Solar Electricity Transfer from MENA to Europe

The option of producing solar[1] electricity under the ideal meteorological conditions in the sunbelt countries of the Middle East and North Africa (MENA) and transferring part of this electricity to Europe (EU) has been discussed and proposed in many occasions in the past /Knies et al. 1999/, /TREC 2006/, /Asplund 2004/, /Czisch 2005/, /DPG 2005/, /WBGU 2003/.

It also has been proposed to use hydrogen as energy carrier to produce storable renewable energy comparable to fuel oil and natural gas to supply electricity, heat and transportation. However, as brought to the point by /Bossel 2005/, a solar electricity transfer by hydrogen would force three quarters of the solar power generators to work exclusively for covering the energy losses of the hydrogen conversion chain (Figure 1-1). Under this perspective, the use of hydrogen as an energy carrier for solar electricity from North Africa to Europe must be discarded.

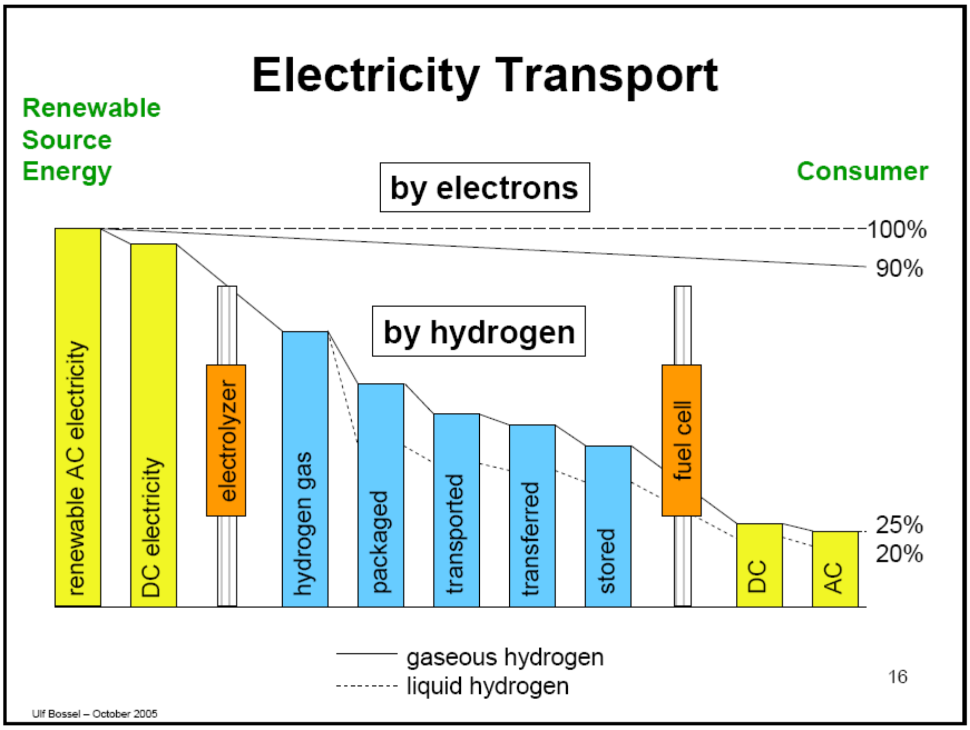


Figure 1-1: Comparing the losses of electricity transport by electrons and by hydrogen /Bossel 2005/

This chapter describes the technical possibilities of solar electricity transfer through the conventional alternating current (AC) electricity grid and by means of an additional future backbone grid based on high voltage direct current (HVDC) technology.

1.1 Present Electricity Transfer Capacities in EUMENA

The interconnected synchronous European network of the Union for the Coordination of Transmission of Electricity (UCTE) supplies about 450 million people with electric energy.

---

[1] This does not exclude wind energy or other renewables, as they will be part of a future electricity mix. However, solar energy is the only renewable energy source that is superior to the expected future electricity demand in MENA and thus the only source that could produce significant surpluses for export to Europe /MED-CSP 2005/.

Europe has a very dense network of high voltage power lines of different capacity, from 132 kV to lines with 750 kV (Figure 1-2). Currently, the union counts 23 member states, 33 transmission providers and 230,000 km in the high voltage network supplying 2300 TWh/y at an installed plant capacity of 560 GW. In wide parts of the UCTE 380 kV is the highest voltage level, whereas transmission voltages of 500 kV, 750 kV and even 1200 kV are used in other countries outside the UCTE, for instance Russia, in order to bridge very long distances. At a voltage over 800 kV it is also spoken of ultra high voltage /Kießling et al. 2001/.

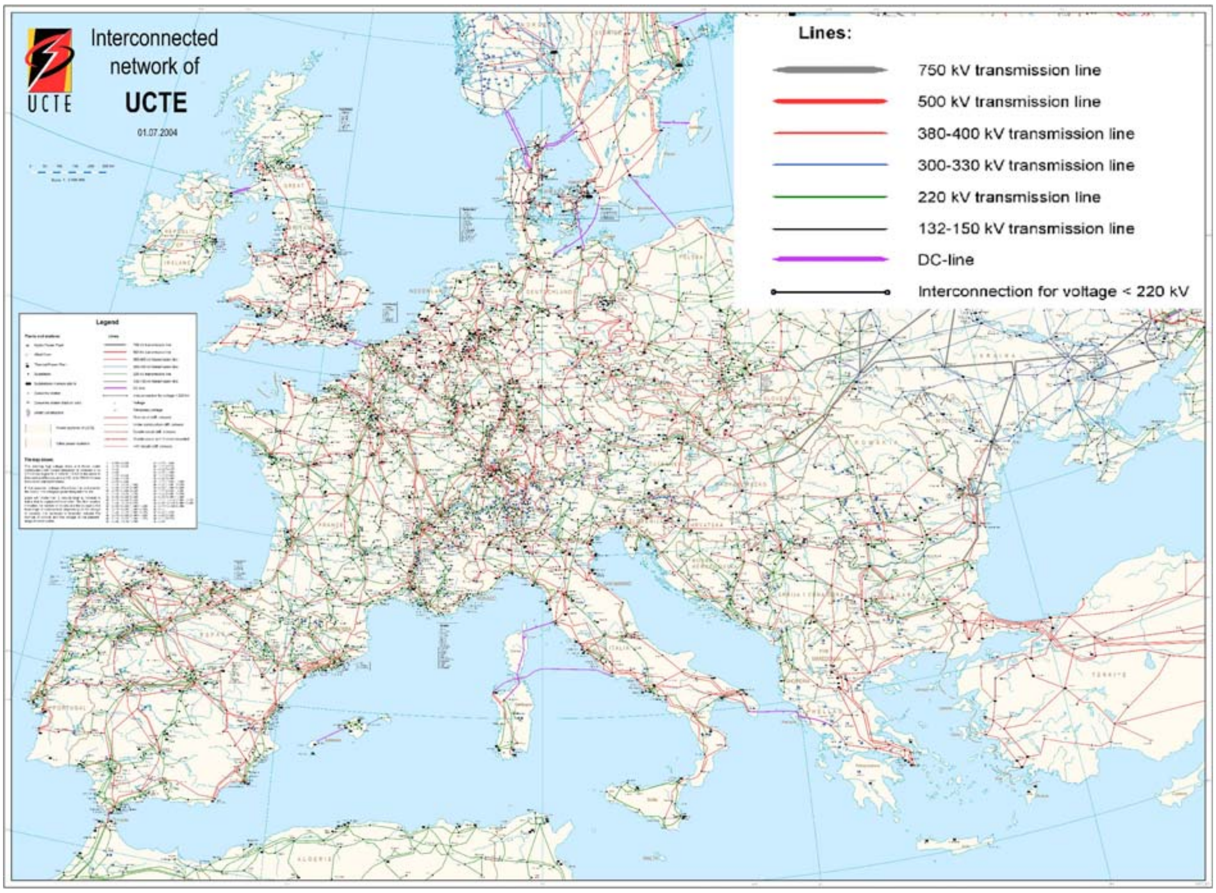


Figure 1-2: Present interconnected network of UCTE and neighbouring regions /UCTE 2005-2/.

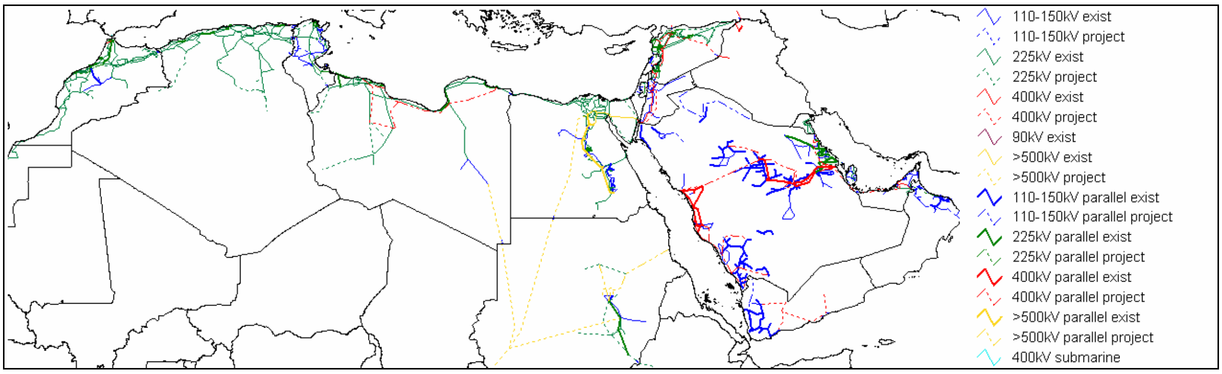


Figure 1-3: Present interconnected network of the North African and Middle East countries /NERC 2004/.

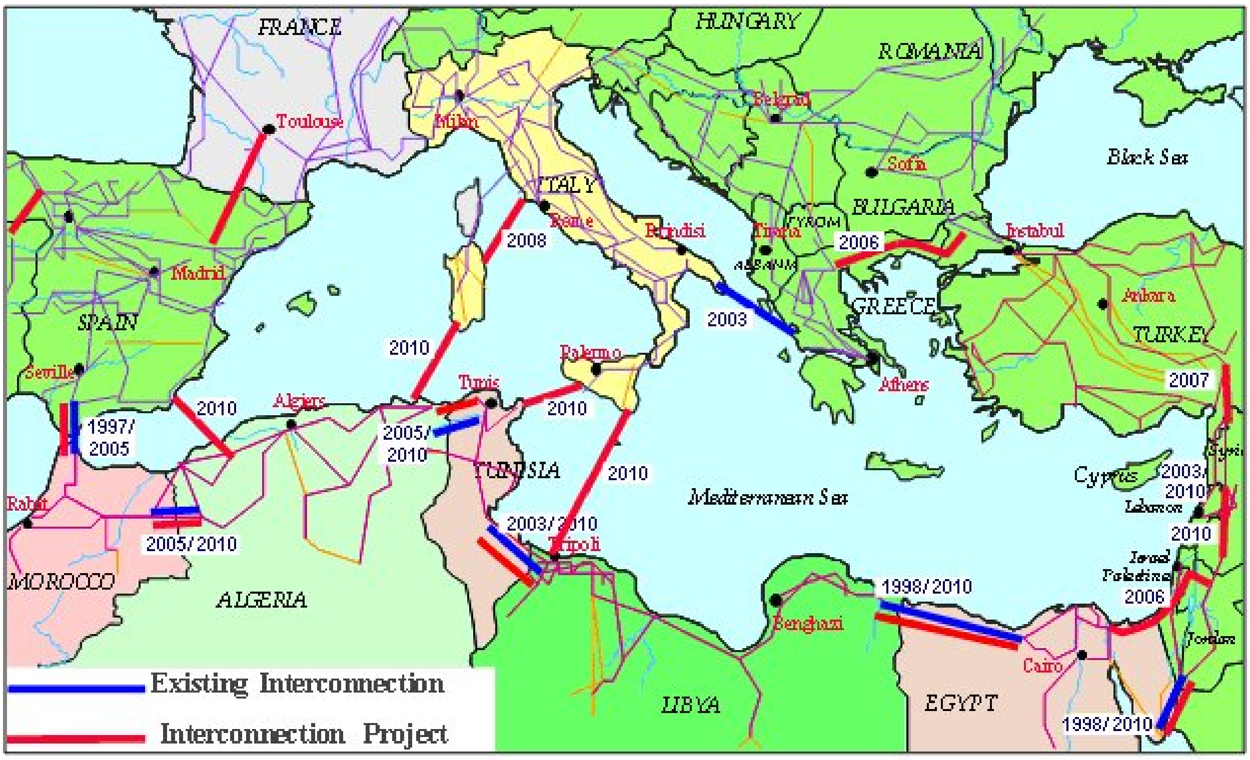


Figure 1-4: Networks and interconnection projects until 2010 in the Mediterranean region /Hafner 2005/

Project	Thermal limit [A]	Length [km]	Voltage [kV]	Design	Year of operation
Spain-Morocco	960	28,5	400 AC	Submarine cable	2005
Spain-Algeria	2000		500 DC	Submarine cable	2005/2010
Italy-Algeria			400/500 DC	Submarine cable	2010
Italy	Tunisia	500	500 DC	Submarine cable	2010
Algeria-Morocco	2 x 1720	250	220 (400) AC	Submarine cable	2003/2005
Algeria-Tunisia	1720	120	220 (400) AC	Submarine cable	2004/2010
Tunesia-Libya		210	400 AC	Submarine cable	2010
Libya-Egypt			400/500 AC	Overhead Line	2010
Reinforcement (ELTAM)			400 AC	Overhead Line	2010
Egypt-Jordan	880	20	500/400 DC	Submarine cable	2008
Egypt-Palästina	1440		220	Overhead Line	2005
Palästina (WB-Gaza)	1440		220/240	Overhead Line	2006
Palästina-Jordan	1450		400	Overhead Line	2006
Jordan-Syria		210	400 AC	Overhead Line	2010
Lebanon-Syria	1660	22	400 AC	Overhead Line	2003/2010
Syria-Turkey	1440	124	400 AC	Overhead Line	2007
Turkey-Greece	2165/2887	250	400 AC	Overhead Line	2010

Table 1-1: Planned interconnections between Mediterranean neighbouring states /OME, 2003/.

Both the British island network and the Scandinavian network of NORDEL are linked to the UCTE network by submarine cables. Since 1994 some European states have been able to make use of the major hydropower potentials of Scandinavia. The CENTREL states have been connected to the interconnection network since 1995 and have been full members only for short time. Since 1997 the interconnection with the Maghreb states has been realized by a submarine cable, through which approximately 1.5 TWh/y have been exchanged. Rumania and Bulgaria have been the latest members since 2003. UCTE 2 as a former part of the synchronous network was separated by the war in former Yugoslavia in the year 1991 and has been integrated again recently.

The electricity grid in North Africa and the Middle East is much less dense than in Europe, and – following human activities – concentrated to the coastal regions and the Nile valley (Figure 1-3). The major part of the existing MENA network is based on 220 kV. Only between Egypt, Jordan and Syria and between several Mediterranean neighbouring states of the EU exist 380 kV lines. Since 2003 there has been a single 630 kV interconnection between Libya and Tunisia. The so-called 'MED-Ring-Project' of the South Eastern Mediterranean Countries (SEMC) and the North Mediterranean Countries (NMC) is aimed at closing the networks around the Mediterranean Sea (Figure 1-4 and Table 1-1). Final closing of the ring by coupling the Turkish block and the UCTE block will result from the connection between Syria and Turkey scheduled in 2006 /Eurelectric 2003/. The ring will have an overall net transfer capacity of about 400 MW in 2010.

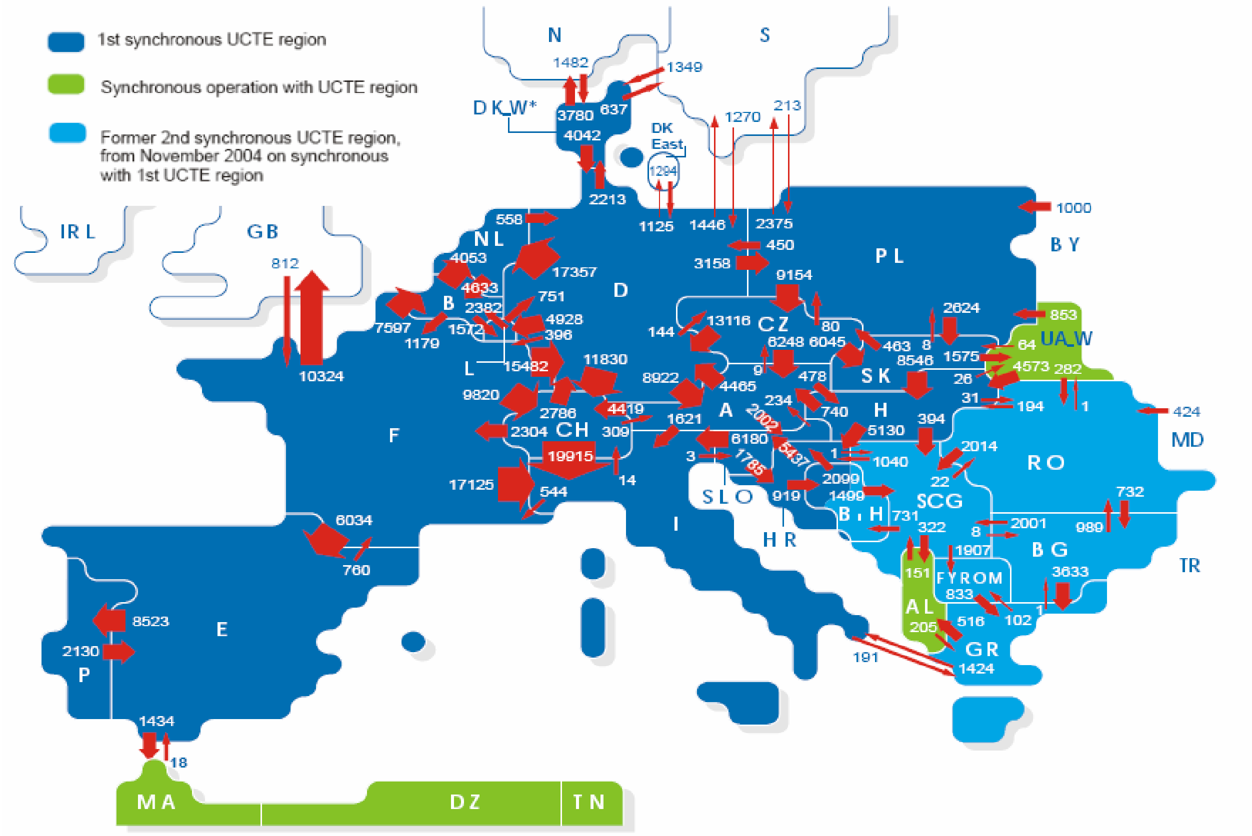


Figure 1-5: Physical electricity exchanges in GWh/y in the UCTE grid in 2004 /UCTE 2005-1/

The benefits of such a large grid interconnection are the gain of additional reserve capacity and the compensation of local power and plant outages respectively. The so-called 'n-1 criteria' guarantees a secure supply by substituting one broken plant for another intact. Within a large grid there is a higher utilisation of the single power plants, and the electricity exchange over national borders is easier (Figure 1-5). In the year 2004 electricity exchanges inside the UCTE interconnection network amounted to approximately 270 TWh for import and 281 TWh for export /UCTE, 2005a/. The largest amounts of electricity are transferred from Germany to Netherlands and from France and Switzerland to Italy, ranging in the order of 17-20 TWh/y.

Looking at the net power transfer capacities in northern direction (Figure 1-6) it becomes clear that the capacity of the conventional electricity grid for solar electricity from North Africa is very limited. Although there are very large transfer capacities across the borders of Switzerland, there are limitations within the rest of the grid, with about 2500 MW in the central European region and about 400 MW limiting the interconnections between Europe and MENA. Even assuming that MENA will expand in the medium and long term it's electricity grid to achieve values comparable to those in Europe today, this would restrict the net transfer capacities to the order of 3 GW or 15 TWh/y (or two times this value accounting for both the Western and Eastern interconnection). In view of the required capacity of around 600 GW or 2500 TWh/y in terms of annual electricity consumption, a solar electricity transfer from MENA to Europe in the medium and long term through a mature, conventional AC electricity interconnection would therefore be restricted to about 1 % of the European demand. If we assume that all six EUMENA interconnections shown in Figure 1-4 would be empowered to a net transfer capacity of 2500 MW each, solar electricity transfer through the common AC grid could reach about 3.5 % of the European demand under the condition that those links would exclusively transfer electricity from South to North and not be congested by other uses.

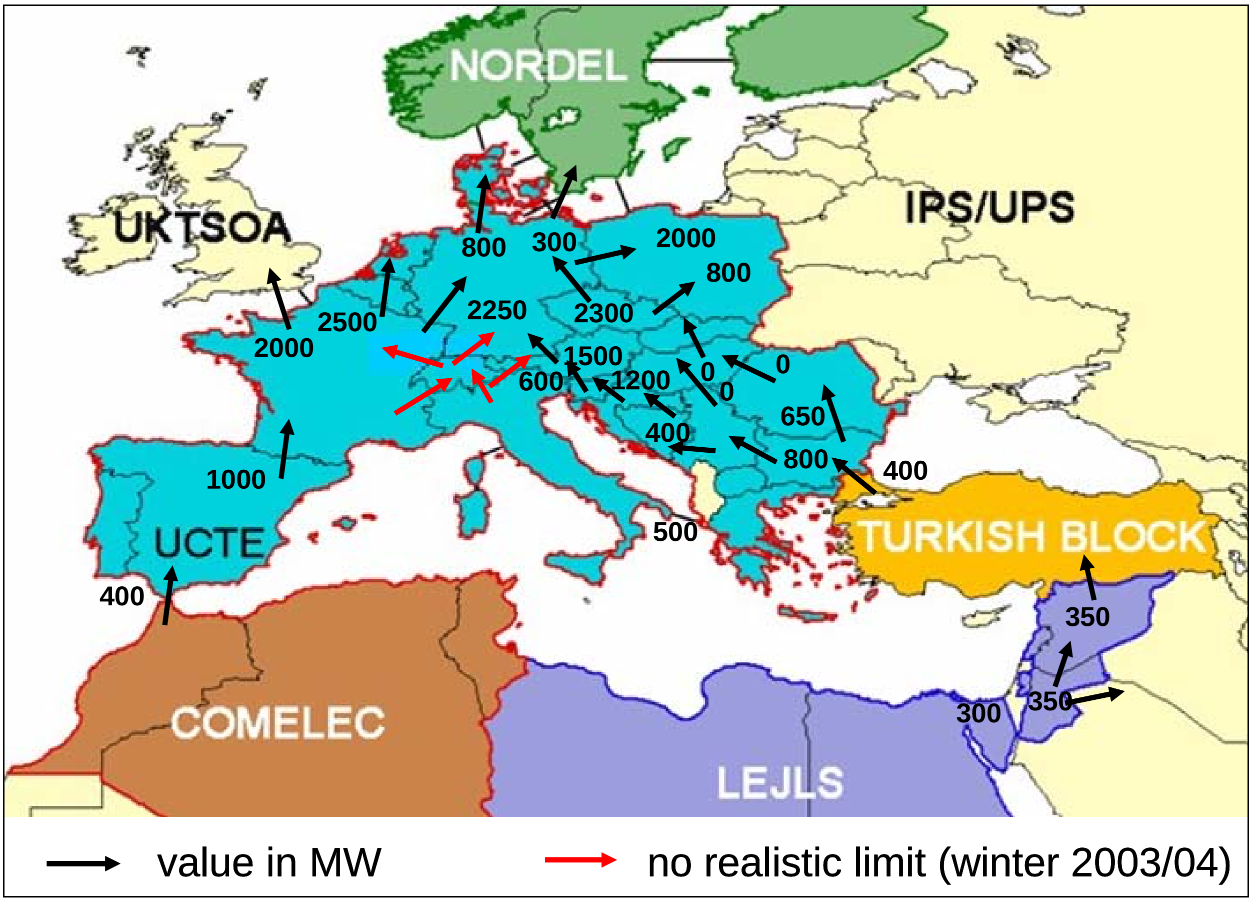


Figure 1-6: Present net transfer capacities in EUMENA in Northern Direction. Source: /etso 2004/, /Eurelectric 2003/. The bottleneck of transfer capacity from MENA to Europe is at present about 400 MW. Assuming that EUMENA would achieve a transfer capacity standard as Central Europe today, it could increase to about 2500 MW by 2050. This would allow an annual electricity transfer of less than 15 TWh/y through each north-south interconnection.

1.2 High Voltage Alternating Current Transmission (HVAC)

In the European high voltage area electric energy is mainly transmitted in the form of three-phase alternating current, whose direction and amount changes with a sinusoidal periodicity. The frequency of the European electricity supply network amounts to 50 oscillations per second, which means, that the current flows 50 times per second in the same direction. Here, the current is also called three-phase alternating current because of three time-shifted phases. Single-phase alternating current is mainly applied in public railway traffic.

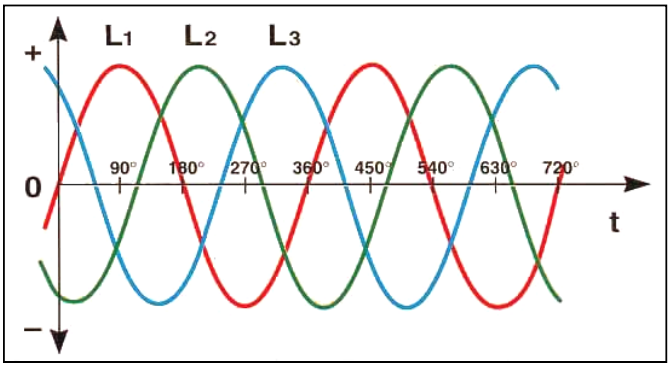


Figure 1-7: Three-phase alternating current /Leuschner 2005/.

Alternating current is produced in a power plant by a generator, whose magnet is driven mechanically and passes three 120°-shifted coils during one rotation. Accordingly, the induced alternating currents are also 120°-phase-shifted. Each current is forwarded by the respective conductor. Because with symmetrical load the sum of the three currents amounts to zero at every moment, there is no need to have a return wire like in case of single-phase alternating current.

The decisive advantage of three-phase alternating current is the simple regulation of voltage and frequency. The voltage can be stepped up and stepped down with few losses by a transformer and everywhere it is possible to branch off electrical power with the same. In addition, engines driven by alternating current can be produced small, compact and cheap /Leuschner 2005/.

One disadvantage is that the synchronicity of producer and consumer voltage is absolutely necessary. Otherwise, unwanted swings could lead to serious problems with the network stability. The failure of one conductor results in the total failure of the whole circuit.

Losses of alternating current

The current-carrying conductor produces a magnetic field around itself. If it concerns alternating current, this magnetic field changes periodically and induces a voltage. Thus the power line behaves like a coil and puts up resistance to the alternating current through self-induction, that in turn causes a decrease in current. This is called the inductive reactance when the voltage runs in front of the current at a maximum phase angle of 90°.

In the opposite case alternating current is intensified because of the capacitive reactance so that the voltage runs after the current. The problem of storage of electric charges especially occurs with cables, which behave like a condenser due to their multi-layered structure.

These resistances cause no heat losses in contrast to the Ohmic resistance, but they create a un usable reactive power which swings permanently between generator and power source and reduces this way the effective power capacity.

The maximum transferable load and transmission length are more limited by the drop of voltage along the line than by the thermal power rating of the conductor. That is why in practice installations for the compensation are used every 600 kilometres /Rudervall et al. 2000/.

Losses of Overhead Line

In addition to current-dependent losses there are also voltage-dependent losses in the form of gas discharges in areas of heavy curved surface and high field strength. These requirements are fulfilled by the conductors. If then the electric field at the conductor surface (fringe field) exceeds the disruptive field resistance of air, the ionization of air molecules is possible. Electron-impact ionization can happen if previously released electrons hit neutral molecules. The energy needed for that is taken from the electric field.

Such corona discharges can be perceived as a luminous appearance and crackling sounds. Therefore bundle conductors restricting the field strength at the fringe are utilized from 110 kV upwards. At the same time the transferable load increases because the cross-section of the conductor is apparently enlarged by overlapping of the single fields.

In the annual mean the corona losses amount to approximately 2-3 kW/km for a 400 kV-system /Laures 2003/. /Knoepfel 1995/ states 1-10 kW/km for a 380 kV system and 2-60 kW/km for a 750 kV system that strongly depends on the respective atmospheric conditions and can be neglected in this order of magnitude.

Altogether losses in high voltage AC-systems come to 15 %/1000 km (380 kV) and 8 %/1000 km (750 kV) respectively. In addition to this, each transformer station can loose 0.25 % of the energy /Knoepfel 1995/.

Losses of Ground Cables

In case of ground or sea water cables it is also distinguished between current-dependent losses, which only appear while electricity flows, and voltage-dependent losses, which appear under the effect of an electric field in the isolation and therefore are described as dielectric losses.

Heat losses in the conductor and additional losses in the metallic sheath, screen and armour belong to current-dependent losses. Current heat losses increase with the power of 2 with the current. For that reason it is generally aimed at keeping the current as small as possible by raising the voltage. Nevertheless, there are ohmic heat losses caused by the conductor material, which increase proportionally to the transmission length and furthermore depend on the conductor cross-section and the operational temperature. These current heat losses increase more if the frequency rises due to self-induced turbulent currents in the magnetic field of the conductor. As they are directed to the opposite of the operational current, this current is displaced at the edge of the conductor (‘Skin-Effect’). Thus it cannot use the whole cross-section of the conductor and, in addition to this, the risk of exceeding the maximum allowable temperature of the conductor increases because of the high current density in the outer rim.

Moreover, turbulent currents can be generated by magnetic field emissions of adjacent cables, which become more intense with an increasing distance of cables (‘Proximity-Effect’). Here a triangle arrangement of phases has a better effect than side by side laying of cables.

Additional losses can occur in the residual metallic components of the cable. Induced current losses (longitudinal-voltage induction) and turbulent current losses in the jacket and the same losses together with magnetisation losses in the steel armour belong to it. Applicability of an alternating current cable is limited by two aspects /Peschke, Olshausen 1998/:

Maximum transmission length

The capacitive charging current increases proportional to the cable length and overlays the actual effective load at the same time. This is especially the case of cables with a multi-layered isolation. The capacity of a cable rises with the increasing relative permittivity and rated voltage. The maximum transmission length of a 380 kV-cable with 1000 mm² copper conductor and paper isolation amounts to just 35 km due to the capacitive charging current. A VPE[1]-cable has a reach of 50 km instead. If dielectric losses are included, this length is more reduced. The resulting reduction of the voltage endangering stability along the line must be counteracted by compensational measures (which is of course very difficult for underwater cables).

Maximum transmission capacity

The transmission capacity only increases up to a certain voltage level, which depends on the dielectric properties, and after that decreases again. The higher the dielectric loss and the smaller the heat removal, the sooner the economic cut-off voltage is reached. Accordingly, the cut-off voltage of a 1600 mm² copper conductor with paper isolation comes to approximately 500 kV and with a VPE-isolation to more than 1200 kV. The transmission capacity of an underground cable is particularly limited by the removable heat lost. On optimum conditions a maximum heat removal rating of 90 W/m can be realized. Hence there is a thermal breakeven performance of approximately 1000 MVA for an oil-paper cable with 2500 mm² copper conductor and approximately 1450 MVA for a VPE-cable at a transmission voltage of 500 kV. Altogether an AC-cable system can only reach 50 % of the capacity of an overhead system in spite of lower heat losses. For the same transmission capacity it calls for a double cable system, an artificial cooling or a completely different transmission technology.

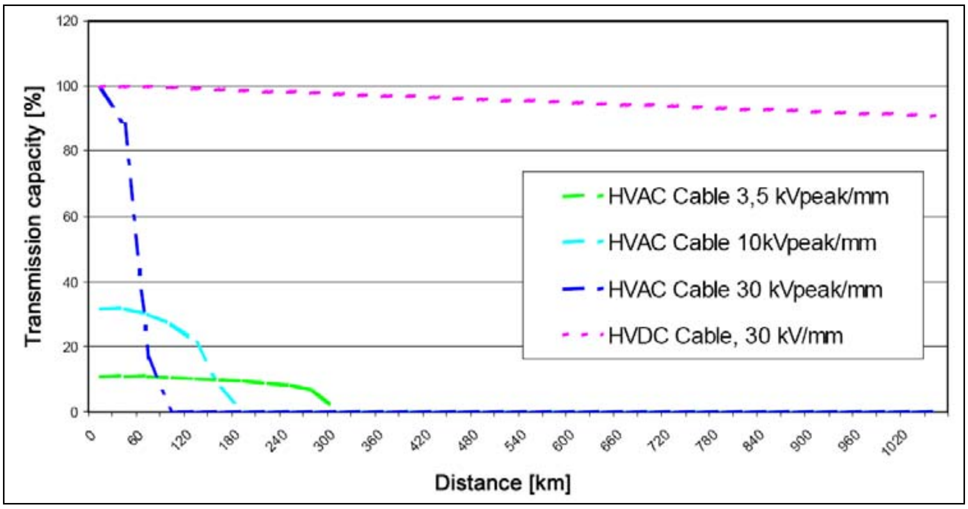


Figure 1-8: Comparison of transmission capacities of AC- and DC-cables (Source: Asplund, o. J.).

Figure 1-8 shows how the transmission capacity of an AC sea cable is rapidly reduced with increasing distance. Moreover, it becomes clear that with an AC-cable at a lower voltage it is possible to bridge long distances, but only transmitting less energy. Therefore compensational measures would be required, which are not realizable with submarine cables in practice.

---

[1] isolation with polyethylen grid structure

1.3 High Voltage Direct Current Transmission (HVDC)

Direct current flows continuously in one direction with a constant amperage. It can be generated by electrochemical processes or by rectification of alternating current. In case of rectification the amount of amperage can change periodically because of a rest of ripple.

Capacity and losses

The utilization of direct current has diverse advantages if compared with alternating current. First of all the transmission length is only limited by ohmic resistance. The cheaper the power input is, the less important the heat losses are. Besides, there are no capacitive, inductive or dielectric losses which would result in a drop of voltage along the line. Current displacements at the edge of the conductor, which are typical for alternating current, do not matter as well so that the whole cross-section of the conductor can be used up to the thermal breakeven point.

The circumstance that no reactive power is transmitted with direct current causes a further increase in power by transmitting sheer effective power. Reactive power must only be provided for the inverse transformation by the rectifier.

In comparison with a three-phase AC-system of three conductors a high voltage direct current transmission requires only two conductors (bipolar case) or just one conductor (monopolar case) while the current flows back via earth (Figure 1-9). This leads to lower costs for the lines, especially at long distances. The requirements on the line also turn out lower regarding pylon height and width.

If one conductor of a bipolar HVDC fails, a short-term back current is possible for approximately 10 minutes via earth while the transmission capacity is halved. This way much more time is available to bridge areas concerned than in case of a conventional system where failures occur within split seconds /Peschke, Olshausen 1998/, /Schymroch 1985/.

Stability and controllability

HVDC can contribute to security of the network stability, for instance by connecting power plants with a high energy rating. Because no short-circuit currents can be transmitted, the short-circuit current is equal the nominal current in fact.

A direct current system has no problems with stability in principle and is quickly adjustable via rectifiers. However, rectifiers cannot be overloaded. The controllability of the power flow in amount and direction is gaining increasing importance in decentralized electricity markets. Since the source voltage and the voltage at the load are allowed to be asynchronous, HVDC as back-to-back station is predestined to couple networks with different frequencies /Schymroch 1985/.

Disadvantages

Direct current has the disadvantage of not being directly transformable to another voltage, by which the erection of networks with different voltage levels becomes difficult. Besides, it is not easy to switch off the current with conventional switches at a high network voltage. A subsequent branching of power is also difficult in an existing direct current system and is only possible via an additional rectifier, which shows higher investment costs and a higher space requirement than usual power substations /Beck 2000/.

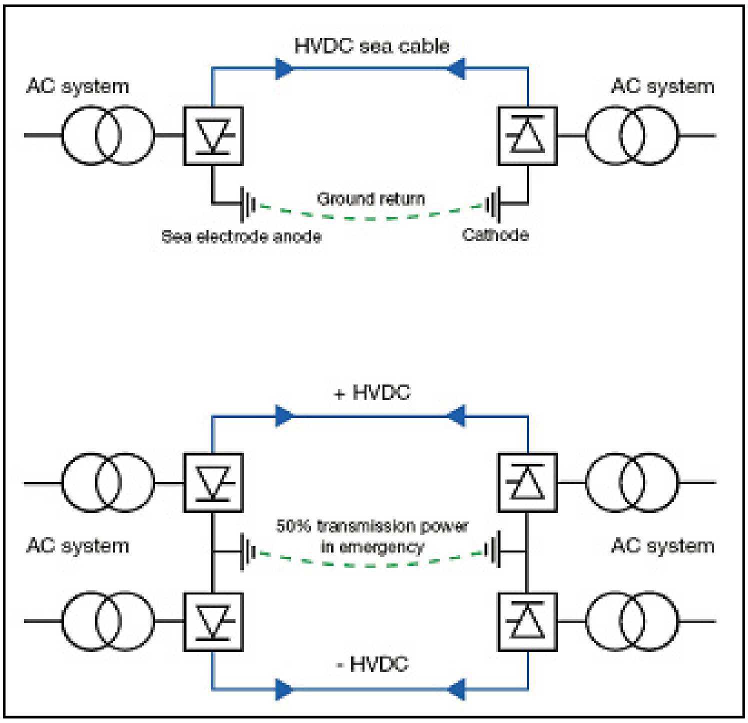


Figure 1-9: Schematic diagram of the interconnection of a monopolar (above) and bipolar HVDC system (below) with the conventional AC grid /Söderberg, Abrahamsson 2001/.

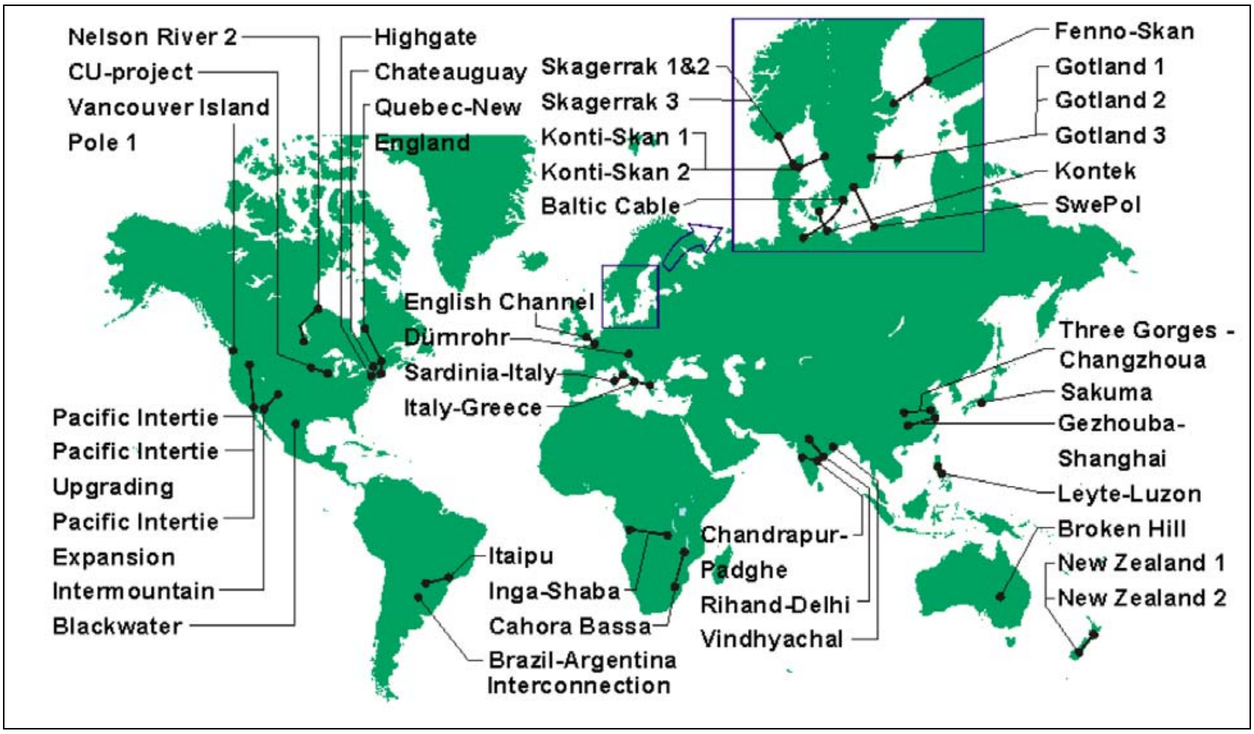


Figure 1-10: World wide HVDC transmission lines cumulate today to a total cpacity of over 75 GW in more than 90 projects. Put in one line, they would reach around the globe. Many of them connect renewable power sources from hydropower (e.g. Inga-Shaba, China, Brasil, New Zealand) or geothermal power (e.g. Phillipines) with distant centres of demand. Others are used to interconnect countries over sea (e.g. SwePol, Baltic Cable, Italy-Greece, Sardinia). (Source: www.abb.com).

Nowadays a power of about 75 000 MW is transmitted by HVDC lines in more than 90 projects all over the world (Figure 1-10 and Table 1-2). Nevertheless, the potential of this transmission technology is not fully utilized. For the long-distance transmission of electricity with overhead lines the voltage level will increase at 800 kV in the near future. This means that one pole will have a capacity of 2500 MW. In this context it is also spoken of ‘Ultra High Voltage Direct Current’ (UHVDC).

The development to higher transmission voltages is also foreseeable in the ground and sea cable manufacture. Thus a bipolar ±600 kV mass-impregnated cable would be able to transfer 2000 MW. Oil-pressure cables would be able to transfer 2400 MW at the same voltage level. Indeed, they can only be used for middle distances. Lately, HVDC-light cables are built in the range of ±150 kV which are also able to transfer 700 MW (bipolar case) over long distances /ABB 2005/.

Hence, the following applications for HVDC are feasible:

- 2-point transmission over long distances
- Utilization as submarine cable
- Utilization as underground cable in congested areas
- Connection of asynchronous networks via back-to-back station
- Connection of power plants
- Multi-terminal system (> 2 stations)

HVDC/country	**Design*)**	**Start of operation**	**Power [MW]**	**Voltage ±[kV]**	**Length [km]**	**System**
SACOI/Sardinia-Corsica-Italy	**SC, O**	**1967**	**300**	**200**	**423**	**Bipole, Multi-terminal**
Cahora Bassa/ Mozambique-South Africa	**O**	**1977-79**	**1930**	**533**	**1420**	**Bipole, 2 lines**
Inga-Shaba/Congo	**O**	**1982**	**560**	**500**	**1700**	**2x Monopole**
Itaipu/Brasilia	**O**	**1984-87**	**6300**	**600**	**800**	**Double-Bipole**
Québec-New England/Canada-USA	**O**	**1990-92**	**2000**	**450**	**1480**	**Bipole, Multi-terminal**
BalticCable/Swe-Ger	**SC**	**1994**	**600**	**450**	**250**	**Monopole**
SwedPol/ Sweden-Poland	**SC**	**2000**	**600**	**450**	**260**	**Monopole, Metallic return**
Italy-Greece	**UC, SC, O**	**2001**	**500**	**400**	**310**	**Monopole**
Murraylink/Australia	**UC**	**2002**	**220**	**150**	**177**	**Bipole, HVDC Light**
NorNed/Nor-NL	**SC**	**2007**	**700**	**450**	**580**	**2x Monopole**

*O – overhead line, SC – submarine cable, UK – underground cable

Table 1-2: Selection of HVDC Links /ABB 2005/

1.4 Performance, Economy and Impacts of High Voltage Transmission

The cost of transferring electricity is dominated by the investment cost of the transmission lines and by the electricity losses during transmission. Table 1-3 compares the losses and investment cost of AC and DC transmission lines at comparable voltage levels for a transmission of 5 GW.

At present, overhead lines predominate since the cost of an overhead line amounts to only 15 - 20 % of the cost of a ground or sea cable /Schlabbach 2003/. The transmission losses of HVAC overhead lines are roughly twice as high as those of HVDC. The cost of overhead lines is similar for the lower voltage level, but at 800 kV HVDC lines are much less expensive than comparable AC lines. On the other hand, rectifier stations of HVDC links are considerably more expensive than the transformer stations of AC systems. Therefore, for shorter distances and lower voltages AC is often the preferred choice, while HVDC lines are applied at distances well over 500 km (Figure 1-11). The high losses and cost of HVAC sea cables limits their applicability to about 30 kilometres, however HVDC is preferably applied for this and for longer distances.

Parameter	**Unit**	**HVAC**		**HVDC**	
Operation Voltage	**kV**	**750**	**1150**	**± 600**	**± 800**
overhead line losses	%/1000 km	8%	6%	5%	2.5%
sea cable losses	%/100 km	60%	50%	0.33%	0.25%
terminal losses	%/station	0.2%	0.2%	0.7%	0.6%
overhead line cost	M€/1000 km	400 - 750	1000	400 - 450	250 - 300
sea cable cost	M€/1000 km	3200	5900	2500	1800
terminal cost	M€/station	80	80	250 - 350	250 - 350

Table 1-3: Cost and performance parameters of high voltage alternate current and direct current transmission systems from different references according to /May 2005/ and own calculations for 5000 MW rated transmission capacity.

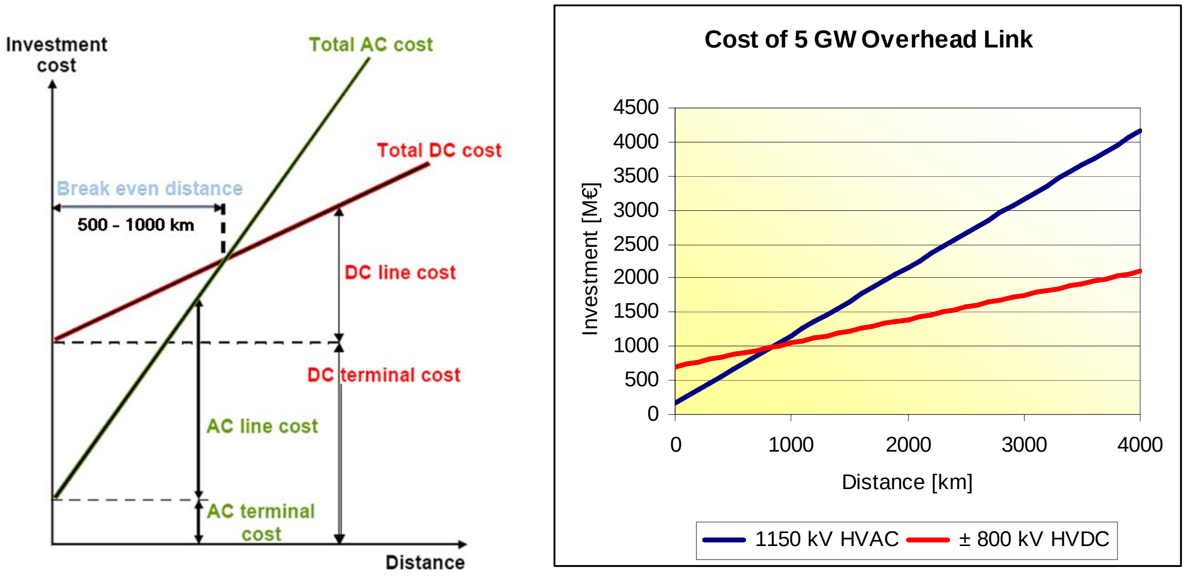


Figure 1-11: Comparison of AC and DC investment costs /Rudervall et al. 2000/ (left) and cost model used here for a 5 GW interconnection with overhead line (right). Break even point is at 830 km distance.

The so-called ‘Break-Even-Distance’ terms the shortest distance where the investment costs of a direct current transmission are identical with the costs of an alternating current transmission. It depends on the transmission capacity and topography of the area in detail /Heuck, Dettmann 2002/. In the beginning high investment costs of the rectifier make a significant difference compared with the lower cost of transformers. With an increasing transmission length the total costs of HVAC are affected by the higher costs for conduction and network losses so that many advantages result from the use of HVDC from the ‘Break-Even-Point’ upwards. In addition, the maximum transferable loads are not restricted by the thermal limit of the conductors, but by the guaranty of a stable voltage along the line. In contrast in case of HVAC, additional costs must be added for compensational measures realized every 600 km /Rudervall et al. 2000/.

In the TRANS-CSP model the following assumptions have been made for costing HVDC:

- Voltage ± 800 kV, Unit Capacity 5 GW
- Overhead Line Investment 350 M€/1000 km
- Sea Cable Investment 2500 M€/1000 km
- Converter Stations Investment 350 M€/Station
- Overhead Line and Cable Losses 2.5 %/1000 km, Stations 0.9 %/Station
- Economic Lifetime 40 years
- Discount Rate 5 %/y
- Operation & Maintenance Cost 1 % of Investment per year.

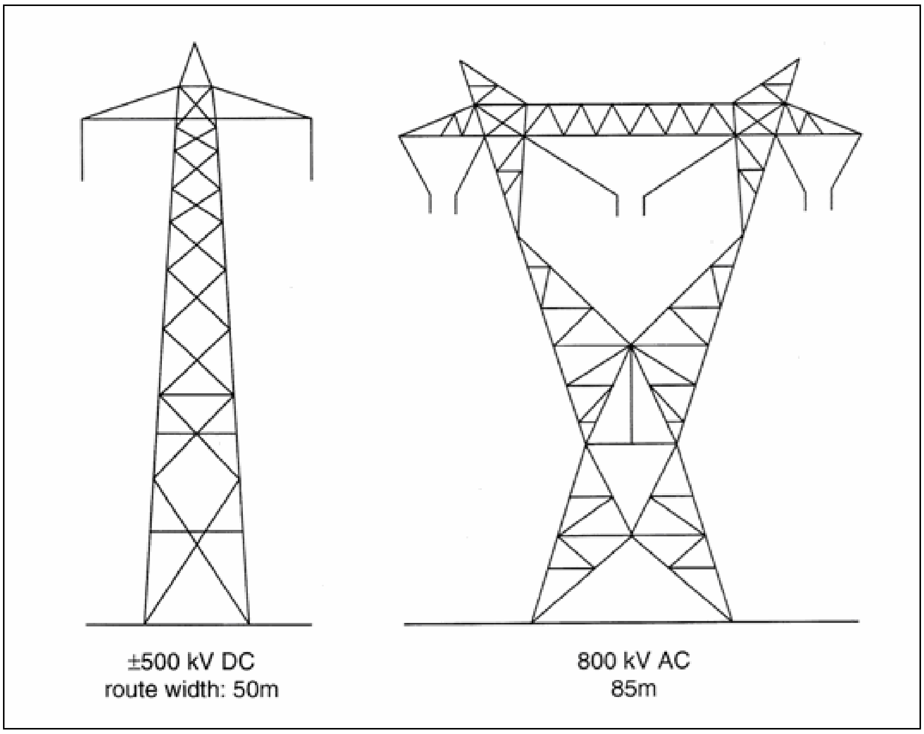


Figure 1-12: Typical pylon constructions of a HVAC and HVDC overhead line (Source: Arrillaga, 1998).

The space requirement of an overhead line can be subdivided in a permanent use while the line is operated, and a temporary use during the construction phase.

Areas are occupied permanently by the fundament of pylons, for example approximately 22 m² by the massive concrete fundament of a ton mast medium-sized. A typical Danube mast with four pedestal fundaments can have a local space requirement of nearly 64 m². /Knoepfel 1995/ states an enclosed area of 50 m²/km for a ±500 kV DC pylon and 100 m²/km for a 750 kV AC pylon. Further space requirement through transformers and rectifiers must be added. A rectifier station with a capacity of 5000 MW requires an area of 800 m x 700 m (560,000 m²) /Normark 2005/, whereas a medium-sized transformer station takes up 10,000-15,000 m².

Moreover, there are time-limited places for barrels and winches every 2-3 km nearby the line and repositories every 20 km with a size of 5000 - 6000 m² where wires, isolators and armatures can be stored. Here a reserve of oil absorber of at least 100 kg is also held /APG 2004/. In addition to this, there is a temporary working stripe with a width of 5 m per month along the line /Knoepfel 1995/.

The actual width of the line depends on the pylon construction, the voltage level and the correlative safety distance, which must be observed between the conductor wires themselves and the surrounding area. For reasons of safety a ±800 kV double dipole ought to be separated into two lines. Typical pylon constructions for this voltage level and the associated width of the line are shown in Figure 1-12.

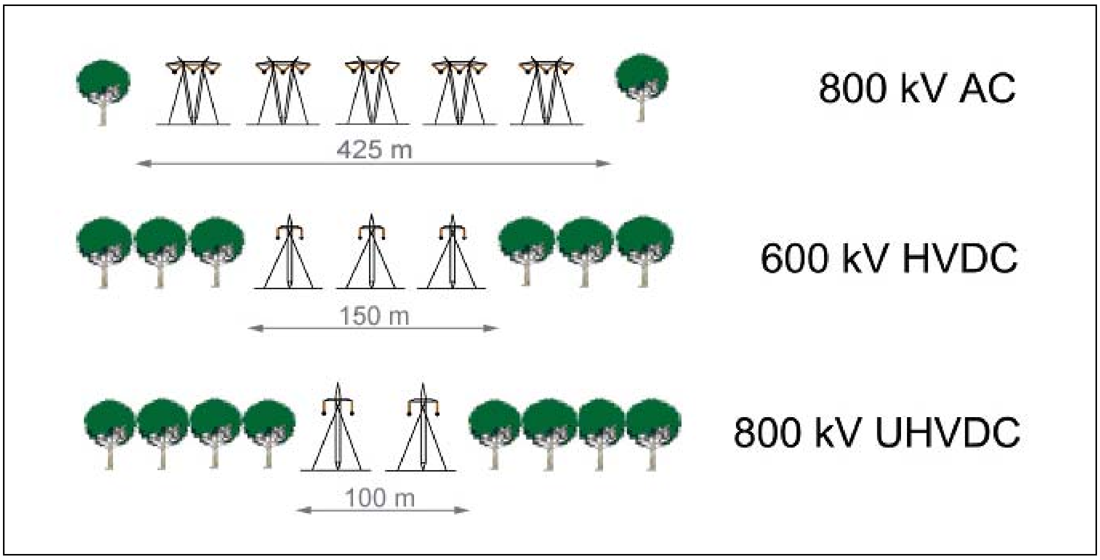


Figure 1-13: Comparison of the required number of parallel pylons and space to transfer 10 GW of electric capacity. Adapted by /May 2005/ from /Asplund, 2004/

For a given transfer capacity, the space requirement of HVDC overhead lines can be four times lower than that for HVAC lines (Figure 1-13). While a 800 kV HVAC line would require a width of 425 meters over the total length of a power link of 10 GW, a HVDC line of the same capacity would only require a band of 100 meters width. This leads to considerable differences in the environmental impact of both technologies (see also Chapter 5).

As a conclusion, High Voltage Direct Current (HVDC) technology is the best choice for long distance solar electricity transfer from MENA to Europe, bridging several thousand kilometres with electricity losses of only 10 – 15 % and providing stable, high capacity transfer at reasonable cost and with low environmental impact.

1.5 The Vision of EUMENA Electricity Highways

The Swedish island of Gotland is situated in the middle of the Baltic sea. It earlier got all its power though two HVDC cables from the Swedish mainland. Actually, Gotland had in 1954 the first commercial HVDC project in the world.

As the wind conditions on the island are excellent a large number of wind power stations were built on the southern part of the island. This made it possible to reduce electricity imports. However, the AC network on the island was not designed for feeding power from the south to the centre of the island. This could have been solved by constructing a new AC line, but due to the crossing through a bird protection area it was judged to be less suitable with overhead lines. Instead a HVDC system using underground cables was built (Figure 1-14). This solved the problem to transmit the power and made very important contributions to stabilize the voltage in the AC network on the whole island. With this reinforcement of the AC grid on Gotland wind power can be further expanded on the island. In fact, already today it happens that more power is produced by the wind mills on the island than what is consumed (there are around 50 000 inhabitants) and the surplus is exported to the mainland. So Gotland already today could be taken as an example of what might in happen in the future on international level /Asplund 2004/.

HVDC has also attracted interest in Denmark, both for transmitting large amounts of offshore wind power, but also to supply the wind generators with reactive power. As most wind generators are asynchronous machines, they consume a lot of reactive power and this can cause voltage stability problems in the generator end. In the other end where the transmission line is connected to the AC grid, there might also be problems as the short circuit power of that point is usually not very strong.

It is also favourable if one can adopt the frequency of the wind generators to the wind speed as this increases their efficiency. All this together led to the construction of a demonstration plant in conjunction to a small park of four wind generators. This plant has demonstrated operation with variable frequency and serves as a demonstration for a bigger wind park far out at sea.

HVDC technology is becoming increasingly important for the stabilisation of large electricity grids, especially if more and more fluctuating resources are incorporated to that grid. HVDC over long distances contributes considerably to increase the compensational effects between distant and different renewable energy sources like wind and solar energy, makes possible the use of Norwegian hydropower storage for compensation of power demand in Germany, and allows to compensate blackouts of large power stations through distant backup capacity. HVDC electricity highways will considerably increase the redundancy and stability of the future Trans-European power grid /Fischer et al. 2004/.

As a spin-off effect of this development, the import of solar electricity from MENA will become an attractive diversification of the European power generation portfolio. Solar and wind energy, hydropower, geothermal power and biomass will be generated in the regions of best performance and abundance, distributed all over Europe through a highly efficient HVDC grid on the upper voltage level, and finally delivered to the consumers by the conventional interconnected AC grid on the lower level (Figure 1-15).

Analogue to the network of interstate highways, a future HVDC grid will have a low number of inlets and outlets to the conventional AC system, as it will primarily serve long distance transfer, while the AC grid will have a function analogue to country roads and city streets.

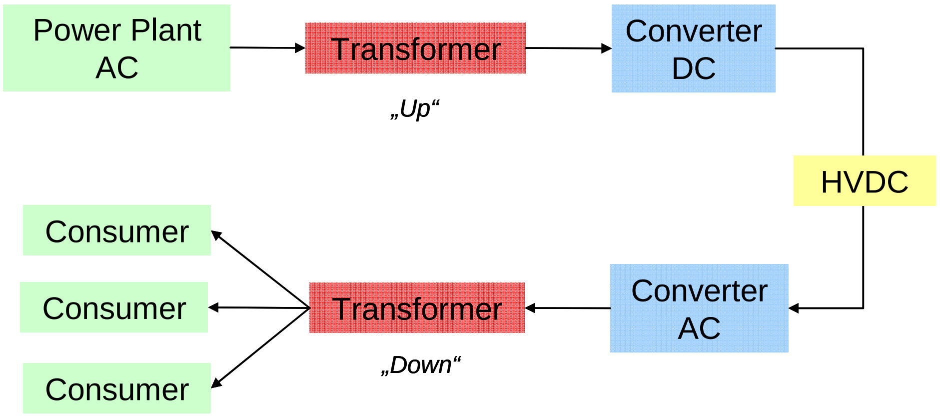


Figure 1-14: Schematic diagram of interconnecting HVDC and AC technologies.

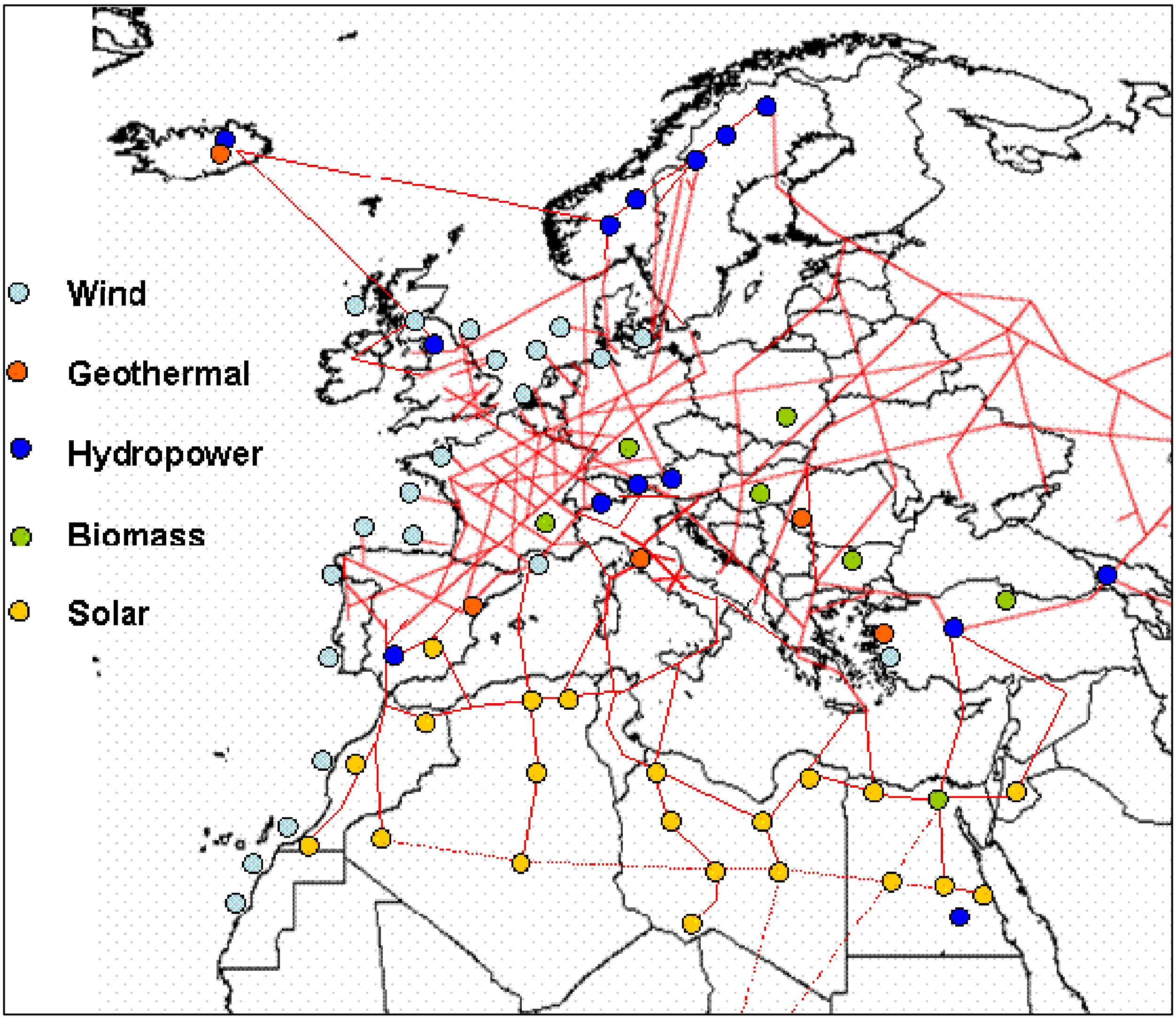
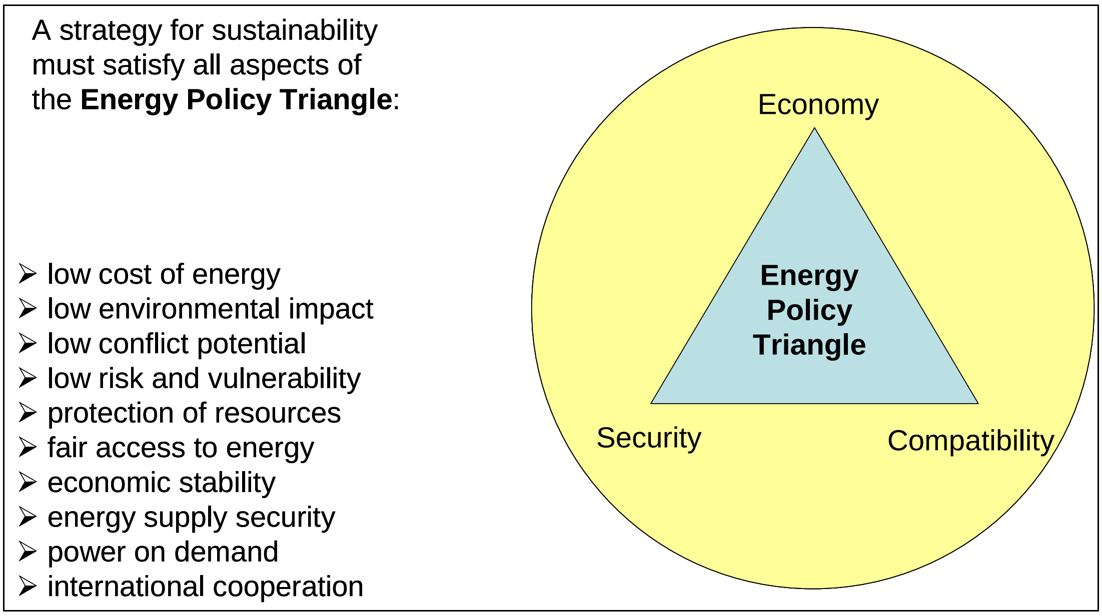


Figure 1-15: Vision of an EUMENA backbone grid using HVDC power transmission technology as “Electricity Highways” to complement the conventional AC electricity grid. Based on /Asplund 2004/

2 A Scenario for Sustainable Electricity

Sustainability is a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs /Brundtland 1987/. It is a necessary strategy of survival of a growing humanity on a limited planet /Knies 2006/. With respect to power generation, the concept of sustainability implies that certain economic, social and environmental requisites are satisfied to provide affordable, secure and lasting energy. Those requisites can be summarised in the "Energy Policy Triangle" shown in Figure 2-1, which was used as guideline for the scenario developed within the TRANS-CSP project /BMU 2004-3/.



A strategy for sustainability must satisfy all aspects of the **Energy Policy Triangle**:

- low cost of energy
- low environmental impact
- low conflict potential
- low risk and vulnerability
- protection of resources
- fair access to energy
- economic stability
- energy supply security
- power on demand
- international cooperation

Figure 2-1: The principle of sustainability in the energy sector is represented by the energy policy triangle. This principle is applied to the electricity supply scenario of the TRANS-CSP study /BMU 2004-3/.

Compatibility

Almost all sustainability criteria are violated by our present electricity supply system, due to the un-damped exploitation of finite mineral fuel resources and the dumping of their residues in the biosphere. The negative impact of this attitude on the environment and society is well known, ranging from massive pollution of urban centres to the proliferation of plutonium and global climate change. This incompatibility to the natural and social environment is at present the main motivation for international efforts to reach sustainability.

Renewable forms of energy have impacts on the environment and society, too, but at a different level. While coal and nuclear plants massively risk the health of the population, a wind park mainly disturbs the visibility of the landscape.

Economy

Affordability is an even more immediate requisite for sustainability. The above mentioned incompatibilities take effect in the long term, but the immediate demand has often a higher priority in human acting and thinking. Long term necessary measures are not initiated if immediate needs are not satisfied. For this reason, most national economies rather subsidize their fossil and nuclear fuel based electricity sector and hide external costs for the sake of a seemingly secure and affordable supply /RIVM 2001/, /EEA 2004/. However, this is a self-delusion, as in this case, the real cost of power generation is not paid by the consumers of electricity, but by the health, environmental, military and disaster control sectors of the national economy. The external social costs of fuel based power generation have been generally accepted by the European Union to be in the order of about 3 - 8 cent/kWh in terms of electricity cost, without accounting for future, possibly irreversible damages to our habitat /ExternE 2003/, /EWEA 2002/.

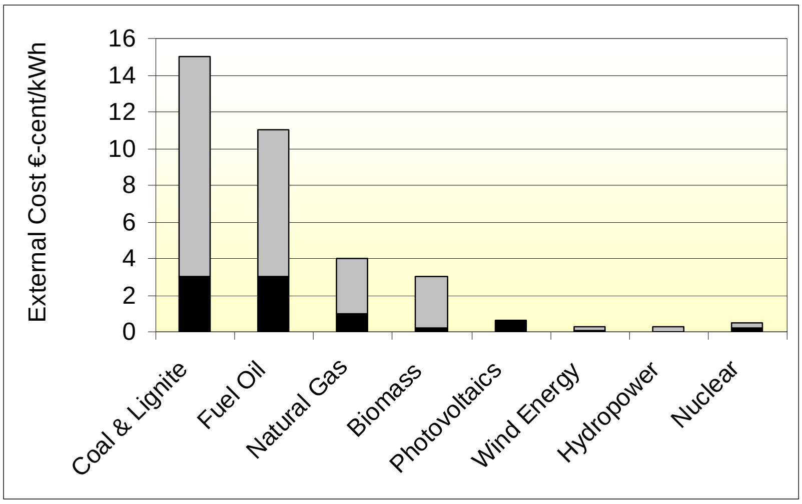


Figure 2-2: External cost range (minimum black, maximum grey bar) of electricity generation by different energy sources in the countries of the EU15 /ExternE 2003/

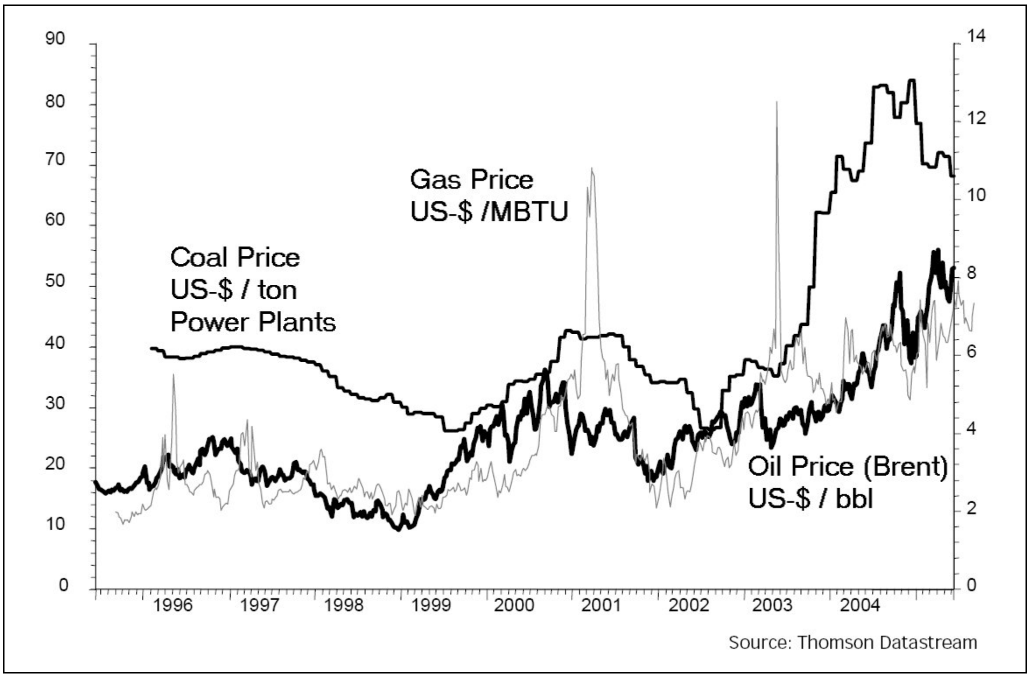


Figure 2-3: Spot prices of oil, coal (left scale) and gas (right scale) from 1995 to 2005. Source: /Thomson 2006/. For uranium prices see /Cameco 2006/

The price stability of conventional energy carriers assumed in the past has finally been unmasked as an illusion, too, with a cost escalation on the world market place of over 200 % in the past 5 years for coal, around 300 % for oil and gas, and close to 400 % for uranium (Figure 2-3). The access to affordable energy is more and more becoming a privilege of industrialised nations. This creates an increasing conflict potential in those countries that need affordable energy sources for their economical and infrastructural development.

Renewable forms of energy are the only energy sources that become cheaper with time (Table 2-1). Due to research and development and to the effects of mass production and larger unit scales, the cost of most renewable forms of energy is reduced by 10 to 20 % each time the installed capacity doubles /EXTOOL 2003/, /WETO 2003/. Wind, biomass and CSP plants are already today competitive with fuel oil at 50 $/barrel, and heading for competitiveness with natural gas and coal. As mentioned before, this cost reduction does not happen spontaneously, but requires continuous investment and extension of capacities on a global level. The initially higher cost of renewables is a necessary investment into a better and cheaper energy supply in the near term future, and pays back immediately once cost break even is achieved. Money spared in the past by not investing in renewables is spent today many times for escalating fuel prices and for the external costs of energy consumption. Compared to the fossil energy costs for power generation in the year 2000, which by that time were still expected to remain stable /IEA 2002/, the European electricity consumers and governments spend today additional 35-70 billion € per year or roughly 1-2 cent/kWh of consumed electricity, with increasing trend (also refer to /IEA 2004/).

Technology	Typical Characteristics	Typical Energy Costs (cents/kWh)	Cost Trends and Potential for Cost Reduction
Power Generation			
Large hydro	*Plant size:* 10 MW–18,000 MW	3–4	Stable.
Small hydro	*Plant size:* 1–10 MW	4–7	Stable.
On-shore wind	*Turbine size:* 1–3 MW *Blade diameter:* 60–100 m	4–6	Costs have declined by 12–18% with each doubling of global capacity. Costs are now half those of 1990. Turbine size has increased from 600–800 kW a decade ago. Future reductions from site optimization, improved blade/generator design, and electronics.
Off-shore wind	*Turbine size:* 1.5–5 MW *Blade diameter:* 70–125 m	6–10	Market still small. Future cost reductions due to market maturity and technology improvement.
Biomass power	*Plant size:* 1–20 MW	5–12	Stable.
Geothermal power	*Plant size:* 1–100 MW *Type:* binary, single-flash, double-flash, or natural steam	4–7	Costs have declined since the 1970s. Costs for exploiting currently-economic resources could decline with improved exploration technology, cheaper drilling techniques, and better heat extraction.
Solar PV (module)	*Cell type and efficiency:* single-crystal: 17%, polycrystalline: 15%, thin film: 10–12%	—	Costs have declined by 20% for each doubling of installed capacity, or by about 5% per year. Costs rose in 2004 due to market factors. Future cost reductions due to materials, design, process, efficiency, and scale.
Rooftop solar PV	*Peak capacity:* 2–5 kW	20–40	Continuing declines due to lower solar PV module costs and improvements in inverters and balance-of-system components.
Solar thermal power (CSP)	*Plant size:* 1–100 MW *Type:* tower, dish, trough	12–18 (trough)	Costs have fallen from about 44 cents/kWh for the first plants in the 1980s. Future reductions due to scale and technology.

Table 2-1: Costs and characteristics of renewables in 2004. Source: Renewables 2005 Global Status Report /REN 2005/

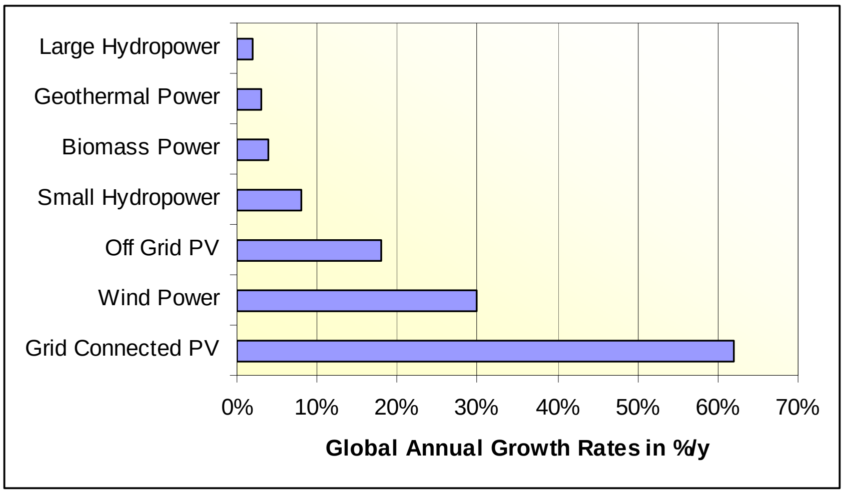


Figure 2-4: Average annual growth rates of global renewable power capacities 2000 – 2004 /REN 2005/

Today, there is a total of 3800 GW of installed power capacity worldwide. As a consequence of their economic advantages, renewables are increasingly gaining ground on the global power market. Existing renewable electricity capacity worldwide in 2004 totalled 720 GW for large hydropower and 160 GW for all other renewables, mainly small hydro and wind power, with very impressive growth rates (Figure 2-4). Today, renewables hold 20–25 percent of the global annual power sector investment of $110 – 150 billion per year with increasing trend /REN 2005/.

Security

It is a common belief that there is no alternative to fossil and nuclear energy to guarantee the security of supply required by modern economies. Security of supply implies long-term stable supply structures and, especially in the electricity sector, immediate satisfaction on demand. Only fossil and nuclear fuels can be used at any moment and to any extent as required for power generation, because they represent ideally stored primary energy. Only fossil and nuclear fuelled power plants can provide constant base load power around the clock, and only oil or gas fired plants can provide peaking electricity whenever required.

However, this belief is probably the most fatal error of our present energy supply system: like a squirrel eating in summer the nuts gathered for wintertime, we are burning our valuable fossil energy reserves for quotidian daily use, instead of using for this purpose those energy sources that are daily available like wind, solar, biomass and geothermal energy, and saving fossil fuels for the times when an ideally stored energy carrier is really needed.

In fact, there is no explicit need for power plants to operate at constant capacity. The electrical load is the sum of millions of dispersed, fluctuating and unpredictable consumers and in this sense, a phenomenon very much related to the fluctuating output of wind and PV plants. The electrical load of a country as a whole shows seasonal and daily fluctuations that fit much better to the time pattern of electricity supplied by a well balanced mix of wind, hydro, biomass and solar energy than to the constant output of a lignite or nuclear plant. For example, the seasonal and daily peak load caused by air conditioning systems naturally fits very well to the electricity yield of the concentrating solar power stations operating in California since 1986. Eventually remaining gaps between the load and the supply from renewables can be compensated by standard peaking power plants, while fossil and nuclear base load plants can be subsequently replaced by an adequate mix of renewables, as will be shown later in this Chapter.

Security is also a question of availability. Today, fossil energy reserves are burned at a high rate and becoming more and more concentrated in few regions of the world /HWWA 2005/. Today’s developing countries increasingly claim for their share of the global energy cake to develop their economies, and the pressure on the remaining resources is dramatically increasing. It is hard to imagine that the MENA region, which in the year 2050 will have a similar energy demand as Europe, will satisfy this demand by the conventional oil and gas infrastructure it is used to today. While fossil resources become increasingly scarce and expensive, the primary solar energy potential in MENA equals a layer of crude oil of 0.25 meters thickness on the total land surface every year, of which only 1/1000 part harvested by concentrating solar power plants would suffice to cover the total regional demand even in 2050 /MED-CSP 2005/. Two parts out of 1000 of this potential would cover Europe’s demand as well.

Interconnection is another very important security factor. Being interconnected gives the security of backup capacities and diversification in case of a local failure, and makes possible production, communication, marketing and trading even in remote regions. Missing infrastructure and interconnection always leads to excessive centralisation, as e.g. in the case of 25 % of the total Mexican population living in the country’s capital Mexico City. On the other hand, the existence of infrastructure and interconnection allows global marketing even in the Black Forest of Germany. The closing of the electricity grid around the Mediterranean Sea described in Chapter 1 is another example of interconnection that serves to increase the security and redundancy of electricity supply in this region /EURELECTRIC 2003/.

Cooperation

In Europe, there is an increasing call for energy autonomy to avoid the obvious conflicts arising from our so called fossil fuel addiction. Representatives of renewable as well as nuclear power technologies both claim to have the solution for energy independency in Europe, on one side propagating large centralised nuclear breeders and fusion reactors, on the other hand opting for small renewable energy systems and decentralised, autonomous grid structures to achieve energy autonomy. Although having the same goal, both views of the world polarise in a controversial discussion, while the dependency on fossil fuels steadily increases. In fact, the autonomy goal – as well as the proposed solutions – is rather questionable in terms of ethics and sustainability: it propagates a Europe unaffected by the eventual future misery of its neighbours, and fosters the illusion of independency on a rather small and crowded planet.

In contrast to independency, inter-dependencies have always been a stabilising factor in international relations and policies. If based on a fair and eye-to-eye level cooperation, economic and social inter-dependencies are a guarantor for good neighbourhood and conflict prevention. The most delicate and at the same time the most rigorous inter-dependency of all cultures on earth is the biosphere, and it has become a global challenge to protect it in a sustainable way. It is obvious that such a global challenge can only be met by global cooperation. However, it is crucial that the goals of such an international cooperation do not remain global as well, but condense into very concrete projects /WBGU 2003/. The purpose of the study at hand is to provide the basis for such a policy for the electricity sector of the EUMENA region.

2.1 Outlook of Electricity Demand in Europe

Electricity demand was modelled for each of the European countries, taking into account the individual growth of population and economy. Empirical correlations derived from the analysis of the electricity demand of 25 countries over a 40 years time period between 1960 and 2000, served to assess the functional correlation of per capita economic growth and per capita electricity demand that was used for extrapolation to the future. The methodology is described in /MED-CSP 2005/, the used input data and the results for Europe are described here. The scenario assumes a rather moderate transformation of the power sector. Sharp changes of paradigm, like a quickly increasing use of electricity in the heat or mobility sector, e.g. for the production of hydrogen, is not considered. Such a scenario would further increase the electricity demand of the European countries beyond the limits shown here (Figure 2-5).

The total electricity demand of the 30 analysed countries starts with roughly 3500 TWh/y in the year 2000 and reaches a maximum of 4300 TWh/y in 2040. After that, it is reduced to shortly 4000 TWh/y, mainly due to stagnating and in some countries even retrogressive population and also due to an only moderate economic growth, although at high level. Moreover, efficiency gains lead to subsequent de-coupling of economic growth and electricity demand.

The outlook for the individual countries is very heterogeneous, ranging from a strong growth of electricity demand in Turkey and Serbia and Montenegro to stagnating or even retrogressive demand in countries like France and Belgium. For country details please refer to the Annex.

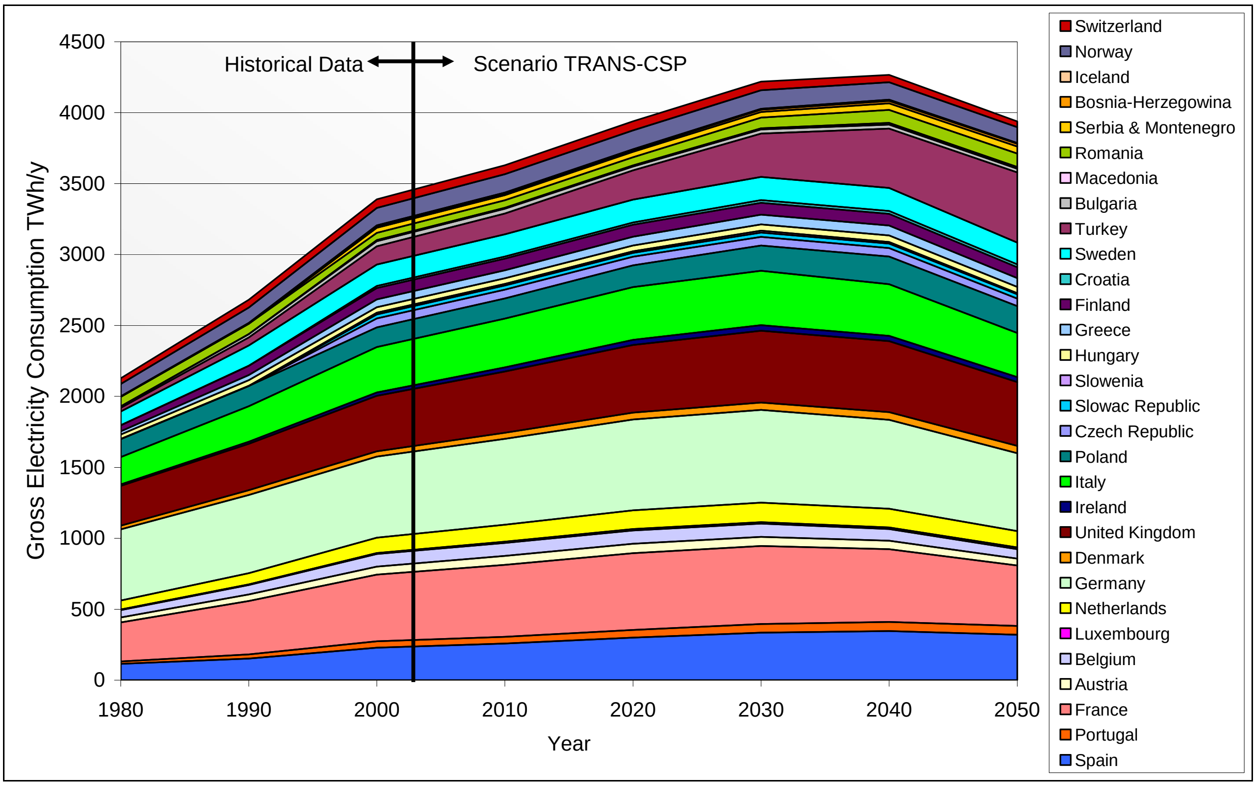


Figure 2-5: Electricity consumption of the European countries analysed within the TRANS-CSP study between 1980 and 2050. The data that served as basis for this analysis is described in this chapter.

The study shows that the electricity demand of Europe in 2050 will be only slightly higher than today. In the long term the strongly growing MENA region will achieve a demand in the same order of magnitude, as described in the MED-CSP study report. Thus, in terms of electricity demand, MENA will become an eye-to-eye neighbour for Europe by that time.

Figure 2-6 shows the average per capita growth rates of the Gross Domestic Product (GDP) for each of the analysed countries assumed in the TRANS-CSP scenario for the time span of 2000 to 2050. The four European regions expect economic growth rates ranging from 1.2 to 2.2 %/y in Western Europe and Scandinavia, and from 2.2 to 4.3 %/y in Eastern and South-Eastern Europe. These values reflect a convergence of the European economies and an overall average economic growth rate of about 2 %/y until 2050 for the region as a whole.

In the year 2000, the per capita GDP of the European economies ranged between 15,000 and 30,000 €/cap/year in Western Europe and Scandinavia, and between 4,000 and 15,000 €/cap/year in Eastern and South-Eastern Europe (Figure 2-9). In our scenario, by 2050, the Western and Scandinavian countries will have achieved a per capita GDP of 40,000 to 50,000 €/cap/y, while the Eastern and South-Eastern economies will range between 30,000 and 40,000 €/cap/y, considerably closing the present economic gap between the different regions. In view of a growing European Union and considering the present development of the European economies, this is both a feasible as well as a desirable scenario of economic development in Europe.

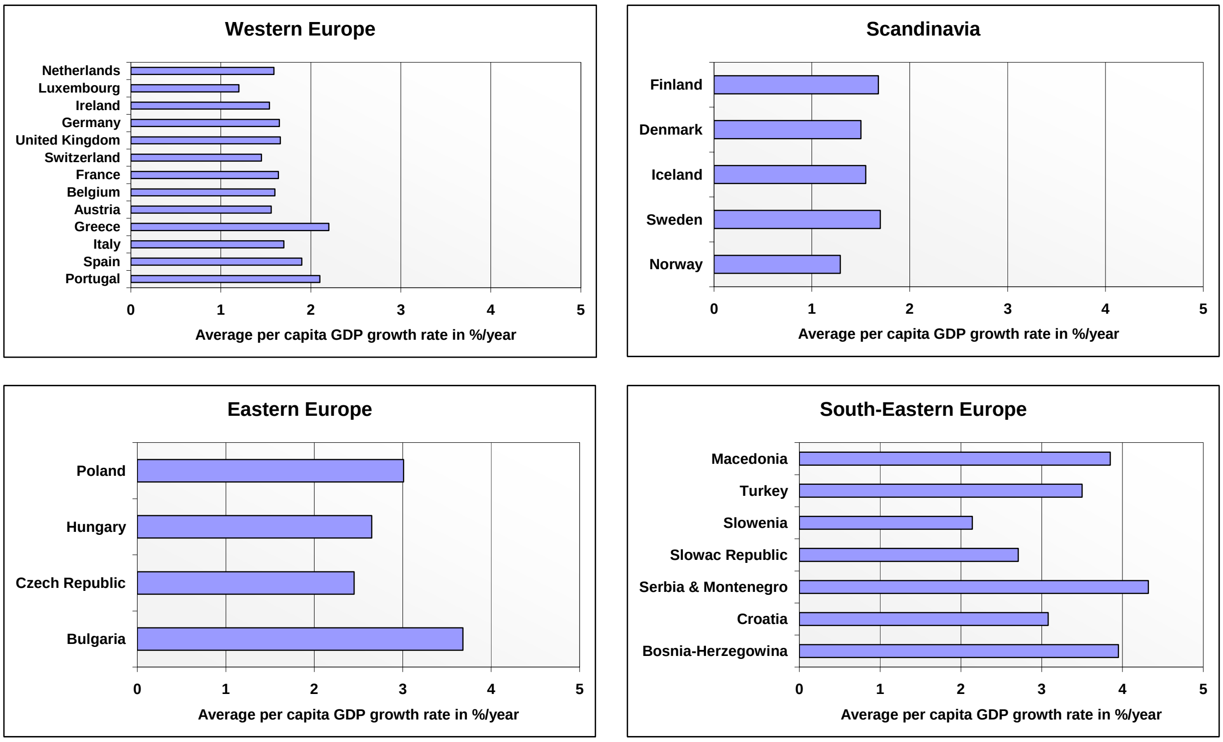


Figure 2-6: Average per capita GDP growth rate in the analysed countries for the time span from 2000 to 2050 assumed in the TRANS-CSP scenario. Strong economic growth at lower level in the South and East, slow growth at high level in the West and North of Europe.

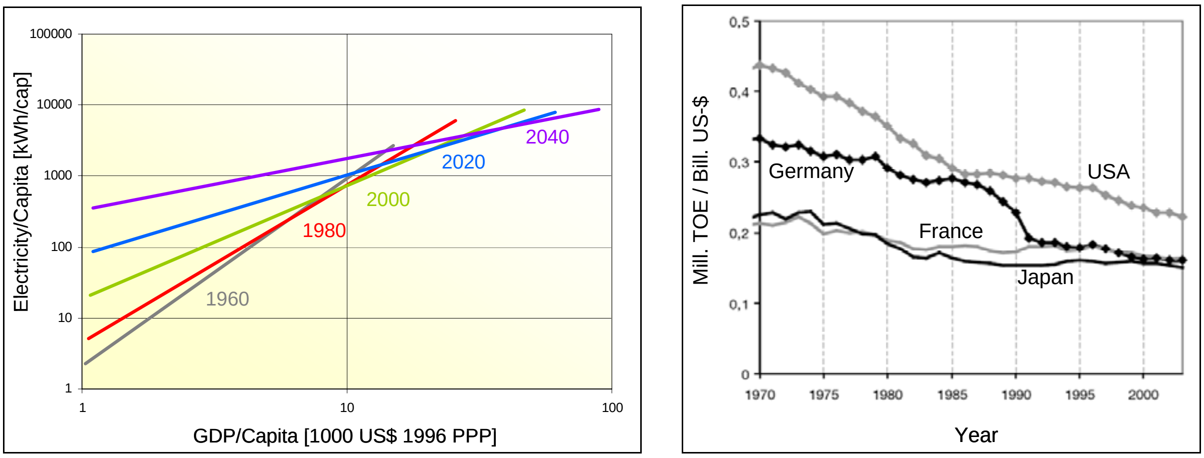


Figure 2-7: Left: The relation of per capita electricity consumption and per capita GDP as parameter for demand side modelling in the TRANS-CSP study. The curves from 1960 to 2000 are fitted to historical data of 25 countries, while the curves of 2020 and 2040 are extrapolated for the scenario analysis. Typically, a decoupling of GDP growth and energy demand growth can be observed, which is motivated by enhanced efficiency of power generation and distribution. For further details please refer to /MED-CSP 2005/. Right: Energy intensity in million tons of oil equivalent per billion US-$ gross domestic product /HWWA 2005/. The German experience after 1989 shows that targeted efforts can have a considerable effect on energy efficiency.

Analysing the historical data of many countries as described in /MED-CSP 2005/, there is evidence of a decoupling of economic growth and growth of electricity demand as shown in Figure 2-7. The reason for this is that growing economies increasingly invest into energy efficiency and enhanced infrastructure for distribution and rational use of energy, especially in the power sector. Such measures lead to increasing GDP but at the same time reduce power consumption. Thus, growing economies are not necessarily bound to a proportionally growing power demand, but usually achieve a lower growth rate for electricity than for their economy.

From the economic development represented by the growing GDP per capita (Figure 2-9) and the correlation of GDP growth and electricity consumption in Figure 2-7, a scenario for the specific per capita electricity consumption in each of the analysed countries can be developed. The result of this calculation for each country is shown in Figure 2-10.

Present per capita power consumption in Europe is rather heterogeneous. The general level of consumption is highest in the Scandinavian countries, ranging from 7,000 kWh/cap/y in Denmark, which is closer related to Central Europe, to more than 25,000 kWh/cap/y in Norway, which relies mainly on hydropower and additionally to the traditional power sector, uses electricity for room heating and many process heat applications. The high level of consumption in Scandinavia is in general maintained within the scenario, leading to similar values in 2050.

Lowest electricity consumption levels are detected today in South Eastern Europe, with about 2000 kWh/cap/y in Turkey and Romania, while Greece and Slovenia have a much higher level of 6000 kWh/cap/y. There is also a large band width of consumption in Western Europe, from about 4000 kWh/cap/y in Portugal to 8500 kWh/cap/y in Switzerland and Belgium. These numbers reflect the different economic situation and life style of the respective countries. In the non-Scandinavian countries, an approximation of the per capita electricity consumption to values between 5000 and 7000 kWh/cap/y can be detected from the scenario analysis. This again reflects the economic and technical convergence of the different European regions. The much higher level of electricity consumption of the Northern Scandinavian countries is due to their specific climatic situation, their extensive use of electricity for space heating, and to the availability of abundant renewable sources, mainly hydropower and biomass, for power generation.

The last step for calculating the total electricity consumption of each country is multiplying the per capita electricity consumption with the expected numbers of population, shown in Figure 2-11. Except for Turkey and the smaller South-Eastern countries, most countries in Europe show stagnating or even retrogressive population after 2030. Therefore, the main reason for a growing electricity consumption in Europe is the expected growth of economy. The calculation leads to the result in Figure 2-5 that was already discussed before.

Our scenario is based on the assumption that the development of the power sector is not hampered by very strongly escalating costs or by a severe shortage of primary energy for power generation. Such severe changes of paradigm are difficult to predict and their consequences for economy and the power sector are very difficult to quantify. Anyway, we do not see a high probability of such a scenario, as in case the fossil fuel reserves would become extremely scarce or expensive, renewables will take over most power services at a slightly higher speed than assumed here, stabilising energy costs and opening new ways of supply for Europe.

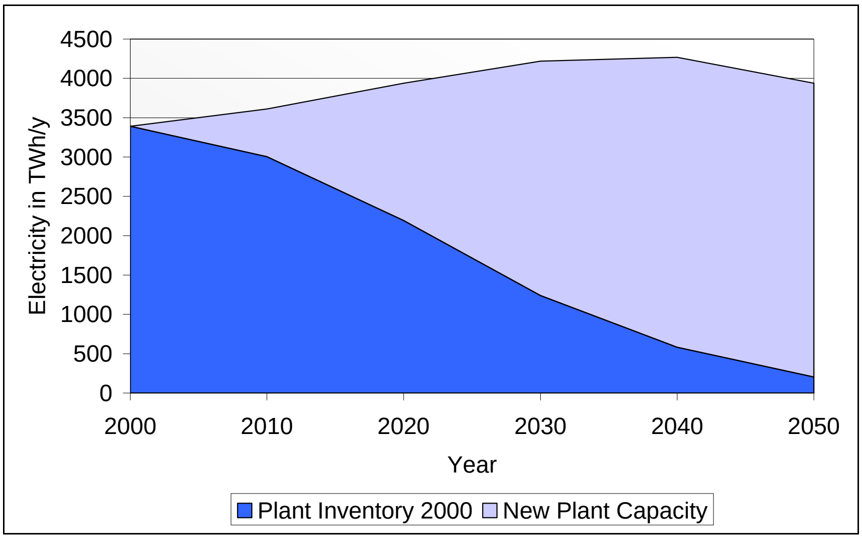


Figure 2-8: Life inventory of power plants existing in the year 2000. "New Plant Capacity" defines the difference between existing and subsequently decommissioned plants and the electricity demand. This gap must be filled with new supply systems, summing up new demand and replacement capacities for old plants. Hydropower plants are considered to be subsequently re-powered, and therefore are partially still existing in 2050. Based on data from /Platts 2004/.

The demand for new power plant capacity is defined by plant life and investment cycles. Figure 2-8 shows the opening gap between the presently existing (and subsequently decommissioned) plants and the growing power demand. It is based on the UDI world power plant inventory, assuming a lifetime of 20 years for gas turbines and combined cycles, 40 years for steam cycles and nuclear plants, 15 years for wind plants and 60 years for hydropower plants.

The demand for new power plant capacity will be partially covered by renewable and conventional power sources, as described in the following. All plants are assumed to operate for their full economic life time. That means that coal or natural gas fired plants installed in 2030 will still be operating in 2050 and beyond.

In view of the long life and investment cycles of power plants, it is obvious that any decision for or against a technical option today will significantly affect the mix of energy sources and its economic, environmental and social sustainability up to the middle of this century.

The window for changing to a sustainable scheme is open now, but will be closed by about 2020. Europe now has the chance to invest into a cost efficient, sustainable electricity scheme, or it will depend on and suffer under the costly and in the meantime obsolete supply structures of the past century.

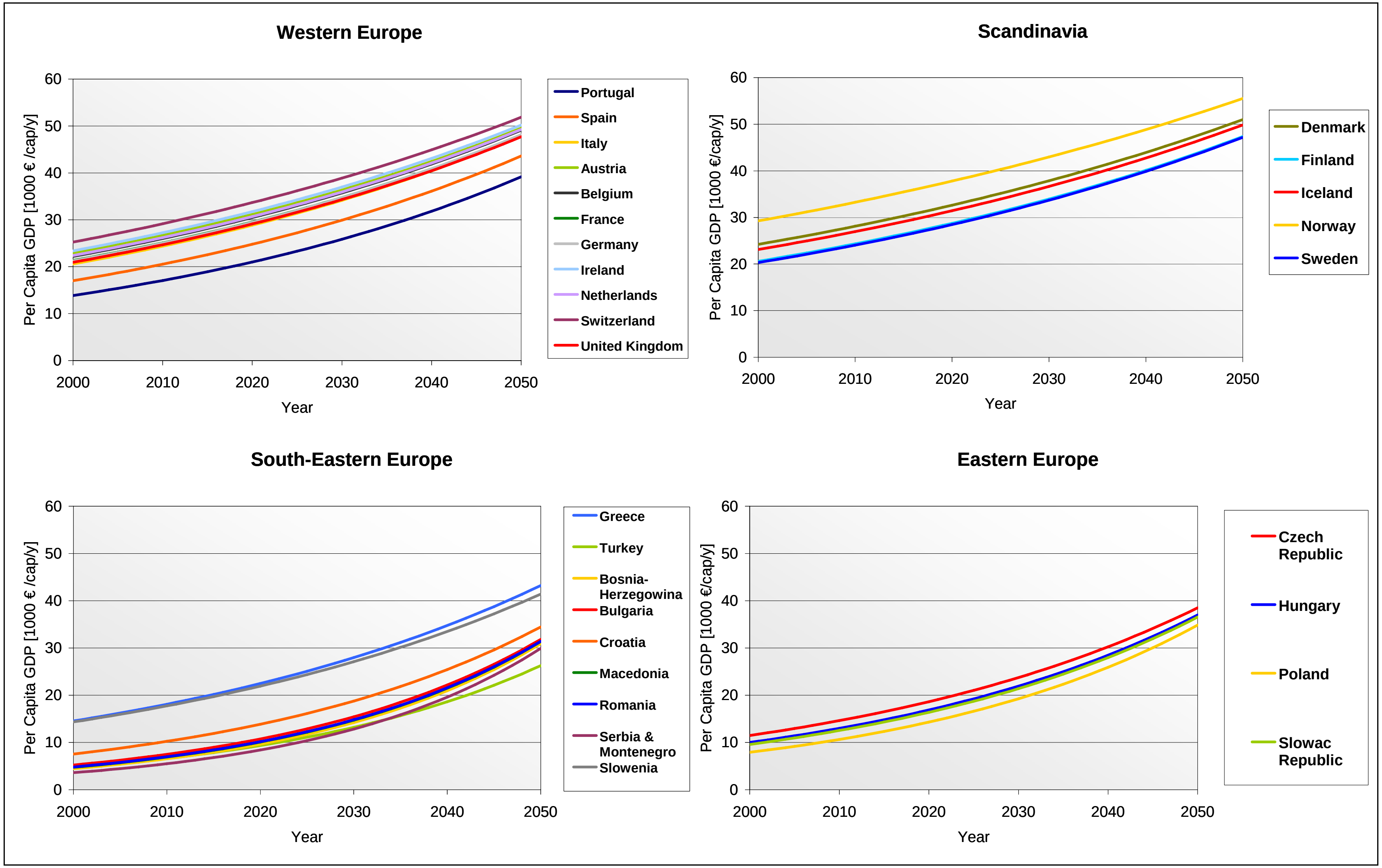
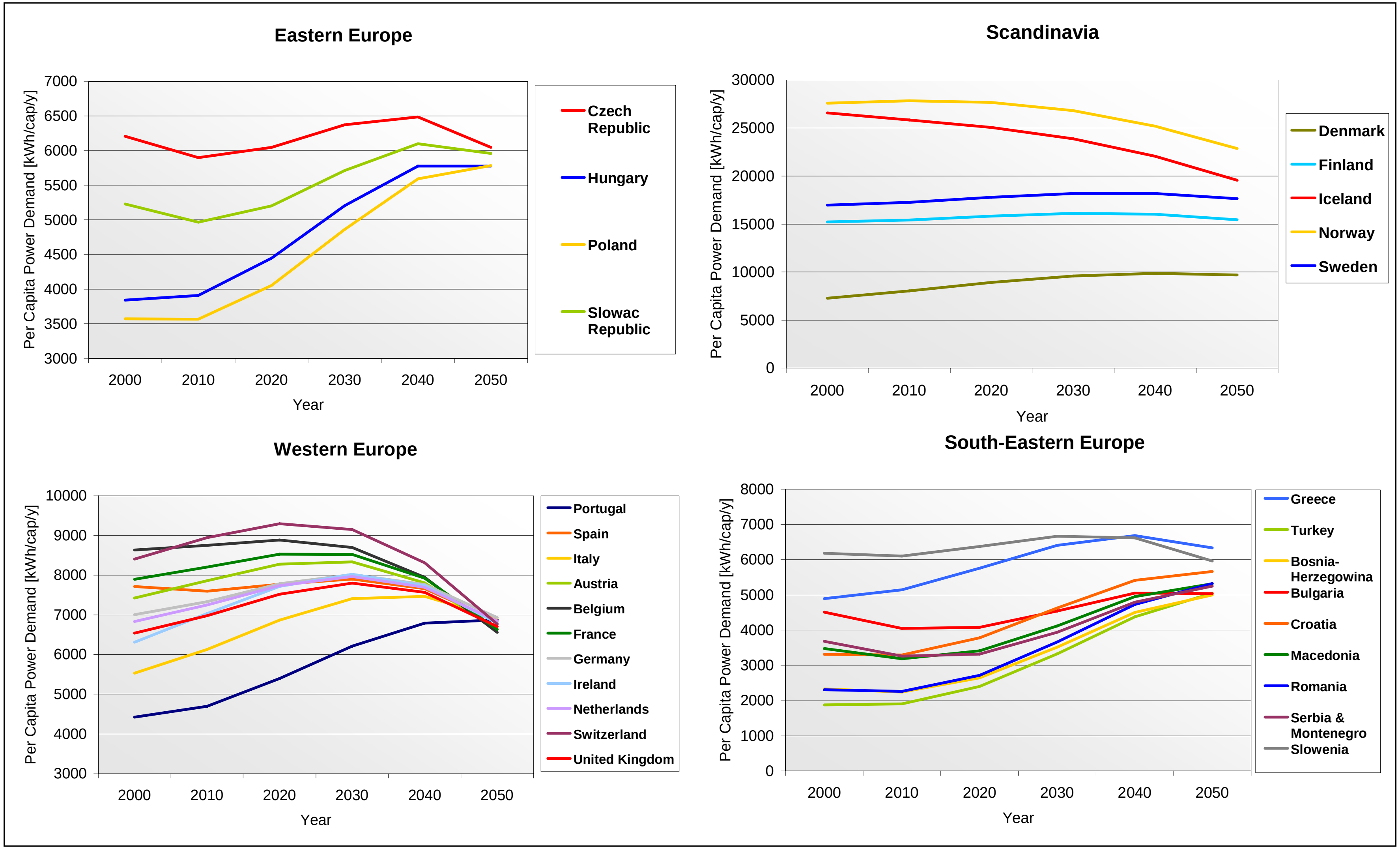


Figure 2-9: Economic development as driving force for electricity demand: the evolution of the per capita gross domestic product in the European countries in the TRANS-CSP scenario.



Eastern Europe

Scandinavia

Western Europe

South-Eastern Europe

Figure 2-10: Per capita electricity consumption for the European countries until 2050 in the TRANS-CSP scenario

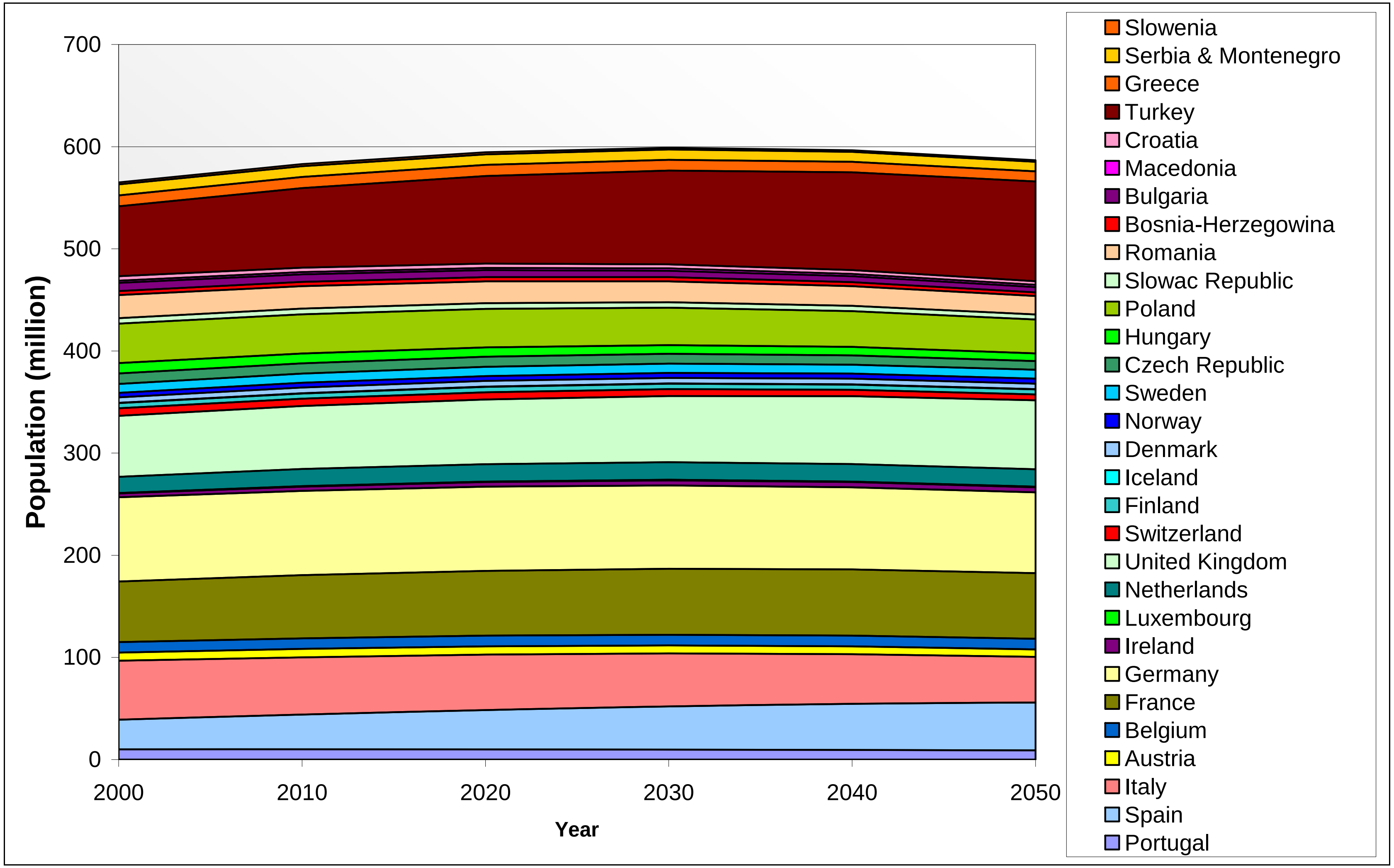


Figure 2-11: Population of European countries according to the UN medium growth scenario is a major driving force for electricity demand /SBA 2003/

2.2 Renewable Electricity Potentials in Europe

For Europe, reliable references are available to quantify the renewable energy potentials for wind, photovoltaics, concentrating solar power, geothermal, biomass, wave and tidal power (Figure 2-12). Those numbers already consider the availability of land area for the placement of the converters and other socio-economic and environmental restrictions. They can be considered as generally accepted /BMU 2004-3/.

The European renewable energy potential of about 40,000 PJ/y equals about twice the present electricity consumption and 75% of the present heat consumption in Europe. All in all it could supply 62 % of the present primary energy consumption in Europe. The use of those resources differs widely. About 80 % of the existing hydropower potential and 50 % of the biomass potential is already used today, while the other available resources are hardly used up to now.

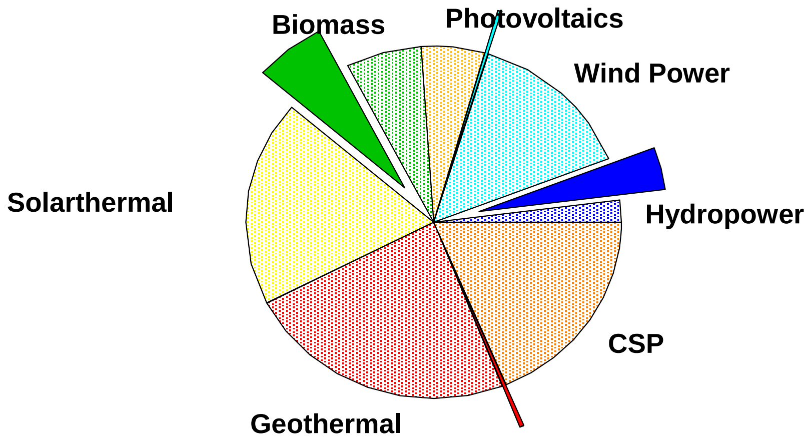


Figure 2-12: The technical potential of renewable energy in Western Europe amounts to approximately 40,000 PJ/y. Only 12 % of this potential are used at present, mainly hydropower and biomass /BMU 2004-3/

Once renewable energy technologies are well established, their potentials could be extended in the long term by making use of further resources and technologies. Here are some examples:

- Use of wind-offshore potentials along the European coast lines with a potential of roughly 2.000 TWh/y of electricity;
- Energy crops on additional agricultural areas, especially in Eastern Europe, with a potential of about 30 million hectares equalling 3.500 PJ/y of primary energy;
- Use of geothermal energy in Western Europe with a potential of up to 1.700 TWh/y;
- Importing solar electricity from concentrating solar power plants from the MENA region in the frame of a Mediterranean renewable energy partnership with a potential of several 100,000 TWh/y which is well beyond the European electricity demand.

This sums up to a total renewable energy potential which would more than suffice to cover the European energy needs. In the TRANS-CSP study, the renewable energy resources for power generation in Europe were assessed on the basis of different sources described later in this chapter. The direct normal irradiance (DNI) used by concentrating solar power systems was assessed by DLR’s high resolution satellite remote sensing system /SOLEMI 2004/.

	Hydro		Geo		Bio		CSP		Wind		PV		Wa/Ti	
	Tech.	Econ.	Tech.	Econ.	Tech.	Econ.	Tech.	Econ.	Tech.	Econ.	Tech.	Econ.	Tech.	Econ.
Austria	56,0	56,0	n.a.	4,1	n.a.	30,6	n.a.	n.a.	n.a.	3,0	n.a.	2,9	n.a.	n.a.
Cyprus	24,0	1,0	n.a.	n.a.	n.a.	0,6	23	20	n.a.	6,0	n.a.	0,1	n.a.	0,2
Denmark	0,0	0,0	n.a.	n.a.	n.a.	6,6	n.a.	n.a.	n.a.	55,0	n.a.	1,3	n.a.	2,2
Finland	20,0	20,0	n.a.	n.a.	n.a.	53,7	n.a.	n.a.	n.a.	27,0	n.a.	1,7	n.a.	2,0
France	72,0	72,0	n.a.	14,1	n.a.	79,1	n.a.	n.a.	n.a.	129,0	n.a.	23,4	n.a.	12,0
Czech Republic	4,0	3,0	n.a.	n.a.	n.a.	20,0	n.a.	n.a.	n.a.	5,8	n.a.	1,1	n.a.	n.a.
Belgium	0,3	0,5	n.a.	n.a.	n.a.	7,3	n.a.	n.a.	n.a.	13,0	n.a.	2,1	n.a.	0,2
Ireland	1,0	1,3	n.a.	n.a.	n.a.	6,2	n.a.	n.a.	n.a.	55,0	n.a.	1,1	n.a.	4,0
Luxembourg	n.a.	1,0	n.a.	n.a.	n.a.	0,4	n.a.	n.a.	n.a.	0,0	n.a.	0,8	n.a.	n.a.
Netherlands	0,1	0,1	n.a.	1,3	n.a.	9,6	n.a.	n.a.	n.a.	40,0	n.a.	4,3	n.a.	1,0
Sweden	130,0	90,0	n.a.	1,3	n.a.	80,4	n.a.	n.a.	n.a.	63,5	n.a.	3,7	n.a.	2,0
Switzerland	41,0	38,3	n.a.	n.a.	n.a.	8,0	n.a.	n.a.	n.a.	0,0	n.a.	3,7	n.a.	n.a.
United Kingdom	7,8	8,0	n.a.	0,3	n.a.	30,7	n.a.	n.a.	n.a.	344,0	n.a.	7,8	n.a.	60,0
Poland	14,0	7,0	n.a.	1,7	n.a.	52,1	n.a.	n.a.	n.a.	65,0	n.a.	3,1	n.a.	1,0
Bulgaria	15,0	12,0	n.a.	0,8	n.a.	7,7	n.a.	n.a.	n.a.	8,9	n.a.	2,0	n.a.	n.a.
Slowac Republic	7,0	6,0	n.a.	3,1	n.a.	10,7	n.a.	n.a.	n.a.	0,7	n.a.	2,0	n.a.	n.a.
Slowenia	9,0	8,0	n.a.	0,4	n.a.	6,3	n.a.	n.a.	n.a.	0,3	n.a.	1,0	n.a.	n.a.
Germany	26,0	26,0	120,0	28,2	n.a.	87,0	n.a.	n.a.	n.a.	262,0	n.a.	23,4	n.a.	7,0
Hungary	5,0	4,0	n.a.	51,9	n.a.	11,3	n.a.	n.a.	n.a.	1,3	n.a.	2,0	n.a.	n.a.
Greece	15,0	12,0	n.a.	9,4	n.a.	7,2	44	4	n.a.	49,0	n.a.	3,9	n.a.	4,0
Italy	105,0	65,0	n.a.	19,6	n.a.	46,1	88	7	n.a.	79,0	n.a.	17,6	n.a.	3,0
Malta	n.a.	n.a.	n.a.	n.a.	n.a.	0,1	2	2	n.a.	0,2	n.a.	0,1	n.a.	0,1
Portugal	33,0	20,0	n.a.	14,1	n.a.	15,2	436	142	n.a.	18,0	n.a.	3,9	n.a.	7,0
Spain	70,0	41,0	n.a.	28,2	n.a.	40,4	1646	1278	n.a.	93,0	n.a.	19,5	n.a.	13,0
Turkey	216,0	122,0	n.a.	300,1	n.a.	44,7	405	131	n.a.	110,0	n.a.	15,6	n.a.	n.a.
Macedonia	6,0	4,0	n.a.	n.a.	n.a.	2,6	n.a.	n.a.	n.a.	0,1	n.a.	0,6	n.a.	n.a.
Croatia	9,0	8,0	n.a.	1,1	n.a.	8,9	n.a.	n.a.	n.a.	2,6	n.a.	0,8	n.a.	3,0
Romania	36,0	18,0	n.a.	1,0	n.a.	40,9	n.a.	n.a.	n.a.	7,9	n.a.	2,0	n.a.	n.a.
Serbia & Montenegro	27,0	27,0	n.a.	4,1	n.a.	14,3	n.a.	n.a.	n.a.	0,3	n.a.	1,0	n.a.	2,0
Bosnia-Herzegowina	24,0	19,0	n.a.	n.a.	n.a.	9,5	n.a.	n.a.	n.a.	0,1	n.a.	0,6	n.a.	n.a.
Iceland	64,0	40,0	n.a.	182,4	n.a.	0,1	n.a.	n.a.	n.a.	1,0	n.a.	0,3	n.a.	10,0
Norway	200,0	178,0	n.a.	n.a.	n.a.	25,8	n.a.	n.a.	n.a.	76,0	n.a.	1,0	n.a.	10,0
Total		**908**		**667**		**764**		**1584**		**1517**		**154**		**144**

Table 2-2: Technical and economical renewable energy potential for electricity generation in Europe not including solar electricity import. The total potential of 5600 TWh/y exceeds by far the present and future electricity demand of around 3500 – 4000 TWh/y of the analysed countries.

The data for the other renewable energy options was taken from materials kindly provided by the renewable energy scientific community. We have taken into consideration the following renewable energy resources for power generation:

- Direct Solar Irradiance on Surfaces Tracking the Sun (Concentrating Solar Thermal Power Plants in Southern Europe and MENA)
- Direct and Diffuse (Global) Solar Irradiance on a Fixed Surface tilted South according to the Latitude Angle (Photovoltaic Power)
- Wind Speed (Onshore and Offshore Wind Power Plants)
- Hydropower Potentials from Dams and River-Run-Off Plants
- Heat from Deep Hot Dry Rocks (Geothermal Power)
- Biomass from Municipal and Agricultural Waste and Wood
- Wave and Tidal Power

Both the technical and economic potentials were defined for each renewable energy resource and for each country. The **technical potentials** are those which in principle could be accessed for power generation by the present state of the art technology (Table 2-2). For each resource and for each country, a **performance indicator** was defined that represents the average renewable energy yield with which the national potential could be exploited (Table 2-4). The **economic potentials** are those with a sufficiently high performance indicator that will allow new plants in the medium and long term to become competitive with other renewable and conventional power sources, considering their potential technical development and economies of scale.

The main characteristics of each technology with respect to its integration to the electricity supply system are given in Table 2-5. The renewable energy potentials for power generation differ widely in the countries analysed within this study. They are more or less locally concentrated and not available everywhere, but can be distributed through the electricity grid. The following analysis shows the quantity and the geographic distribution of the different renewable energy sources in Europe represented by the main performance indicators of each technology.

One of the pre-conditions of the electricity mix is that it must cover the power demand at any time, with a preset security margin of 25 % of minimum remaining reserve capacity. The different technologies of our portfolio contribute differently to secured power: fluctuating sources like wind and PV contribute very little, while fossil fuel plants contribute at least 90 % of their capacity to secure power on demand (Table 2-5). Hourly time series of resource data for wind and solar radiation have been used to estimate those limitations. Besides of the total demand of electricity of each country, also the secured coverage of peaking demand has been used as frame condition for the scenario. The individual country scenarios have been designed such that they satisfy this condition at any time of the year.

One of the consequences of renewable energy scenarios is that the ratio of the total installed power plant capacity to peak load increases, or in other words, the average capacity factor of the power park decreases. The increasing capacity overhead is due to the fluctuating supply from wind and PV plants that have a rather low capacity factor and that do not contribute substantially to secured power. However, this does not necessarily lead to an augmentation of fossil fuel based peaking duties, as there are a number of effects that compensate such fluctuations:

- temporal fluctuations of a large number of distributed wind or PV plants will partially compensate each other, delivering a much smoother capacity curve than single plants,
- temporal fluctuations of different, uncorrelated renewable energy resources will partially compensate each other, together delivering a much smoother capacity curve than one single resource
- fluctuations can be compensated by distribution through the electricity grid,
- biomass, hydro-, geothermal and solar thermal plants can deliver power on demand and be applied as renewable backup capacity for fluctuating inputs,
- load management can enhance the correlation of demand and renewable supply,
- fossil fuel fired peaking plants can be used for final adaptation to the load.

In effect, controlling many distributed, fluctuating and unpredictable elements within a power system is nothing new. Exactly the same occurs with the load induced by millions of consumers connected to the grid. All together deliver a relatively stable and predictable load curve. A large number of distributed renewable energy sources in a well balanced mix can even show a better adaptation to the time pattern of the load than nuclear or coal fired base load plants with a flat capacity curve, as shown later in this chapter.

Today lignite, nuclear and river runoff hydropower plants are typically used for base load, as they are rather expensive and cannot be quickly adapted to changing load patterns. Coal, oil and gas fired plants are used for intermediate load. Peaking load is covered by gas or oil fired plants and by hydropower storage. In 2050, the valuable fossil fuel resources will be only used for the purpose they are best suited for: peaking power, while base load will be provided mainly by renewables. The principle characteristics of the power mix of our scenario are described in the following:

Oil and Gas fired Power Plants

Oil and gas fired power plants are today the most applied resource for peaking power as they can react quickly to changing load patterns. They will take over the part of closing the gap between the fluctuating load and renewable power. Due to their priority on peaking duties, their average fossil fuel consumption and their CO_2 emissions will be reduced faster than their installed capacity. Due to their high cost, fuel oil fired plants will fade out in most countries after 2020.

Coal Steam Plants

Coal is an important primary energy for power generation in Europe. However, coal is also considered a heavy burden for climate stability. In our scenario, the capturing and sequestration of carbon dioxide (CCS) from the power plant’s flue gases is therefore implemented in all new power plants in Europe after 2020. The model assumes an overall extraction of 85 % of CO_2 and an additional cost of 1.5 cent/kWh for plants using CCS. In the medium term, coal gasification may provide increasing shares of the gas demand of peaking power plants.

Nuclear Fission and Fusion

Nuclear fission is a fading technology with unsolved problems of nuclear waste disposal and very high environmental risks. The net present value of decommissioning of such plants is reported to be in the order of 1000 €/kW that must be added to the investment /WISE 2006/, /VDE 2006/. The nominal civil liabilities for decommissioning of nuclear plants in the United Kingdom are even reported to be in the order of 6000 €/kW /NDA 2002/. A number of European governments like Germany and Sweden have decided to fade out nuclear power plant operation within the coming decades. With present consumption – only 5 % of the world primary energy demand[1] is covered by nuclear energy today – the global uranium resources will not last longer than 50 years and are becoming more and more expensive /HWWA 2005/. Breeder technology could expand those resources but would lead to a dangerous proliferation of plutonium and increase the amount of nuclear waste materials by a factor of 10 compared to simple fission. At the moment, nuclear power has a share of global power sector investment of less than 1 % (for comparison: renewables had a share of 25 % in 2005).

In spite of R&D expenditures of more than a billion Euro per year spent by the OECD for several decades and scheduled to be spent also in the future, electricity from nuclear fusion is not expected to be available before 2050, and the outcome of this effort is not sure. The expected cost of commercial fusion reactors ranges between 8 – 12 €-cent/kWh /HGF 2001/, which would be much higher than the cost of renewables by that time. Nuclear plants are only economic if they are allowed to run at constant full capacity. However, as will be shown later in this chapter, there will be no functional window for such plants in the future energy mix. For all those reasons, nuclear power technologies cannot contribute considerably to climate stability or to sustainable development within the time span analysed in our study. In view of those limitations and unsolved problems, nuclear fission is not considered a serious alternative or complement for energy sustainability in our scenario and is consequently faded out, while nuclear fusion is not expected to function commercially within the analysed time span until 2050.

Wind Energy

Wind is a strongly fluctuating energy source that cannot be easily controlled by demand. However, distributed wind parks partially compensate each others fluctuations and show a relatively smooth transition of their total output. Depending on the different situation in each country, up to 15 % of the installed wind capacity can be considered as firm. Hourly wind data was taken for selected sites from the World Wind Atlas /WWA 2004/.

The European Wind Energy Association EWEA gives a wind energy onshore potential of 650 TWh/y for the EU15 and Norway in its report /EWEA 2002/. For the Eastern European and EBRD countries, the report gives a potential of a total of about 280 TWh/y that could be realised until 2020. In addition to that, an offshore potential of 460 – 560 TWh/y is available, while other sources even give an offshore potential of up to 3000 TWh/y for Europe.

In the TRANS-CSP study, we have identified a total economic potential of about 1500 TWh/y for the analysed countries (Table 2-2). This includes both onshore and offshore potentials and

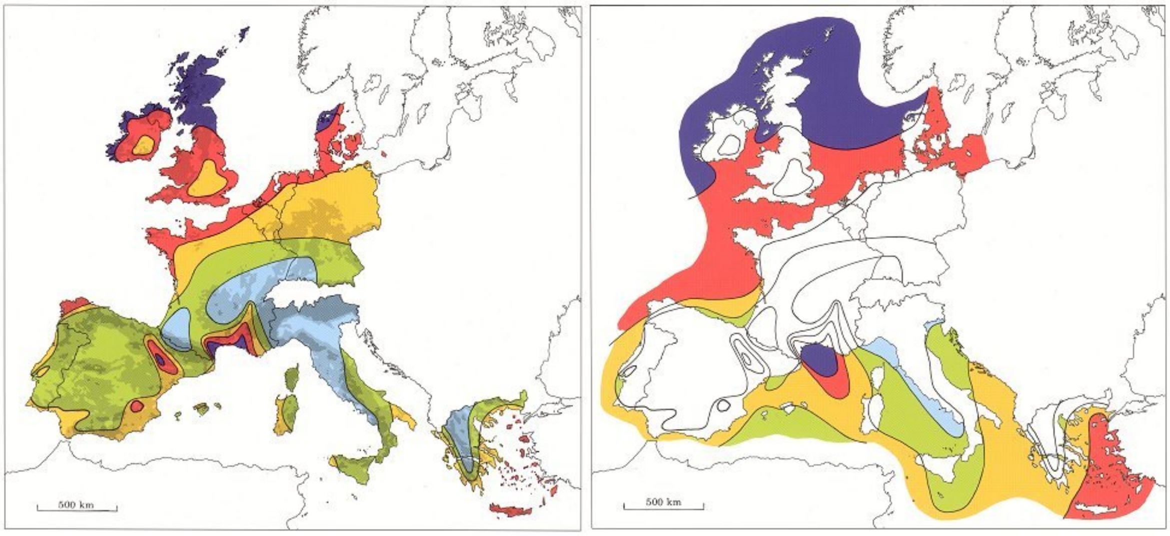
---

[1] This value includes the waste heat of nuclear plants; considering electricity only, the global nuclear energy share is in the order of 2 %

was based on the literature mentioned above or calculated according to the methodology described in /MED-CSP 2005/. The geographic allocation of the potentials represented by the wind velocity 50 meters above ground can be estimated from the European Wind Atlas prepared by Risø National Laboratory, Denmark, shown in Figure 2-13.

Wind power plants use the kinetic energy of the wind to produce electricity. They have a typical unit capacity of several kW to about 5 MW for the largest plants available today (Table 2-5). Wind parks of several 100 MW capacity are possible. They can have an annual utilisation ratio – represented by the capacity factor – of about 15 % to over 50 % at the best available sites in offshore regions, equivalent to over 4500 full load operating hours per year. E.g. a capacity factor of 30 % indicates that the energy produced by a wind converter during the year equals full load operation of 2628 hours out of a total of 8760 hours per year.

However, those operating hours are statistically distributed during the year and not controllable by the operator. Wind energy is fluctuating, and only at very good sites with a very steady wind regime there is a considerable contribution to firm power capacity. Wind cannot supply peaking demand at all, as it is controlled by the resource and not by demand. However, at very good sites and considering a broad geographic distribution of wind converters in a country – that leads to a compensation of the fluctuations of single plants – its contribution to firm capacity can be up to 30 % of the installed capacity. This is represented by the “capacity credit” and must not be confused with the “capacity factor” that gives the average utilisation of the plants. The capacity factor and the capacity credit as function of the wind speed is given in /MED-CSP 2005/, pp. 46.



	Protected Terrain $m\,s^{-1}$	Open Plain $m\,s^{-1}$	Coast $m\,s^{-1}$	Offshore $m\,s^{-1}$	Mountains and Crests $m\,s^{-1}$
🟪	> 6.0	> 7.5	> 8.5	> 9.0	> 11.5
🟥	5.0-6.0	6.5-7.5	7.0-8.5	8.0-9.0	10.0-11.5
🟨	4.5-5.0	5.5-6.5	6.0-7.0	7.0-8.0	8.5-10.0
🟩	3.5-4.5	4.5-5.5	5.0-6.0	5.5-7.0	7.0- 8.5
🟦	< 3.5	< 4.5	< 5.0	< 5.5	< 7.0

Figure 2-13: Wind velocity 50 m above ground in 5 different categories of terrain. Left Onshore, Right: Offshore. Source: European Wind Atlas, Risø National Laboratory, Roskilde, Denmark, /Risoe 1998/.

In our scenario, wind power technology is subsequently enhanced. The average annual full load hours increase in each country from the values reported in the year 2000 to a maximum performance indicator identified by the mapping of wind speed at 80 meters above ground which would be reached in the year 2050 (Table 2-4).

In the year 2000, the installed wind power capacity in the analysed countries was about 12 GW producing 23 TWh/y of electricity /Enerdata 2004/. This is equivalent to an average of 1900 full load hours per year. According to our analysis, the total wind electricity potential of the region amounts to 1500 TWh/y, of which 780 TWh/y (280 GW) could be exploited until 2050. According to this, the average performance indicator of the total wind power park in 2050 would increase to 2800 full load hours per year which is due to enhanced power plant efficiency and an increasing share of offshore capacities. In the TRANS-CSP scenario, wind power capacities will grow with an average rate of 6.5 %/y until 2050.

Photovoltaic Systems

PV power is strongly fluctuating and only available during daytime. There is no contribution to secured power, but a good correlation with the usual daytime power demand peak of most countries. PV is specially suited for distributed power supply. Hourly global irradiance on a fixed surface oriented south and tilted according to its latitude was taken from the Meteonorm database /METEONORM 2004/ to calculate the output of PV generators as a function of time.

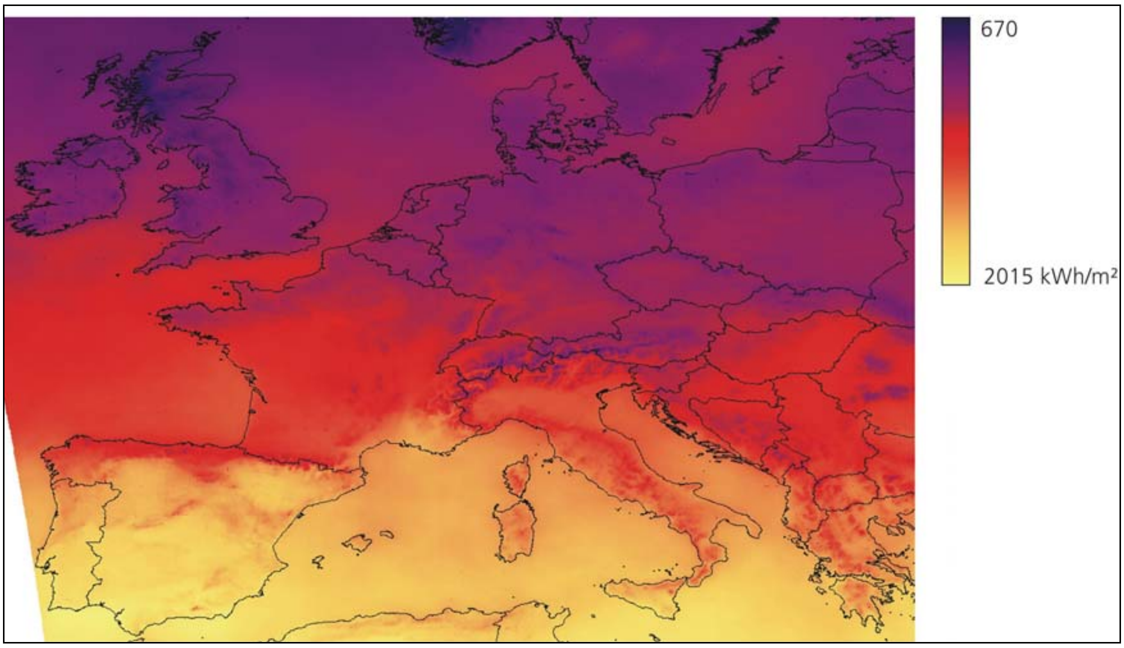


Figure 2-14: Annual sum of the global horizontal irradiance (kWh/m²/y) of the year 2004 in Europe as resource for non-concentrating PV systems. Source: Virtuelles Institut für Energiemeteorologie /vIEM 2006/.

Non-concentrating photovoltaic systems use the direct and diffuse (global) irradiance for electricity generation. PV systems can be installed anywhere and at any size, from 1 W stand alone systems to large grid connected plants of several 10 MW of capacity. PV systems cannot provide firm capacity due to the transient of clouds and to the diurnal cycle. Fluctuating electricity from PV systems can in principle be stored in pump storage, compressed air and batteries, however, storage capacities for electricity are limited and rather expensive. For Europe, literature gives extensive information of the potentials for PV expansion, ranging from optimistic /EU 2004/, /Greenpeace 2005/ to rather pessimistic expectations /EU 2003/, /WETO 2003/. The annual global irradiance increases from North to South (Figure 2-14), with typical 500 - 800 full load operating hours per year in Northern Europe and over 2000 h/y in the South, equivalent to capacity factors between 5 and 20 %.

The European solar energy atlas in Figure 2-14 explains the great difference of PV performance comparing Northern and Southern Europe. A fourfold output of PV systems in Southern Europe has of course a significant impact on the economic performance compared to the Northern European countries. Due to subsequently enhanced system efficiencies, the utilisation ratio of PV systems is expected to increase over time. This is represented by a steadily growing capacity factor as shown in Figure 2-15 for the different solar irradiance levels available in Europe. More information about the methodology is given in /MED-CSP 2005/, pp. 46.

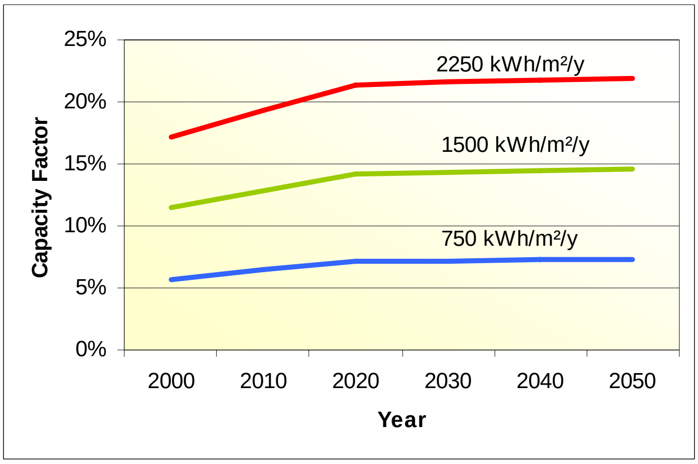


Figure 2-15: Capacity factor of grid connected PV systems as function of global irradiance on a surface tilted at latitude angle (kWh/m²/y) and the year of commissioning. There is no capacity credit for PV power.

In the year 2000, the total installed PV capacity in Europe amounted to about 190 MW producing 165 GWh/y of electricity. This is equivalent to an average of 870 full load hours per year. Most of this capacity was installed in Germany in the frame of the German Renewable Energy Act. According to our scenario, the PV capacity in the analysed countries will increase to 122 GW in the year 2050 producing about 155 TWh/y with an enhanced utilisation of 1270 full load hours per year. In spite of the relatively low level of solar irradiance and limited storability, PV will achieve a considerable share of 4 % of European electricity generation. Our scenario assumes an average PV growth rate of 14 %/y over the analysed time span of 50 years.

Hydropower

Hydropower from dams can be delivered on demand, but is usually subject to seasonal fluctuations. If used in times when PV and wind power are low, it acts like a natural complement and as a storage system for those resources. In our scenario, hydropower is increasingly saved when wind and PV energy is available and preferably used during peaking periods, while its annual capacity factor remains constant.

Hydropower technologies are well established since many years. There are large hydropower storage dams in Norway, Switzerland and Austria, and river run-off plants in most other European countries, ranging from large schemes with several 100 MW capacity to micro-hydropower systems with less than 1 kW capacity. Depending on the seasonal fluctuations and the available storage capacities of dams, the capacity factor of hydropower ranges between 10 and 90 %, while the capacity credit can be considered to range between 50 and 90 % (Table 2-5).

Hydropower potentials in Europe are well documented in the literature /WEC 2004/, /Horlacher 2003/. The annual full load hours are used as performance indicator. For the year 2000, they were calculated from the reported installed capacities and electricity generation in each country /Enerdata 2004/. The map in Figure 2-16 illustrates the geographic distribution, Table 2-2 quantifies the technical and economic potentials of hydropower.

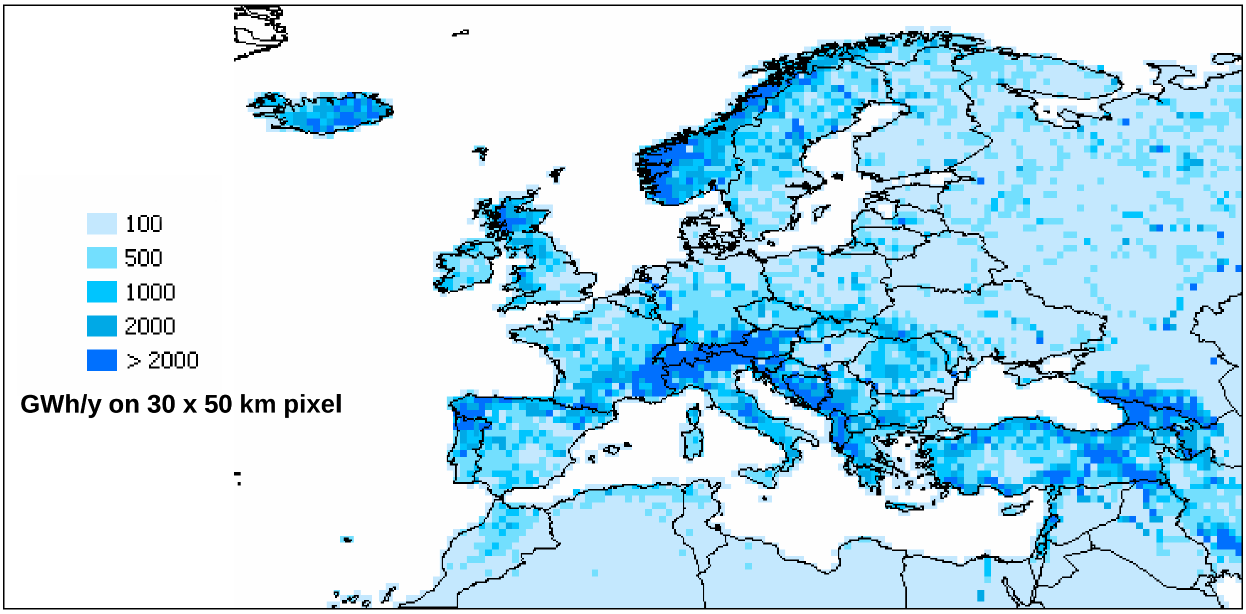


Figure 2-16: Gross physical hydropower potentials in Europe in GWh/y for unit elements of 30 km x 50 km size. Source: WaterGap, /Lehner et al. 2005/.

The total economic hydropower potential of all countries analysed in the TRANS-CSP study amounts to roughly 910 TWh/y. In the year 2000, European hydropower schemes produced 615 TWh/y of electricity with an installed capacity of 190 GW in 3250 full load operating hours per year. The numbers scheduled for 2050 in the TRANS-CSP scenario are 235 GW of installed capacity producing 750 TWh/y, respectively.

There is certain evidence that climate change is having an increasing impact on hydropower generation with the possibility of reductions of up to 25 % in the long term in the Southern European countries, /Lehner et al. 2005/. Although we have not quantified such impacts in the study we believe that this is a serious concern that should be taken into account in energy planning. Efficiency of hydropower use should be enhanced systematically in order to counteract at least partially such effects. Due to the already extensive use of hydropower in Europe, the expected growth rates until 2050 are rather moderate, with an average of around 0.5 %/y.

Geothermal (Hot Dry Rock)

Geothermal power can be delivered on demand as base, intermediate or peaking power using the earth as natural storage system. It can be used to compensate the fluctuations from wind and PV-power. Geothermal heat at over 200 °C can be delivered from up to 5000 m deep holes to operate organic Rankine cycles or Kalina cycle power machines. Unit sizes are about 1 MW today and limited to about 100 MW maximum in the future. Geothermal energy is often used for the co-generation of heat and power. Geothermal power plants are used all over the world where surface near geothermal hot water or steam sources are available, like in USA, Italy and the Philippines. In Europe those conventional geothermal potentials are significant in Island, Italy, Turkey and the Balkan region. Conventional geothermal resources were taken from literature /GEA 2004/, /WEC 2004/. Medium term geothermal power potentials are described in /EU 2004/. Those potentials are small in comparison to the Hot Dry Rock potentials and are not quantified separately in the study. In the year 2000, about 6 TWh/y of electricity were generated by conventional geothermal power plants, mainly in Iceland and Italy.

The Hot Dry Rock technology aims to make geothermal potentials available everywhere, drilling deep holes into the ground to inject cold water and receive hot water from cooling down the hot rocks in the depth /IGA 2004/. However, this is a rather new though promising approach and its technical feasibility must still be proven. Geothermal power plants provide power on demand using the ideal storage of the earth's hot interior as reservoir. They can provide peak load, intermediate load or base load electricity. Therefore, the capacity factor of geothermal plants is defined by the load and their operation mode. Assuming a plant availability of 90 %, their capacity credit would have that same value.

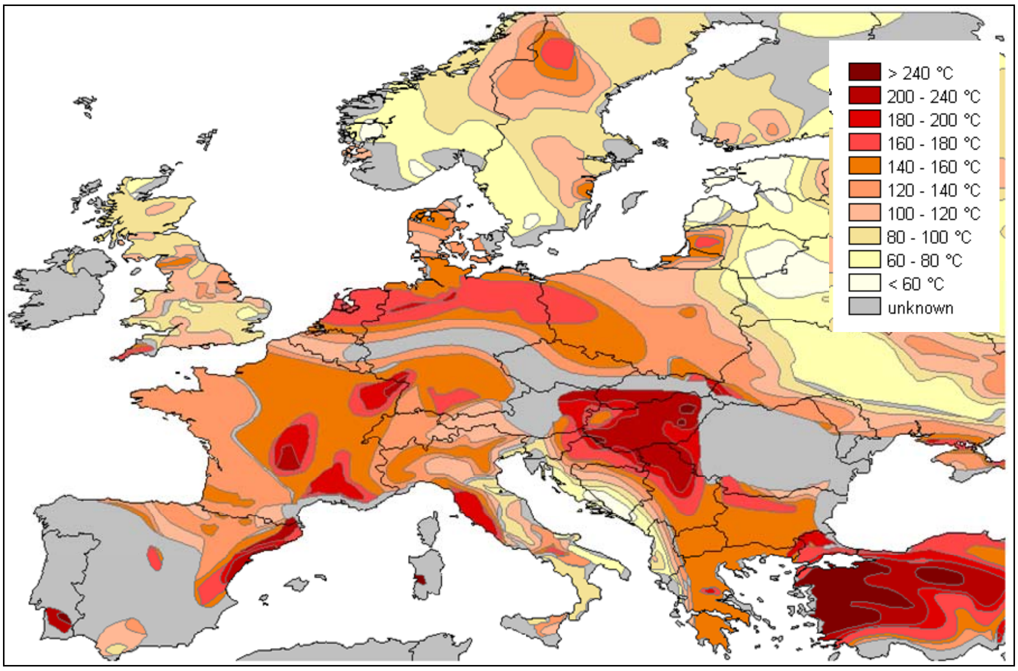


Figure 2-17: Rock temperatures in 5000 meters depth as indicator for HDR electricity potentials in Europe /Bestec 2004/.

A map of subsoil temperatures at 5000 m depth was taken to assess the total areas with temperatures higher than 180°C as economic potential for Hot Dry Rock technology (Figure 2-17). It was assumed that a layer with 2 km thickness in 5000 m depth was used as heat reservoir /BMU 2003-2/, /GGA 2000/. The total heat in place was then calculated from that volume with the temperature range available in each country according to the methodology described in /MED-CSP 2005/, pp. 47 and pp. 63. The resulting potentials for each country are given in Table 2-2. In 2050, a total potential of 200 TWh/y with a capacity of 41 GW could be activated by this technology, if the presently ongoing efforts of research and development are successful.

Biomass

Biomass can deliver power on demand as it is easily storable. However, biomass is subject to seasonal fluctuations. As a strategic guideline, biomass can be supplied in times when wind and PV power is low in order to compensate those sources, and shut down when wind and PV power is available to save the scarce biomass resources. It will also be used for cogeneration.

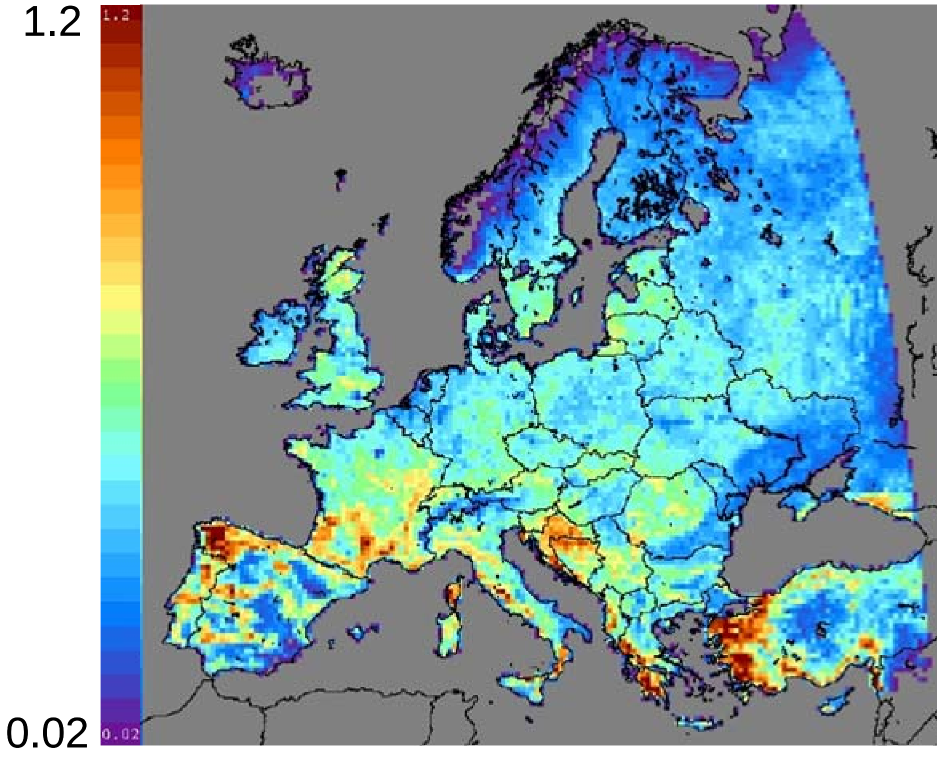


Figure 2-18: Net primary production of the total biomass by photosynthesis in million tonnes of carbon units per year on land surface units (pixel) of 27,5 x 27,5 km in the year 1998 (to obtain dry matter please multiply by 2) /WDC 2006/

There are a number of potential sources to generate energy from biomass: biogas can be produced by the decomposition of organic materials like municipal liquid waste, manure or agricultural residues. Biogas reactors require large quantities of water. The calorific value of biogas is about 6 kWh/m³. Biogas can be used in combustion engines or turbines for electricity generation and for co-generation of heat and power. Landfill gas can be used in a similar way.

Solid biomass from agricultural or municipal residues like straw, cane trash and wood can be used to generate heat and power. From every ton of dry solid biomass about 1.5-2.5 MWh of heat or 0.5-1.0 MWh of electricity can be generated in steam cycle power plants /BMU 2004-1/.

There is also the possibility to raise crops specifically for energy purposes. However, this option has been neglected in the TRANS-CSP scenario as there will be probably a priority to use energy crops for the transport sector (biofuels) rather than for electricity generation /UBA 2004/.

The size of biomass plants ranges from some kW (combustion engines) to about 25 MW. Biomass can be stored and consumed on demand for power generation. However, there are often seasonal restrictions to the availability of biomass. Typical power plants using biomass in co-generation have capacity factors between 0.4 and 0.6 that are equivalent to 3500 – 5500 full load hours per year. They are usually operated to provide intermediate or peaking power but seldom for base load. The availability of biomass plants is high at 90 % and so is their capacity credit.

If used for co-generation of electricity and heat, biomass electricity must be considered part of the base load segment of the power market, as it is not controlled by electricity demand, but usually by the heat load.

Electricity generation from biomass is calculated with the methodology described in /MED-CSP 2005/, pp. 49 and pp. 65. and compared to potentials given in the literature /EU 2004/ and /Greenpeace 2005/. The results of the study are given in Table 2-4 and Table 2-2.

In the year 2000, a total capacity of 11 GW was installed in Europe producing 49 TWh/y of electricity. In the TRANS-CSP scenario, the European biomass electricity potential was estimated to be in the order of 764 TWh/y of which 495 TWh/y could be used until 2050, with an installed capacity of 135 GW. The tenfold increase until 2050 is equivalent to an average growth rate of power generation from biomass of 5 %/y over the total time span.

	2050						2000	2010	2020	2030	2040	2050
	Max	Agr.Res.	Agr.Res.	Forest	Prod.	Wood	Mun.Waste	Mun.Waste	Mun.Waste	Mun.Waste	Mun.Waste	Mun.Waste
	TWh/y	1000 t/y	TWh/y	1000 km²	t/ha/y	TWh/y	TWh/y	TWh/y	TWh/y	TWh/y	TWh/y	TWh/y
Austria	30,62	10610	10,61	39	4,8	18,72	1,42	1,42	1,41	1,38	1,34	1,29
Cyprus	0,58	280	0,28	1	1,7	0,17	0,10	0,11	0,12	0,12	0,13	0,13
Denmark	6,62	3500	3,50	5	4,4	2,20	0,93	0,95	0,96	0,95	0,94	0,92
Finland	53,68	11200	11,20	219	1,9	41,61	0,91	0,92	0,93	0,92	0,90	0,87
France	79,15	26600	26,60	153	2,7	41,31	10,38	10,82	11,13	11,30	11,34	11,24
Czech Republi	19,98	6000	6,00	26	4,8	12,48	1,80	1,78	1,74	1,68	1,60	1,50
Belgium	7,29	2000	2,00	7	5	3,50	1,79	1,82	1,84	1,84	1,82	1,79
Ireland	6,25	1800	1,80	7	5,1	3,57	0,67	0,74	0,80	0,84	0,86	0,88
Luxembourg	0,44	270	0,27	0	5	0,05	0,08	0,09	0,10	0,11	0,12	0,12
Netherlands	9,57	5000	5,00	4	4	1,60	2,78	2,90	2,97	3,01	3,01	2,97
Sweden	80,35	16500	16,50	271	2,3	62,33	1,55	1,57	1,58	1,58	1,56	1,52
Switzerland	8,03	1250	1,25	12	4,8	5,76	1,25	1,24	1,21	1,16	1,10	1,02
United Kingdo	30,68	8500	8,50	26	4	10,40	10,46	10,80	11,10	11,37	11,59	11,78
Poland	52,14	16600	16,60	93	3,2	29,76	6,77	6,73	6,62	6,42	6,14	5,78
Bulgaria	7,74	2750	2,75	37	1,1	4,07	1,42	1,31	1,21	1,11	1,01	0,92
Slowac Republ	10,75	3000	3,00	20	3,44	6,88	0,94	0,95	0,95	0,93	0,91	0,87
Slowenia	6,25	2350	2,35	11	3,3	3,63	0,35	0,34	0,33	0,32	0,30	0,27
Germany	87,00	25000	25,00	107	4,5	48,15	14,40	14,44	14,40	14,29	14,11	13,85
Hungary	11,35	4800	4,80	18	2,9	5,22	1,75	1,67	1,59	1,51	1,42	1,33
Greece	7,24	3000	3,00	36	0,7	2,52	1,91	1,91	1,90	1,86	1,80	1,72
Italy	46,05	14200	14,20	100	2,4	24,00	10,08	9,84	9,50	9,05	8,50	7,85
Malta	0,07	2	0,00	0	0	0,00	0,06	0,07	0,07	0,07	0,07	0,07
Portugal	15,16	1000	1,00	37	3,4	12,58	1,75	1,76	1,74	1,71	1,65	1,58
Spain	40,40	13500	13,50	144	1,3	18,72	5,09	5,94	6,74	7,41	7,90	8,18
Turkey	44,74	13200	13,20	102	1,7	17,34	7,86	9,53	11,05	12,39	13,50	14,20
Macedonia	2,58	1300	1,30	3	3	0,90	0,35	0,37	0,38	0,39	0,39	0,38
Croatia	8,93	2900	2,90	18	3	5,40	0,78	0,76	0,73	0,70	0,67	0,63
Romania	40,91	15000	15,00	65	3,5	22,75	3,94	3,84	3,72	3,56	3,38	3,16
Serbia & Monte	14,34	4000	4,00	29	3	8,70	1,85	1,84	1,81	1,77	1,71	1,64
Bosnia-Herzeg	9,52	2000	2,00	23	3	6,90	0,70	0,73	0,74	0,73	0,69	0,62
Iceland	0,06	0	0,00	0	1,1	0,00	0,05	0,05	0,06	0,06	0,06	0,06
Norway	25,77	8000	8,00	89	1,9	16,91	0,78	0,82	0,84	0,85	0,86	0,86
Total	764		226			438	95	98	100	101	101	100

Table 2-3: Summary of the biomass electricity potential from agricultural and municipal waste and wood in Europe according to the methodology described in /MED-CSP 2005/, based on data from /WEC 2004/, /UBA 2004/ and /EU 2004/. Municipal waste potentials consider demographic and technical development.

Concentrating Solar Power

A major advantage of concentrating solar thermal power plants is their capability for thermal energy storage and hybrid operation with fossil or bio-fuels, allowing them to provide firm power capacity on demand. The principle of operation is drafted in Figure 2-19 for the cogeneration of heat and power. The use of a simple power cycle for electricity is of course possible as well. In the future European mix of energy sources for power generation, CSP can serve to cover base load, intermediate load or peaking load and even to compensate the fluctuations of PV and wind power. From the point of view of a grid operator, CSP behaves just like any conventional steam cycle power station, thus being an important factor for grid stability and control. CSP plants can be designed from 5 MW to several 100 MW capacity.

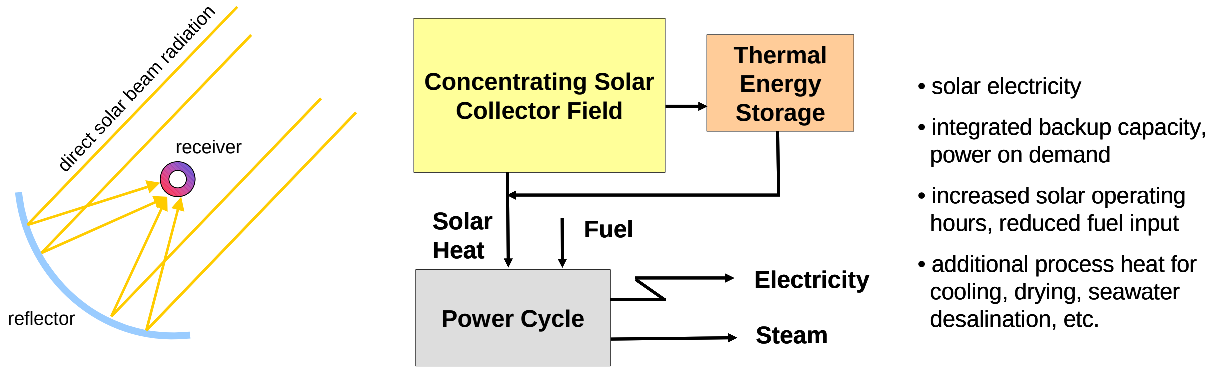


Figure 2-19: Principle of a concentrating solar collector (left) and of a concentrating solar thermal power station for co-generation of electricity and process heat (right).

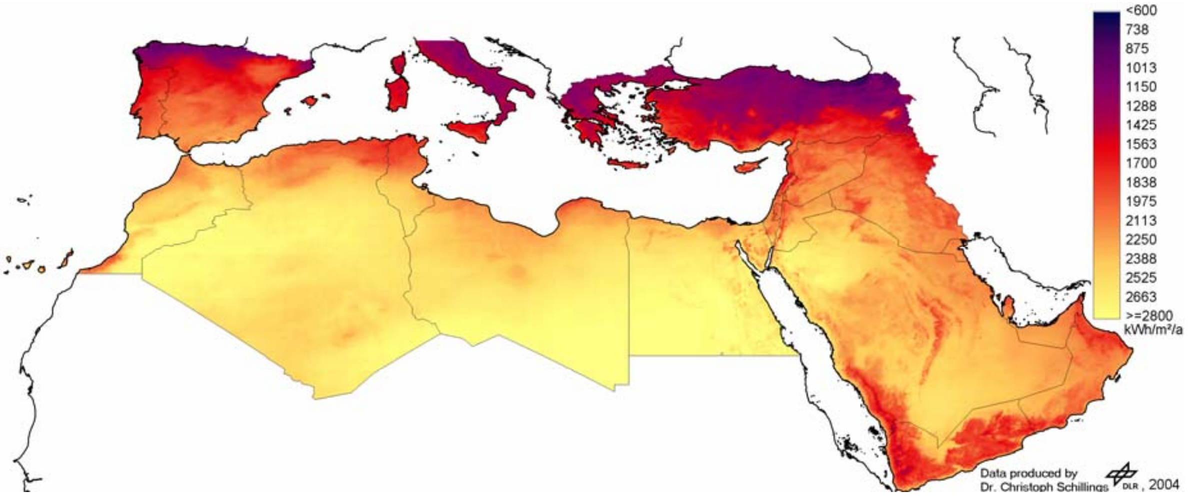


Figure 2-20: Annual direct normal irradiance in kWh/m²/y. In terms of primary energy, the direct solar irradiance in North Africa equals a layer of crude oil of 0.25 meters thickness on the total land surface every year. This gigantic resource is several orders of magnitude larger than the global energy demand. A small part could be harvested by concentrating solar thermal power stations and exported to Europe via High Voltage Direct Current interconnections /MED-CSP 2005/

A reasonable economic performance of concentrating solar power plants is given at an annual direct solar irradiance of more than 2000 kWh/m²/y. The economic potential of CSP in Europe has been assessed in /MED-CSP 2005/, pp. 58 and pp. A-11. It is limited to Spain, Portugal, Greece, Turkey and the Mediterranean Islands and amounts to 1580 TWh/y of which 1280 TWh/y are located in southern Spain (Table 2-2). Although there is a relatively large CSP potential in Europe, more attractive sites are located south of the Mediterranean sea, with an annual direct solar irradiance of up to 2800 kWh/m²/y (Figure 2-20).

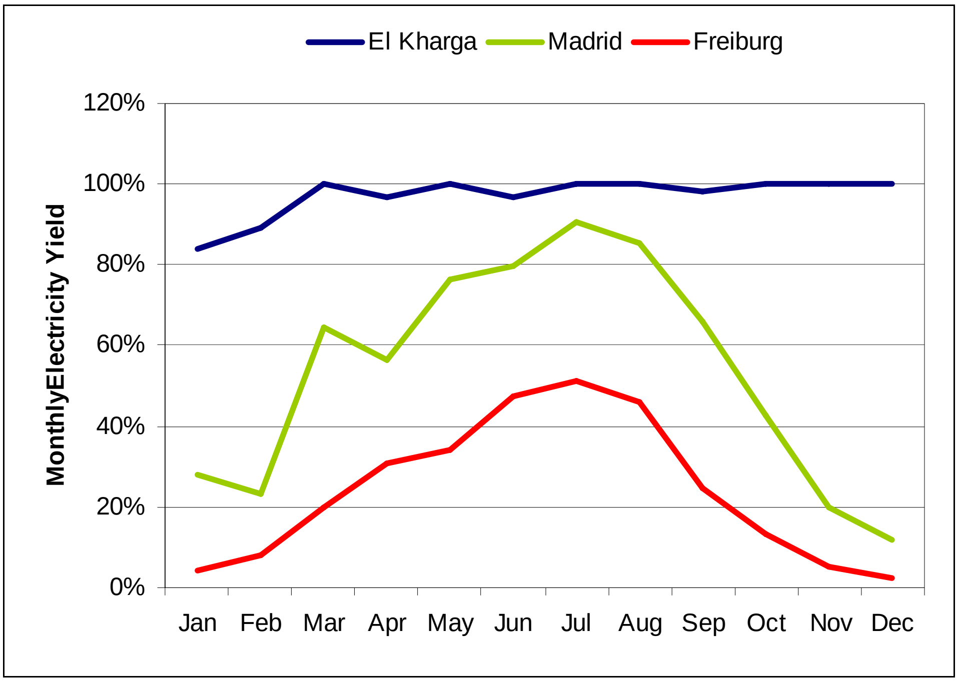


Figure 2-21: Simulation of the relative monthly electricity yield of a solar thermal power plant with 24 hour storage at sites with different annual solar irradiance and latitude. Solar only operation without fuel input. Equivalent annual full load hours: Freiburg (Germany) 2260 h/y, Madrid (Spain) 5150 h/y, El Kharga (Egypt) 8500 h/y /May 2005/.

Figure 2-21 shows the monthly electricity yield of a solar thermal power plant with 24 hour storage capacity at different locations in Europe and North Africa. The site El Kharga in Egypt represents the best case of all. Throughout the whole year the energy yield stays at almost 100 %, just in January and February it declines to about 85 %. The more the plant is located to the North, the lower is its monthly electricity yield. In Madrid and Freiburg values of less than 20 % are achieved in wintertime, and nether achieves 100 % in summer.

For this reason, the TRANS-CSP study investigates the feasibility of activating part of the valuable and powerful solar energy resources of North Africa for export to Europe by means of High Voltage Direct Current power transmission (HVDC) as complement to the European renewable energy sources. There is an economic potential of 1584 TWh/y, of which 111 TWh/y (19 GW) would be used until 2050, with a growth rate of 9 %/y.

Resource	Hydro	Geo	Bio	CSP	Wind	PV	Wa/Ti
Indicator	Flh	THDR	FLh	DNI	FLh	GTI	FLh
Unit	h/y	°C	h/y	kWh/m^2/y	h/y	kWh/m^2/y	h/y
Austria	3608	200	4500	820	1176	1380	0
Cyprus	0	100	3500	2200	3423	2100	4000
Denmark	2818	100	5000	950	3304	1180	4000
Finland	4933	100	5500	950	3310	1180	4000
France	2838	200	4500	1060	2618	1560	4000
Czech Republic	1100	100	4500	760	1789	1130	0
Belgium	4466	100	4500	700	2449	1140	4000
Ireland	2264	100	4500	700	3260	1120	4000
Luxembourg	789	100	4500	700	1176	1130	0
Netherlands	2432	180	4500	700	3413	1120	4000
Sweden	4852	180	4500	1070	2638	1240	4000
Switzerland	2894	100	4500	990	1176	1170	0
United Kingdom	1857	180	4500	660	3733	1100	4000
Poland	1881	180	4500	790	2355	1140	4000
Bulgaria	1667	180	5500	1070	1176	1510	0
Slowac Republic	2000	180	4500	750	1176	1430	0
Slowenia	4419	180	4500	860	1176	1250	4000
Germany	3667	180	4500	900	3459	1260	4000
Hungary	3771	220	4500	1100	1176	1370	0
Greece	1331	213	3500	1900	2252	1730	4000
Italy	2502	200	3500	2000	2289	1800	4000
Malta	0	100	3500	2000	2095	2150	4000
Portugal	2589	213	3500	2100	2862	1910	4000
Spain	1705	213	4500	2250	2494	2020	4000
Turkey	2762	281	3500	2000	2235	1900	4000
Macedonia	2667	100	4500	1100	1176	1450	4000
Croatia	2823	180	4500	940	1176	1400	4000
Romania	3086	190	4500	1200	1176	1500	0
Serbia & Montenegro	3715	220	4500	1250	1176	1550	4000
Bosnia-Herzegowina	3091	100	4500	1100	1176	1450	4000
Iceland	6038	400	4500	810	2708	970	4000
Norway	5164	100	5000	580	2708	850	4000

Table 2-4: Performance indicators of the different renewable energy sources in Europe. The resource indicators quantify the average performance quality of the economic potential in each country. Flh: Full Load Hours per year, THDR Temperature of Hot Dry Rocks in 5000 m depth, DNI Direct Normal Irradiance, GTI Global Irradiance on surfaces Tilted according to latitude. Wa/Ti Wave and Tidal Power.

	Unit Capacity	**Capacity Credit ***	**Capacity Factor ****	**Resource**	**Applications**	**Comment**
Wind Power	1 kW – 5 MW	0 – 30 %	15 – 50 %	kinetic energy of the wind	electricity	fluctuating, supply defined by resource
Photovoltaic	1 W – 5 MW	0 %	5 – 25 %	direct and diffuse irradiance on a tilted surface	electricity	fluctuating, supply defined by resource
Biomass	1 kW – 25 MW	50 - 90 %	40 – 60 %	biogas from the decomposition of organic residues, solid residues and wood	electricity and heat	seasonal fluctuations but good storability, power on demand
Geothermal (Hot Dry Rock)	25 – 50 MW	90 %	40 – 90 %	heat of hot dry rocks in several 1000 meters depth	electricity and heat	no fluctuations, power on demand
Hydropower	1 kW – 1000 MW	50 - 90 %	10 – 90 %	kinetic energy and pressure of water streams	electricity	seasonal fluctuation, good storability in dams, used also as pump storage for other sources
Solar Chimney	100 – 200 MW	10 to 70 % depending on storage	20 to 70 %	direct and diffuse irradiance on a horizontal surface	electricity	seasonal fluctuations, good storability, base load power
Concentrating Solar Thermal Power	10 kW – 200 MW	0 to 90 % depending on storage and hybridisation	20 to 90 %	direct irradiance on a surface tracking the sun	electricity and heat	fluctuations are compensated by thermal storage and (bio)fuel, power on demand
Gas Turbine	0.5 – 100 MW	90 %	10 – 90 %	natural gas, fuel oil	electricity and heat	power on demand
Steam Cycle	5 – 500 MW	90 %	40 – 90 %	coal, lignite, fuel oil, natural gas	electricity and heat	power on demand
Nuclear	>500 MW	90 %	90 %	uranium	electricity and heat	base load power

Table 2-5: Some characteristics of contemporary power technologies. * Contribution to firm capacity. ** Average annual utilisation.

2.3 Outlook for Electricity Supply in Europe

Comparing the expected future electricity demand in Europe with the economic renewable energy potentials shows that in principle enough potentials are available to cover the demand with a surplus of 45 % (Table 2-6). However, it must be taken into account that about 30 % of the analysed countries show considerable deficits, while on the other hand considerable surpluses are concentrated in only 7 countries. Roughly one quarter of the potential is represented by one single resource in one single country, that is concentrating solar power in Spain.

Unit: TWh/y	**Demand**	**Total Ren.**	**Coverage**
	2050	**Econ. Pot.**	**in 2050**
Austria	**49,0**	**96,6**	**197%**
Cyprus	**5,0**	**27,9**	**558%**
Denmark	**51,1**	**65,1**	**127%**
Finland	**76,4**	**104,3**	**137%**
France	**426,0**	**329,7**	**77%**
Czech Republic	**51,7**	**29,9**	**58%**
Belgium	**67,0**	**23,2**	**35%**
Ireland	**34,0**	**67,6**	**199%**
Luxembourg	**10,9**	**2,2**	**20%**
Netherlands	**116,0**	**56,3**	**48%**
Sweden	**153,7**	**240,9**	**157%**
Switzerland	**39,4**	**50,0**	**127%**
United Kingdom	**451,2**	**450,8**	**100%**
Poland	**190,9**	**129,9**	**68%**
Bulgaria	**26,5**	**31,4**	**119%**
Slowac Republic	**29,5**	**22,5**	**76%**
Slowenia	**9,3**	**16,0**	**171%**
Germany	**548,8**	**433,6**	**79%**
Hungary	**43,9**	**70,5**	**161%**
Greece	**62,1**	**89,5**	**144%**
Italy	**310,6**	**237,2**	**76%**
Malta	**2,4**	**2,3**	**95%**
Portugal	**62,0**	**220,1**	**355%**
Spain	**320,1**	**1513,1**	**473%**
Turkey	**494,1**	**723,4**	**146%**
Macedonia	**11,5**	**7,3**	**63%**
Croatia	**20,3**	**24,4**	**120%**
Romania	**96,1**	**69,8**	**73%**
Serbia & Montenegro	**49,2**	**48,8**	**99%**
Bosnia-Herzegowina	**17,8**	**29,2**	**164%**
Iceland	**6,6**	**233,8**	**3567%**
Norway	**112,0**	**290,7**	**259%**
Total	**3945**	**5738**	**145%**

Table 2-6: Electricity demand in 2050 compared to the total economic renewable electricity potential of the analysed countries without solar electricity imports. Red indicates those countries where the domestic renewable electricity potential is smaller than the expected demand, green indicates sufficiently high potentials to cover the expected demand.

The available potentials will probably not cover by 100 % the total European electricity demand in 2050, for the following reasons:

- About 60 % of the economic renewable electricity potential in Europe is represented by wind and solar energy, both highly fluctuating resources that cannot deliver power on demand. As explained in Figure 2-21, even concentrating solar thermal power (CSP) must be considered a fluctuating resource under European conditions. Biomass and hydropower resources are not submitted to short term, but to seasonal fluctuations. Therefore, a 100 % coverage of the annual electricity demand would ether require the installation of considerable over-capacities by a factor 2 or 3 /Quaschning 2000/ or the use of conventional fossil backup power, consequently reducing the renewable energy share to less than 100 %. The same would result from the use of hybrid CSP plants.
- Most renewables except hydropower and wind energy are not yet visible in the European energy mix today. To grow to considerable shares requires time, defined by the growth rates of the respective industrial production capacities. Although growing quickly today, with spectacular rates of 25-60 %/y for wind and PV, a considerable share of renewables will not become visible in the total energy mix before 2020. To cover the power demand until renewables can really take over the core of electricity supply, and considering the demand for new power capacities as shown in Figure 2-8, new fossil fuel based power capacities will have to be installed from here to 2050. Once installed, those capacities will not be decommissioned before their economic lifetime is over, thus still blocking the respective market segment in 2050 and afterwards.
- The economic learning curves of renewable energy technologies will require a certain time span to come to a competitive level. Geothermal (HDR) plants still require considerable R&D efforts, while the economic performance of PV plants is limited by the rather low solar irradiance in northern Europe. Public concern is increasingly pushing wind power to offshore regions, and hydropower plants are subject to increasing environmental constraints, creating additional challenges for each technology that still must be overcome and will take time to be solved.
- Public support of renewables must balance the expectations of private investors with adequate incentives for cost reduction to achieve an optimal allocation of funds. Therefore, only a support exactly fitting to the real cost level of each technology and subsequently reduced over time will induce optimal learning and development. Nether scarce nor excessive funding would be helpful to achieve that goal. Renewables will need time to come to overall electricity costs comparable to the starting point of the scenario in the year 2000, but on the other hand, only renewables have the potential to come back to that level at all, while fossil generation is already far beyond that point.

The scope of our study was to find a well balanced mix of domestic and imported, fossil and renewable sources to provide compatible, secure and affordable electricity for each of the analysed European countries, not to maximise renewable electricity generation.

To calculate the TRANS-CSP scenario we have followed the methodology described in /MED-CSP 2005/, pp. 111 ff, which is guided by the energy policy triangle. We must point out again that a scenario is not a prediction of future events, but a consistent path to the future that will require efforts to become reality. The scope of a scenario analysis is to identify a viable and consistent future situation, to evaluate its desirability and to provide the necessary data base for the finding of strategies for its achievement.

Frame Parameters for the Scenario

The frame conditions and assumptions used to narrow down the set of viable paths to the future have been selected to be plausible and “conservative” in terms of the expansion of renewables, assuming e.g. a relatively low cost escalation for fossil fuels. There can be different scenarios based on more optimistic or more pessimistic assumptions. We think that the frame parameters chosen here are within a reasonable range of possibilities. The TRANS-CSP scenario was calculated under the following economic assumptions (Figure 2-22):

- Oil price: 25 $/bbl in 2000 rising to 80 $/bbl in 2050.
- Gas price starting with 3.5 $/GJ in 2000 escalating to 10 $/GJ in 2050.
- Coal price rising from 48 $/ton to 80 $/ton.
- Capture and sequestration of 85 % of the carbon dioxide emitted from new fossil fuel fired plants starting in 2020 with average 1.5 ct/kWh additional electricity cost.
- Real discount rate 5 %/y.
- Average exchange rate of € / US$ = 1.

The following potential barriers and frame conditions have also been taken into account to narrow down the course of market development of renewable forms of energy in the scenario:

- existing grid infrastructure
- growth rates and market shares of renewable energy technology production
- annual electricity demand
- peaking power demand and firm reserve capacity
- replacement of old plants
- cost of electricity in comparison to competing technologies
- opportunities of finance
- policies and energy economic frame conditions

All those parameters are not treated as static constants, but are analysed in their dynamic transition towards a sustainable energy scheme.

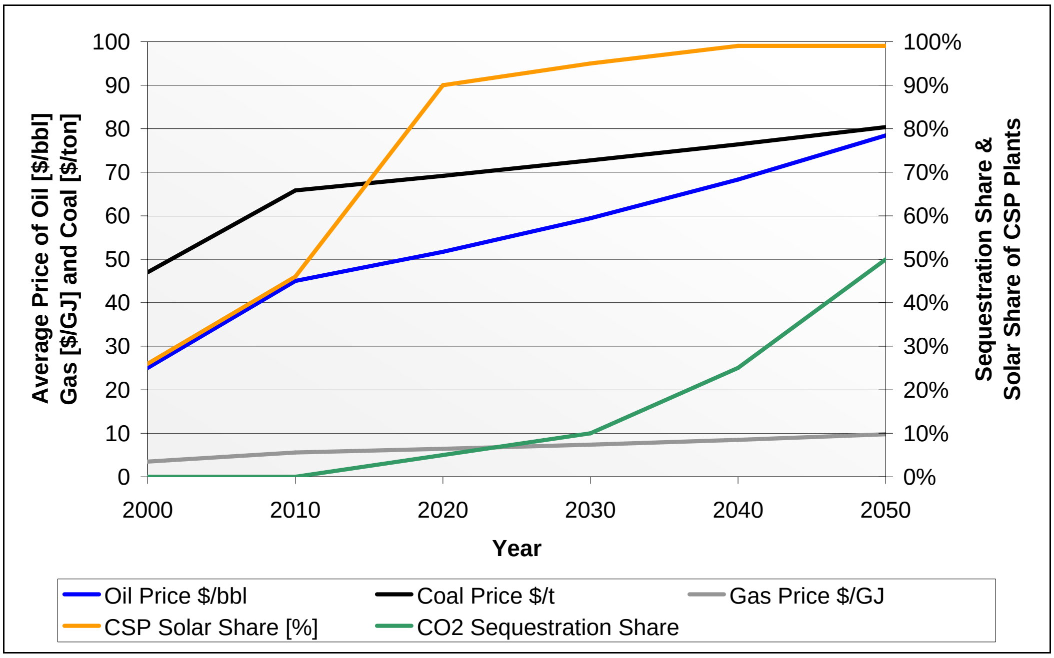


Figure 2-22: Energy economic frame parameters and assumptions used for the TRANS-CSP scenario calculations.

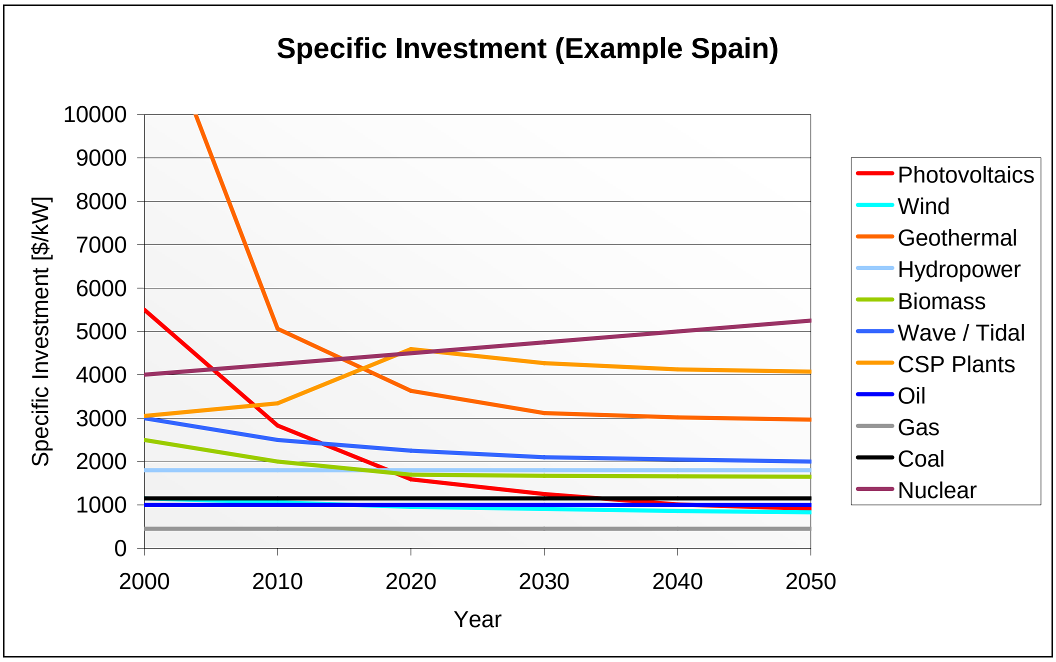


Figure 2-23: Specific investment of power technologies in the TRANS-CSP scenario, including the costs of decommissioning depreciated with a discount rate of 5%/y over the economic lifetime. CSP plants are subsequently built with larger collector fields and thermal storage, therefore, their specific investment increases proportionally to their solar operating time. The investment of all other plants is reduced with time according to their specific learning curves. Nuclear power investments include subsequently higher costs for security and nuclear waste disposal (+25 % until 2050).

Our scenario assumes that the European countries will introduce CO_2-capturing and sequestration after 2020, and will reach a sequestration share of 50 % of their conventional power generation capacity by 2050. Carbon capture will increase the cost of conventional power generation of newly installed plants by a minimum of 1.5 cents/kWh. We consider this a rather optimistic estimate to describe the cost of carbon capture technology /NREL 2004/.

All technologies analyzed within this study are subject to technology development and economies of scale. While renewables have still a rather elevated investment cost, they are in a phase of fast technological progress with market growth rates of over 25 % per year, which will lead to a significant cost reduction in a relatively short time (Figure 2-23). This has been observed in the past and will continue in the future – although slowing down with increasing market presence /EXTOOL 2003/, /WETO 2003/.

On the contrary, fossil and nuclear power technologies are mature since many years and are massively applied world wide. Investment cost reductions are hardly noticeable at present, although existent. However, many cost reductions have been compensated by the necessity of adding measures for security and the protection of the environment, like e.g. filters and chemical flue gas treatment, and nuclear waste disposal. Moreover, the primary energy sources used by those technologies are not for free and everlasting like solar or wind energy, but increasingly becoming scarce, expensive and burdened by severe environmental constraints like e.g. global climate change.

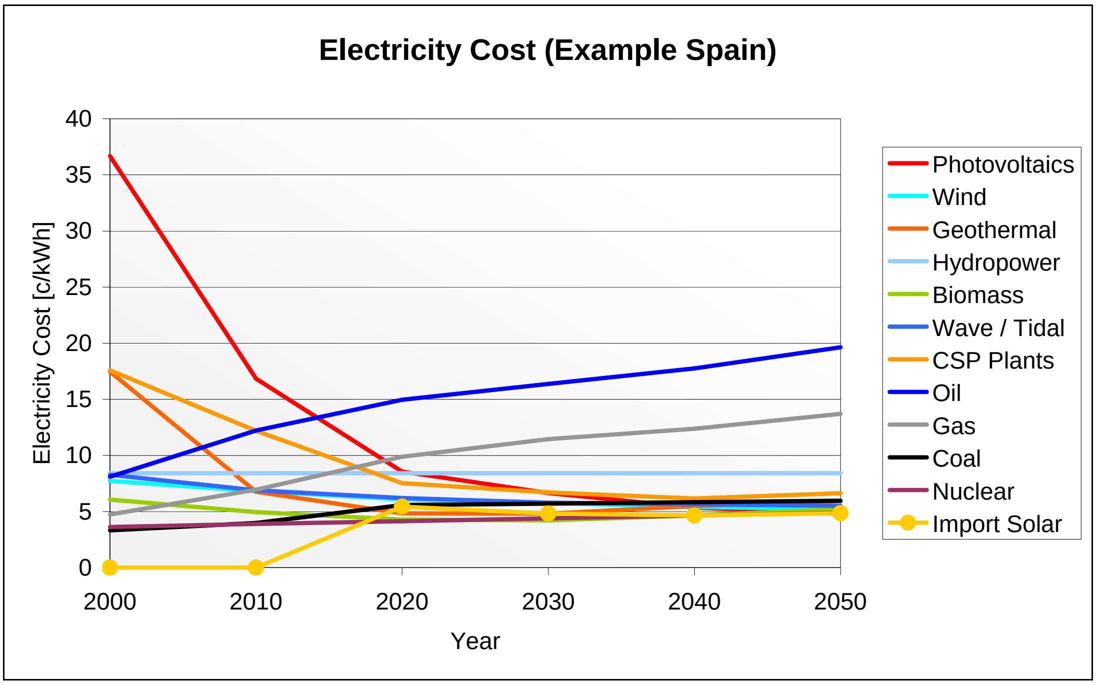


Figure 2-24: Electricity generation cost of new plants resulting from the specific investment (Figure 2-23) and from the performance indicators of each country and source in Table 2-4. In the long term, renewables are not only the more valuable, but also the least cost option for power.

The cost of renewables will strongly depend on the meteorological conditions in each country, which may widely differ. The electricity cost scenario was calculated with an average real discount rate of 5 %/year. All numbers are given in real values of €-2000. The electricity cost of renewable sources is calculated as function of the performance indicators described before and taking into consideration realistic learning effects by economies of scale and technical progress. The electricity cost of all power technologies is calculated by the following equation:

$$C_{el} = \frac{Inv \cdot FCR + O\,\&\,M + F}{E_{year}}$$

C_{el} cost of electricity in €-2000/kWh

Inv investment cost in €-2000

FCR fixed charge rate as function of interest rate and economic lifetime (annuity)

$O\&M$ annual cost of operation and maintenance, personnel, insurance, etc.

F annual fuel expenses

E_{year} electricity generated per year = installed capacity (MW) · full load hours (h/y)

	Economic Life years	Efficiency % *	Fuel Price Escalation %	Operation & Maintenance % of Inv./y	Annual Full Load Hours hours/year*
Steam Coal Plants	40	40%	1.0%	3.5%	5000
Steam Oil Plants	30	40%	1.0%	2.5%	5000
Combined Cycle Natural Gas	30	48%	1.0%	2.5%	5000
Wind Power	15			1.5%	2000
Solar Thermal Power	40	37%	1.0%	3.0%	8000
Hydropower	50	75%		3.0%	2600
Photovoltaics	20	10%		1.5%	1800
Geothermal Power	30	13.5%		4.0%	7500
Biomass Power	30	35%		3.5%	3700

* vary for different countries and sites

Table 2-7: Example of parameters used for the calculation of the electricity cost.

A set of parameters used for the calculation of the electricity cost as a function of time is given in Table 2-7, showing some parameters that vary for each country and site and others that are assumed to be equal for all countries within the scenario calculation. The cost of solar import electricity is calculated on the basis of the CSP performance parameters in North Africa and includes the investment and operation cost of the HVDC transmission lines as well as the electricity losses caused by transmission as described in Chapter 1.

A Well Balanced Energy Mix

Coal (inclusive lignite) and nuclear power are the main sources for electricity in Europe in the starting year 2000, followed by hydropower and natural gas (Table 2-8), (Figure 2-25). The installed power capacity is dominated by coal and hydropower, followed by natural gas and nuclear plants (Table 2-9), (Figure 2-26). The present electricity mix violates a number of requisites for sustainability as described in Figure 2-1. The past and present carbon emissions of the power sector are a major cause for climate change, the valuable fossil energy resources – especially those existing in Europe – are gradually depleted, import dependency of the European power sector is increasing, and the world market price of all primary energy sources used for power generation has become today more than three times that of the year 2000, with a persisting trend upwards. Today European electricity consumers are already paying approximately 35-70 billion €/y more for fuels for power generation than in the year 2000.

Year	2000	2010	2020	2030	2040	2050
Wind	23,2	172,8	496,4	667,4	743,0	780,7
Photovoltaics	0,2	4,1	26,4	78,9	118,3	153,8
Geothermal	5,9	10,2	29,3	76,0	130,5	200,6
Biomass	49,3	84,8	156,4	223,7	371,3	495,4
CSP Plants	0,0	3,2	14,6	53,5	87,5	111,5
Wave / Tidal	0,0	2,6	10,4	24,1	42,6	66,7
Hydropower	615,8	642,3	668,8	695,3	721,8	748,3
Oil	195,4	152,2	111,8	58,0	8,8	0,0
Gas	528,9	720,0	797,6	910,2	823,5	431,9
Coal	1000,6	1031,5	1031,1	955,6	744,0	362,0
Nuclear	970,1	804,2	537,5	259,7	62,3	0,0
Import Solar	0,0	0,0	60,0	231,0	473,0	707,5
Total	**3389**	**3628**	**3940**	**4233**	**4327**	**4058**

Table 2-8: Electricity generation in TWh/y in the analysed countries in the TRANS-CSP scenario

Year	2000	2010	2020	2030	2040	2050
Wind	12,8	73,9	196,3	254,0	272,5	276,6
Photovoltaics	0,2	3,7	21,5	63,5	94,6	122,3
Geothermal	0,8	1,4	4,1	12,0	24,3	41,2
Biomass	10,8	19,0	35,6	52,7	95,4	138,6
CSP Plants	0,0	0,8	2,3	8,2	13,8	18,8
Wave / Tidal	0,0	0,6	2,6	6,0	10,6	16,7
Hydropower	190,3	203,5	214,1	224,1	228,8	235,7
Oil	64,0	55,0	42,8	29,6	3,3	0,0
Gas	136,9	197,6	261,7	314,3	328,7	259,4
Coal	210,4	205,7	192,0	171,1	127,7	58,6
Nuclear	137,8	115,0	77,5	37,3	8,7	0,0
Import Solar	0,0	0,0	11,5	38,7	69,3	102,2
Total Capacity	**763,9**	**876,3**	**1062,0**	**1211,4**	**1277,7**	**1270,0**

Table 2-9: Installed capacity in GW in the analysed countries in the TRANS-CSP scenario

The external costs caused by the damages of power generation to health and the environment are accepted to be in the order of 3-8 cents/kWh with increasing trend, together with the expenses for military and intelligence to secure the remaining global fossil energy resources mainly in the Middle East and North Africa, and to protect the highly vulnerable energy supply infrastructure in Europe. External costs and direct energy subsidies for fossil and nuclear fuels add another 80 billion €/y to the real cost of fossil fuels for power generation in Europe (Chapter 4).

At the same time, many industrial countries as well as the strongly growing economies in transition, specially in Asia, exert an increasing pressure on the global fossil fuel resources, claiming their share of those energy reserves and driving prices further up. Some analysts predict a cost of 120 $/bbl for crude oil until 2030, and there is evidence that considerable cost escalation will affect the other primary energy sources as well /HWWA 2005/.

Escalating fossil fuel costs as well as European policies to reduce climate change will accelerate the expansion of renewable energy sources. Starting with 20 % renewables and 80 % fossil and nuclear power in the year 2000, the TRANS-CSP scenario leads to a transition to 20 % fossil fuels and 80 % renewables within the electricity supply of the year 2050 (Figure 2-25). By that time, the risky use of nuclear power will not be necessary any more.

The European countries show rather large potentials of hydropower, wind power and biomass and less potential for solar and geothermal power generation. This is due to the fact that PV, CSP and geothermal HDR production capacities are still very small today, and once they become visible after 2020, the electricity demand in Europe is already stagnating or retrogressive. Also, in comparison to the large power demand of this region, economic solar power potentials are relatively limited. Hydropower potentials are already used to a considerable extent today, and there is only a moderate growth for this technology in view. Biomass potentials are large in Europe, however there will be competing biomass applications in the heat and mobility sector, thus reducing the potentials for power generation. Wind power is a very strongly growing technology today, with several GW of capacity installed every year in Spain and Germany alone. By 2050 it will have the same share of electricity generation as hydropower.

Comparing the results of TRANS-CSP to the trends under current policies published recently by the European Commission’s Greenpaper on Sustainable, Competitive and Secure Energy (Figure 2-27), we see a slightly lower growth of electricity demand in our scenario which is due to a higher exploitation of the potentials of rational use of energy and energy efficiency, specially in the new European countries.

We also have a higher content of renewables and natural gas in the year 2030, and less coal and nuclear power. This is due to the fact that increased shares of renewables – specially wind and PV – will primarily substitute base load capacities from nuclear and coal (non-regulative power), while on the other hand existing and additional intermediate/peaking capacities using natural gas will be required for the complementation of these resources.

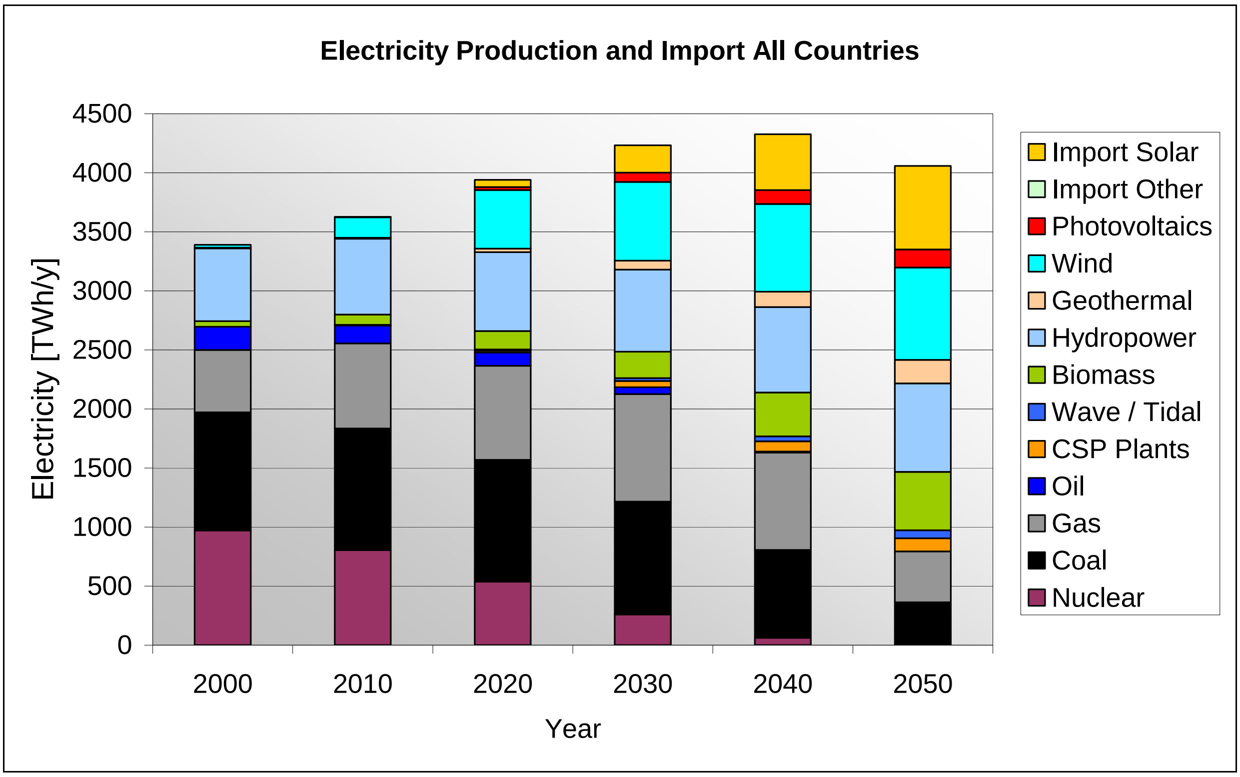


Figure 2-25: TRANS-CSP scenario of gross electricity production and import for the analysed European countries until 2050

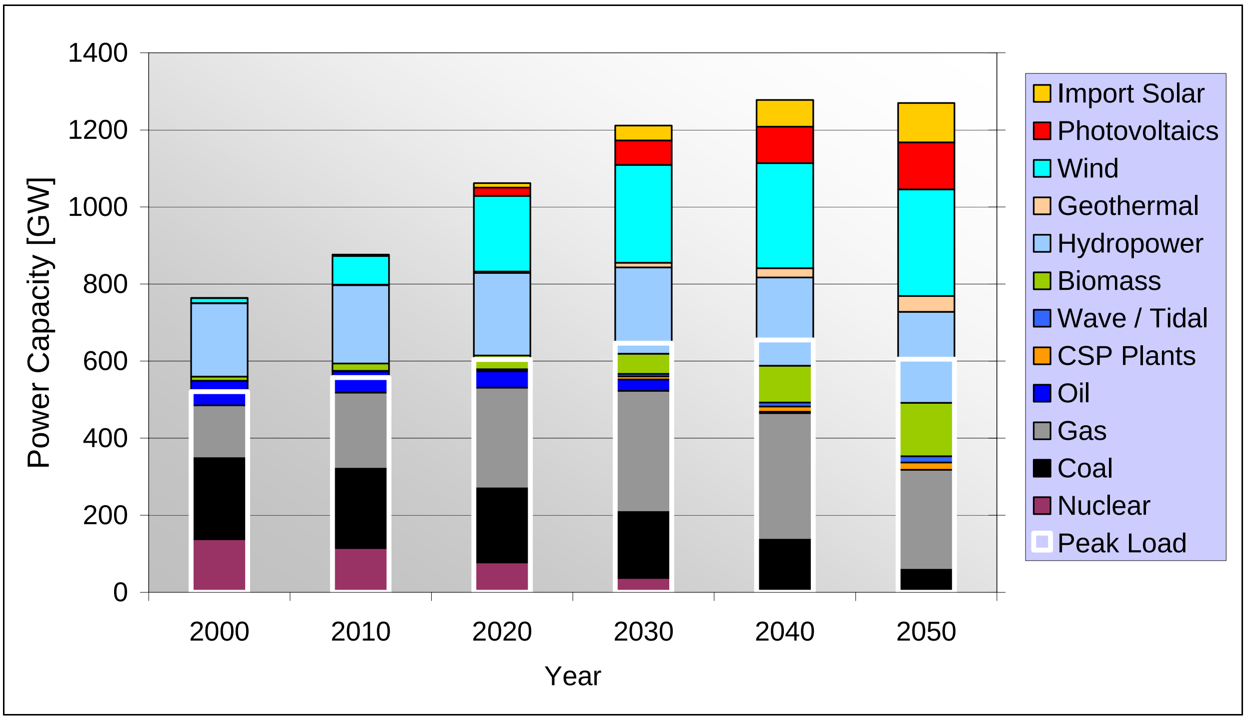


Figure 2-26: TRANS-CSP scenario for installed capacities and peak load for the analysed European countries

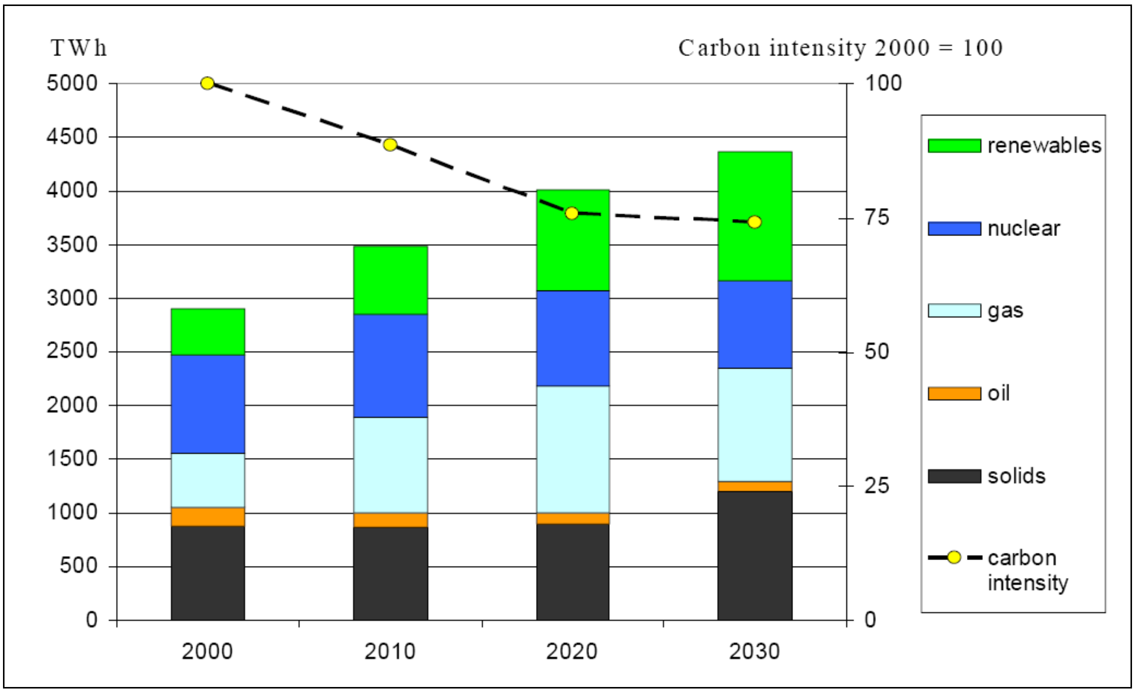


Figure 2-27: Electricity production by fuel and trends under current policies in the EU 25 according to the EU-Greenpaper for sustainable, competitive and secure energy /EU 2006/

European energy import dependency is a factor often discussed in the context of sustainability e.g. in the EU Green Paper /EU 2006/. Due to the subsequent depletion of the European domestic fossil and nuclear primary energy sources, imports are steadily growing, and concerns for the security of supply increase. Nuclear power is often mentioned as the solution of this dilemma, however European uranium resources are depleting as well – the EU 15 reserves are close to zero – and import dependency is expected to increase (Figure 2-28). This trend is reversed by the TRANS_CSP scenario after 2020 due to the improved use of domestic renewable energy sources. This will not only reduce the necessary energy imports, but will also prolong the useful lifetime of the remaining domestic fossil fuel resources in Europe.

The Need of Firm Power Capacity

To achieve the annual electricity production in Figure 2-25 the capacities shown in Figure 2-26 must be installed. It can be noted that the share of PV and wind capacities is higher in terms of installed capacity than in terms of electricity, which is due to the relatively low capacity factor (annual utilisation) of those technologies. For example, the installed PV capacities are comparable to those of biomass, but their annual electricity yield is only 20 % compared to that of the biomass plants. As a consequence, the ratio of the total installed capacity to peak power demand for the total power plant park increases from 1.5 in the year 2000 to 2.1 in the year 2050. Reserve capacities of about 25 % with respect to peak load are usually necessary to have enough reserves for the case of overhaul and failure of power plants in the present energy mix, but with the increasing use of wind and PV power, the over-capacities increase to 110 %.

The subsequently growing over-capacities in the scenario are due to the low capacity credit of PV and wind power, requiring other renewable or fossil backup plants to provide the necessary minimum firm capacity, which we have set to 125 % of the peaking demand in order to have a 25 % reserve.

It is a common misbelieve that for every wind park a conventional power plant of the same capacity must be installed and operated. The necessary peaking capacities remain more or less the same for the whole period until 2050. That means that the necessary peaking capacities to compensate the fluctuations of the PV and wind parks scheduled in the scenario already exist today. No considerable extra capacities must be installed, but the existing peaking capacities must be maintained. From the point of view of a peaking plant, it does not make any difference if the load fluctuates (as usual) or if the power delivered by another power plant fluctuates. The transients that must be compensated by peaking plants are just the same (Figure 2-29 and Figure 2-30), they just occur at another time. However, it is true that wind and PV plants do not replace other power plant capacities, they just reduce their fuel consumption. Wind and PV plants reduce the necessary operation time of other power plants, but they cannot replace their firm capacity.

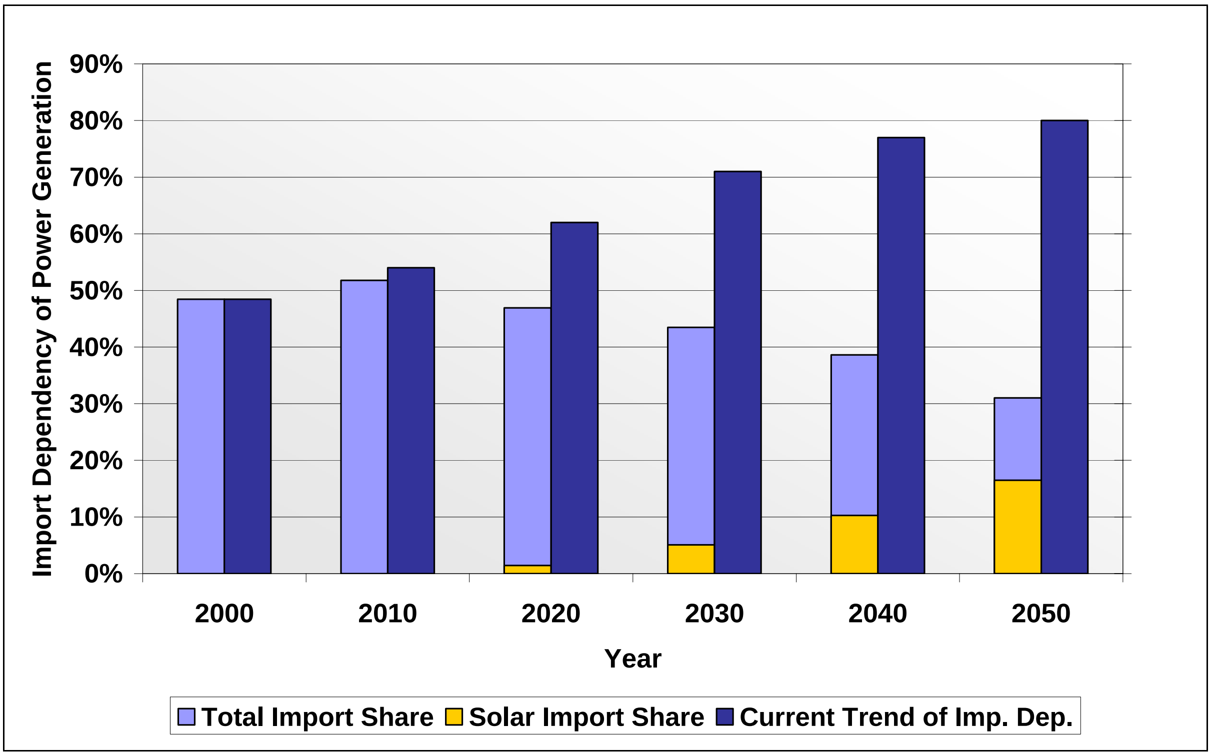


Figure 2-28: Total import share of power generation inclusive import from concentrating solar power from MENA in the TRANS-CSP scenario, versus the currently projected trend of import dependency of power generation in the EU according to /EU 2006/.

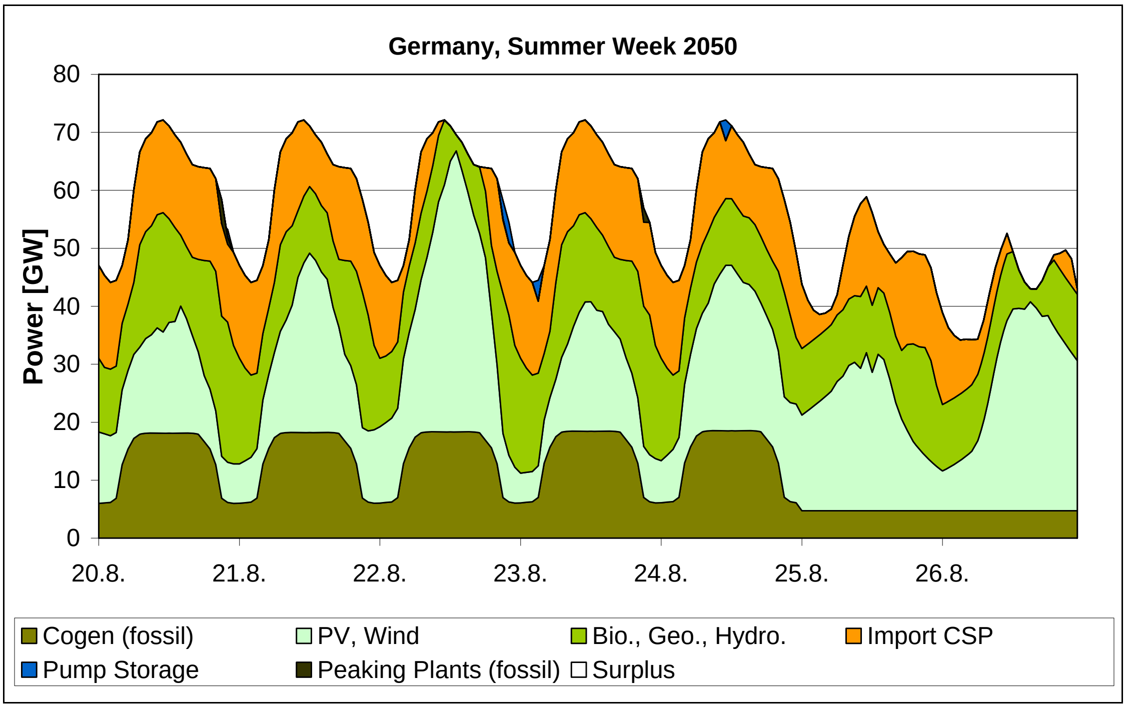


Figure 2-29: Hourly time series of power generation during a summer week in the year 2050 in Germany modelled in the TRANS_CSP scenario. For the other countries please refer to the Annex. Base load electricity is provided by cogeneration plants and by renewable sources. Fossil fuelled power is only required for peaking purposes. There is no functional window for conventional base load plants with constant capacity.

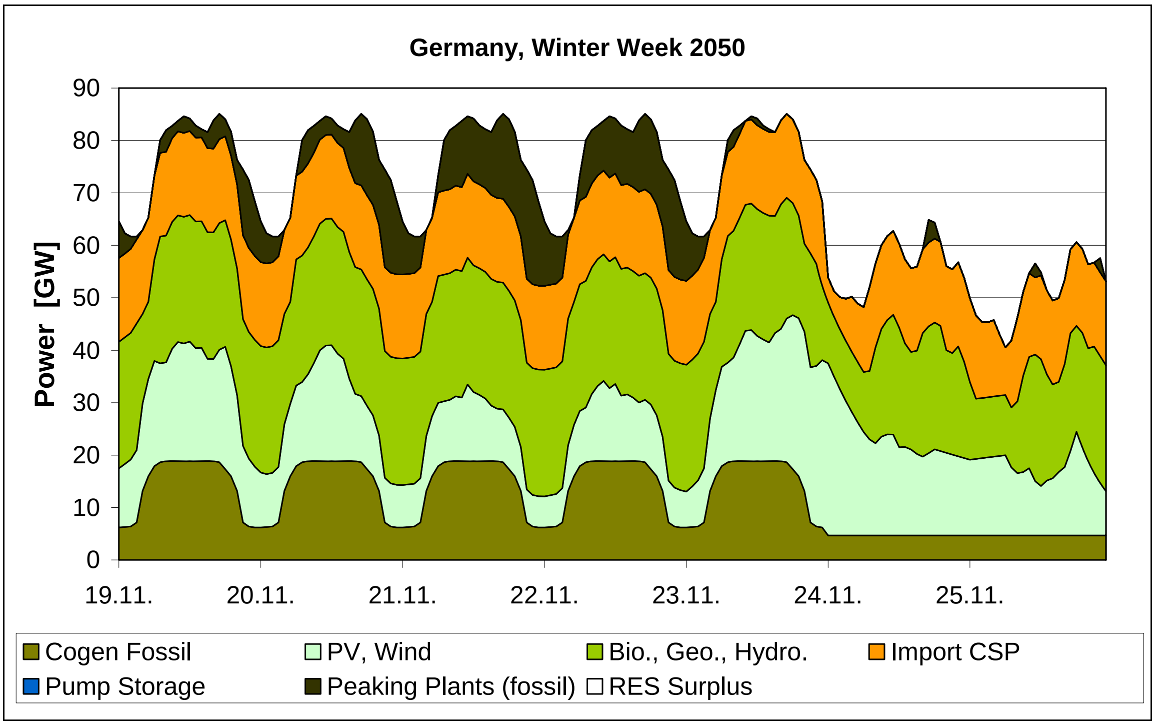


Figure 2-30: Hourly time series of power generation during a winter week in the year 2050 in Germany modelled in the TRANS-CSP scenario. For other countries please refer to the Annex. Base load electricity is provided by cogeneration plants and by renewable sources. Fossil fuelled power is only required for peaking purposes. There is no functional window for base load plants operating at constant power capacity.

As a consequence of the increasing share of renewable electricity generation, the need and usability of constant capacity base load plants will subsequently disappear until 2050 (Figure 2-29, Figure 2-30 and Figure 2-31). Base load demand will be covered mainly by co-generation, wind power, CSP import and photovoltaics, following the daily load curve instead of providing flat constant power.

Intermediate power will be supplied by hydropower storage, biomass, geothermal power, CSP and solar electricity imports. Peaking demand will be satisfied by pump storage, hydropower storage and fossil fuel based peaking plants. In the future, peaking times will differ significantly from the present peaking time defined solely by the load. Future peaking periods will rather be defined by the difference between load and fluctuating renewable electricity supply.

The conventional, fossil fuel fired power capacities remaining in 2050 will exclusively serve peaking duties and co-generation of heat and power. This is in line with the initially mentioned strategy of using those valuable, ideally storable primary energy sources exclusively for what they are best suited for, and not wasting them for quotidian use. Flat capacity base load plants fuelled by nuclear fission, fusion or lignite will not be able to function within such a mix, as they are not capable of following the transients to fill the gap between the partially fluctuating supply from cogeneration and renewables and the otherwise fluctuating demand. Gas driven plants will be the preferred choice for this purpose /Brischke 2004/.

There is a persistent myth claiming that renewables cannot provide base load electricity, as they are highly dispersed, fluctuating and unpredictable. The contrary is true: river-run-off, PV and wind plants can only provide base load capacity, but no peaking power. However, a well balanced mix of renewable and fossil plants can provide secure power on demand and at the same time save valuable fossil fuels that anyway should only be used for peaking. Considering that the electric load is the result of many dispersed, fluctuating and unpredictable elements - the consumers - it is little surprising that renewables and electric load fit fairly well to each other: they are related phenomena. Thus, inflexible, constant capacity base load plants fired by nuclear energy or lignite will totally disappear, as they will not be able to serve the remaining peaking demand. As their economic lifetime is about 40 years, this must be considered seriously for today’s investment decisions.

As described in /DENA 2005/, local problems may occur if e.g. large wind capacities are fed into a weak grid infrastructure, like e.g. at the coast line in Northern Germany. It must be considered that a wind park is a large centralised installation just like a hydropower, nuclear or coal plant, and of coarse such large amounts of electricity cannot be fed into a remote part of the grid, but must be connected to the large centres of demand via adequate transmission lines. This will be the case for large offshore and onshore wind parks as well as for large hydropower and solar schemes, just as it is the case for large nuclear, lignite or coal plants today. As described in

Chapter 1, this will be (and is already) solved by introducing HVDC technology to transfer power e.g. from large wind parks to the closest centres of demand.

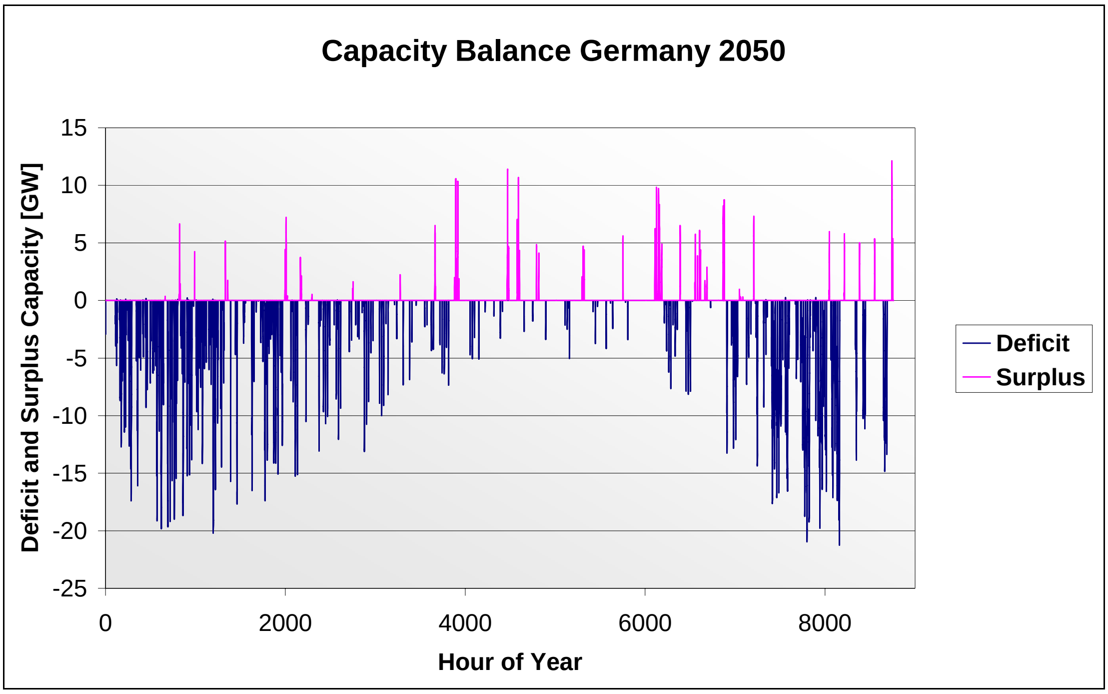


Figure 2-31: Balance of electricity load and renewables including co-generation for the German power park in 2050 calculated on the basis of hourly time series for the TRANS-CSP scenario. The surpluses are due to PV and wind power. A maximum deficit of about 22 GW must be covered by fossil fuelled peaking plants. At present, the available peaking capacity in Germany is about 35 GW.

With respect to sustainability, our scenario leads to a desirable goal, which is characterised by

- low cost of energy,
- low environmental impact,
- low conflict potential,
- access to new energy sources,
- fair distribution and access to energy,
- low risk and vulnerability,
- prolongation of fossil fuel resources,
- reduced energy import dependency,
- cost stability,
- enhanced energy supply security,
- enhanced international cooperation.

The wide-spread argument that renewables are too expensive has been proven wrong: in fact, they are the least cost option for energy sustainability. Initial investment is required to achieve a better and more affordable energy mix and to get rid of the open and hidden subsidisation of the power sector. An outstanding portfolio of technologies is available today to achieve that goal, and it is due time to initiate the broad application and expansion of those technologies in order to profit from their benefits as soon as possible, instead of subsequently burdening the national economies by the exploding costs of the obsolete energy supply schemes of the past century.

The scenario shows, that a sustainable mix of energy sources for power generation is possible not only for Europe as a total, but also for each of its single member states (ref. to Annex). The transition from today's fossil and nuclear fuel driven power schemes will take time. In spite of a fairly strong initial growth of renewables, considerable renewable electricity shares will not become visible before 2020 (ref. Figure 2-32 to Figure 2-34). However, as soon as industrial production capacities will have grown to a mature level, the share of renewable sources of energy will quickly increase, not only due to environmental concerns, but mainly due to economical reasons and security of supply. By 2050, a renewable electricity share of 80 % will be easily achieved, stabilizing electricity costs and relieving the environment, the global climate and the national economies from further pollution and subsidies. This development has already started in a few but not yet in all countries of Europe.

Table 2-10 quantifies the market volumes for fossil and renewable energy in the TRANS-CSP scenario. From the total demand and the total and renewable plant inventory in the year 2000, the market shares of renewable and fossil energy are calculated. The free market volume is the capacity of new plants that can be installed in the respective time span of 10 years, which is limited by new demand, replacement capacities and by the renewable and fossil capacities installed in the respective prior decade. The market share of renewables in 2004 accounted for 25 % /REN 2005/. Starting with 10 % in 2000, the scenario achieves relatively stable renewable market shares of around 50 % after 2020. On average, the renewable electricity market share grows by about 200 TWh/y each decade, reaching a market share of newly installed capacity of almost 1000 TWh/y equivalent to 80 % of the total power plant market volume in 2050.

Year		**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Total Plant Inventory 2000	TWh/y	3390	3004	2193	1239	581	203
Total Demand	TWh/y	3390	3628	3940	4233	4327	4058
Total Market Volume	TWh/y		624	1747	2994	3745	3855
Free Market Volume	TWh/y		624	1123	1247	1375	1233
Renewables Inventory 2000	TWh/y	695	695	695	695	581	203
Ren. Market Share	TWh/y		225	539	598	729	969
Ren. Market Share	%	**10%**	**36%**	**48%**	**48%**	**53%**	**79%**
Total Renewable Share	TWh/y	695	920	1459	2057	2672	3264
Total Renewable Share	%	**21%**	**25%**	**37%**	**49%**	**62%**	**80%**
Fossil Market Share	TWh/y		399	584	648	646	264
Fossil Market Share	%	**90%**	**64%**	**52%**	**52%**	**47%**	**21%**
Total Fossil Share	TWh/y	2695	2708	2481	2176	1654	795
Total Fossil Share	%	**79%**	**75%**	**63%**	**51%**	**38%**	**20%**

Table 2-10: Market statistics of the TRANS-CSP scenario. Renewable energy market shares in 2004 were reported 25 % of total electricity investment /REN 2005/.

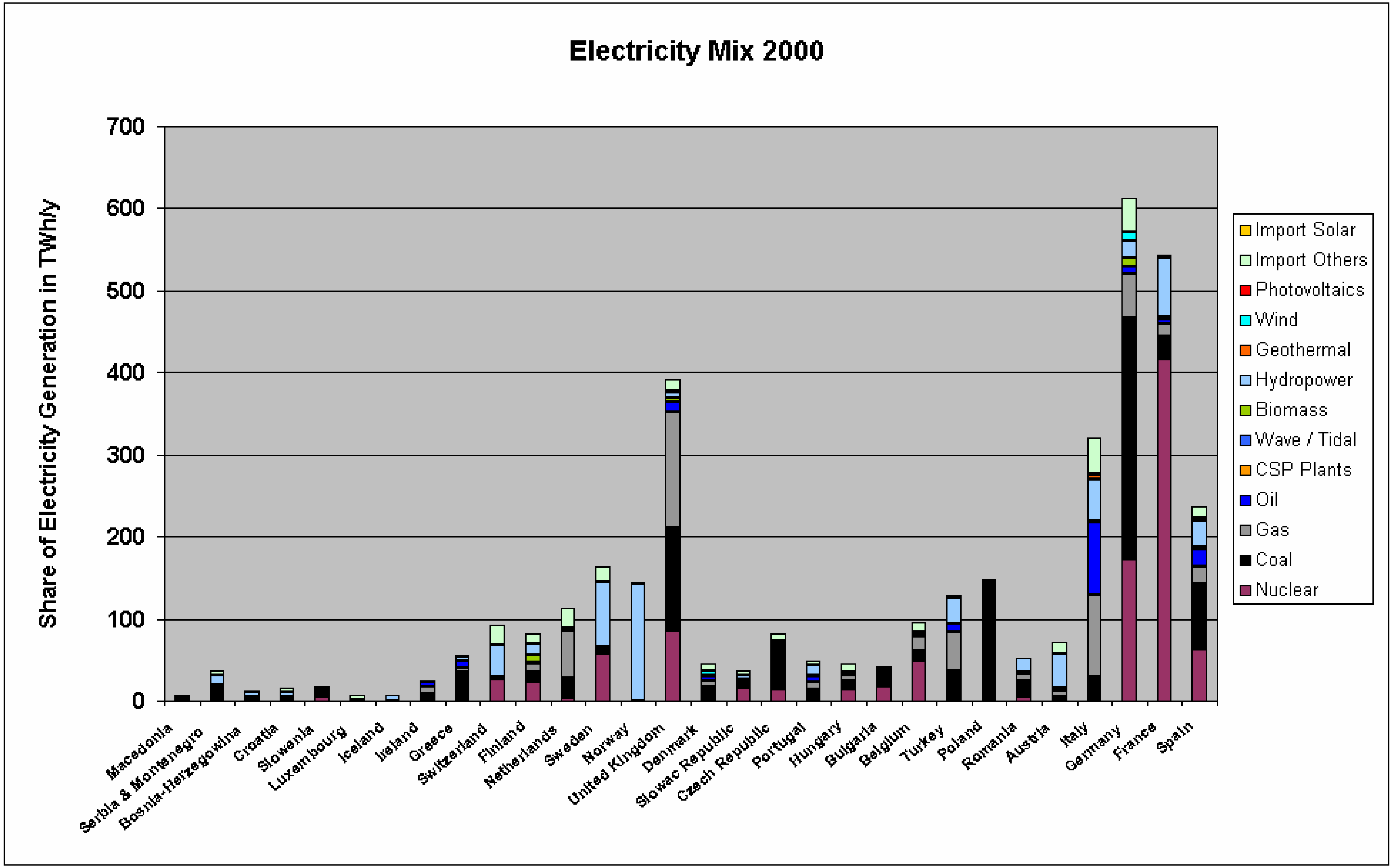


Figure 2-32: Starting point for the scenario: electricity generation in the analysed European countries in the year 2000 by resources /enerdata 2004/

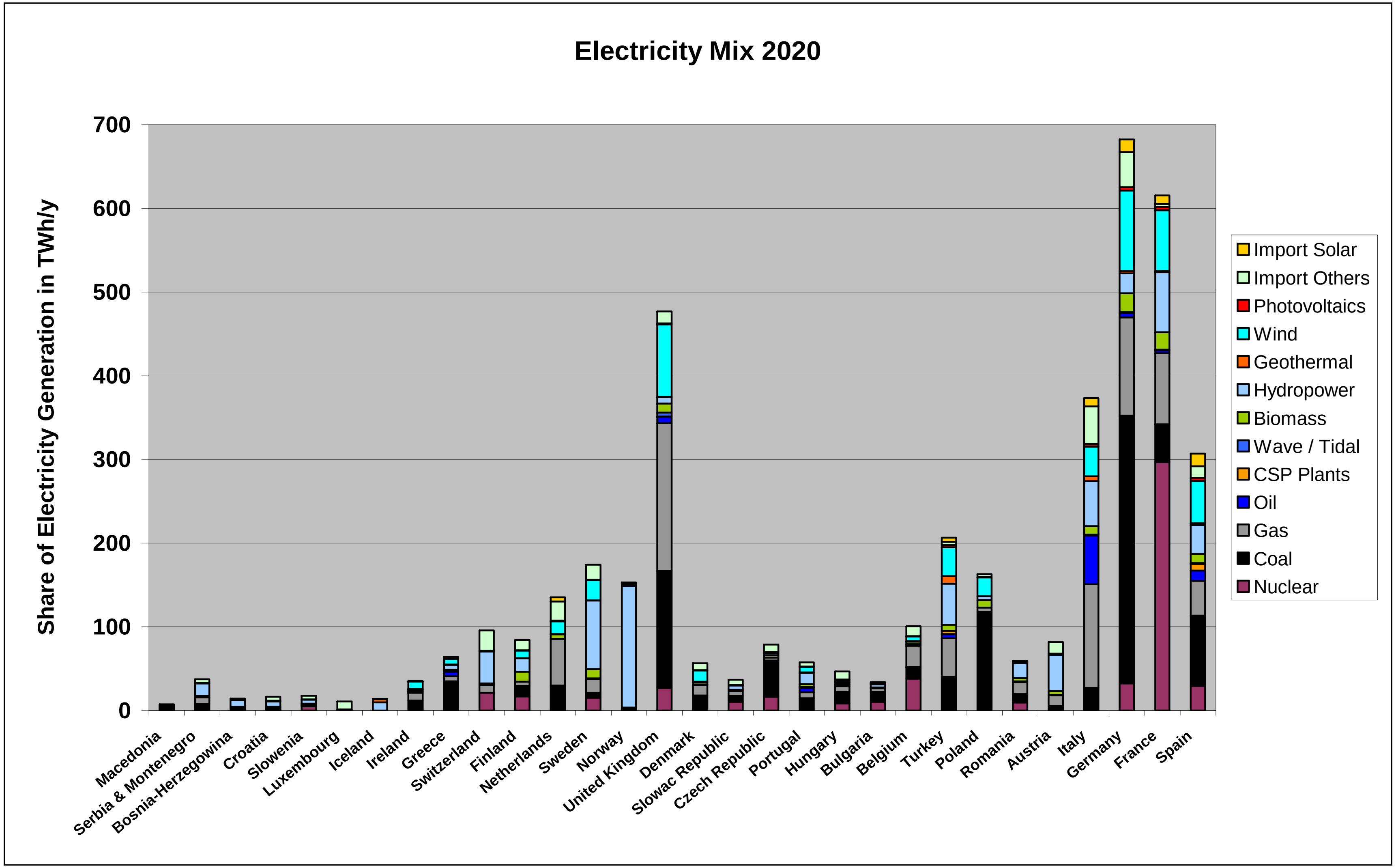


Figure 2-33: European electricity mix in 2020 in the TRANS-CSP scenario.

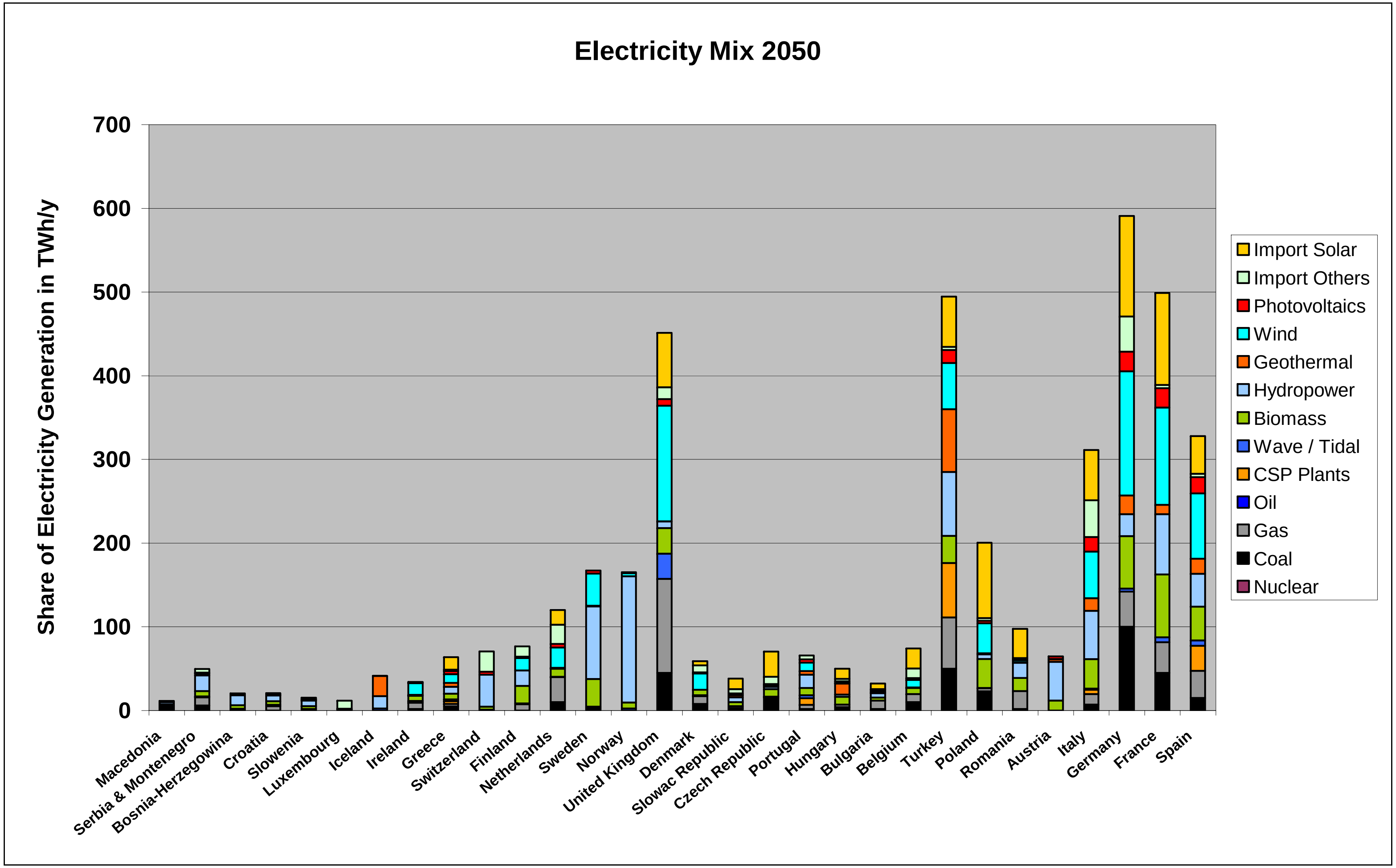


Figure 2-34: European electricity mix in 2050 in the TRANS-CSP scenario.

2.4 Market Potential for Solar Import Electricity

Solar electricity imports from North Africa to Europe through the conventional Alternate Current (AC) electricity grid will have only minor importance. With a transmission capacity of today 0.5 GW and a maximum 1-2 GW by 2020, such an interconnection would be capable of transmitting not more than about 5-10 TWh/y, which can be neglected in view of the total European electricity demand of roughly 3500 TWh/y.

For the transmission of large amounts of solar electricity from MENA to Europe, for the use of the hydropower storage capacities of Scandinavia and the Alps, as well as for the integration of large offshore wind parks, an intercontinental High Voltage Direct Current (HVDC) grid infrastructure will be necessary. Such a HVDC grid will interconnect the best sites for renewable electricity with the largest centres of demand. From there, electricity will be further distributed through the conventional AC grid. The planning and the international agreements necessary for such a large Trans-European infrastructure will easily take 15 to 20 years of time. Therefore, a transfer of solar electricity from MENA to Europe through HVDC cannot be expected considerably before 2020. Table 2-11 gives the potential of solar electricity imports of all countries analysed in the study (please refer to the Annex for country details).

Year		2020	2030	2040	2050
Transfer Capacity GW		2 x 5	8 x 5	14 x 5	20 x 5
Electricity Transfer TWh/y		60	230	470	700
Capacity Factor		0.60	0.67	0.75	0.80
Turnover Billion €/y		3.8	12.5	24	35
Land Area km x km	CSP HVDC	15 x 15 3100 x 0.1	30 x 30 3600 x 0.4	40 x 40 3600 x 0.7	50 x 50 3600 x 1.0
Investment Billion €	CSP HVDC	42 5	143 20	245 31	350 45
Elec. Cost €/kWh	CSP HVDC	0.050 0.014	0.045 0.010	0.040 0.010	0.040 0.010

Table 2-11: Main indicators of the total EUMENA High Voltage Direct Current (HVDC) interconnection and Concentrating Solar Power (CSP) capacities from 2020 – 2050 according to the TRANS-CSP scenario. In the final stage in 2050, 20 lines with a capacity of 5 GW each will transmit about 700 TWh/y of electricity from 20 different locations in the Middle East and North Africa (MENA) to the main centres of demand in Europe.

In the TRANS-CSP scenario we have assumed that the HVDC interconnections will be realised in units of 5 GW each. Connecting to those lines, power lines with lower capacity would be used. They will interconnect different sources of solar power generation in MENA with different centres of demand in Europe, as described in Chapter 1. In 2050, about 20 major links could be installed, with a total transfer capacity of 100 GW, equivalent to 7 % of the total installed power capacity in Europe by that time. With an average use of 7000 full load operating hours per year, these lines would transfer 700 TWh/y of solar electricity to Europe, with a value of 35 billion €/y at an average cost of 5 cents/kWh.

This cost is composed of 4 cents/kWh for solar electricity production by CSP plants in MENA and 1 cent/kWh for the transmission to Europe including electricity losses, capital cost and cost of operation, and assuming a discount rate of 5 %/y as for the other technologies. The total investment of this infrastructure would be 395 billion € between 2020 and 2050, that is an average of 10 – 15 billion € per year over that time span. The annual performance with 7000 full load hours per year and the specific investment including decommissioning of 4000 €/kW are both similar to the cost and performance of equivalent nuclear power plants. The relative land area consumed in MENA and Europe by the CSP and HVDC infrastructure is in the order of 0.03 %. Other environmental impacts are also low as described in Chapter 5.

As shown in the example in Figure 2-24, solar import electricity is one of the least cost options for electricity in Europe. It is attractive in terms of both economical and technological integration to the power park, as it provides firm power capacity for grid stability and control at very low cost. Just like natural gas or fuel oil, it can be used for base, intermediate and peaking power, in this context clearly beating other technologies like wind, PV and even nuclear power, that may be cheaper under very good conditions, but are also less worth.

The analysis shows that CSP electricity imports from MENA through HVDC lines are a valuable supplement of the future European power supply system. It will require considerable efforts in terms of finance, technology and international cooperation to realise such a large infrastructure, but similar to the introduction of interstate highways for transport and mobility, a Trans-European HVDC grid will create manifold synergetic effects for the benefit of the total European community and its neighbours in the South and East. Besides of being a requisite for the use and distribution of the best renewable energy sources of the region, such a grid will enhance the stability, capacity and redundancy of the European power supply system with considerable benefits for each of its member countries. Furthermore, it could be the physical basis for a Euro-Mediterranean Free Trade Area for Renewable Energy as described in Chapter 3.

For the analysis of the market potential of solar thermal electricity imports from MENA to Europe, it is important to define the market segments that shall be covered by this resource. Looking at a typical daily electricity load curve as in Figure 2-35, base load is traditionally covered by river run-off hydropower, nuclear power, lignite and coal (lately also gas fired combined cycle systems are used for this purpose), intermediate power is delivered by coal and gas fired plants and peaking load is covered by oil, gas and pump storage. Industrial power is fed to the grid if public load and industrial surplus – often from co-generation – coincide, it can therefore be considered as part of the base load segment, comparable to the slightly fluctuating, only partially controllable input of river run-off plants.

The base load segment summarises those sources that cannot easily be adapted to fluctuating load conditions, e.g. flat capacity nuclear and lignite plants, part of the coal plants, and river run-off plants. Intermediate load plants are turned on and shut down once per day, using for this purpose usually coal or gas plants and partially, if available, stored hydropower.

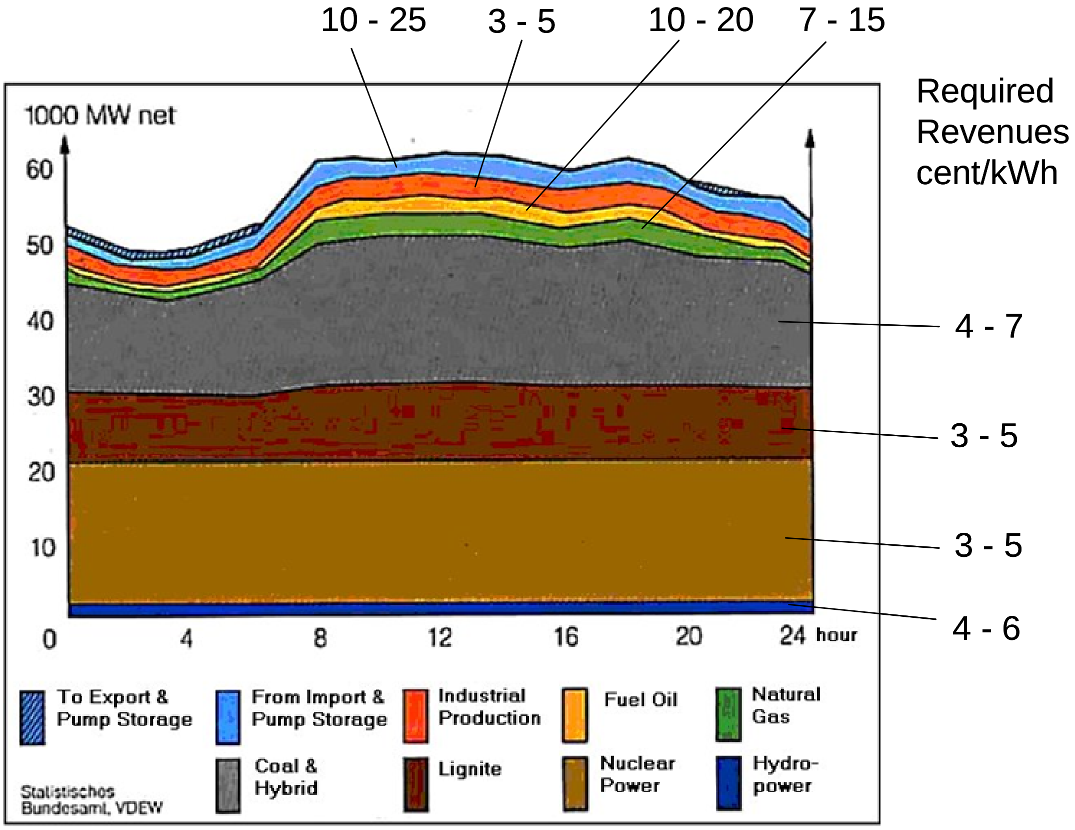


Figure 2-35: Coverage of a typical national daily load curve by conventional power technologies /VDEW 1990/ and the typical range of required revenues of each technology considering today's level of world market prices of oil (50 $/bbl), coal (65 $/t), natural gas (6 $/GJ), the different capacity factors in each market segment as explained in the text and a discount rate of 5 %/y (own calculations).

Peaking plants must react quickly to cover the remaining gap between the load and the other sources. Only hydro pump and dam storage, gas and oil plants are suited for this purpose.

The three market segments differ by their annual capacity factor and time of operation: peaking plants operate from several 100 to about 2000 hours per year, with a high share of part load operation, intermediate plants work 2000 to 5000 h/y, and base load plants typically 6000 to over 8000 h/y, mainly under full load conditions. Due to their different utilisation time, the electricity cost of peaking plants is usually much higher than that of base load plants, and so is their typical required revenue (Figure 2-35).

Spec. Invest. €/kW	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Wind	1150	1058	956	908	859	832
Photovoltaics	5500	2830	1590	1250	1010	910
Geothermal	13093	5063	3631	3120	3018	2966
Biomass	2500	2000	1700	1670	1660	1650
CSP Plants	3052	3341	4595	4269	4125	4075
Wave / Tidal	3000	2500	2250	2100	2050	2000
Hydropower	1800	1800	1800	1800	1800	1800
Oil	1000	1000	1000	1000	1000	1000
Gas	450	450	450	450	450	450
Coal	1150	1150	1150	1150	1150	1150
Nuclear	4000	4250	4500	4750	5000	5250
Import Solar CSP			4200	3750	3550	3500
Import Solar HVDC			500	500	450	450

Table 2-12: Investment cost of power technologies including decommissioning discounted over lifetime

Electricity Cost c/kWh	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Wind	7,7	6,8	6,1	5,8	5,4	5,2
Photovoltaics	36,7	16,9	8,6	6,6	5,3	4,8
Geothermal	17,5	6,8	4,8	4,8	5,5	5,9
Biomass	6,1	4,9	4,3	4,2	4,7	5,2
CSP Plants	17,6	12,2	7,5	6,7	6,2	6,6
Wave / Tidal	8,3	6,9	6,2	5,8	5,6	5,5
Hydropower	8,4	8,4	8,4	8,4	8,4	8,4
Oil	8,1	12,2	15,0	16,4	17,8	19,6
Gas	4,7	7,0	9,9	11,5	12,4	13,7
Coal	3,3	4,0	5,6	5,7	5,8	6,0
Nuclear	3,6	3,9	4,1	4,4	4,6	4,9
Solar Import Electricity			5,4	4,8	4,6	4,9
TRANS-CSP Average	**4,8**	**5,9**	**6,9**	**6,7**	**6,8**	**6,6**
Electricity Mix 2000	**4,8**	**5,7**	**6,8**	**7,2**	**7,6**	**8,0**

Table 2-13: Development of the electricity cost of new plants of different power technologies in the example of Spain on the basis of the investment cost development in Table 2-12 and the different performance indicators representing each technology in each country following the TRANS-CSP scenario until 2050. From 2030 onwards, biomass, geothermal and CSP plants subsequently take over peaking duties, which is the reason for their cost elevation. Peaking power is also supplied by natural gas fired plants. Coal and gas fired combined cycle plants are mainly used for cogeneration. Oil and nuclear plants are faded out in most countries. For comparison a business as usual scenario was calculated, assuming that the growing demand is covered by an electricity mix like in the year 2000.

Looking at the different market segments of electricity, each technology competes with a certain set of competing technologies, as shown in Table 2-14. Applicability in different market segments is an advantage, as it allows for higher revenues for a specific technology, and also for a larger potential market. In the long term CSP imports achieve the same cost as nuclear power, in spite of the fact that nuclear power is scheduled to operate 8400 h/y in flat base load, while CSP is operating only an average 5600 h/y, subsequently taking over increasing peak load duties in the electricity mix, which is not possible by nuclear power.

Segment	Source / Technology	Min. Rev.	Max. Rev.
		ct/kWh	ct/kWh
Peak Power	Pump Hydro Storage	10	25
	Fuel Oil		
	Gas Turbine		
	Biomass		
	Geothermal		
	CSP		
Intermediate Power	Coal	5	12
	Gas Combined Cycle		
	CSP		
	Biomass		
	Geothermal		
Base Load	Coal	3	6
	Lignite		
	Nuclear		
	River Run-Off		
	Gas Combined Cycle		
	Co-generation		
	Wind		
	Photovoltaics		
	CSP		
	Geothermal		

Table 2-14: Technologies and range of required revenues in the different electricity market segments

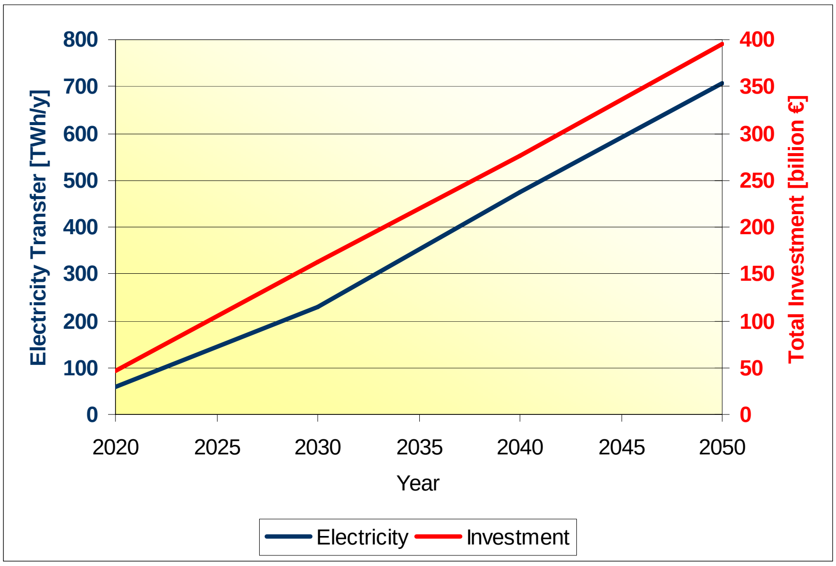


Figure 2-36: European market potential for solar import electricity from MENA based on CSP generation and HVDC transmission as described in Chapters 1 and 2.

With the exception of the vast hydropower storage resources in Norway, CSP imports and geothermal (HDR) power plants are the only renewable sources that can operate in all three segments of the power market, while others like lignite, nuclear, PV and wind power can only operate within the base load segment. The only conventional sources capable of operating in all three segments, too, and thus the natural competitors of CSP imports and geothermal power would be natural gas and oil, both being clearly more expensive by that time, even under the conservative cost estimate for oil and gas assumed here.

Solar import electricity is the best option to fill the respective market segment. If not realised in the proposed time, this market segment will have to be covered by fossil resources due to the need of firm power capacity in the electricity mix. Once installed, fossil plants will block that market segment for their lifetime beyond 2050. Wind, European CSP and PV power will not be able to cover the demand for firm capacity. Hydropower, biomass and geothermal power potentials are already used to a large extent, and doubling their electricity output would require the exploitation of all three resources completely up to their limits. Due to the fact that many of the hydropower and geothermal resources are relatively concentrated in a few regions, especially in Iceland, this will also require to connect those regions via HVDC to the European centres of demand /Knies et al. 1999/. This would be a reasonable complement, but not a realistic substitute for solar electricity imports from MENA. The higher diversity of supply, the extensive solar electricity potential and its low cost remain very good reasons for solar power import.

2.5 Solar Power for Europe – Water and Development for MENA

As proposed recently by the Trans-Mediterranean Renewable Energy Cooperation /TREC 2006/, concentrating solar thermal power stations in MENA could be used for export electricity to Europe as well as for providing regional freshwater from combined thermal desalination of sea water. The electricity produced in CSP plants can be used for domestic needs and export, as well as for additional desalination of sea water through reverse osmosis (RO), if required (Figure 2-37). The design of such combined solar power and desalination plants can be flexibly adapted to any required size and need. The advantages of this concept lay at hand:

- outstanding overall conversion efficiency of over 80 % for both solar heat and fuel,
- outstanding economic efficiency through the second valuable product freshwater,
- energy, water and income for the sustainable development of arid regions.

This concept may provide a key solution for the pressing freshwater deficits in the Middle East and North Africa, as reported by many sources /MED-CSP 2005/, /FAO 2003/, /Al-Zubari 2002/. In this chapter, we have analysed the potential of combining CSP exports to Europe with local sea water desalination for the MENA region.

At present, the countries of the Middle East and North Africa suffer from a freshwater deficit of about 60 billion cubic meters per year, equivalent to the average annual volume of the Nile River. In view of the growing population and economy of the MENA region, this deficit will increase to about 165 billion m^3/y by 2050, if no measures are taken at time to prevent such a disastrous situation (Figure 2-38).

Today, this deficit is poorly covered by over-exploitation of groundwater resources and by the desalination of sea water using fossil fuel resources (Figure 2-39). It is a question of only one or two decades, that most groundwater resources will be depleted and desalination by fossil fuels will have become too expensive for quotidian use. The only solution is the extended desalination of sea water by a sustainable and affordable energy source, supported by enhanced water management and by a more efficient use of water with increased reuse of wastewater and enhanced municipal water treatment.

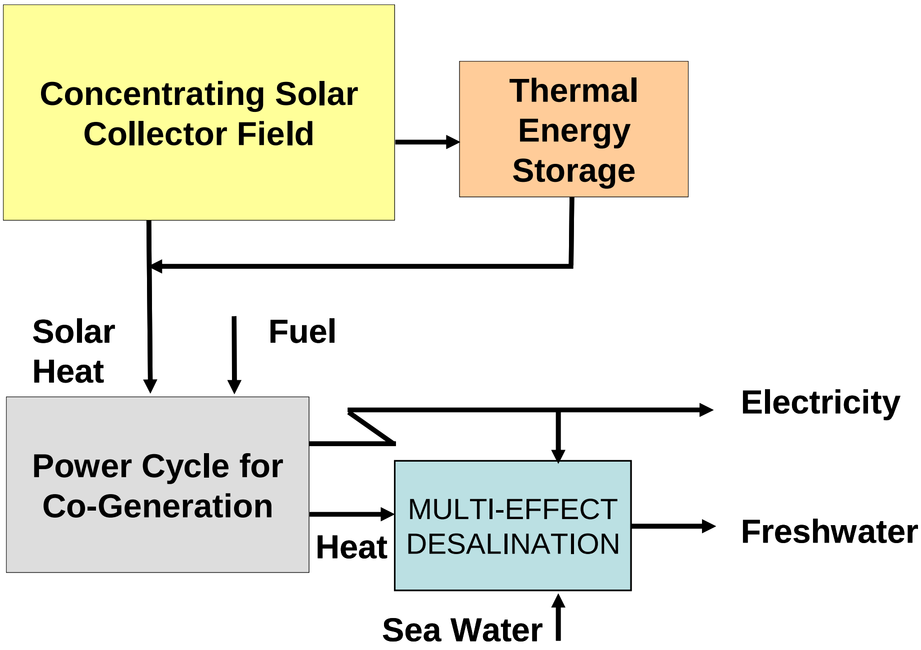


Figure 2-37: Principle of a concentrating solar power station with combined thermal sea water desalination. The generated electricity can be used for domestic needs, export and for desalination via reverse osmosis.

Nether energy nor water are scarce in MENA, looking at the large seawater bodies and the infinite solar energy resources available in this region. The use of CSP for combined power and desalination is economically attractive, as recently confirmed by a first pilot project of this type in Jordan /SolWater 2006/. The cost of desalted water from such plants will range between 1.5 and 0.5 €/m³.

Combined solar power and desalination plants will not only be able to tackle the challenges related to a sustainable energy supply at low cost, but also those related to clean water and to the conservation of productive soils. In the world's arid regions, such plants could become the nucleus of a totally new social paradigm: the conservation and recuperation of land endangered by desertification, comparable to the conservation and recuperation of land flooded by the sea in the Netherlands. Providing power, water, shadow and foreign exchange from the export of green power and revived agriculture, such multi-purpose plants could provide all what is needed to effectively combat desertification and to regain land for human settlement and agriculture that otherwise would be lost to the desert (Figure 2-40, Figure 2-41).

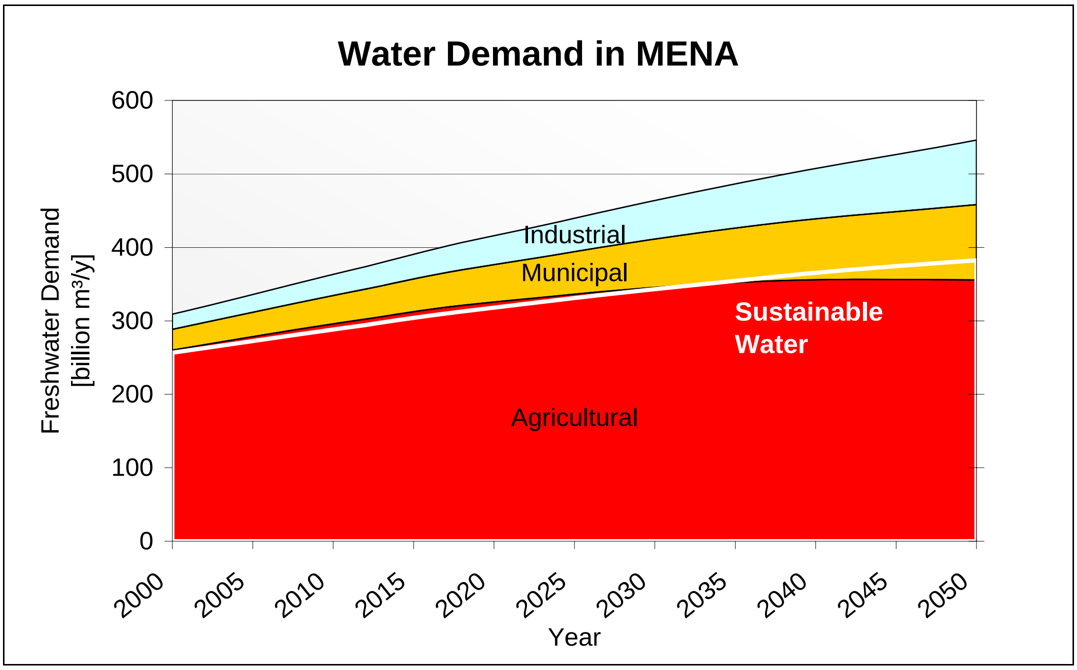


Figure 2-38: Freshwater demand for agriculture, industrial and municipal use in MENA in comparison to the renewable freshwater resources available in this region (white line). At present, the deficit of roughly 60 billion cubic meters per year is covered by overexploitation of groundwater resources and by desalination using fossil fuels /MED-CSP 2005/.

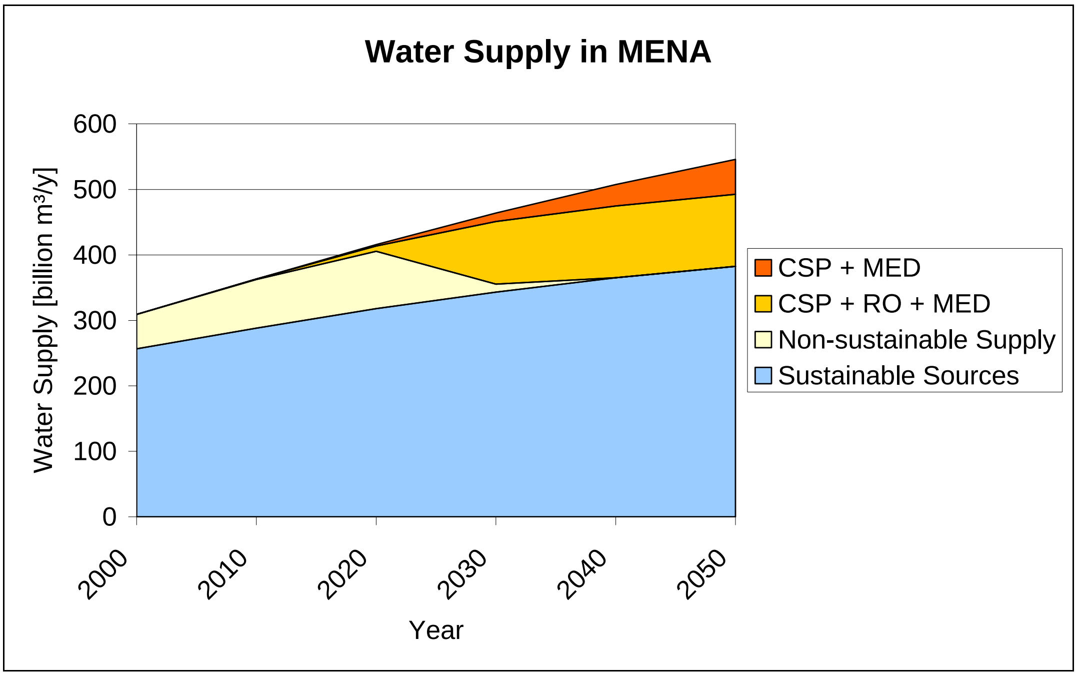


Figure 2-39: Water supply scenario for MENA /MED-CSP 2005/. Non-sustainable supply is based on over-exploitation of groundwater and desalination based on fossil fuel. The present deficit will augment until 2020. Then, CSP production capacities will be large enough to take over part of the necessary demand, partially by multi-effect thermal desalination combined with domestic and export electricity (CSP + MED), and mainly by CSP plants designed exclusively for water desalination, using electricity for Reverse Osmosis (RO) and combined heat for thermal Multi-Effect Desalination (CSP + RO + MED).

Arable land resources in the MENA region and globally are disappearing at a speed of several hectares per minute /IUCN 2006/. Concentrating solar multipurpose plants in the margins of the desert could generate solar electricity for domestic use and export, freshwater from seawater desalination, and in addition provide shade for agriculture and other human activities. Such plants could turn waste land into arable land and create labour opportunities in the agriculture and food sector. Tourism and other industries could follow. Desertification could be stopped. Other decentralised renewable energy sources could also come to use in those newly developed regions, like e.g. photovoltaics, solar thermal collectors, wind energy and biomass.

Solar energy and salt water are unlimited resources if used in a way compatible with environmental and socio-economic constraints. The economic figures of most renewable forms of energy indicate clearly that within a manageable time span they will become much more cost effective than fossil fuels. Renewable energy sources are the least cost option for energy and water security in the MENA region. With increasing electricity intensity in a developing world, their importance will steadily grow, being only limited by demand, and not by resources.

The combination of export solar electricity with sea water desalination will have only a moderate contribution to the coverage of the water deficit, because CSP exports will start relatively late, compared to the extremely pressing situation in the water sector (Figure 2-39). Therefore, CSP plants exclusively producing water with reverse osmosis (RO) and thermal multi-effect desalination (MED) will provide the core of the desalination capacity in MENA.

In the year 2050, a maximum 30 billion m^3/y could be desalted by about 40 % of the installed CSP export plants, covering roughly 20 % of the freshwater deficit. 25 billion m^3/y would be desalted by domestic CSP plants, while 110 billion m^3/y must be desalted by exclusive CSP desalination plants with RO and MED, and by other sustainable sources, that have not been quantified here separately. A detailed evaluation of the CSP desalination potential in MENA will be assessed in the AQUA-CSP study scheduled for 2006/2007, commissioned by the German Federal Ministry for the Environment and projected as a follow up investigation on the MED-CSP and TRANS-CSP studies.

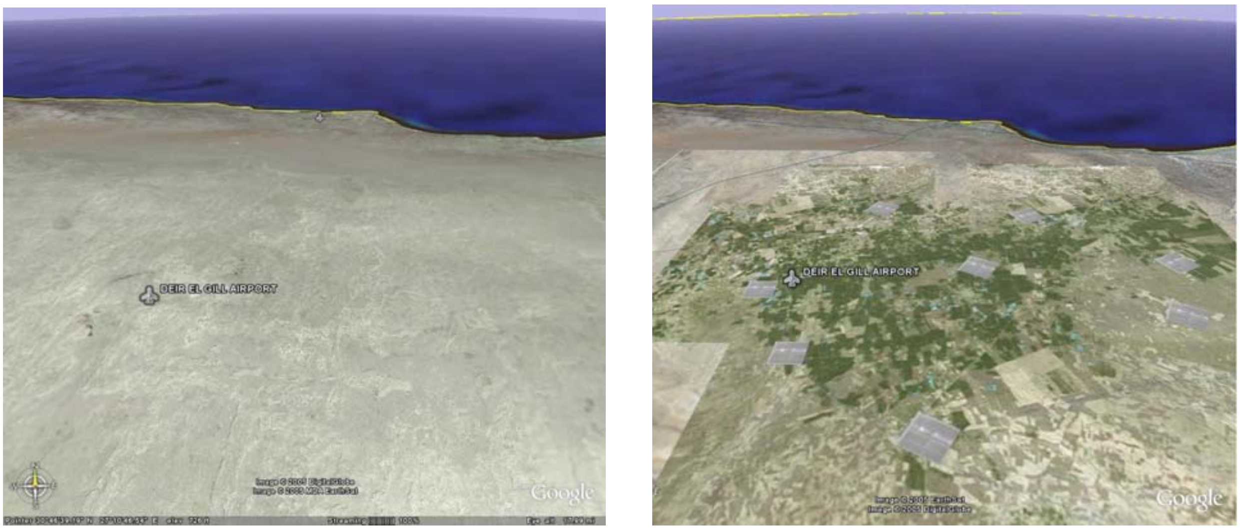


Figure 2-40: Left: typical region at the Mediterranean coast in Northern Egypt from Google Earth (left). Right: artist impression of the same region with large CSP plants for power and desalination connected to the national utility grid and to a trans-continental HVDC link that could be a key for the economic development of desert regions along the coasts of the Mediterranean Sea, the Red Sea and the Persian Gulf.

Figure 2-41: Photo of the top of a Linear Fresnel Concentrating Solar Collector and artist view of a greenhouse installed underneath to protect the plants from excessive irradiance and evaporation. This could be a concept for multi-purpose plants for power, water and horticulture. Other local uses include shade for parking and the production of steam for cooling and process heat. Source: Solarmundo, DLR)

3 Policies and Finance

Policies have a major impact on the speed and extent of renewable energy development. The International Energy Agency observed in 2004 that significant market growth has always resulted from combinations of policies, rather than single policies, that longevity and predictability of policy support is important, that local and state authority and involvement are important, and that individual policy mechanisms are evolving as countries gain more experience /IEA 2004/, /EEA 2004/. By mid-2005, all EU 25 countries had a national target for renewable energy supply. The European Commission has set a Europe-wide target for renewables of 21 percent of electricity and 12 percent of total energy by 2010. However, present European energy policies are still far away from being sustainable.

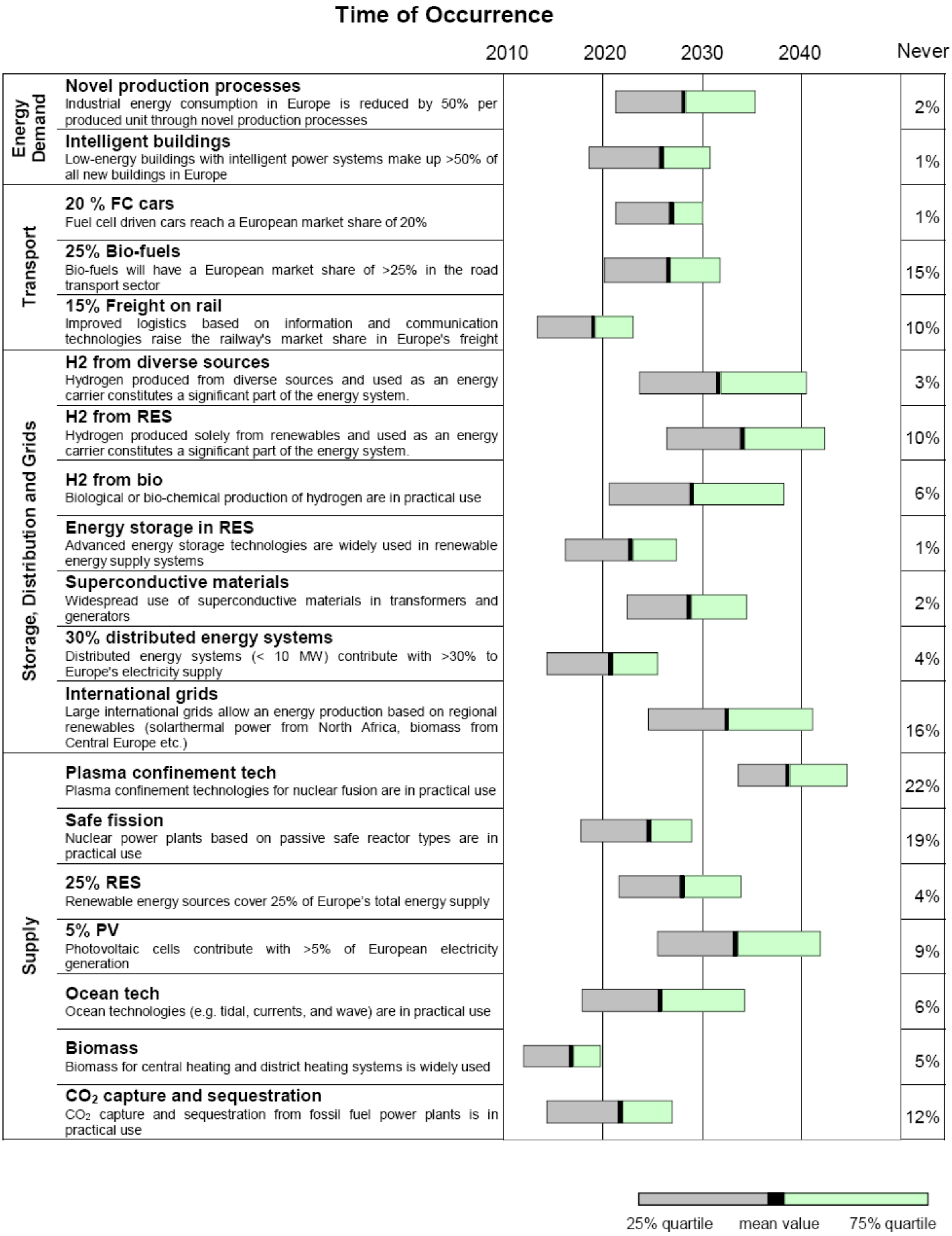
3.1 Discrepancy of Awareness and Action

The EurEnDel Delphi questionnaire of 2004 has assessed the opinion of about 1000 international experts from 48 countries about their expectations of the socio-economic impacts of 19 innovative technologies in the energy sector (Delphi statements, left side in Figure 3-1), and the time frame of their possible achievement /EurEnDel 2004/, in order to provide a guidance for the identification of research, development and demonstration efforts (RD&D) that should be supported by public funding. The assessed impact categories included Wealth Creation, Environment, Quality of Life and Security of Supply (Figure 3-2).

A high share of 25 % of renewable energies in Europe around 2030 was the statement ranking as number one for the achievement of positive impacts in the four impact categories, with a broad consensus of 96 % of the experts believing that this will happen sooner or later. On the other hand, the realisation of large international electricity grids for the intensified use of renewable energies in Europe was not considered realistic before 2020, with 16 % of the experts totally neglecting this option. Nuclear fission and fusion are both ranking within the last 5 places, with 20 % of the experts totally neglecting their long-term importance.

In principle, the TRANS-CSP scenario in Chapter 2 confirms the Delphi results, both regarding the importance of renewable energies for socio-economic sustainability and also with respect to the time frame required for the necessary changes of the energy system. According to the TRANS-CSP scenario, it will take at least until 2020 that renewables really become visible in the European electricity mix, but they will have a considerable, increasing importance in the long term perspective. Import solar electricity from MENA will not achieve a share over 15 % before 2050.

On the other hand, the Delphi expert opinions clearly contradict past and present energy research and development policies, that have fixed a share of renewable energies of less than 10 % of the total government energy RD&D funding in the IEA member countries (Figure 3-3).



	Statement	Never
Energy Demand	**Novel production processes** Industrial energy consumption in Europe is reduced by 50% per produced unit through novel production processes	2%
	Intelligent buildings Low-energy buildings with intelligent power systems make up >50% of all new buildings in Europe	1%
Transport	**20 % FC cars** Fuel cell driven cars reach a European market share of 20%	1%
	25% Bio-fuels Bio-fuels will have a European market share of >25% in the road transport sector	15%
	15% Freight on rail Improved logistics based on information and communication technologies raise the railway's market share in Europe's freight	10%
Storage, Distribution and Grids	**H2 from diverse sources** Hydrogen produced from diverse sources and used as an energy carrier constitutes a significant part of the energy system.	3%
	H2 from RES Hydrogen produced solely from renewables and used as an energy carrier constitutes a significant part of the energy system.	10%
	H2 from bio Biological or bio-chemical production of hydrogen are in practical use	6%
	Energy storage in RES Advanced energy storage technologies are widely used in renewable energy supply systems	1%
	Superconductive materials Widespread use of superconductive materials in transformers and generators	2%
	30% distributed energy systems Distributed energy systems (< 10 MW) contribute with >30% to Europe's electricity supply	4%
	International grids Large international grids allow an energy production based on regional renewables (solarthermal power from North Africa, biomass from Central Europe etc.)	16%
Supply	**Plasma confinement tech** Plasma confinement technologies for nuclear fusion are in practical use	22%
	Safe fission Nuclear power plants based on passive safe reactor types are in practical use	19%
	25% RES Renewable energy sources cover 25% of Europe’s total energy supply	4%
	5% PV Photovoltaic cells contribute with >5% of European electricity generation	9%
	Ocean tech Ocean technologies (e.g. tidal, currents, and wave) are in practical use	6%
	Biomass Biomass for central heating and district heating systems is widely used	5%
	CO_2 capture and sequestration CO_2 capture and sequestration from fossil fuel power plants is in practical use	12%

Figure 3-1: Mean value of time of occurrence of the 19 EurEnDel technology statements in the Delphi project in the opinion of the interrogated experts. Left side of the bar indicates 25% quartile, right hand side 75%. The share of experts that never expect the achievement of the statements is given at right /EurEnDel 2004/.

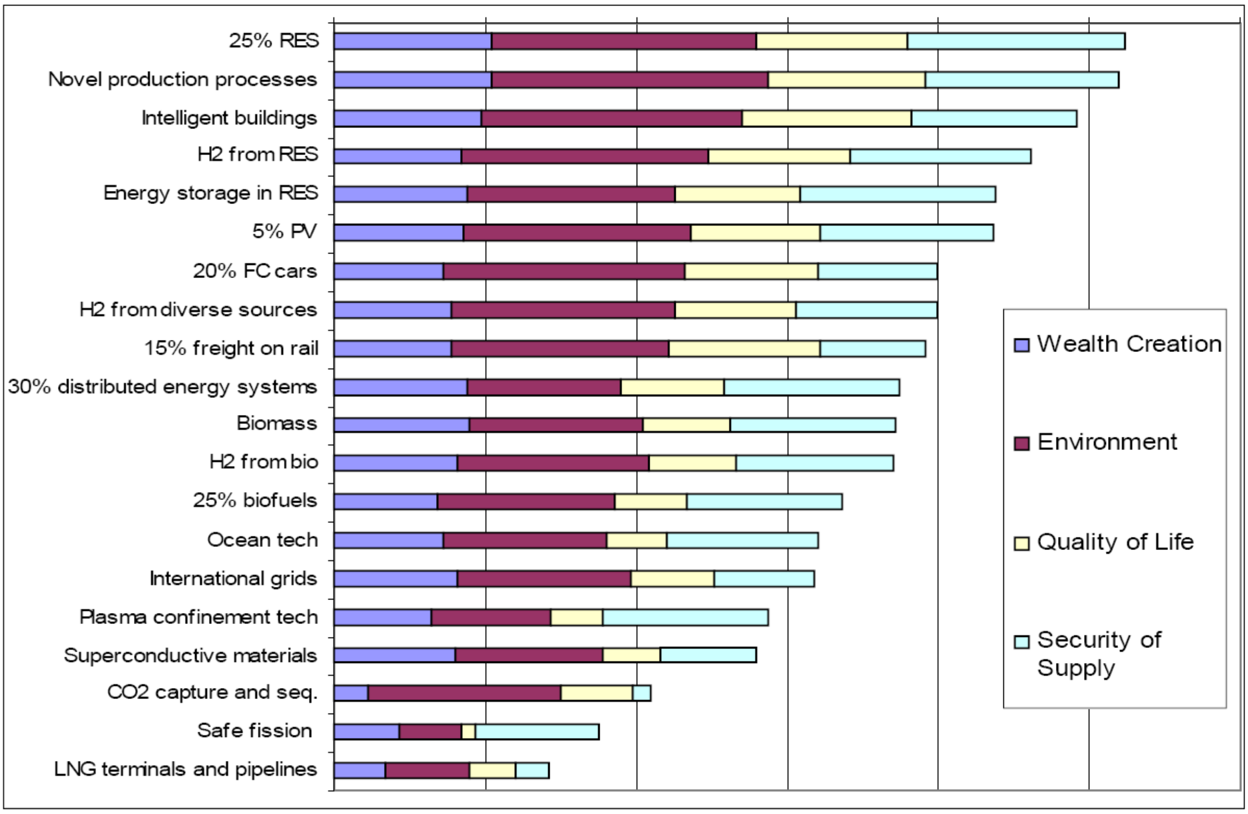


Figure 3-2: Impact ratings of 19 Delphi statements (at left) for four impact categories assessed in the Delphi questionnaire /EurEnDel 2004/. The statements are ranked according to the average impact rating which is proportional to the length of the bar.

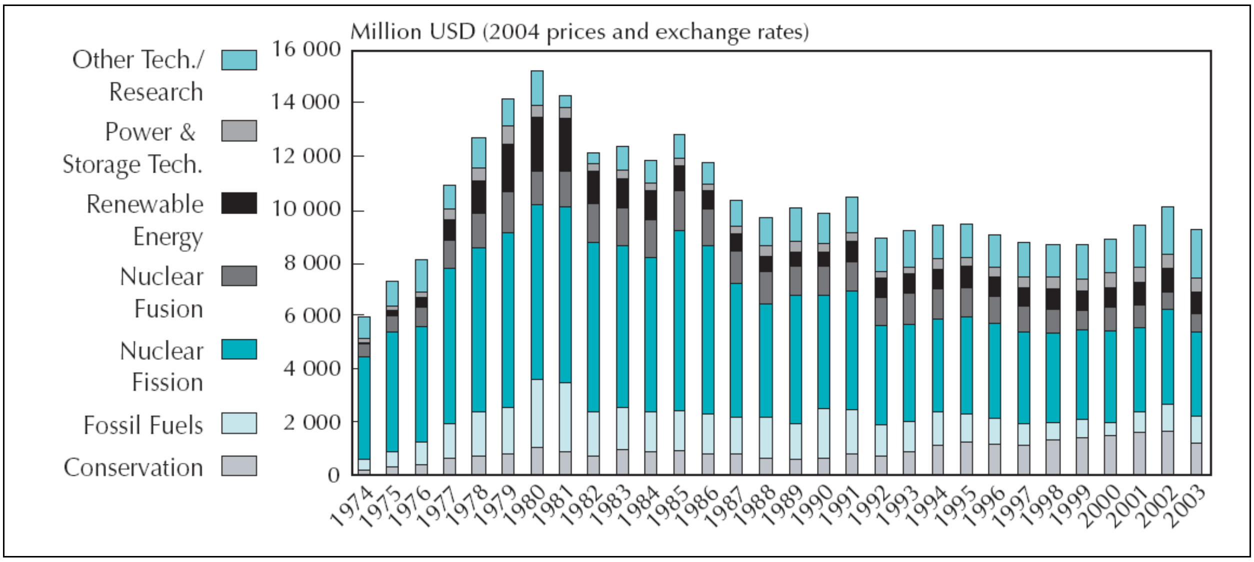


Figure 3-3: Reported government energy research, development and demonstration (RD&D) budgets in member countries of the International Energy Agency, 1974-2003 /IEA 2006-1/.

From 1974-2003, reported renewable energy RD&D budgets of IEA member countries totalled about USD 27.4 billion, some 7.6 % of total energy RD&D funding of USD 308 billion. Expenditures for renewables RD&D grew rapidly in the late 1970s and peaked in 1980 at more than USD 2.1 billion. Then, expenditures halved in the early 1980s, but have been relatively stable since in the range of USD 666 million to USD 1.09 billion. Annual expenditures on renewables RD&D for all IEA member countries averaged about USD 752 million from 1990-2003, or 8.2 % of total government energy RD&D budgets. This funding is distributed among 9 renewable energy technology mainstreams, as shown in Figure 3-4, that means that energy R&D funds for each renewable energy source are in the order of 1 % of the total energy R&D budget. RD&D funding was similar in the EU 15 member countries (Figure 3-5).

Considering the international expert opinion documented by the Delphi report, the large available renewable energy potentials (Chapter 2), the great importance of renewables for energy cost stability (Chapter 4), the increasing dependency on energy imports in Europe, and last but not least the threat of irreversible global climate change (Chapter 5), the present distribution of energy RD&D budgets as well as the overall reduction of energy RD&D funds since 1980 – as if everything was fine with respect to energy supply – are both a clear misallocation of public funds and a serious failure of the energy policies of the past, with considerable negative socio-economic impacts affecting the quality of life and the security of supply of present and future generations as shown in Chapter 4.

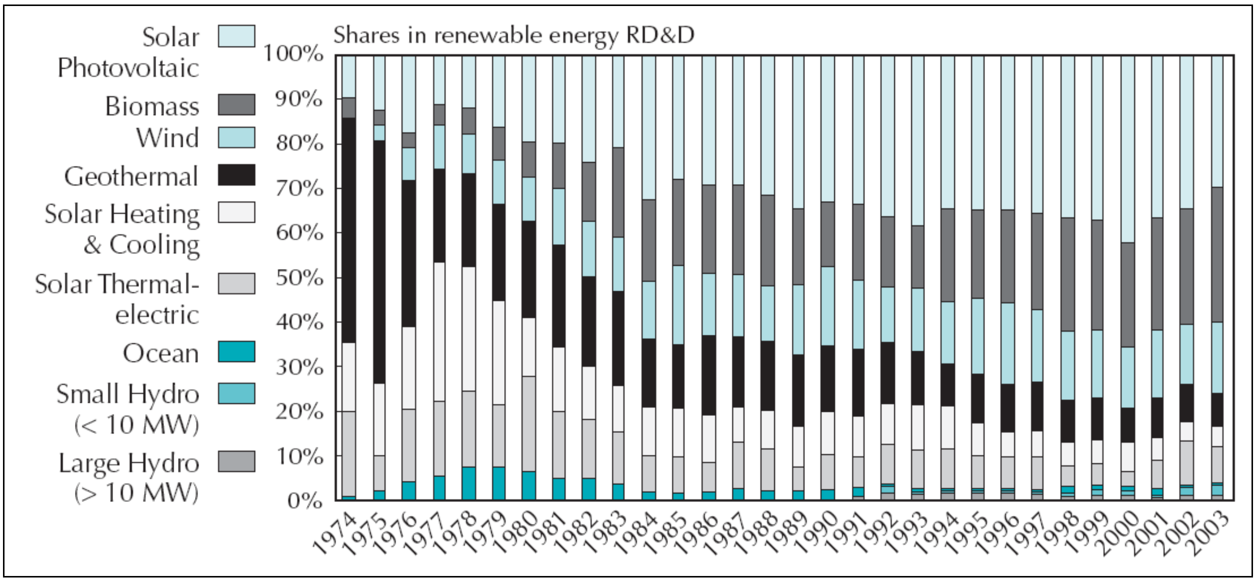


Figure 3-4: Shares of renewable energy technologies in public renewable energy RD&D spending in IEA member countries, 1974-2003 /IEA 2006-1/

In terms of security of supply, the allocation of the scarce funds for renewables was not optimal ether (Figure 3-4 and Figure 3-6). Within the present renewable energy RD&D budget, much too less emphasis is given to the provision of firm (on demand) power capacity, that could be provided best by e.g. geothermal hot dry rock systems and by concentrating solar thermal electric power stations, which at the moment have a share of less than 0.5 % of the total energy R&D budget, each. Innovative energy storage systems for renewables are also of major concern, ranking on places 4 and 5 of the Delphi report, but their funding is negligible. No funds are dedicated at present to the development of base-, intermediate and peaking capacity from long distance renewable electricity transfer, which however is ranking higher according to Delphi than the highly funded nuclear fission and fusion technologies. Again here, a considerable reallocation and extension of RD&D funds for renewables is over due. Present renewable energy RD&D has mainly the goal of cost reduction, already heading for competitiveness with the conventional energy sources available today. As the cost of electricity from renewables depends mainly on investments, not on fuel resources, the price of renewable energy is effectively lowered by learning. Therefore, R&D in renewables is a public investment into low cost energy resources rather than a long-term subsidy as in the case of nuclear and fossil power.

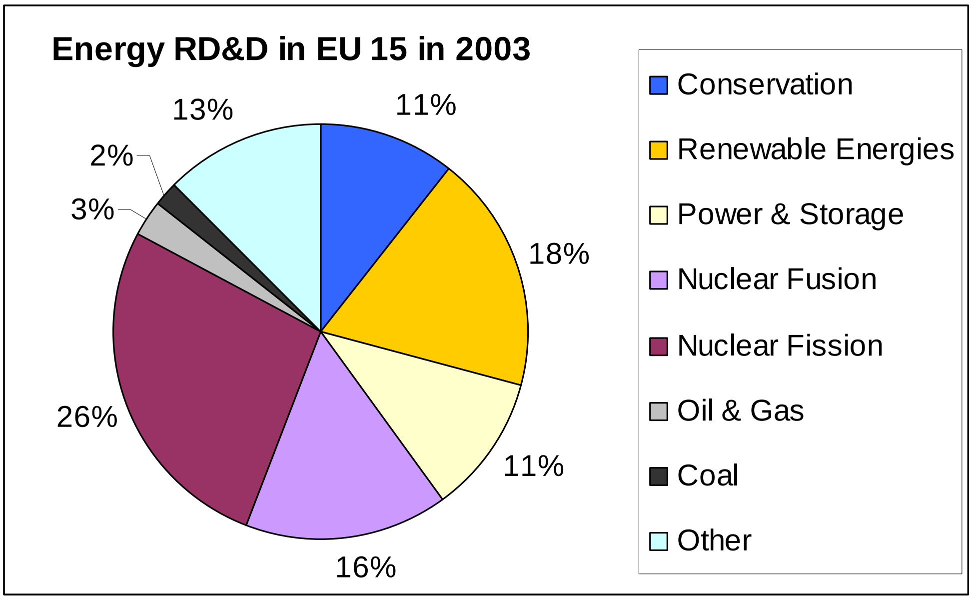


Figure 3-5: Reported government energy research, development and demonstration (RD&D) budgets in EU 15 member countries in 2003. Based on /IEA 2006-2/ and own calculations. The figure does not account for funding through the European Commission (EC) that however has a similar structure.

The Green Paper on Sustainable, Competitive and Secure Energy of the European Commission published in March 2006 is a first step to diversification which should be followed consequently and decidedly. Cooperation with North Africa and the Middle East to establish a EUMENA partnership for energy security based on the plenty renewable and fossil energy resources of this region should also be taken into account in this process.

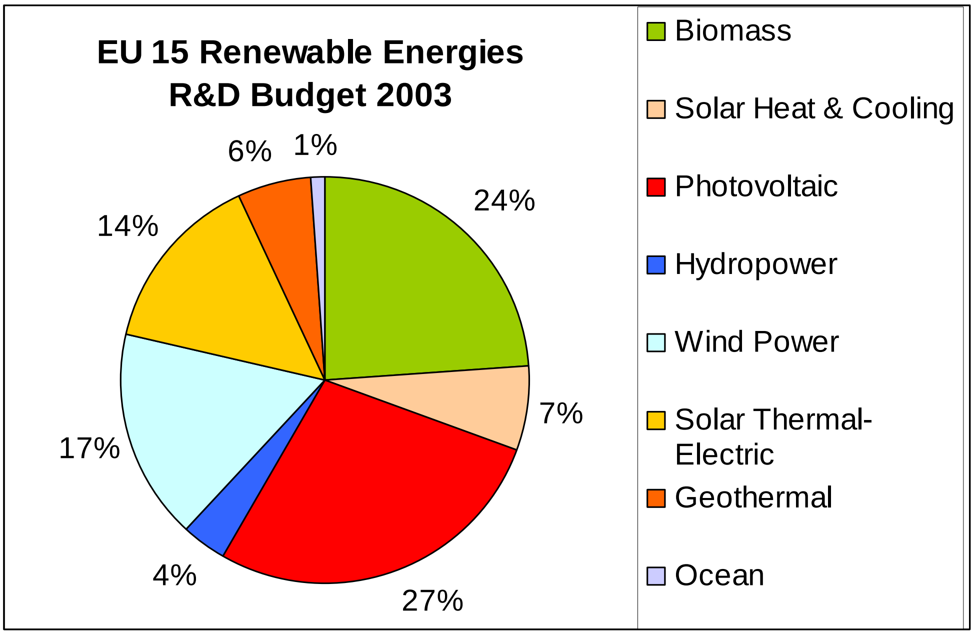


Figure 3-6: Shares of renewable energy technologies in public renewable energy RD&D funding in EU 15 member countries in 2003 from /IEA 2006-2/ and own calculations. Does not include EC funding.

3.2 Concepts of Financing Renewable Energies

An overview of renewable electricity funding and tariffs in the EU 15 is given in /EWEA 2002/, pp. 2005. In the following we provide a brief description of present support policies for renewables /REN 2005/:

Feed-in Tariffs

The most common existing policy for electricity from renewables is the feed-in law, which has been enacted in many countries and regions in the past years. Feed-in tariffs have fostered innovation, increased interest and investment most notably in Germany, Spain, and Denmark. E.g. power from renewable generation under Germany's renewable energy act grew between 2000 and 2004 from 14 TWh/y to 37 TWh/y /BMU 2005/. Due to the relatively high status of maturity of the technology, feed-in policies have had the largest effect on wind power capacities. Spain's feed-in tariff has also helped new investment plans for solar thermal power generation.

Feed-in tariffs vary in design from country to country. They apply to specific technologies and sometimes have a maximum capacity threshold. Most policies establish different tariffs for different technologies, usually related to the cost of generation, for example distinguishing between off-shore and onshore wind power. Some policies also differentiate tariffs by location/region, year of plant operation, and operational season of the year. The tariffs usually decline over time to motivate learning, but last for the typical lifetime of the plants. Some policies provide a fixed tariff (Germany) while others provide fixed premiums added to market- or cost-related tariffs (or both, as in the case of Spain).

Long term power purchase contracts guaranteed by feed-in laws reduce the required revenues and interest rates of investors, as they constitute a high security component of their investment portfolio. Within the German feed-in law, renewable energy projects are usually financed with a typical project rate of return (PRR) of 6-7 %/y, while the average demanded PRR of conventional power investments in the OECD is at least 15 %/y (of which 9 %/y are achieved on average /IEA 2001/). The reduction of risk surcharges on capital investments by feed-in laws is a significant contribution to reduce the cost of market introduction, because in the case of renewables, the capital cost is the dominating component of the overall generation cost.

Renewable Portfolio Standards

Sweden's Renewable Portfolio Standards RPS requires consumers, or electricity suppliers on their behalf, to purchase a given annual percentage of renewable shares, which increases yearly, through either electricity purchases or renewable certificate purchases. Sweden sets penalties for non-compliance at 150 percent of the average certificate price of the prior period. Poland's RPS will reach 7.5 percent by 2010.

Renewable Energy Funds

Some countries have established renewable energy funds used to directly finance investments, provide low-interest loans, or facilitate markets in other ways, for example through research, education, standards, and investments in public facilities. The largest funds of this type are the so-called "public benefit funds" in 14 states of the USA. These funds, often applied to energy efficiency as well as to renewable energy, are collected from a variety of sources, with the most common being a surcharge on electricity sales. These funds are collecting and spending more than $300 million per year on renewable energy. It is expected that they will collect upwards of $4 billion for renewable energy through 2012.

Net Metering

Net metering has been particularly instrumental in facilitating grid-connected solar PV markets in the United States and Japan. Laws exist in at least 7 countries, 35 U.S. states, and several Canadian provinces. Most recently, a 2005 U.S. federal law requires all U.S. electric utilities to provide net metering within three years.

Competitive Bidding

Policies for competitive bidding of specified quantities of renewable generation, originally used in the United Kingdom in the 1990s, now exist in at least seven other countries: Canada, China, France, India, Ireland, Poland, and the United States. China bid and awarded 850 MW of wind power in 2003–2004 and planned another 450 MW of bidding in 2005. The province of Ontario in Canada bid 1,000 MW of wind power in 2004, and other Canadian provinces were following suit. Utilities in many countries use competitive bidding to meet RPS requirements.

Renewable Energy Certificates

Other policies include tradable renewable energy certificates, typically used in conjunction with voluntary green power purchases or obligations under renewables portfolio standards. At least 18 countries had schemes and/or markets for tradable certificates. Many other regulatory measures, such as building codes, administrative rules and procedures, and transmission access and pricing, also serve important roles in promoting renewable power generation. Such regulatory measures can be steps towards future renewable energy markets, particularly in developing countries (Mexico and Turkey are examples of countries taking such regulatory measures). Policies for power-sector restructuring, carbon taxes, fossil fuel taxes, and many others can also affect the economic competitiveness of renewable energy. Eighteen European countries are members of RECS, a renewable energy certificates system founded in the late 1990s to standardize and certify renewable energy certificates and trading. By 2005, a cumulative total of 33,000 GWh of renewable energy certificates had been issued, with nearly 13,000 GWh of certificates used for consumer purchases of green electricity. In the United Kingdom, the distinction between voluntary green power purchases and renewable energy obligations by utilities has been questioned. There have been claims that green power voluntary purchases are not always additional to existing utility obligations.

Green Power Purchasing

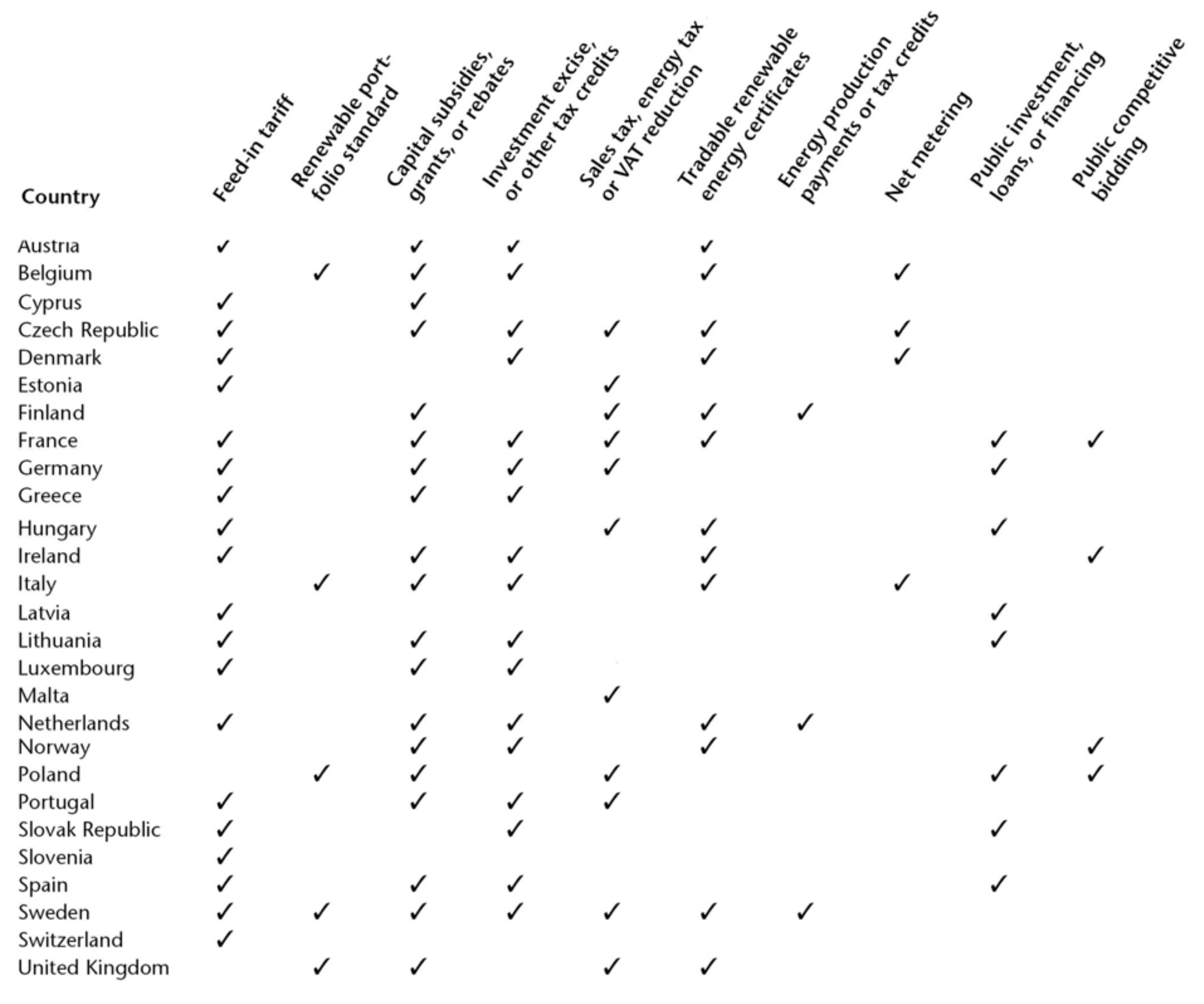
In Europe, green power purchasing and utility green pricing have existed in some countries since the late 1990s. By 2004, there were almost 3 million green power consumers in the Netherlands, supported by a tax exemption on green electricity purchases. Other countries in Europe with retail green power markets include Finland, Germany, Switzerland, and the United Kingdom. Germany’s green power market has grown steadily since 1998, with more than 600,000 consumers purchasing 2,000 GWh in 2004.

Kyoto Instruments

The present prices of carbon certificates in Germany can be found at http://www.co2-handel.de/. Today, the price of CO_2 certificates ranges around 25 €/ton. Assuming e.g. an avoidance of 0.5 tons of CO_2 per Megawatt-hour by renewable electricity (Chapter 5), this translates to an additional revenue of 1.25 €-cent/kWh for renewable electricity producers. Expectations of future prices have a wide range between 35 and 70 €/ton until 2020. In general, it can be expected that CO_2 avoidance will become more difficult and more expensive in the future, because the easy measures will be realised first, and because the baseline of allowances will be subsequently moved to lower emission levels. Carbon trading represents in principle a second income for renewable electricity producers, that will partially compensate the additional costs of renewable power generation. However, the need for initial support of renewables and carbon trade do not really match: while emission certificate prices are low today and will increase in the future, the need for additional funding of renewables is now high and decreasing. However, the additional income generated from carbon trading will help market introduction and accelerate the break-even between renewable and conventional electricity prices.

Other Support Mechanisms

There are many other forms of policy support for renewable power generation, including direct capital investment subsidies or rebates, tax incentives and credits, sales tax and VAT exemptions, direct production payments or tax credits, direct public investment or financing. Some type of direct capital investment subsidy, grant, or rebate is offered in many countries. Tax incentives and credits are also common ways of providing financial support.



Country	Feed-in tariff	Renewable portfolio standard	Capital subsidies, grants, or rebates	Investment excise, or other tax credits	Sales tax, energy tax or VAT reduction	Tradable renewable energy certificates	Energy production payments or tax credits	Net metering	Public investment, loans, or financing	Public competitive bidding
Austria	✓		✓	✓		✓				
Belgium		✓	✓	✓		✓		✓		
Cyprus	✓		✓							
Czech Republic	✓		✓	✓	✓	✓		✓		
Denmark	✓			✓		✓		✓		
Estonia	✓				✓					
Finland			✓		✓	✓	✓			
France	✓		✓	✓	✓	✓			✓	✓
Germany	✓		✓	✓	✓				✓	
Greece	✓		✓	✓						
Hungary	✓				✓	✓			✓	
Ireland	✓		✓	✓		✓				✓
Italy		✓	✓	✓		✓		✓		
Latvia	✓								✓	
Lithuania	✓		✓	✓					✓	
Luxembourg	✓		✓	✓						
Malta					✓					
Netherlands	✓		✓	✓		✓	✓			
Norway			✓	✓		✓				✓
Poland		✓	✓		✓				✓	✓
Portugal	✓		✓	✓	✓					
Slovak Republic	✓			✓					✓	
Slovenia	✓									
Spain	✓		✓	✓					✓	
Sweden	✓	✓	✓	✓	✓	✓	✓			
Switzerland	✓									
United Kingdom		✓	✓		✓	✓				

Table 3-1: Renewable Energy Promotion Policies in Europe according to /REN 2005/

3.3 Necessary Political Framesets

This chapter is focused on political actions that could be helpful to make possible the North-South cooperation for renewable energy in EUMENA. It has been kindly edited by Prof. Abdelaziz Bennouna and Dr. Gerhard Knies, members of the Trans-Mediterranean Renewable Energy Cooperation /TREC 2006/. It reflects the first draft of a road map designed within the TREC initiative. Valuable information on renewable energy policies can also be found at /OECD 2004/, /REN 2005/ and /Martinot 2006/.

The TRANS-CSP scenario for renewable energy expansion is technically possible, but in order to become reality suitable political actions and regulatory frameworks are required. The TRANS-CSP scenario will not become reality automatically. In fact, some of the present political trends are pointing into different directions:

- The Arab Human Development Reports 2003 and 2004 indicate developmental stagnation in several MENA countries. A developmental path “enlarging the gap” is not an exotic fiction.
- At present the attention of the European Union is much more in the direction East than South. In the East there are large energy resources of high importance for Europe, and also new markets and new opportunities for European industries.
- The most striking feature of the 10-year Barcelona Summit in November 2005 was the absence of all Arab political leaders.

In view of these political indicators the development of EUMENA relations needs new momentum into the proper direction. This could in fact be generated by the synergies of a renewable energy co-operation between sun-belt and technology-belt. The overabundant solar energy resources in MENA and the developed solar technologies available in Europe hold the promise of solving the energy, water and climate problems for these regions and beyond, when they can be joined “as if there were no borders”. Proper general conditions could generate considerable economic and ecological win-win configurations for all countries of EUMENA. In fact, a properly designed Free Trade Area for renewable energies could become a flag ship for the Barcelona Process, the Euro-Mediterranean Partnership, like the Community of Coal and Steel gave the early push towards European integration.

There are differences though: while the European integration was to overcome traditional hostilities between equally developed partners, the Barcelona process has to deal with overcoming developmental differences between neighbours of different cultural background.

Salient factors for the relations between EUMENA regions

The region of EUMENA is coined by tremendous differences between its parts. There are significant differences such as

1. level of literacy and vocational education
2. income per capita
3. religion
4. participation of population in public/societal matters
5. industrialization
6. significance of science and technology
7. gender equality
8. climatic living conditions

It is not exaggerating to say that the regions Europe on one side and MENA on the other are separated by a large cultural and infrastructural gap. But by history and by geography they are neighbours, and they have significant commons. The most important and challenging common however is their future. The process of globalization leaves no perspective for continued separation. Modern means of communication and transport irreversibly put an end to sealed societies. Problems, unrest and wars cannot be concealed. Globalization is a challenge to the Mediterranean riparian countries to pay careful attention to how they shape their common future. Are we doomed to a clash of civilizations, or can we use differences as complementing capacities for synergies, in support of achieving common goals? In fact, there are goals that either side would consider as an advantage:

1. peace within and between these regions
2. energy security
3. water security
4. environmental stability
5. sustainable and fair prosperity

The study demonstrates how cooperation for renewable energies could generate win-win configurations and bring all these goals into reach. Some remaining questions are:

1. Could the common goals overcome frictions and suspicions based on cultural differences?
2. Can these regions co-operate without endangering their cultural identities?
3. Can all countries become winners of a co-operation?

A positive answer to question 1 is the big hope for the common future of these regions. In fact, co-operation for the use of renewable energies bears the promise of enclosing or even of eliminating the frictions due to the present struggles for access to the limited fossil energy resources in MENA.

The answer to question 2 depends on the intention behind the co-operation. If the intention of one side is to impose its cultural values onto the others, then co-operation will no longer be embraced by the others. The absence of all Southern and Eastern Mediterranean state leaders from the 10 year anniversary convention at Barcelona may convey this message. Co-operation on renewable energies must not be abused as vehicle for other goals. The drive for any cultural or societal development must be coming from inside the respective society. The frameset for co-operation on renewable energies must exclude its abuse for cultural, economic or political hegemony.

Based on the MED-CSP and TRANS-CSP studies question 3 can be answered with a clear yes if proper political and economic general conditions were in place.

In summary, a proper political framework for energy partnership must

1. enable feasibility and enhance productivity of the co-operation,
2. ensure advantages for all sides,
3. support stability of the interregional relations,
4. bar the abuse for hegemony and cultural domination.

Economic co-operation between Europe and South and East Mediterranean countries

Comprehensive co-operation between Europe and the Southern and Eastern Mediterranean Countries (SEMC's) is the aim of the Barcelona process. In 1995 the goal of an European-Mediterranean Free Trade Area (EMFTA) was proclaimed. The EMFTA is intended to be in place in 2010. So far EMFTA is under preparation for 3 sectors:

- Industrial products
- Agricultural products
- Services

There is however not much common enthusiasm among the partners of the EU and the SEMC's. In fact, there are a number of problems in merging those very different economies. /study../

EMFTA for industrial products

Why should production of cars, of computers or of computer software, or of components for them be transferred from Western Europe to a country in North Africa? The only advantage would be lower costs for wages. But there are a number of draw backs: low qualified labour force could endanger the whole production process and the reliability of the products, and so eventually render the enormous investment into the production facilities useless. In Eastern Europe, wages are also low, but vocational and general education and infrastructure are superior. Cheaper produced cars are already coming from Brazil, Rumania and soon also from China and Russia. Computers are largely produced in Eastern Asia. Except for some niche products MENA runs into stiff competition.

EMFTA for agricultural products

With Europe having over-production of agricultural goods, lower cost oranges or tomatoes from North Africa will put out of work European orange and tomato farmers. Unless Europeans multiply their consumption of oranges and tomatoes we will face a win-loose configuration. Also in view of the mounting water scarcity in the South, the expansion of food production in MENA for export has narrow limits.

How to ensure a long-term win-win co-operation

The European integration represents a long-term win-win co-operation. Its success is based on economic or commercial win-win configurations, as in the "community of steel and coal", unleashing significant synergies. A similarly effective win-win configuration seems to be at hand for a EUMENA Renewable Energy Co-operation.

There are two basic factors for a win-win configuration:

1. The co-operating partners contribute supplementing and not competing capacities.
2. The co-operating partners have common and not conflicting goals.

How a solar or more generally a renewable energy co-operation between EU and MENA complies with condition 1 is subject of this study. Five common goals are summarized above. In addition, there are unilateral advantages, like technological and industrial development for MENA – even though economic growth may be taken as common goal – or cheaper electricity for Europe. Therefore, an EMFTA for renewable energies (RE-EMFTA) is a promising case for bringing more dynamics into the Barcelona process.

Policies should provide incentives for a quick start and for investment security in the long run. The problem to overcome is the competition with the only seemingly cheaper fossil energies, since they are not charged with their environmental costs and/or receive heavy subsidies. Therefore the EUMENA regions in their best self-interest in and in their responsibility for a sustainable future should create regulations that boost the use of renewable and in particular solar electricity, which is the gateway towards a secure, reliable, clean and least cost energy supply.

A Euro-Mediterranean Free Trade Area for Renewable Energies

In the following we present a proposal for a suitable political framework that would allow for the developmental path of the MED-CSP and TRANS-CSP scenarios for MENA and Europe, respectively: a Renewable Energy European-Mediterranean Free Trade Area (RE-EMFTA). RE-EMFTA is along the lines of EMFTA described above. Just the sector of trade area would be renewable energies and the members could be going beyond the SEMCs. How to achieve successfully a rapid expansion of renewable electricity production has been demonstrated by the method of a feed-in regulation with guaranteed tariffs as in operation in about 30 countries. The specific innovation to be made here would be a trans-national feed-in regulation, such that solar or wind electricity from a MENA country would be eligible for feed-in tariffs in the EU. The tariff is to be designed to provide commercial viability and long-term security for the necessary investments in MENA countries. Another specific is that there are 2 feed-in modes: virtual feed-in (phase 1 before 2020) without and physical feed-in (phase 2 after 2020) with transmission from MENA to EU. This way production of clean electricity for MENA consumers can also be stimulated by the EU and eventually credited to its climate protection obligations.

Once the cost of solar technology has been brought down, solar power from the sun belt becomes attractive for import by EU countries. Thus the EU countries could save a lot of power cost in two ways,

1. by accelerating the solar cost reduction process thru early investments in solar plants in and for the MENA region (phase 1),
2. and by importing reliable and economical solar and wind power from the MENA region (phase 2).

For MENA countries production and export of clean power is a long-term source of income, and the local production of solar technology a driving force for scientific development and for industrialization. The transition to a knowledge based economy is the great challenge in the MED-CSP scenario /MED-CSP 2005/.

An additional incentive could be provided by a MENA Technology Development Fund, which would pay an additional charge per kWh proportional to the share of parts in the plant that are produced in MENA.

As key elements for making a RE-EMFTA operational and successful we consider:

1. A set of agreements stimulating production and ensuring free trade for RE
2. A mechanism to secure investments, at least in the early stage
3. A EUMENA board to set and to ensure the necessary pace for achieving the common goals.

Regulations of a RE-EMFTA

The RE-EMFTA could be based on the following or a similar set of agreements:

1. Renewable energy products (like power, hydrogen) can cross any border duty-free, without administrative restrictions and without discrimination in comparison with domestically generated renewable energy products.
2. Renewable energy technology can cross any border duty-free and without administrative restrictions.
3. Renewable energies (products, technology) are given in each country at least the same subsidies or financial support as is given directly or indirectly to competing fossil or nuclear energies.
4. Members cooperate on creating the infrastructure for RE transmission.
5. Each member establishes appropriate feed-in regulations.
6. Each member gives legal securities for investments from other countries.

7. The EU declares targets for renewable energy imports, based on recommendations by a EUMENA Panel on Energy, Water and Climate Security (PEWCS) and will set up a feed-in regulation that ensures compliance with these targets.
8. During phase 1 the EU makes purchase agreements for “virtual” clean power from selected solar power plants by providing the feed-in surcharge for a contingency recommended by the PEWCS to reach its own climate goals.

Membership: EU, and individual MENA countries (may be beyond present SEMCs).

The RE-EMFTA makes a win-win configuration of partners from sun-belt and from technology-belt accessible for investments.

EUMENA Energy, Water and Climate Security Fund

In addition, all members create a joint EMFTA Energy, Water and Climate Security Fund (EWCSF) . This fund guarantees power purchase agreements, and ensures tariffs for clean power and water that cover the investment costs and attract investors in a way that the energy, water and climate security goals will be achieved.

EUMENA Energy, Water and Climate Security Panel

The EWCSP is an advisory board to the EU commission and to governments in the MENA countries. Its function is to give recommendations to the political responsible bodies in EUMENA for measures required to ensure energy, water and climate security. It includes scientists with expertise in the fields of energy, water and global climate. It works in a style similar to the global IPCC. In the long run an EWCSP could become a driving force for an integrated sustainability region EUMENA and a nucleus of a regional governance structure for sustainable development.

The ideas described here are a first draft of a EUMENA renewable energy partnership that will require further intensive discussion on all levels of policy, industry and society in general.

3.4 Policies and Finance for Solar Electricity Imports

The cost of import solar electricity from MENA in 2020 will range between 5.5 to 6.5 cent/kWh as shown in Chapter 2 (for the individual cost in each country please refer to the Annex). If we assume a level of carbon certificate prices of 35 €/ton (today 15 €/ton)and the fact that solar electricity imports from CSP in MENA would substitute the burning of coal and gas resources for power generation in Europe with specific emissions of 0.5 to 0.9 tons/MWh (Chapter 5), the value of carbon trading would range between 1.5 and 3 €-cents/kWh, which can be subtracted from the electricity generation cost. This would fully cover the cost of electricity transfer of about 1.5 €-cent/kWh. Thus, the effective cost of solar electricity in Europe would equal it's generation cost in MENA of about 4-5 €-cent/kWh, assuming base load operation. If solar import electricity would be used for intermediate or peaking load with less full load hours, it's cost and revenues would be accordingly higher. Thus, solar import electricity would be highly competitive.

Solar electricity imports will contribute to the stabilisation of electricity costs and to grid stability, through their exceptional controllability and flexible performance. The solar electricity import potential of 65 TWh/y in 2020 growing to 700 TWh/y in 2050, that was identified by the scenario analysis in Chapter 2, can be taken as a plausible market potential for CSP import electricity. The scenario comprises a total cumulated investment volume of 47 billion € until 2020 and 395 billion € until 2050 for the necessary CSP and HVDC installations.

However, the realisation of the necessary power plant capacity and grid infrastructure in the proposed time frame requires to start immediately the following activities:

- preparation of an internationally accepted expert document that demonstrates the technical and economical feasibility, a possible roadmap and the impacts of such a Trans-Mediterranean renewable energy interconnection,
- preparation and realisation of the necessary international agreements among the involved EUMENA countries, possibly in the frame of the Barcelona process, to found a Trans-Mediterranean Renewable Energy Partnership that provides the necessary political and legal frame, establishing a Trans-Mediterranean Renewable Energy Free Trade Area,
- establishment of adequate financial frame conditions to trigger the necessary investments of 10 - 15 billion €/y from 2020 to 2050 in MENA and Europe,
- selection and thorough planning of the first power line, its technology, cost and impacts, and start of a well founded information campaign,
- realisation of about 5000 MW of installed CSP capacity world wide and the development of commercial large scale thermal energy storage facilities for CSP until 2015 to achieve the assumed cost reductions and economies of scale.

The realisation of these pre-conditions and the construction of the first 5 GW HVDC power line between MENA and Europe will take at least 15 years from now. Therefore, our scenario starting in 2020 with two 5 GW lines over several 1000 km length and 10 GW of CSP with 18 hour thermal storage capacity in MENA established and operating specifically for the purpose of power export, will be quite a challenge, if not unrealistic. Its realisation in due time will require a high motivation and engagement of many stakeholders from policy, industry and finance.

In the past, there has been a strong public resistance in Europe against large utility grid structures that must be overcome by thoroughly planning for minimized environmental impact and an adequate information campaign. Public acceptance and environmental concerns will be an important market delimiter for solar electricity imports. Therefore, the socio-economic and environmental impacts must be carefully evaluated and explained to the public (Chapters 4, 5).

3.5 General Conclusions for Policy and Finance

With respect to energy policy, we come to the following conclusions: (for comparison refer to /OECD 2004/ and /EU 2006/):

- Diversification of the energy portfolio with renewables is a key to energy security.
- Quickly reacting, gas-fired plants for peaking power combine well with renewables, while investments into constant base load power capacity should be reconsidered carefully.
- Energy RD&D budgets in Europe must be reallocated, RD&D for the cost reduction of renewables must be extended considerably and more emphasis must be given to renewables and storage technologies that can provide firm power capacity.
- Feed in tariffs for electricity from renewable energy sources that cover the cost difference to present market prices are very effective, as they foster energy diversification and reduce the risk surcharges on private investments. If tariff additions are gradually reduced to zero, they can be considered a public investment rather than a subsidy.
- A EUMENA free trade zone for renewables should be established in the medium term, political work in this direction should start immediately.
- The planning and evaluation of EUMENA electricity highways based on HVDC technology to increase the redundancy of power supply should start immediately.
- As a general principle, the subsidisation of energy technologies should be limited to a reasonable time span and should in all cases be subsequently reduced to zero.
- Present electricity pricing is not sustainable. With the growing, over-due need for new investments in the power sector, market prices will increasingly reflect full and not only marginal costs.
- European support for MENA for the market introduction of renewables can attenuate the growing pressure on fossil fuel resources that would otherwise origin from the economic growth of this region, thus helping indirectly to secure fossil fuel supply in Europe.

4 Socio-Economic Impacts

4.1 Wealth Creation

A recent modelling of the world economy by the International Energy Agency (IEA) in collaboration with the OECD Economics Department and with the assistance of the International Monetary Fund (IMF) Research Department shows that there is a considerable negative impact of rising oil prices on macro-economic indicators such as Gross Domestic Product, Consumer Prices and Unemployment /IEA 2004/. The study analysed the difference of these indicators between a base case defined by an oil price of 25 $/bbl and a relatively sharp increase to 35 $/bbl as experienced in 2003/2004 for different regions and on global level (Figure 4-1).

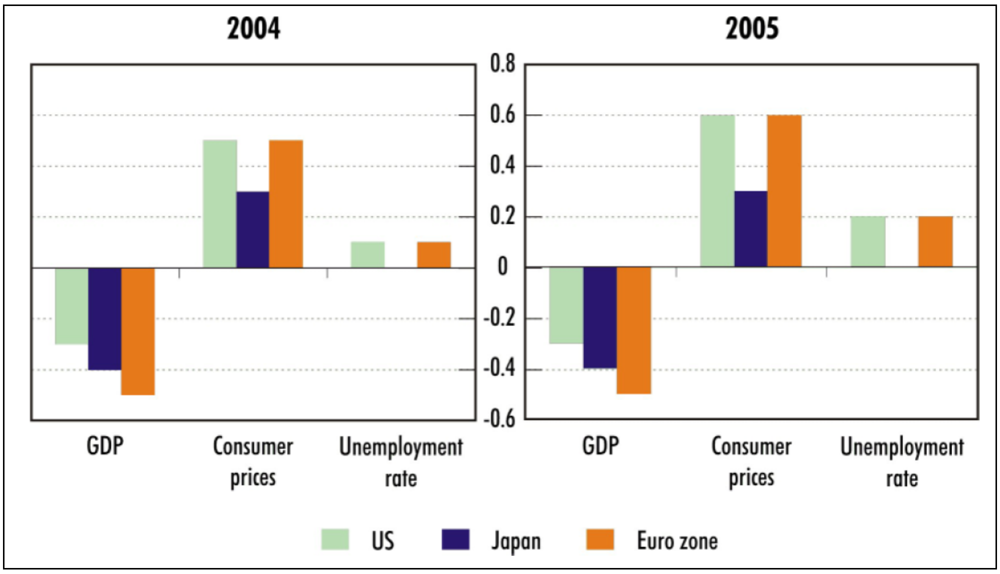


Figure 4-1: Short term impact of higher oil prices on the macro-economic indicators by Region/Country. Deviation from base case in percentage points. Oil prices are assumed to be 10 $/bbl higher than in the base case (25 $/bbl). The reaction of the GDP in the Euro region amounts to – 0.5 % /IEA 2004/.

In the case of a 10 $/bbl increase, the annual GDP in the Euro zone is reduced by 0.5 %, while consumer prices increase by 0.6 % and unemployment by 0.2 %. In absolute numbers, there is a loss of about 42 billion US-$ in GDP and about 400,000 jobs in all OECD countries. The average oil price level of over 50 $/bbl in 2005, however, is 25 $/bbl above the base case, with proportionally higher impact on the national economies. Moreover, fuel price escalation goes on undisturbed (60 $/bbl in January 2006) with up to 120 $/bbl expected for 2030 /HWWA 2005/.

Figure 4-2 shows the historical prices of fuel oil #2 in the past 30 years and the equivalent cost of energy from a concentrating solar collector field as projected for the next 30 years under the operating conditions of North Africa. The comparison shows that the primary solar energy cost will reach by 2015 a price level equivalent to that of fuel oil in the 1990ies. The crude oil price by that time was between 15 and 20 $/bbl. This cost reduction of solar energy can significantly help to counteract the negative impacts of fossil energy price escalation and to stabilize energy costs at a reasonably low level, if the renewable energy shares become significant. Also other renewables show such a trend. In contrary to the volatility of fuel prices, the learning curves of renewables are rather predictable within a reasonable range. However, a major requisite of cost reduction is the expansion of capacities and production /WETO 2003/, /EXTOOL 2003/.

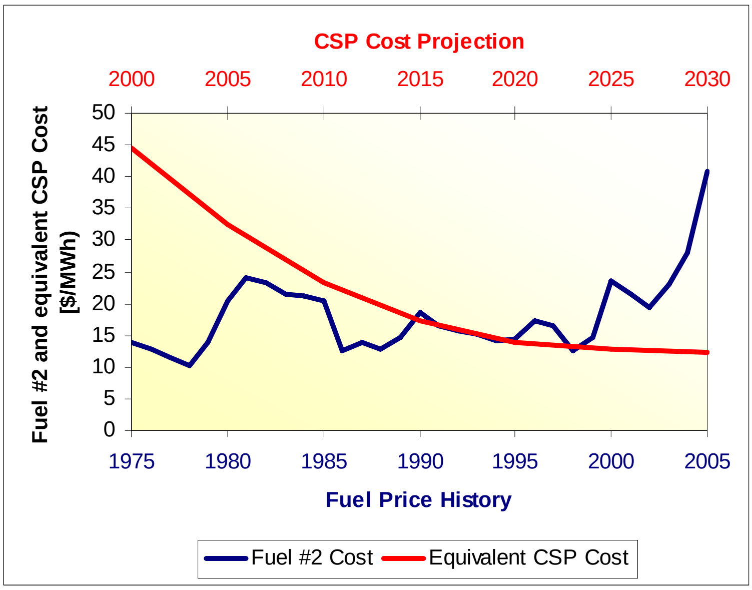


Figure 4-2: Historical prices of fuel oil #2 and cost of equivalent solar energy from concentrating solar power projected for a comparative time span of 30 years /oilnergy 2005/ and own calculations.

Therefore, an increasing, noticeable share of renewables is a key for stabilising the socio-economic indicators mentioned before. However, due to the present low share of renewables on primary energy, and even considering the high market participation and growth rates of renewables today, those beneficial effects will hardly become noticeable on a global scale before 2020. On the other hand, the simple fact that fossil fuels will increasingly have to compete with renewables all over the world will have a stabilising effect on fossil fuel prices.

The IEA study also predicts that lower prices than in the base case would bring economic benefits. The results of a second simulation, which assumes a $7 per barrel fall in oil prices compared to the base case over the full projection period of 5 years, suggests that the economic benefit of lower prices is as pronounced as the harm caused by higher prices. After the first two years of the sustained lower price case, GDP is 0.3 % higher whilst inflation and the rate of unemployment are 0.4 % and 0.2 % lower compared to the base case. This is more or less what could be expected theoretically if oil would be substituted by CSP or other renewable sources. Unfortunately, a full substitution within such a short time span of 5 years is not realistic at all.

However, there will be considerable socio-economic benefits from the increased use of renewables in Europe and world wide.

4.2 Reduced Subsidies and External Costs

“The private sector carries no obligation to address long-term energy security or environmental issues. It is the responsibility of governments, through market pricing and appropriate regulatory frameworks, to ensure that the private sector adequately responds to these challenges” /EEA 2004/. This is often done through energy subsidisation.

In a recent study, the European Environmental Agency has quantified the energy subsidies in the European Union /EEA 2004/. According to this analysis, the direct and indirect subsidisation of energy amounts to about 86 billion € per year (Table 4-1). They classify subsidies into three categories: on-budget subsidies, off-budget subsidies, and the failure to impose external costs.

On-budget subsidies are cash transfers paid directly to industrial producers, consumers and other related bodies, such as research institutes, and appear on national balance sheets as government expenditure. Grants may be given to producers, mainly to support commercialisation of technology or industry restructuring, and to consumers. On-budget subsidies also include low interest or reduced-rate loans, administered by government or directly by banks with state interest rate subsidy (Table 4-2).

Subsidies [billion €/y]	Coal/Lignite	Oil/Gas	Nuclear	Renewables	Total
on-budget	6,4	0,2	1,0	0,6	8,2
off-budget	6,6	8,5	1,2	4,7	21,0
external costs *	36,0	16,0	2,7	2,3	57,0
Total EU 15	**49,0**	**24,7**	**4,9**	**7,6**	**86,2**

*** average of minimum and maximum estimate to show the order of magnitude**

Table 4-1: Energy subsidies /EEA 2004/ in the European Union in 2001and externalities calculated from /ExternE 2003/

Off-budget subsidies are typically transfers to energy producers and consumers that do not appear on national accounts as government expenditure. They may include tax exemptions, credits, deferrals, rebates and other forms of preferential tax treatment. They also may include market access restrictions, regulatory support mechanisms, border measures, external costs, preferential planning consent and access to natural resources. Regulatory support mechanisms make up the other most significant area of off-budget support for the energy sector. These mechanisms most commonly take the form of price guarantees and demand quotas for specific energy sources. They are introduced to support environmental, economic, employment or energy security policy objectives. Some of these mechanisms, such as feed-in tariffs or competitive tenders can be described as ‘supply push’ mechanisms, in that they stimulate production. Others, such as purchase obligations are ‘demand pull’ mechanisms in that they create an artificial demand to which the market responds.

Research undertaken in the United States provides a useful indicator of the respective levels of total subsidy support for nuclear power and wind power at similar stages of technological development. According to this analysis, the nuclear industry in the USA received about 30 times more support per kWh electricity output than wind power in the first 15 years of the industry’s development with comparable power generation /Goldberg 2000/.

In contrast to fossil and nuclear power technologies, renewable energy, with the exception of large hydro-electric power, represents a range of technologies still in their infancy. Due to R&D inputs and wider commercial application, the capital costs of renewable energy have fallen considerably in the past and will fall further substantially, making production from renewable energy sources increasingly competitive. Rather than subsidy, the public support of renewables – if properly balanced – can be interpreted as a sound investment into a cheaper, less volatile and ecologically compatible energy supply. Especially support schemes like the renewable energy feed-in tariffs in Austria, Spain and Germany allow (force) the direct beneficiaries of this strategy, the energy consumers, to directly invest into their own area of interest.

Fuel cycle externalities are the costs imposed on society and the environment that are not accounted for by the producers and consumers of energy, i.e. are not included in the market price (Table 4-3). They include damage to human health, the natural and built environment, and include non-compensated effects of air pollution, occupational disease and accidents. They also include the external costs of climate change. In theory, if the costs of external impacts are known, they should be incorporated into the price of the energy concerned. In that way, producers, consumers and decision makers could get accurate price signals and reach optimal decisions about how to use the resources. In practice, the measurement of environmental impacts and associated costs is a complex and evolving science, and neither markets nor governments effectively price these costs. EU governments have recognised this and have invested in modelling, in particular through the European Commission’s ExternE project, which has demonstrated that most renewable energy sources have significantly lower environmental impact per kWh than fossil fuels, and have similar immediate impacts to nuclear power, without the same risk of accident and nuclear materials proliferation (Figure 4-3).

Due to the subsequent cost reduction of renewables, their increased utilisation can slowly relieve the European economies from the heavy burden of energy subsidies and external costs, at the moment amounting to about 80 – 100 billion € per year in the EU 15 alone, not accounting for the political and nuclear external costs involved. It will depend on the speed of market introduction and expansion of renewables, if this burden can be unloaded from European society before major damages to economy and environment take place and become irreversible.

On the other hand, the additional burden on the public energy budget during the market introduction phase of renewables is relatively low, as the share of renewables in this phase is low, too. Once the share of renewables becomes bigger – specially after the break even point with fossil fuels – it's cost will be lower, thus effectively combating energy cost escalation (Figure 4-7).

The subsidisation of technologies that have been introduced to the market more than 50 years ago like fossil or nuclear power, and the – transient – necessary support for the market introduction of renewables are of totally different quality: the former is a real, long term and potentially unlimited and increasing subsidisation of technologies that have already passed beyond their economic summit and become more and more expensive the longer they are subsidized. In contrast to that, the support of renewables has the quality of a limited, initial investment necessary to achieve a better, cheaper and more compatible energy supply system.

Both the present RD&D strategy and the energy subsidisation schemes of the European region must urgently change from the visible dead end track of fossil and nuclear power to a sustainable path based mainly on renewable energy and a well balanced mix of resources and technologies.

Government intervention	Examples
Direct financial transfers	Grants to producers
	Grants to consumers
	Low-interest or preferential loans to producers
Preferential tax treatments	Rebates or exemption on royalties, duties, producer levies and tariffs
	Tax credit
	Accelerated depreciation allowances on energy supply equipment
Trade restrictions	Quota, technical restrictions and trade embargoes
Energy-related services provided by government at less than full cost	Direct investment in energy infrastructure
	Public research and development
Regulation of the energy sector	Demand guarantees and mandated deployment rates
	Price controls
	Market-access restrictions
	Preferential planning consent and controls over access to resources
Failure to impose external costs	Environmental externality costs
	Energy security risks and price volatility costs

Table 4-2: Types of energy subsidy. Adapted from /IEA,UNEP 2002/.

Social Costs (quantified in ExternE)

- Damages to Health (e.g. pollution of air and water)
- Damages to Materials and Buildings (e.g. acid rain)
- Damages to Crops (e.g. over nutrition, acid rain)

Environmental Costs (quantified in ExternE)

- Damages to Ecosystems (e.g. over nutrition, acid rain)
- Greenhouse Effect (e.g. desertification, weather extremes, global climate change)
- Environmental Overuse (e.g. deforestation)
- Smog (e.g. Asian Brown Cloud)

Political Costs (not quantified)

- Political and Military Presence to Secure Energy Resources (e.g. USA in Saudi Arabia)
- Wars on Resources (e.g. Persian Gulf Wars)
- Political Decisions Influenced by Dependency on World Market (e.g. see today's newspaper)

Nuclear Costs (partially quantified in ExternE)

- Nuclear Waste Disposal for over 25 000 years (still unsolved)
- Protection of Transport of Nuclear Waste Materials (Castor Transports in Germany)
- Hazard of Nuclear Accidents (e.g. Tschernobyl, no insurance available for such risks)
- Proliferation of Nuclear Materials (e.g. Threat of Dirty Bombs with Plutonium)

Table 4-3: Types and examples of external costs. The first two categories are quantified in the ExternE project of the European Commission in Figure 4-3.

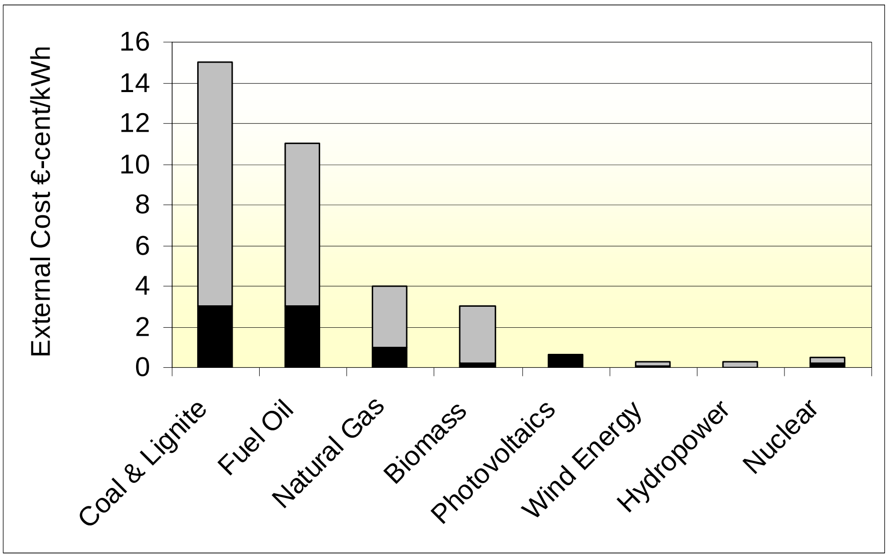


Figure 4-3: External cost range for electricity production in the EU 15 countries for existing technologies in € cent per kWh according to /ExternE 2003/ (minimum black, maximum grey). Nuclear externalities do not include all costs . ExternE does not ether include political costs according to Table 4-3. Please refer to /Krewitt and Schlomann 2006/ for more recent analysis.

4.3 Improved Diversity and Security of Supply

There is a clear answer to the question of security, well established in the financial and insurance business: the diversification of the portfolio of assets. This has been recognised by the Green Paper on Sustainable, Competitive and Secure Energy of the European Commission that has set out the energy realities facing Europe /EU 2006/. According to this paper, Europe's energy policy should have three main objectives:

- Sustainability : (i) developing competitive renewable sources of energy and other low carbon energy sources and carriers, particularly alternative transport fuels, (ii) curbing energy demand within Europe, and (iii) leading global efforts to halt climate change and improve local air quality.
- Competitiveness: (i) ensuring that energy market opening brings benefits to consumers and to the economy as a whole, while stimulating investment in clean energy production and energy efficiency, (ii) mitigating the impact of higher international energy prices on the EU economy and its citizens and (iii) keeping Europe at the cutting edge of energy technologies.
- Security of supply: tackling the EU's rising dependence on imported energy through (i) an integrated approach – reducing demand, diversifying the EU's energy mix with greater use of competitive indigenous and renewable energy, and diversifying sources and routes of supply of imported energy, (ii) creating the framework which will stimulate adequate investments to meet growing energy demand, (iii) better equipping the EU to cope with emergencies, (iv) improving the conditions for European companies seeking access to global resources, and (v) making sure that all citizens and business have access to energy.

The present situation and future trends of the energy sector present several serious challenges to the European Union. Future security of supply, particular of oil and gas is uncertain, and indigenous production is declining rapidly. High oil and gas prices weigh on the budget of consumers and companies and gas and electricity prices pose a potential threat to competitiveness of EU companies. Greenhouse gas emission, particularly CO_2, are persistently stable or even slightly increasing at a time where Kyoto commitments and post 2012 climate policy would require clear decreases in emissions.

Security of Supply

The TRANS-CSP scenario starts in the year 2000 with the 5 major sources of power generation used at present in Europe, that is coal, nuclear power, natural gas, fuel oil and hydropower (Figure 4-6). In 2050, the power demand is covered by 10 major sources, including the renewables portfolio with 7 new resources, and fading out expensive oil and risky nuclear power. Most of the renewable energy sources used are domestic, thus doubling the diversity of resources and at the same time reducing the dependency on energy imports.

The import of solar electricity through HVDC lines is a security issue, as the sudden outage of power lines with 5 GW capacity would be a challenge for the present UCTE grid. At the moment, the short term primary reserve of the European grid allows for outages of about 3 GW. In case of an outage of a bipolar 5 GW HVDC line, the immediate outage is 2.5 GW if only one conductor is affected, while 2.5 GW can be maintained for about 10 minutes through back-currents by earth, enough time to activate further reserve capacities, while conventional power lines fail totally within split seconds /Peschke, Olshausen 1998/. Thus, the outage of one conductor of a bipolar, 5 GW HVDC line would be the maximum tolerable failure within the present European utility grid.

The same limits are valid for the operation of nuclear fusion plants scheduled to have 5 GW flat base capacity /HGF 2001/. In any case it will be necessary to strengthen the European electricity grid by a HVDC infrastructure – similar to electricity highways – that allows for the quick transfer of electricity over long distances to compensate possible outages of high capacity at single points. HVDC will thus become anyway the basis for network stability in the future.

The TRANS-CSP scenario proposes a HVDC import capacity of 100 GW from CSP plants in Northern Africa with average 7000 full load operating hours per year, through 20 lines with 5 GW capacity each (Chapter 2). If the CSP plants would normally operate with only 90 % of their capacity, they would have a reserve capacity of about 10 %, thus being able to compensate a short term outage of 2 complete lines with 10 GW. The rotating masses of the steam turbines would act as short term primary reserve capacity, but CSP can also act as long term reserve with base load characteristics. Short term reserve capacities are very important for grid stability. CSP plants can fully provide those services for grid stabilisation.

A HVDC backbone will considerably increase the redundancy of the European electricity grid /Fischer et al. 2004/. While the transmission of electricity through the AC grid in case of an outage is limited to about 3 GW, the capacity of a HVDC grid is virtually unlimited compared to the maximum unit capacity that could suffer an outage. Therefore, a HVDC backbone grid will probably be implemented in Europe within this century to enhance security and stability. A spin-off of this grid will be the possibility to interconnect the best sites for renewable energy use from hydropower, wind and solar energy (Figure 4-4). This will increase the compensation effects of fluctuating renewable energy resources within the power system, because the time correlation of the different sources decreases considerably with their distance. Thus, a HVDC electricity system will not only increase the redundancy of supply, but also will smoothen the temporal fluctuations of the renewable energy mix.

The technical vulnerability of highly dispersed electricity generation from relatively small units of renewable power generators is much lower than that of a system based on large centralised power generators. E.g. drastic measures are necessary to protect nuclear reactors from September 11 type attacks, with considerable (external) costs for society, while it is virtually impossible to attack simultaneously the highly dispersed wind and solar electricity generators of a renewable energy mix. The technical vulnerability of the present electricity grid is rather high, but a HVDC backbone will effectively reduce the vulnerability of the transmission system of the future.

We assume a capacity credit of wind power of maximum 16 % and 0 % for PV. Our scenario shows a subsequently fading demand for flat base load power plants with constant capacity, and increasing demand for quickly reacting gas fired power plants to provide firm capacity on demand. This is due to the fact that the fluctuating wind and PV resources will primarily substitute base load capacity, reducing the consumption of energy, but they cannot replace major shares of firm capacity.

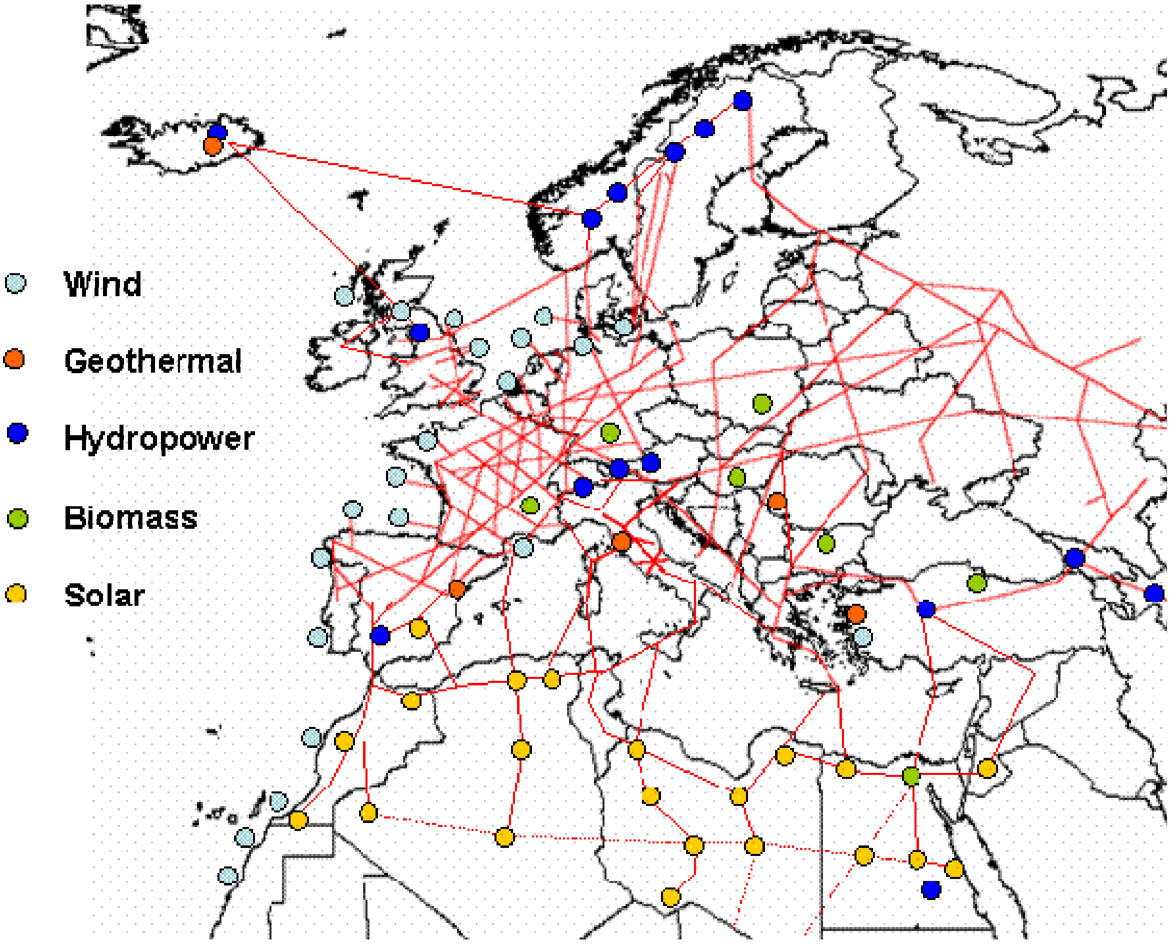


Figure 4-4: Vision of a Trans-European HVDC grid acting as "electricity highways" to increase the redundancy of power supply and to activate the best sites for renewable electricity generation. Based on /Asplund 2004/ with modifications according to the results of TRANS-CSP.

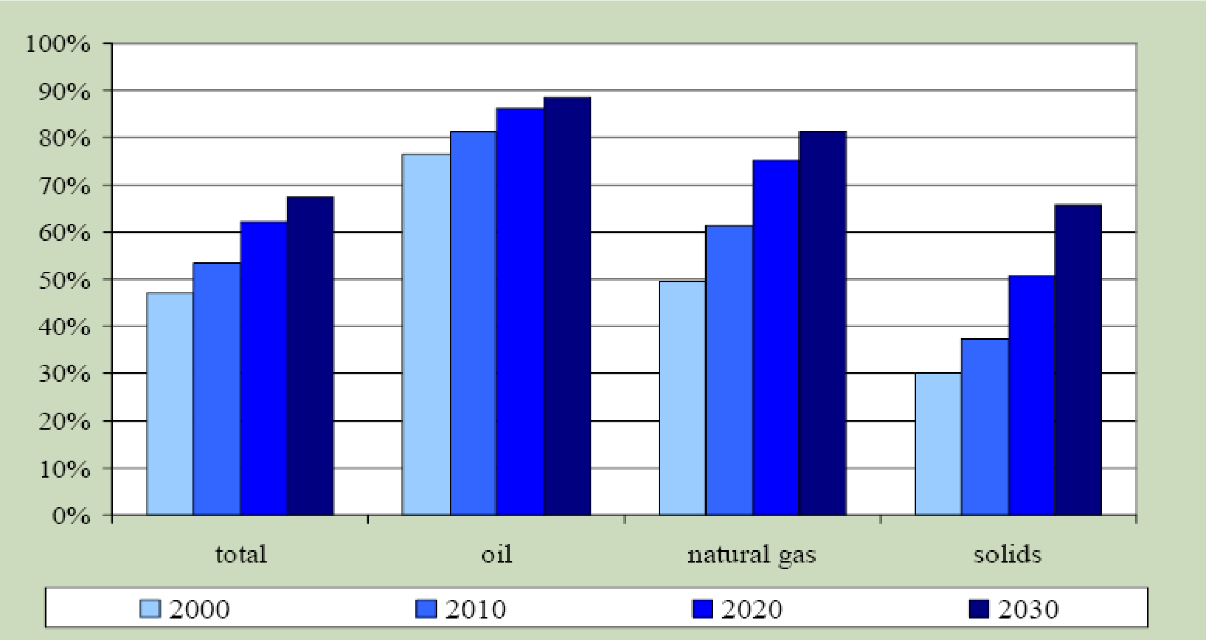


Figure 4-5: Energy import dependency in the EU 25 expected in a scenario that follows present policy trends /EU 2006/

In order to benefit from gas fired firm capacity and at the same time reduce the consumption of natural gas, it will be important to install renewables at the same or at a faster rate than gas fired plants. Gas fired peaking plants and renewables combine very well. On the other hand, considering the long investment cycles of 40-50 years, investments into constant capacity base load plants should be considered carefully. With a well balanced mix of technologies, it will be possible to substitute coal and nuclear base load capacity by renewables and natural gas, without stressing too much the gas resources. In the TRANS-CSP scenario, there is an interim doubling of gas consumption until 2030, which is then retrogressive and ends in 2050 with the same consumption as today (Figure 4-6). Coal consumption is maintained steady until 2030, then it goes back to 40 % of the 2000 value by 2050. Part of the demand for natural gas will be supplied by coal gasification, depending on the cost of both options. Nuclear power is faded out. In this mix, there is certain room for variances of the shares of gas, coal and nuclear plants which will depend on the respective national and European energy policy and subsidisation.

The TRANS-CSP scenario maintains a minimum firm power capacity of 125 % of the national peak load in each country. However, as peaking demand does not occur simultaneously in all countries the overall peak load will be smaller. With a well balanced mix of renewable and fossil backup power plants, and the considerable backup capacity of a HVDC grid interconnecting all European regions, the TRANS-CSP scenario shows an effective way to increase substantially the security of European electricity supply.

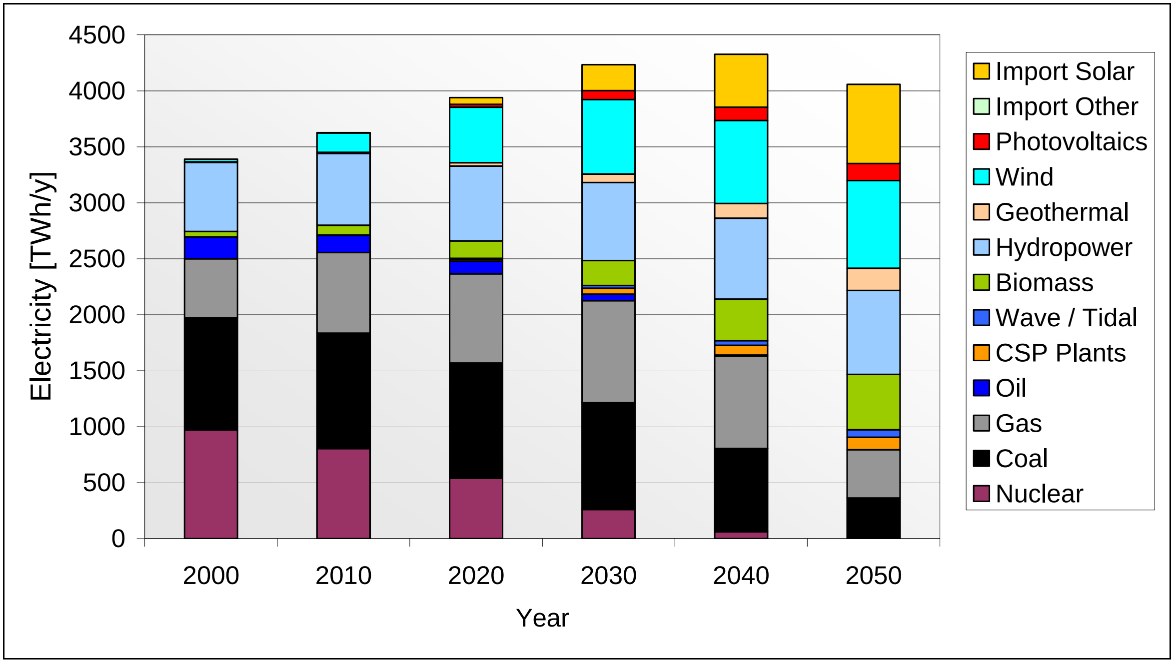


Figure 4-6: European electricity mix in the TRANS-CSP scenario (see Annex for single countries)

Economical Security

Managing the economical risk associated with energy supply is an increasingly important policy driver. Security of energy supply covers a wide range of issues — from protecting energy distribution infrastructure from disruption, to diversifying sources of supply and developing strategic stockpiles. In economic terms, risk is best measured by price volatility.

Governments have traditionally made planning decisions for new capacity based upon the lowest cost option between different technologies and fuels (Quotation from /EEA 2004/). This has tended to support more established fuel sectors rather than renewable technologies, which have higher capital costs but which may have other benefits in terms of diversifying supply and reducing import dependence. With investment decisions transferred to the private sector and downward pressure on electricity prices, the demand for lowest cost options has become even greater. Current electricity prices in Europe reflect rather the marginal cost of power generation of 3-4 €-cent/kWh, while the real cost which also covers the investments of new power plants is estimated to be in the order of 6 €-cent/kWh /EU 2006/. As a consequence, investments in the power sector are not realised in the required amount, creating an unbalanced situation of demand and supply. This is a common situation in developing countries, but has recently also influenced grid outages in USA, Denmark and Italy.

This creates problems for energy planners, who have recognised that current market designs do not guarantee an adequate level of security of supply. Over-reliance on fossil fuels can increase fuel price volatility — the likelihood that energy prices will fluctuate more widely and more often — and expose economies to significant macroeconomic costs.

Financial portfolio modellers seek to identify the efficient or optimal assets mix that produces the most economically efficient outcome for a given level of risk: efficient portfolios maximise expected return (or minimise expected cost) at any given level of risk, while minimising risk for every given level of expected return /Awerbuch and Berger 2003/.

Awerbuch and Berger examined the use of portfolio theory in reducing risk and potential costs and demonstrated that current energy mixes can be significantly enhanced, and that by adding renewable energy to energy portfolios dominated by fossil fuels, price risk could effectively be hedged. They compared the 2000 and projected 2010 EU 15 electricity generation mix and concluded that risk and cost can be reduced 'by adjusting the conventional mix and including larger shares of wind or similar renewable technologies' and that 'any expansion in natural gas should be accompanied by an increased deployment of renewables'.

The presence of each primary fuel in an energy portfolio with minimised risk has a real economic value, but this is currently disconnected from mainstream discussion, energy models and private sector investment decisions. Further work needs to be done to quantify the economic benefits of risk and cost management to ascertain the extent to which current levels of support reflect the potential benefits of renewable energy. What is clear is that the role of technologies for exploiting renewable energy in diversifying energy price risk is not yet fully recognised by the market.

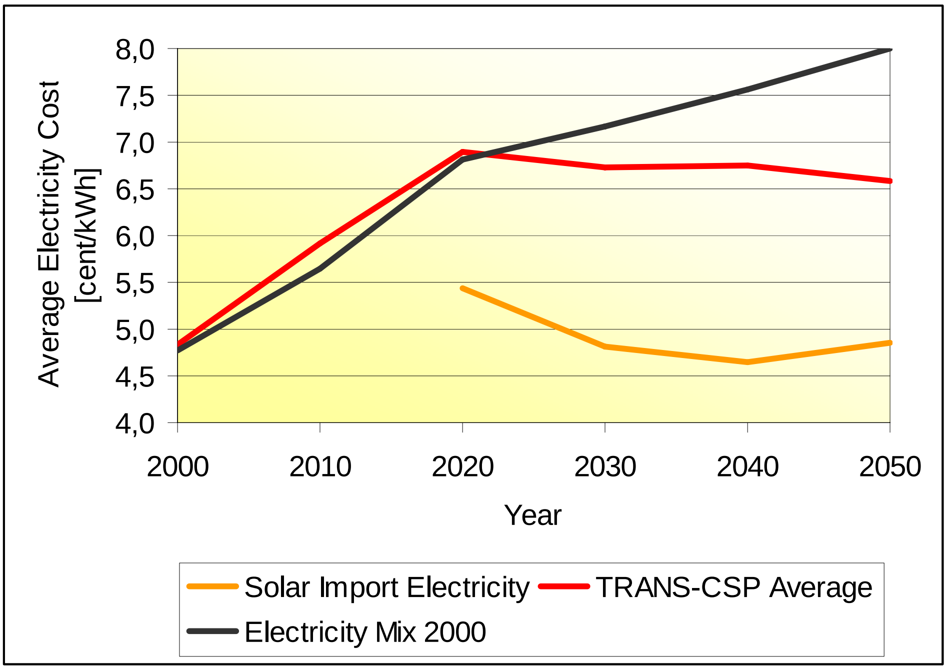


Figure 4-7: Average cost of electricity from new plants in the TRANS-CSP scenario and in a conservative scenario based on the electricity mix of the year 2000, in comparison to the cost of electricity imports from MENA for the example of Spain. For other countries please refer to the Annex.

Based on the investment cost and the development of the electricity mix defined in the TRANS-CSP scenario in Chapter 2 we have calculated the generation cost of each technology and of the average total electricity mix, neglecting those power plants that operate at marginal cost (Figure 4-7). As a reference case, we have calculated the same for a business as usual scenario based on the electricity mix of the year 2000. Starting in 2000 with an average cost of 4.8 cents/kWh, the average electricity cost escalates in both scenarios, with a little higher initial escalation in the TRANS-CSP scenario, due to the higher cost of renewables. Due to the low share of renewables, this difference is rather small. After 2020, the cost of the business as usual scenario keeps on escalating to 8 cent/kWh in 2050, while the trend of the TRANS-CSP scenario is reversed and the average cost is stabilised at about 6.5 cent/kWh. Within a range of 5.5 to 4.5 cent/kWh, the cost of import solar electricity from MENA is significantly lower than the average cost of both scenarios, thus contributing very economically to the European electricity mix.

It must be noted that the cost of the energy mix calculated here neglects the operation of older plants that have fulfilled their capital return and operate at marginal cost, so that the real cost level of the future electricity mix can be expected to be slightly lower than assumed here. Renewable energy technologies – that do not consume fossil fuels which make up the main part of the marginal cost of fossil plants – have an exceptionally low marginal cost of operation of less than 20 % of the cost of new plants, equivalent in most cases to less then 1 €-cent/kWh.

The above calculations confirm the statements given by the European Commission’s Green Paper on Sustainable, Competitive and Secure Energy /EU 2006/, the European Environmental Agency /EEA 2004/ and the Delphi project /EurEnDel 2004/ and show that an adequate mix of renewables including those from the Southern EUMENA region will substantially contribute to energy security in Europe.

Table 4-4 compares several security aspects of a strategy based mainly on renewables with another strategy dominated by nuclear power and fossil fuels. While the first represents a relatively low risk strategy based on proven or demonstrated technologies that need transient initial support to achieve further cost reduction, the second represents a high risk adventure based on the vague hope of major technological breakthroughs, and programmed for high cost and subsidisation.

In view of this comparison it is difficult to find any reason at all for a continuation of the nuclear-fossil energy strategy of the past. However, this strategy still dominates European energy policy, characterised not only by massive subsidisation of fossil and nuclear energy, but also by not supporting adequately or at least evenly the necessary renewable energy alternatives.

Electricity Mix dominated by Renewable Energy with Fossil Fuel Backup	**Electricity Mix dominated by Nuclear Power and Fossil Fuels**
Power on demand by a well balanced mix of renewable and fossil energy sources	Power on demand by using ideally stored forms of energy like uranium, coal, oil and gas
Supply based on many, mostly unlimited resources	Supply based on few, mostly limited resources
Domestic sources dominate the electricity mix	Energy imports dominate the electricity mix *
Low vulnerability of decentralised generation	High vulnerability of large central generation units
Low hazardous waste, recyclable materials	Disposal of nuclear waste and CO_2 unsolved
Low risk of contamination or major accidents	Risks of plutonium proliferation and nuclear accidents
Requires public investment over limited time span	Requires long-term continuous subsidisation
Low environmental impact	Climate change, pollution and nuclear radiation
Intrinsic trend to lower cost and less price volatility	Intrinsic trend to higher cost and price volatility
Requires a change of structures and thinking	Fits to present structures and thinking
Based on proven and demonstrated technologies	Requires major technological breakthroughs: o Safe fission and breeder technology o Commercial fusion reactor o Carbon capture and sequestration (CCS)
=> Low risk strategy	**=> High risk strategy**

* in spite of a convention that declares nuclear power as domestic source, Europe will fully depend on uranium imports after 2025 (today, 30 % of the European Uranium consumption is supplied by domestic sources, mainly in Eastern Europe).

Table 4-4: Comparing a renewable energy strategy for Europe with a nuclear – fossil energy mix

5 Environmental Impacts

The environmental impacts of the different energy technologies used in our scenario have already been summarized in /MED-CSP 2005/, pp. 159 ff. and the respectively quoted references, and will not be repeated here. However, the impacts resulting from the specific TRANS-CSP electricity mix in Europe and the environmental impacts related to the power transmission lines from MENA to Europe will be discussed in more detail.

5.1 Environmental Impacts of the TRANS-CSP Scenario

The goal of our study was to demonstrate the possibility of a sustainable power supply system in the analysed EUMENA countries with considerably reduced greenhouse gas emissions without creating other serious environmental, societal or economic problems. The major environmental impacts resulting from the scenario are related to the emissions of greenhouse gases, land use and other local impacts. They are summarised in the following:

Emission of Greenhouse Gases

The emissions of renewable energy technologies are mainly occurring during the production of the plant's components, because most plants are produced within today's industrial production schemes that use mostly fossil energy. Thus, the emission occurs from fossil power plants that are at present used to provide energy for the production of plant components. The life cycle emissions are valid for a power park with average CO_2 emissions of 700 g/kWh. During operation, only biomass and geothermal plants produce emissions. The emission of greenhouse gases (CO_2 equivalent) of renewable energy technologies are by orders of magnitude lower than those of fossil fuelled technologies. Coal plants usually have emissions of 900 – 1100 kg CO_2/MWh, oil plants around 600 - 700 kg CO_2/MWh. Even coal plants with CO_2 sequestration would still emit more CO_2 than solar or wind power plants, as about 15-20 % of their emissions would still reach the atmosphere. Moreover, it is not yet clear for how long CO_2 reservoirs of sequestration would remain isolated from the atmosphere. Other emissions that mainly occur during combustion like nitrates NO_x and sulphates SO_x as well as phosphoric acids are also avoided in the same proportion as carbon dioxide. They can lead to acidification and over-nutrition of soils and water bodies. Emissions of CSP plants in hybrid operation will gradually be reduced with time applying increased solar thermal storage capacities. For the future fuel-based power generation in Europe, an increasing share of CO_2 sequestration was considered as discussed in Chapter 2.

At present, the total carbon emissions of electricity generation of all countries analyzed in the study amount to approximately 1400 million tons per year. Instead of growing to 2350 million tons per year that would be expected for the year 2050 in a business as usual case maintaining the mix of the year 2000, our scenario achieves a reduction of emissions to 350 million tons within that same time span (Figure 5-1). Of the 2000 million tons avoided every year, 12 % are avoided by carbon capture, 22 % by rational use of energy and energy efficiency, and 66 % by using new renewable energy sources. The scenario avoids a total cumulated 18 billion tons of carbon dioxide until 2050. It is interesting to note that this number is lower than the potential avoidance of the quickly growing MENA countries described in /MED-CSP 2005/.

The scenario reaches a per capita emission of 0.59 tons/cap/y in the electricity sector in 2050. This is acceptable in terms of the maximum total emission of 1-1.5 tons/cap/y recommended by /WBGU 2003/ and /IPCC 2002/. The carbon emission data for every country analysed within the TRANS-CSP study is given in the Annex.

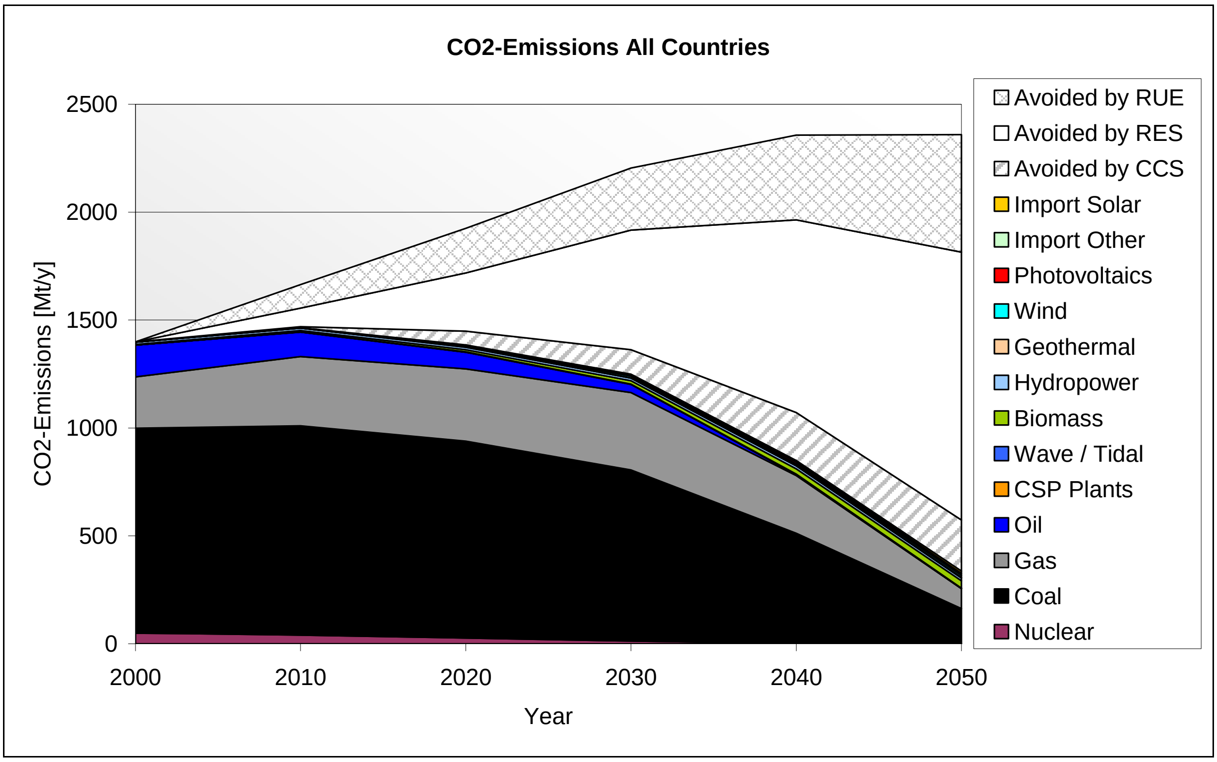


Figure 5-1: CO_2-emissions from electricity generation in million tons per year for all countries of the TRANS-CSP scenario and emissions avoided by Rational Use of Energy (RUE 22 %), Renewable Energy Source (RES 66 %) and by Carbon Capture and Sequestration (CCS 12 %) with respect to an electricity mix equivalent to that of the year 2000. For single countries please refer to the Annex.

Land Use

The specific land requirement of hydropower ranges between 10 km²/(TWh/y) for river runoff and micro-hydropower plants and over 400 km²/(TWh/y) for very large schemes like the Aswan dam in Egypt. In Europe, the values range from 10 to 100 km²/(TWh/y). The average value for Europe resulted in 35 km²/(TWh/y) for the total analysed region, which is only 25 % of the value resulting for MENA /MED-CSP 2005/. Geothermal power requires little land (1 to 10 km²/(TWh/y), average 2 km²/(TWh/y)), and the areas affected are in the subsoil at thousands of meters depth. In our scenario, biomass is produced mainly by agricultural and municipal residues (no extra land use) and from wood, resulting in an average land use of only 3.3 km²/(TWh/y). Energy crops – with a very high land use – were not considered in the MENA countries, as they would compete with food and water supply. For wind power, the average land use was 41 km²/(TWh/y), considering only onshore power generation. The specific values differ considerably according to the different performance indicators in each country.

Concentrating solar thermal power plants in Europe have a specific land use of 8-10 km²/TWh. For the CSP plants in MENA installed for export solar electricity, the land use is 5-6 km²/(TWh/y). However, land could be gained from waste land, if multi-purpose CSP plants are applied as described in Chapter 2. This would mean winning additional land rather than land consumption. Photovoltaic energy has no additional land use if installed on roofs, and a slightly higher land use than CSP if installed in large installations. An average land use of 10 km²/(TWh/y) was assumed, considering that many PV installations will be realised also in Central and Northern Europe, while CSP will only be installed in the Southern countries.

The total energy mix in 2050 within the TRANS-CSP scenario has an average land use of 25 km²/(TWh/y). The total land required for the renewable energy mix amounts to 1.1 % of the total area, which is comparable to the land used for transport and mobility.

For comparison, the land use of gas, oil or coal fired steam cycles ranges between 25 and 100 km²/TWh. Considering the long time during which areas are affected by nuclear waste disposal and uranium mining, nuclear plants also have a high land consumption in the order of 100 km²/(TWh/y), not accounting for nuclear accidents like in Tschernobyl. On a global level, the change to renewable forms of energy will lead to a more efficient land use for power generation.

Other Environmental Impacts

Any power technology has an impact on the environment, which must be evaluated very carefully in order to avoid harmful results. Wind plants may have a negative impact on bird habitats and, through visual effects and noise, on recreational and municipal areas. Offshore wind parks may additionally affect marine habitats in their vicinity. Geothermal hot dry rock technology will establish a water cycle from the depths, which will contain a lot of minerals harmful to the surface environment. Therefore, it must be secured that the water cycle used for extracting the heat from the ground is always returned and not infiltrated into surface or groundwater bodies. The disposal of biomass residues is in fact a positive contribution to the environment. Using wood for energy purposes is more critical in terms of avoiding over-exploitation. Plants must be carefully designed and distributed to not overexploit the natural resources. It must be considered that the use of biomass for electricity will compete with other use for heat and fuel in the mobility sector. All in all the environmental impacts of most renewable energy technologies is manageable if there is a careful prior analysis and design.

The environmental impact of large hydropower schemes is well known and documented world wide. Large dams may affect severely the natural habitat of many species, as they usually dwell in the narrow and shaded canyons of the river beds which are set underwater by the dam. Therefore in most cases large hydro dams must be considered as questionable in terms of environmental compatibility. Anyway, the potentials in Europe not exploited so far are very scarce.

The effects of large scale sea water desalination plants connected to CSP in MENA as proposed in Chapter 2 must also thoroughly be evaluated in order to avoid damages by the salty brine and by chemical additives used against scaling and fouling. Due to the large demand of desalination that can be foreseen, intensive research and development for environmentally compatible desalination technologies is of high priority in order to avoid the overload of the local environment.

All in all, it can be stated that the TRANS-CSP scenario reduces the environmental risks related to electricity generation when compared to the present European supply system. The emission of carbon dioxide is reduced to an acceptable level recommended by the International Panel for Climate Change /IPCC ed. 2001/, /IPCC 2002/, together with other pollutants originating from conventional power generation.

The main impacts are related to the use of land and to visibility, e.g. of large wind parks. However, compared to the risks related to the use of nuclear power, the unsolved problem of nuclear waste disposal, and the risk of the proliferation of plutonium, those impacts have a totally different dimension, although they can and should not be neglected. However, with a sound, well balanced mix of technologies and resources, the local impacts to the environment and society can be limited to an acceptable level, with the benefits more than compensating the drawbacks.

	Hydro	Geo	CSP	Bio	Wind	PV	Total	Country	Area Used
	km²	km²	km²	km²	km²	km²	km²	km²	%
Austria	461	6	0	12	73	29	**581**	**83860**	**0,7%**
Cyprus	30	0	0	0	56	1	**87**	**9251**	**0,9%**
Denmark	2	0	0	5	591	13	**610**	**43093**	**1,4%**
Finland	1289	0	0	66	293	17	**1664**	**338145**	**0,5%**
France	3597	22	0	138	12088	234	**16079**	**544000**	**3,0%**
Czech Republic	133	0	0	8	203	11	**354**	**78864**	**0,4%**
Belgium	27	0	0	7	485	21	**540**	**30518**	**1,8%**
Ireland	63	0	0	7	690	11	**770**	**70284**	**1,1%**
Luxembourg	46	0	0	0	1	8	**55**	**2586**	**2,1%**
Netherlands	6	2	0	4	238	43	**293**	**41864**	**0,7%**
Sweden	4329	2	0	81	1542	37	**5991**	**449964**	**1,3%**
Switzerland	383	0	0	4	0	37	**424**	**41290**	**1,0%**
United Kingdom	395	0	0	26	2096	78	**2595**	**244000**	**1,1%**
Poland	389	3	0	47	2475	31	**2944**	**312684**	**0,9%**
Bulgaria	263	1	0	11	148	20	**443**	**110994**	**0,4%**
Slowac Republic	285	5	0	6	31	20	**347**	**49036**	**0,7%**
Slowenia	236	1	0	3	13	10	**263**	**20252**	**1,3%**
Germany	1300	45	0	54	795	234	**2428**	**357022**	**0,7%**
Hungary	228	26	0	14	101	20	**389**	**93032**	**0,4%**
Greece	322	9	28	32	606	39	**1037**	**131957**	**0,8%**
Italy	2318	30	40	60	3044	176	**5667**	**301300**	**1,9%**
Malta	0	0	3	0	2	1	**5**	**316**	**1,7%**
Portugal	790	9	64	19	232	39	**1152**	**92289**	**1,2%**
Spain	1958	36	240	144	3102	195	**5675**	**504982**	**1,1%**
Turkey	3058	150	520	61	2501	156	**6446**	**779452**	**0,8%**
Macedonia	104	0	0	1	6	6	**116**	**25713**	**0,5%**
Croatia	348	1	0	5	144	8	**506**	**56600**	**0,9%**
Romania	898	1	0	20	263	20	**1201**	**238391**	**0,5%**
Serbia & Montenegro	750	4	0	9	17	10	**789**	**94000**	**0,8%**
Bosnia-Herzegowina	482	0	0	7	6	6	**500**	**51129**	**1,0%**
Iceland	148	48	0	0	6	3	**204**	**103000**	**0,2%**
Norway	1510	0	0	27	199	10	**1745**	**323878**	**0,5%**
Total km²	**26144**	**401**	**895**	**876**	**32044**	**1539**	**61900**	**5623746**	**1,1%**
Electricity TWh/y	**749**	**201**	**112**	**496**	**784**	**154**	**2495**		
Relative km²/(TWh/y)	**34,9**	**2,0**	**8,0**	**3,3**	**40,9**	**10,0**	**24,8**		

Table 5-1: Land area for renewable electricity generation in 2050 in the TRANS-CSP scenario. The two columns at right show the total area of each country and the percentage of this area used for power generation by the renewable energy mix in 2050. Hydropower surface demand varies strongly between countries. Photovoltaic surface demand considers only 50 % of the total because many plants will be installed on roofs. Wind power and CSP surface demand is calculated as if exclusively used for power generation. Biomass surface only considers fuel wood. For comparison, the transport system in EU 15 requires 1.2 % of the land area.

5.2 Environmental Impacts of Overhead Lines

The environmental impacts of high voltage transmission lines have been assessed and described extensively by /May 2005/ and the related references. Within this chapter we will summarise the main results of this analysis.

The space requirement of an overhead line can be subdivided in a permanent use while the line is operated and a temporary use during the construction phase. Areas are occupied permanently by the fundament of pylons, for example approximately 22 m² by the massive concrete fundament of medium-sized ton mast. A typical Danube mast with four pedestal fundaments can have a local space requirement of nearly 64 m². /Knoepfel 1995/ states an enclosed area of 50 m²/km for a ±500 kV DC pylon and 100 m²/km for a 750 kV AC pylon. Further space requirement through transformers and rectifiers must be added. A rectifier station with a capacity of 5000 MW requires an area of 800 m x 700 m (560,000 m²) /Normark 2005/, whereas a medium-sized transformer station needs 10,000-15,000 m².

Moreover, there are time-limited places for barrels and winches every 2-3 km nearby the line and repositories every 20 km with a size of 5000 - 6000 m² where wires, isolators and armatures can be stored. Here a reserve of oil absorber of at least 100 kg is also held /APG, 2004/. In addition to this, there is a temporary working stripe with a width of 5 m per month along the line /Knoepfel, 1995/.

The actual width of the line depends on the pylon construction, the voltage level and the correlative safety distance, which must be observed between the conductor wires themselves and the surrounding area. For reasons of safety a ± 800 kV double-dipole ought to be separated into two lines. Typical pylon constructions for this voltage level and the associated width of the line are shown in Figure 5-2. The size and distances of the pylons are defined by the required security margins to avoid electric discharges and health impacts to the population.

Capacity 10 GW	800 kV HVAC	± 800 kV HVDC
Number of circuits/conductor	**5/15**	**2/4**
Pylon height [m]	**1-level pylon 30 - 40**	**30 - 40**
	Danube pylon 40 - 80	
Pylon width [m]	**40**	**15**
Fundament [m²/km]	**100**	**50**
Line width [m]	**5 x 85**	**2 x 50**

Table 5-2: Sizes of a HVAC and HVDC overhead line /Knoepfel 1995/, /Arrillaga 1998/.

Impacts on the landscape-image, which are caused by a high voltage overhead line, are unavoidable. Large impacts through overhead lines exist in the open plain. Due to the strong restricted possibility of finding new lines in the Central European region, multiple lines with up to six circuits are used almost exclusively in the high voltage area /Kießling et al. 2001/. The very robust, more conspicuous guyed pylons can considerably reduce the recreation value of the environment. Therefore it is aimed at a bundling of lines. It means that high voltage overhead lines are built preferably along the existing infrastructure like highways, railways and other overhead lines.

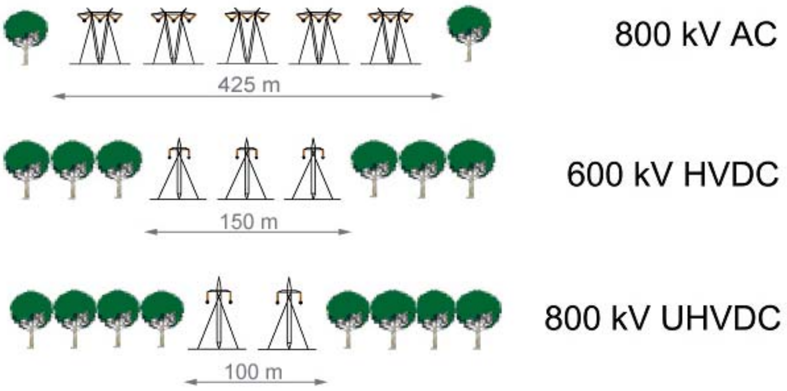


Figure 5-2: Required number of parallel standing pylons to transfer 10 GW /May 2005/.

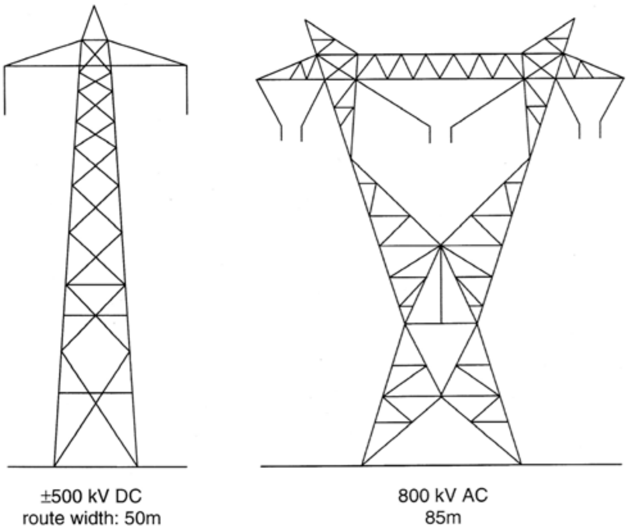


Figure 5-3: Typical pylon constructions of a HVAC and HVDC overhead line /Arrillaga 1998/.

Moreover, it is also attempted to achieve a better integration of steel lattice pylons in the surrounding landscape, although the construction is already transparent. The easiest way of integration is a coat in ‘Camouflage-Green’. Routing along natural lines and shapes is advantageous for the landscape-image but has a higher expenditure. The visibility of lines can also be reduced considerably within woodlands. Lower and less pylons have a favourable effect on the landscape-image, but a rise in distance between pylons also causes a rise in the amount of pylons since a threshold of 10 m above the ground is prescribed for the maximum conductor sag.

The normal ratio of guyed pylon to carrying pylon is 1:4 in flat terrain. Here the distance between several pylons is an average of 400 m. The more difficult the ground is and the more often the direction of the line changes, the higher the number of guyed pylons.

A DC pylon carries only two conductors per circuit in comparison to an AC pylon with three conductors per circuit and therefore is characterized by a lower height and width. The better integration of a DC line into the environment could also have positive influences on the acceptance of the population.

Acceptance for high voltage transmission projects is particularly low in surroundings of cultural assets, religious places and tourist destinations as the typical landscape-image is affected. Under this point of view a GIS[1]-based analysis of the line visibility can be helpful.

An endangering of the avifauna by high voltage overhead lines hardly exists by a direct electroshock in touching the voltage-carrying conductors or grounded components. Isolators of the hanging type make sure that the distance between conductor and pylon is large enough so that even birds with a large wing range are not able to bridge it. Different to the medium voltage area these hanging isolators cannot be used as raised stand.

Rather it comes to collision accidents with the badly visible ground wire due to it's smaller cross-section, while birds are trying to approach the conductor or to make way for the same. This particularly concerns inexperienced young birds. The use of bird spirals and flutter bands at the earth wire or the lower one-level masts can contribute to a better visibility at very dangerous line sections. This way the annual death rate could be reduced by almost 90 %.

Migrants and passage migrants are more endangered than sedentary and breeding birds. They rest preferably in the area around waters, wetlands and open grasslands and sometimes take a lot of space in order to start and alight. Therefore high voltage overhead lines ought not to be erected in such areas. Up to now measures to defuse line sections with a particular risk potential for alighting birds are not legally prescribed and can be carried out voluntarily by the energy supply companies /Schuhmacher 2002/.

Especially what concerns the protected meadow breeders species like European curlew (*Numenius arquata*) and lapwing (*Vanellus vanellus*) it could be proved that breeding areas were depreciated or not so often visited after the erection of a high voltage overhead line. Probably overhead lines impair the environment in a visual way. It happens now and then that the animals keep a distance of 100 m to the line, what in the end amounts to a loss of the breeding area. The sky-lark (*Alauda arvensis*) also showed a significant preference to areas far away the line /Schuhmacher 2002/.

Quite another kind of influence on ground breeders is the utilization of the pylon alienated from its purpose as hatchery by diurnal prey birds. The raised standing predators cannot be chased away from the nest environment and therefore are a permanent danger for the juvenile waders. Consequently, the shift of the predator-prey-relation for the benefit of the predators could lead to the loss of the population in case of a critical size /Schuhmacher 2002/.

Danger of soil compacting by the use of heavy equipment and machinery particularly exists for heavy soils. However, after finishing the project a depth aerator can be used to counteract this danger. If necessary, the use of helicopters is recommended in areas which are difficult to access.

A high danger is represented by erosion processes at the place where the soil is not covered with vegetation. For that reason there is an urgent need in restoring the initial condition as far as it is possible. This also contains the equalization of a possible subsidence.

Where ever fuel and oil consuming devices are used there is a fundamental risk of contaminating the soil and later the groundwater with hazardous substances. Therefore it calls for special care if the aquifer is affected by constructional measures in the range of waterworks. Heavy metal emissions of the pylon can be neglected since modern pylons, whose hot-dip galvanized steel framework is coated with a protective lacquer, are used /Knoepfel 1995/. The professional disposal of waste, such as a contaminated excavation, and the curative dismantling and recycling of disused components is presumed and therefore not be further discussed.

---

[1] GIS Geographic Information System

5.3 Environmental impacts of underground cables

The acceptance of the population for overhead lines has heavily decreased because of the unavoidable impairment of the landscape-image. Both in congested areas and also in semi-natural landscapes people are bothered by the high mast constructions, although often on a subjective emotional level. But also lack of space in congested areas and the strict prevention of impairments of special worth protecting areas lead to an intensified use of underground cables in these areas. If a project has effects on the characteristic region, such as high voltage power lines, protracted permit procedures have to be passed through until the construction can be started.

Furthermore, most of the impacts typically caused by overhead lines can be eliminated with ground cables. First of all this concerns the distinct lower space requirement in comparison with an overhead line. Anyhow, a forest aisle of 5 m width is unavoidable. The placing depth of the cable amounts to nearly 1 m and even after finishing of construction works a radius of 1 m around the cable must not be built over or planted with deep-rooted plants on safety grounds /VDEW 2001/.

The cable isolation shields the electric fields almost completely. Magnetic fields remain uninfluenced by this and can only be minimized if several cables are buried in closer neighbourhood to each other so that fields eliminate themselves mutually. The magnetic field strength rapidly decreases with the increasing distance to the cable and reaches the background value after 5 m.

Another effect of an underground cable is the local dehydration of the surrounding soil. That is because of the reduced quality of heat removal in dependency on the soil texture and humidity. The resulting, minimized heat emission impairs the operating safety of the cable, but affects the vegetation cover, fruit ripeness and vegetation period only in the closest environment of the cable. The specific influences on the microbiology, flora and fauna are still unknown for the most part.

In case of accident there is an acute risk for the environment by the contamination with hazardous substances, especially for the groundwater. The risk potential by leakages is dependent on the used cable type. In the high voltage area low pressure oil filled cables and mass-impregnated cables are preferably employed. The former must be checked regularly for leakages even after placing out of operation and an alarm and measure plan must be made. For that reason it is better to remove the cable at once, whereas the closure of mass-impregnated cables is not such a danger as the endings are sealed and the high-viscosity paper-oil isolation gets more viscous after the cooling down of the cable. PVC cables, which release heavy metals at a $pH < 3$ or hazardous hydrogen chlorides such as dioxin in case of fire, are not used any more in the high voltage area /VDEW 2001/.

5.4 Environmental impacts of submarine cables

Up to now the deepest DC submarine cable in the world has been laid in a depth of maximum 1000 m between Italy and Greece. Figure 5-4 shows the very rough profile through the ‘Street of Otranto’. The HVDC line starts on the Italian side as a 43 km long underground cable. Then it follows a 160 km long submarine cable section where the cable is rinsed into the seabed on the continental shelf or is simply put down on the sea bottom in deeper areas. On the Greek mainland the transmission line runs as 100 km as overhead line. Impacts and influences on the environment respectively occur by the laying of the submarine cable. In the offshore area the cables are directly put down on the sea bottom while they are rinsed in a depth of 1-2 m into the seabed of the shallower coastal zone.

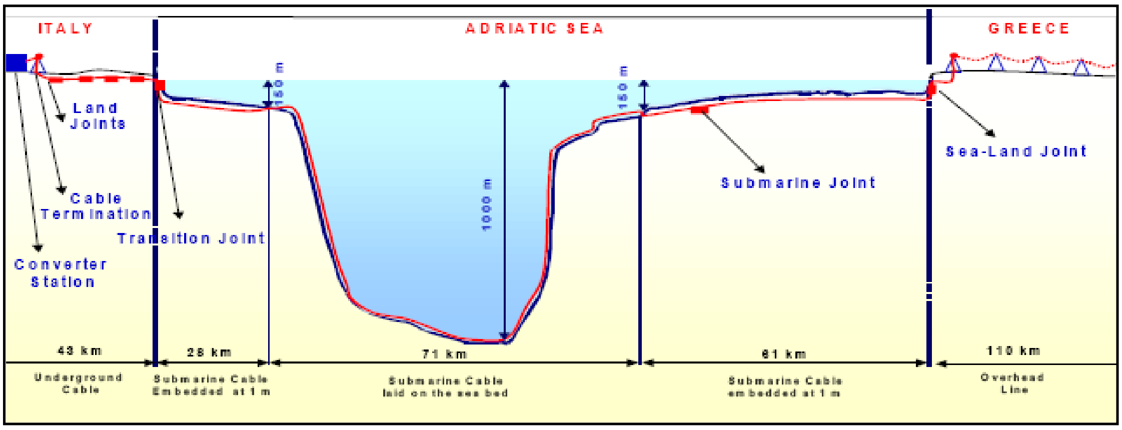


Figure 5-4: Profile through the ‘Street of Otranto’ /Cigre 2002/

In areas with highly dynamic morphology, such as in tide-ways and in front of islands, cable-laying is recommended up to a depth of 3 m to avoid possible free-rinsing. Because of large sediment transfers the loss or influence of the benthic bio co enosis or fish living nearby the ground cannot be avoided /Wirtz, Schuchardt 2003/. The duration of resettlement amounts to at least two years. Furthermore, the fine grain fraction mobilized by sediment transfers also causes a higher turbidity of water, which is separated in time and space. On one hand the activity of the primary producers and the phytoplankton is impaired and on the other hand the simultaneous release of nutrients supports the growth of algae. The latter occurs especially in spring and summer when there is usually a lack of nutrients. The impairment of the marine mammals and avifauna depends on the extent of disturbances in the form of vibration and noise, but altogether it is considered to be low. Nevertheless, the building measures ought not to be carried out during the breeding time and formation of colonies as a precaution /Wirtz, Schuchardt 2003/.

Electric and magnetic fields arise around the conductor during operating. The electric field cannot permeate good cable isolations. First of all the magnetic field of a bipolar DC cable affects the environment, which in turn can induce secondary, electric fields owing to the sea current. In this way also natural, electric fields are generated by moving of water through the earth’s magnetic field. For example, the Gulf Stream produces an electric field with a strength of 50 µV/m /Kullnick & Marhold 2000/. Up to now most of the submarine cables have been performed as mono-polar conductor with back current via seawater so that sea-electrodes are required. The electric fields in a distance of 10 km to such electrodes move on a level of 10^{-4} V/m, what is comparable to natural electric field strengths in the sea.

The electrode is operated as cathode with a surface of 400 m² and 1500 Amperes DC. The resistance of the seawater amounts to 0.8 Ω*m. Because of the rapid decrease of the field strength with the increasing distance towards the electrode an influence of fish is hardly expected after 10 cm. Alternatively, the use of land instead of sea-electrodes would be feasible. Although it is known that the biological activity is connected with weak electric field events, the effect of the weak electric fields arising by the transmission of electricity are largely unexplored /Debus 1998/. Fishes are equipped with special electro-receptors and can react more sensitively as they are able to even perceive electric fields around 1 µV/m. Strong electric fields have field strengths of more than 1 V/m and current densities of at least 5 mA/cm². Such fields produce a galvanic-tactical and anaesthetic effect and have been used as fishing assistance since 1925 /Debus 1998/.

The magnetic field of a HVDC line is the strongest at the cable surfaces and decrease with an increasing distance. At a power of 500 MW the field strength in 6 m distance is equivalent to the natural magnetic field /Söderberg, Abrahamsson 2001/. The magnetic field strength can be reduced by overlapping of two reverse-polarised fields. Therefore it is recommended using closely lying, bipolar conductors (‘Touch-Laying’), in future also in a joint cable (‘Flat-Type’). Additionally, the transmission capacity can be doubled this way and sea-electrodes can be given up. An influence on the orientation of far-migrant fishes like eel (*Anguilla anguilla*) and salmon (*Salmo salar*) could be given as they are still able to perceive the field of a 500 MW HVDC cable in a distance of 160 m /Debus 1998/. However, previous examinations outdoor and in the laboratory provided no clear indications of a barrier effect, deflection or influences on communication of fishes (shy and deflection effect). Most likely a multi-factorial orientation during the fish migration is assumed, in which the natural magnetic field represents only one component. The natural magnetic field becomes more and more important for migration if other factors like sunlight, temperature, salinity and velocity of flow appear not so strong.

Even the migration of animal groups like molluscs (snails and mussels), crustaceans, marine mammals and zooplankton is controlled by several factors. Altogether there is a considerable need in research with regard to the perception and utilization of the natural magnetic field by marine organisms. Therefore possible influences on migration by technical-generated fields cannot be excluded fully /Kullnick, Marhold 2000/.

Beside the fields an increase in temperature can also be observed in the immediate environment of the cable. In case of a 600 MW bipolar cable buried in a depth of 1 m an increase in soil temperature of 3 °C in within a radius of 50 cm can be measured. The change in temperature at the surface of the sediment amounts to 1 °C at most. This local warming of the soil leads to an intensification of the bacterial metabolic rate and a reduced mortality of invertebrates in winter. Moreover, the settlement of thermopile organisms is possible /Wirtz, Schuchardt 2003/.

Here it is just mentioned that theoretically trawl nets and anchors could get caught by free-rinsed cables. The probability of such an accident lies at 1 event in 200 years at a 12 km long cable section /SEP 1997/. It should therefore be aimed at bundling and multiple-shift usage of submarine lines.

5.5 Low Impact Solar Electricity Links

The methodology of finding ecologically optimised lines for the interconnection of sites with high solar electricity potential in MENA with centres of massive electricity demand in Europe was developed and described in detail by /May 2005/. In the following we will present the main results of the analysis of three exemplary lines of a possible future trans-European HVDC electricity grid, interconnecting Western Algeria with Germany, Southern Libya with Italy, and Central Egypt with Poland for the purpose of exporting solar electricity from concentrating solar power plants.

Three exemplary sites for solar electricity generation were simply found by looking at the solar irradiance map of the MENA region and selecting three sites with major solar irradiance potentials of over 2800 kWh/m²/y. In the real world, such an assessment would be made considering much more parameters for site selection, taking into account e.g. political and social constraints, economic performance, accessibility etc. The chosen sites are quite remote and thus constitute something like a worst case for solar power transmission.

On the other side, we had to find out the targets of solar electricity transfer. This is defined on one side by the results of the scenario analysis in Chapter 2, that shows the deficits of firm renewable power capacity in most central European countries and also on the British Island. The other end of the power lines was thus placed in the major centres of electricity demand in Central Europe, in order to effectively backing and taking off some load from the conventional AC electricity grid with firm DC power capacities, and effectively using local AC grids for the distribution of imported solar electricity.

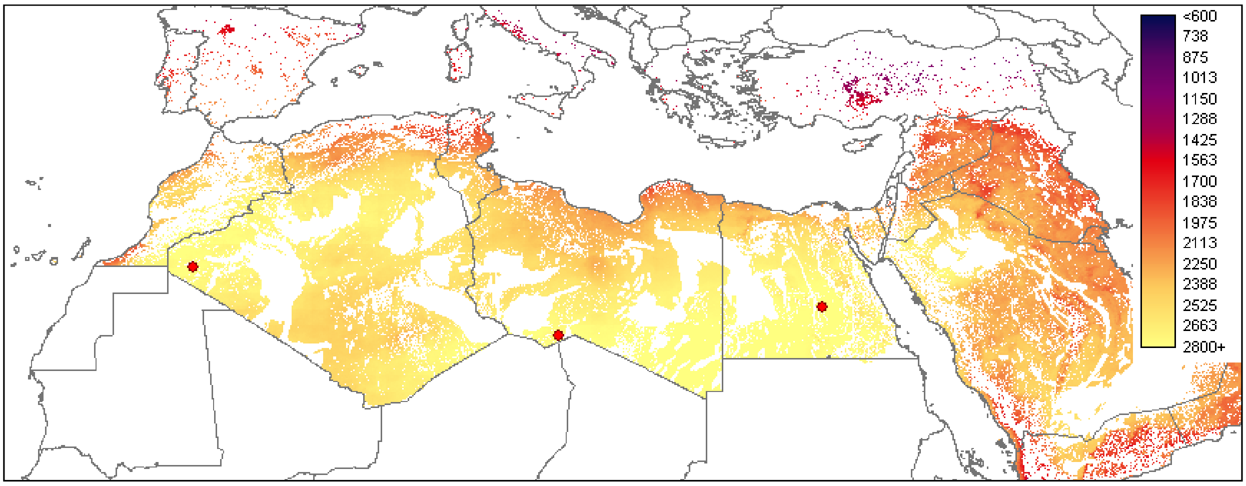


Figure 5-5: Annual solar irradiance atlas in kWh/m²/y with sites excluded for the erection of CSP plants generated in the frame of the study /MED-CSP 2005/. The red dots indicate the sites chosen exemplarily for solar power generation.

The major centres of electricity demand in Europe can easily be found looking at the density of the UCTE electricity grid in Figure 1-2, the population density in Figure 5-6 and the nightly light emission from Figure 5-7 as major indicators for electricity demand. Looking at those maps, we have selected the Ruhr area in Germany, London in the UK, Milan in Italy and Warszawa in Poland as possible headers of the HVDC links coming from MENA.

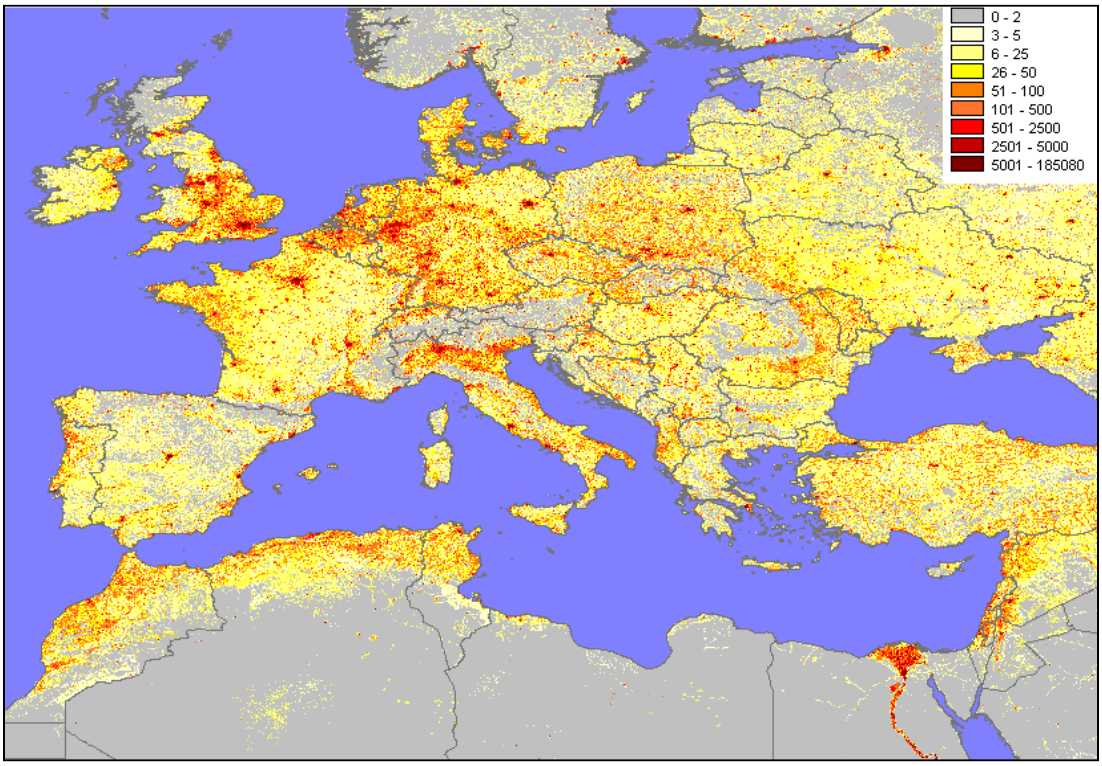


Figure 5-6: Population density in EUMENA in Persons/km² /ORNL 2003/.

Figure 5-7: Satellite view of the EUMENA region at night showing the intensity of light emissions as indicator for electricity consumption /Brockhaus 2005/.

After defining the starting and end point of the three exemplary interconnections Algeria – Germany, Libya – Italy and Egypt – Poland, a thorough analysis of the shortest (most economic), but ecologically most compatible way was undertaken using a geographic information system (GIS) for that purpose (Figure 5-8). The analysis considered the topography of the landscape, protected areas, land cover, population density and infrastructure, cultural and religious sites and natural hazards to find the shortest viable interconnection of both terminals with minimum environmental impact for three lines with 5-10 GW capacity each /May 2005/.

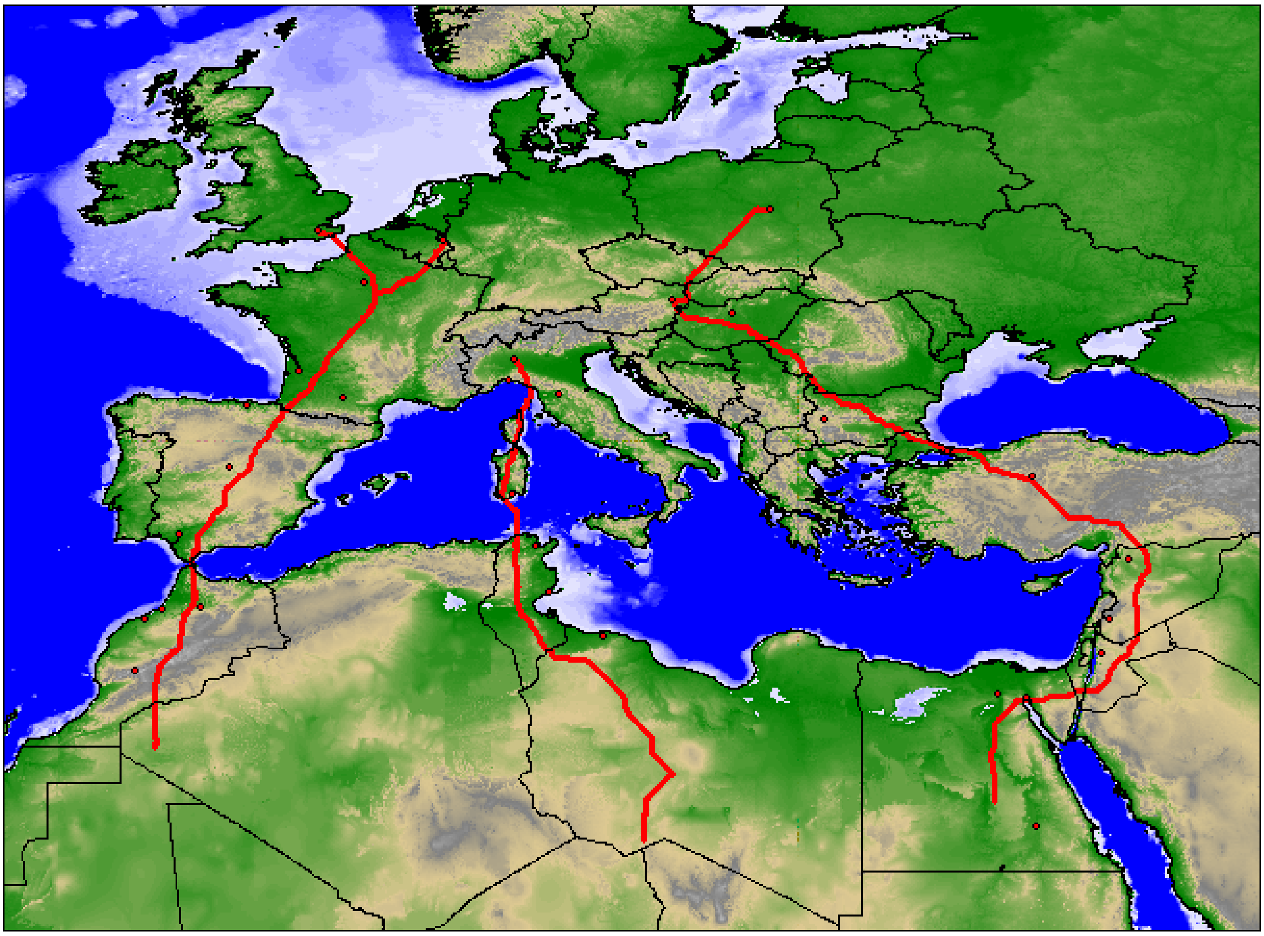


Figure 5-8: Three analysed samples of EUMENA interconnections with HVDC lines with a capacity of 5 GW each. The red dots indicate further centres of demand that are close to the line and could be interconnected, too. The background map shows the topographic features of the landscape /May 2005/

Line 1: Western Algeria - Aachen

The first line starts in the western part of Algeria approximately 100 km to the east of *Tindouf*. From there an overhead line leads exactly in a northerly direction through the desert to Morocco, crosses the *Atlas Mountains* and reaches the *Strait of Gibraltar* after nearly 1090 km. Then the line must be performed as submarine cable on a length of 18 km. At the European coast again it is connected to an overhead line. On the further course the line has to get past the Spain wildlife sanctuaries *Los Alcornocales* and *Sierra de Grazalema* to the east and then to cross the Iberian Peninsula on a length of about 930 km, where the land cover varies heavily between woodlands, grasslands, croplands and semi deserts. On the latitude of the *Pyrenees* the French border is passed. Then the line runs almost straight in a north-easterly direction as only a few areas are excluded in France. The residual area is mainly used for agriculture. After a total of 3117 km the destination *Aachen* in Germany is reached.

Figure 56 shows the ground profile from the centre of demand in the north to the plant site in the south. Along the line a maximum height of 3500 m in the *Atlas Mountains* and a maximum depth of -750 m while the *Mediterranean Sea* must be overcome. The hypsographic summarized curve makes clear that over 50 % of the areas lie between sea level and 500 m above sea level and just 5 % in the high mountain region above 1500 m.

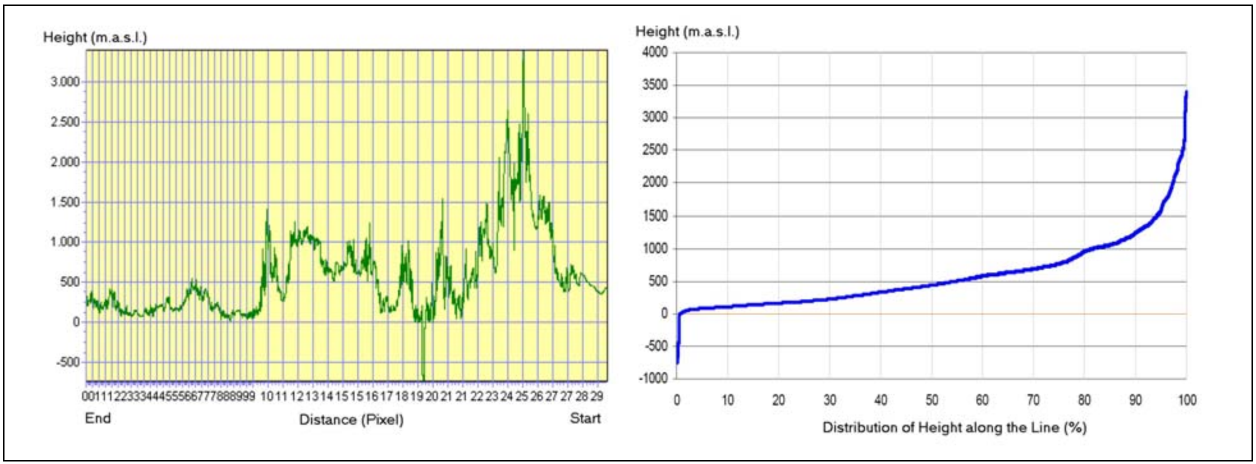


Figure 5-9: Ground profile [height above sea level] of line 1 from Western Algeria to Aachen, Germany and the associated hypsographic elevation model

Line 2: Southern Libya - Milano

The second line has a total length of 3108 km and begins in the south-western part of Libya around 80 km south-easterly of *Al Wigh*. The first 1330 km leads through the *Libyan Desert* in a north-west direction. There the course of the line is mainly determined by geomorphologic features like dunes and fields of lava around *Al Haruj*. Tunisia is centrally passed on a length of 700 km because of the large sand deserts of the *Sahara* (*Erg*) in the west. Altogether over 50 % of the line lies in desert areas. In the northern part of Tunisia areas are hardly excluded due to a low population density and a lot of cropland and grassland. Then comes a 220 km long submarine cable to the Italian island *Sardinia*. On the Mediterranean islands the line follows the course of the already existing HVDC line *SACOI*. The large *National-Regional Park of Corsica* forces the line to go easterly. In order to connect the line with the Italian mainland a submarine cable with a length of nearly 130 km is used. The national park *Arcipelago Toscano* remains untouched. Afterwards the line has to pass the woodlands of the *Apennines* and croplands in the *Plain of the river Po* until the destination *Milano* is reached after 180 km.

The largest heights about 1200 m can be found on *Sardinia* and in the *Apennines*. The deepest point of the line lies at -1968 m in the *Mediterranean Sea*. Along the whole distance no high mountain regions are crossed and almost 90 % of the areas lie between sea level and 1000 m above sea level.

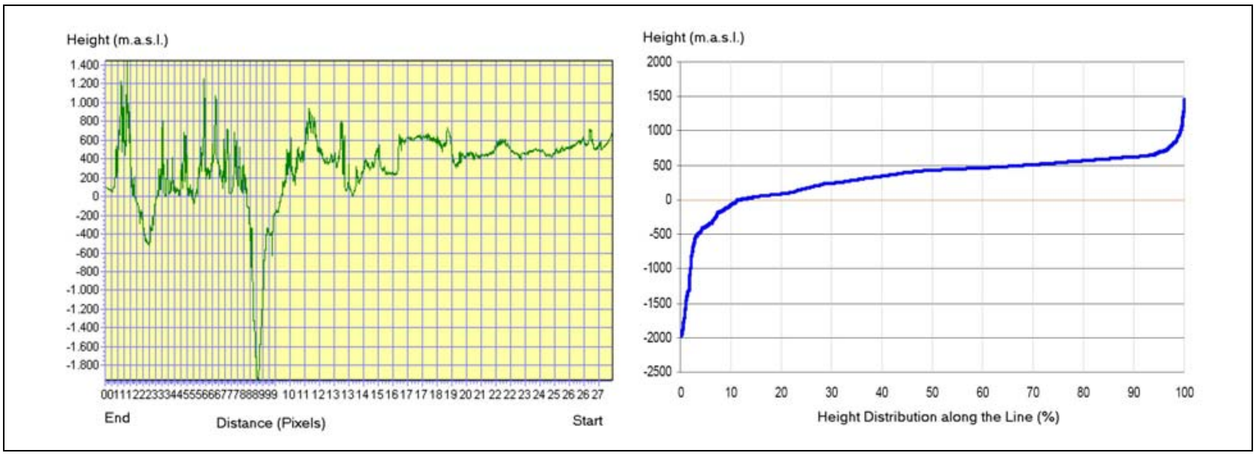


Figure 5-10: Ground profile [height above sea level] of line 2 from Southern Libya to Milano, Italy and the associated hypsographic elevation model.

Line 3: Central Egypt - Warszawa

The solar thermal power plant, which is the starting point of the third line, is located approximately 50 km in the east of the oasis *Kharga* in Egypt. From there the overhead line runs 860 km through Egypt first in northerly and then in easterly direction. On the way the *Nile* is crossed nearly 35 km in the north-west of *Asyut* and afterwards also the *Gulf of Suez* as the populated places of the city *Suez* and dunes in the northern part of *Sinai Peninsula* are excluded.

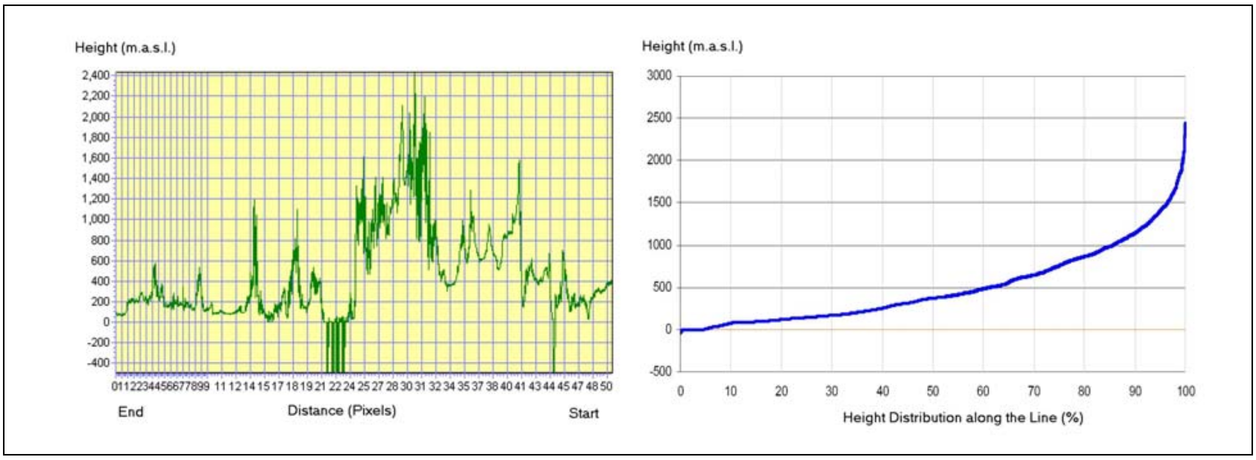


Figure 5-11: Ground profile (height above sea level) of line 3 from Central Egypt to Warszawa, Poland and the associated hypsographic elevation model.

On a distance of 60 km the southern part of Israel is passed exactly between the three natural reservations *Har Ha Negev*, *Ashosh* and *Nehalim Gedolim Uqetura* and afterwards the line leads to *Ma'an* in Jordan. After a total of 380 km the national border to Syria is reached. From there the line runs around 500 km through the *Syrian Desert* and then gets past westerly the water reservation *Buhayrat al Asad*. On a distance of 1300 km the line leads further through the Anatolian part of Turkey, past *Ankara* and *Istanbul* and then runs along the coast of the *Black Sea* over the *Bosporus* and through the European part of Turkey called *Thracia*. Afterwards the countries Bulgaria, Romania and Hungary are passed in a north-westerly direction until *Vienna* is reached after 1370 km. The river *Danube* is first crossed 60 km in the south-west of *Craiova* in Romania and then 60 km in the south of *Budapest*. Then the line goes on to the border of Slovakia and follows that border north to the Czech Republic. From there it crosses the Czech Republic and Poland and reaches Warszawa after further 632 km.

The line has a total length of 5143 km and has to overcome large heights of around 2000 m especially in the *Balkan Region*. More than 90 % of the line lies between 0 and 1500 m above sea level.

Comparative Evaluation of the Three Lines

In the following the lines are submitted to analysis and the results are evaluated regarding their accuracy among others.

Length of the Lines

In Table 5-3 the total length, the shared length of all countries and the sea sections are listed. Accordingly, line 2 has the longest submarine section of 373 km, that corresponds to 12 % of the line. Line 1 has to cross the *Strait of Gibraltar* on a length of 18 km and the 30 km long submarine sections of line 3 lie in *Gulf of Suez* and at the *Bosporus*. However, what concerns line 3 the length of the submarine section has been overestimated. As the line leads along the coast, an overlapping with areas of the *Black Sea* is possible. Line 3 has the longest overhead line section with 5113 km.

Line 1		**Line 2**		**Line 3**	
Country	**Length [km]**	**Country**	**Length [km]**	**Country**	**Length [km]**
Algeria	256	Libya	1326	Egypt	858
Morocco	835	Tunisia	701	Israel	59
Spain	932	Sardinia/Italy	313	Jordan	378
France	907	Corsica/France	216	Syria	495
Belgium	164	Italy	178	Turkey	1324
Germany	5			Bulgaria	448
				Romania	361
				Hungary	518
				Austria	72
				Slovakia	50
				Czech Republic	195
				Poland	355
Overhead line	3099	Overhead line	2735	Overhead line	5113
Submarine cable	18 (0.6 %)	Submarine cable	373 (12 %)	Submarine cable	30 (0.6 %)
Sum	**3117**	**Sum**	**3108**	**Sum**	**5143**

Table 5-3: Line shares of the concerned countries in kilometres.

Land use

The calculation of the respective forms of land use concerned by the lines shows that in all three cases areas are mainly used which have been intended for that. Rice fields and wetlands are not touched by the lines and also agglomerations are almost always omitted (details in /May 2005/). The share of forest does not exceed 10 % (Figure 5-12). This is essentially equivalent to a typical land use of an overhead line mentioned in /Knoepfel 1995/.

Only what concerns line 2, about 10 % of the crossed areas lie in the visual range of certain cultural sites. The shares of the other lines are lower; however, this analysis is based on a database afflicted with a higher uncertainty.

If a line width of 100 m for a 10 GW line is estimated, the space requirement below the line amounts to 100 km² per 1000 km.

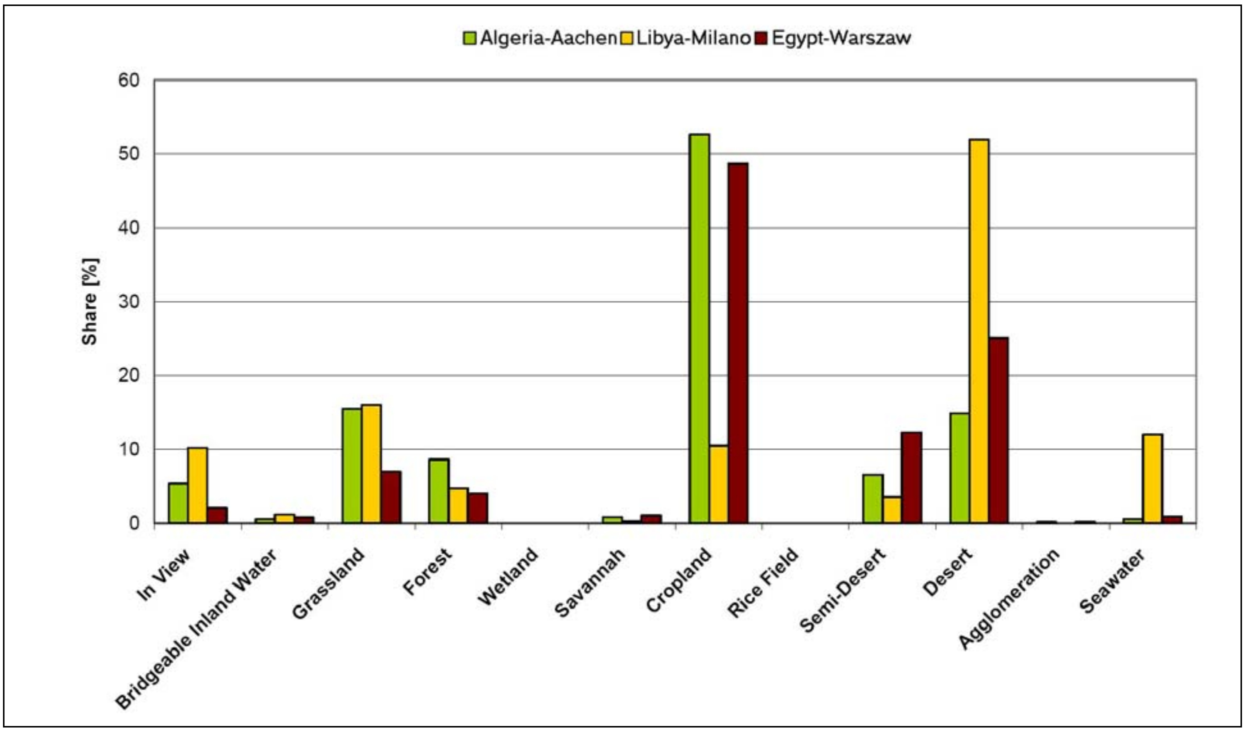


Figure 5-12: Share of land use and visibility of the three analysed lines.

Distance to Highly Populated Areas

In case that it is intended to deliver power to other places in future, provided that the lines would be operated as multi-terminal, the direct distances to important cities along the lines are listed in Table 5-4. Branch line for HVDC can only be realized by a further rectifier terminal. If larger loads are taken out, the line should be extended so that following demand centres can be supplied with electricity.

Accuracy of the Results

The accuracy of the course of the three lines depends on the underlying datasets, especially on their completeness. Especially what concerns the protected areas within the European Union, better datasets could be provided by the cataloguing of the ‘Natura 2000’ areas after their finalization in the near future. Regarding the infrastructure there has not been provided an updated and topographically correct dataset together with attributes up to now. The difficulty lies chiefly in the spatial reproduction of these structures.

Furthermore, the dataset used for the visibility analysis is rated uncertain. Anyhow, it concerns a subjective criterion so that the impacts on the landscape-image should be clarified at another scale and with another method. Here just an approximate estimation for this criterion can be done. For the residual datasets it is assumed a sufficient accuracy with regard to the formulation of the question and the scope of this study. It has been attempted to take a scientific method as a base for the determination of the optimal path, otherwise reasonable estimates were taken.

Altogether it seems that the results, especially with regard to the land use, are plausible and fulfil the requirement of a general representation. The multitude of possibilities to visualize the results within a GIS can contribute to give a clear imagination of the topographic course of the lines. If it is considered on country level, the results could also be interesting for political decision maker. Nevertheless, this analysis does not substitute a detailed planning

Line 1		**Line 2**		**Line 3**	
City	**Distance**	**City**	**Distance**	**City**	**Distance**
Marrakech	96	Tripoli	141	Aswan	233
Casablanca	152	Sfax	128	Cairo	83
Rabat	92	Tunis	79	Suez	12
Fes	39	Cagliari	40	Amman	82
Sevilla	70	Florence	104	Damascus	108
Madrid	57	Genua	62	Aleppo	72
Zaragoza	96			Ankara	12
Toulouse	132			Istanbul	19
Bordeaux	78			Sofija	99
Paris	105			Budapest	55

Table 5-4: Distances of the HVDC lines to selected major cities in km

5.6 Eco-Balance of Solar Electricity Imports

Generally accepted guidelines for the preparation of a Life Cycle Assessment (LCA) can be found in ISO 14040 ff. /ISO 2005/. Modelling of material and energy flows is carried out within the database and modelling tool Umberto® by means of material flow networks. The procedure of the Federal Environmental Agency (UBA) was used for the preparation of the impact assessment /UBA 1999/, /IFEU/IFU 2005/. The results are normalized to 1 kWh (electricity) and compared with a reference electricity mix. In a broad sense the question should be answered if environmental impacts associated with the provision of electricity from fossil primary energy carriers can be reduced by an electricity import from renewable energy resources. Furthermore, it is also interesting to what extent a changed electricity mix for the production of the facilities could have an effect on the balance.

Within the balancing of the plant exploration, mining, processing and transportation of the fuels, especially for the electricity mix as well as the required infrastructure, are covered. Furthermore, the production of single components is considered. This comprises the solar field, the steam generator, the mechanical and electrical engineering, the constructional engineering, the storage and the steam turbine. Certain recycling quotas are given for steel, aluminium and copper. Modelling of the facility operation includes maintenance, i.e., cleaning and material exchange. The disposal of the facility is composed of the demolition (except the buildings) and the depository.

Modelling of the HVDC line comprises the winning of the raw materials, the production and transportation of the materials and components with respect to their destination. Besides, emissions arising during the operating time of the facility are incorporated. There is no reliable data available about maintenance, cleaning measures and the final disposal.

A solar thermal power plant (type Parabolic Trough Solar Electricity Generating System 'SEGS') with thermal storage and dry cooling tower is used for the generation of electricity. The transmission line is a ±800 kV HVDC system performed as double-dipole. Plant location and course of the line correspond to the respective lines from the GIS analysis. Both systems are designed for a capacity of 10 GW. The year 2030 is defined as temporal reference for the facility construction. Accordingly, the electricity mix, the manufacture of steel, aluminium, copper, rock wool, ceramics and flat glass are extrapolated to this year.

An existing model for an 80 MW SEGS power plant with reference to the year 2010 from the SOKRATES project was adjusted to a 10 GW SEGS power plant /Viebahn 2004/. The quality of the original data from the year 1996 is rated high because it concerns information of the producer. Besides, it was updated and added. Input data for the modelling of overhead lines and cables is primary data from the producer ABB /Normark 2005/. In some places it is supplemented with own calculations and bibliographical references /Knoepfel 1995/, /ESA 2004/. In addition, the process database of Umberto® and partially the ecoinvent database 2000 was used /ecoinvent 2003/.

For the long-distance transport of 10 GW a ± 800 kV double-dipole system on two separate lines with a capacity of 5 GW each is used. The conductor deployed is an aluminium-steel compound wire (Al/St 805 mm²/102 mm²). In a 4-string-bundle 2500 MW per Pole can be transmitted with it. The pylons are steel lattice pylons with a concrete fundament and long-rod ceramic isolators.

In order to cross the sea a ± 800 kV mass-impregnated cable with a central copper conductor (2100 mm²) is used. Altogether 8 cables are required to transmit 10 GW.

The rectifier stations and transformers are composed of many different materials, for which no data was available, but they are of no consequence for the balance due to the large length of the HVDC line.

Power plant operating time is defined as 30 years. Thus, just 60 % of the HVDC line, which has an operating time of 50 years, is considered for the balance. The electricity mix of Germany of the year 2030 was taken as reference for the calculation of emissions during construction.

	Unit	Site Algeria	Site Libya	Site Egypt
DNI	kWh/m²/y	2835	2802	2865
Capacity	GW_{el}	10	10	10
Solar field size	Mio m²	227.0	227.0	227.0
Thermal storage	GWh_{th}	590.5	590.5	590.5
Electricity production	TWh/y	77.1	76.2	77.9
Full load hours	h/y	7710	7620	7790

Table 5-5: Performance data of 10 GW base load solar thermal power plants in 2030 at the three starting points in Northern Africa, derived from /ESA 2004/, /May 2005/, as used for the eco-balance.

HVDC	± 800kV Overhead line (2 lines)	± 800kV Submarine cable (8 cables)	Source
Technical Data			
Length	3099 km	18 km	
Conductor	4	8	/Normark 2005/
Line losses	3.7 %/1000 km	1.7 %/1000 km	
Station losses (2x)	1.4 %	1.4 %	/ESA 2004/
Durability	50 a	50 a	/Pehnt 2002/
O_3-emissions	$4.0 * 10^{-9}$ kg/$MJ_{el} *$ km		/Knoepfel 1995/
N_2O-emissions	$0.4 * 10^{-9}$ kg/$MJ_{el} *$ km		/Knoepfel 1995/
Materials			
Aluminium	2 x 17.4 t/km		/Normark 2005/
Steel, high grade	2 x 6.4 t/km	8 x 24 t/km	"
Steel, low grade	2 x 75 t/km		"
Concrete	2x 200 t/km		"
Ceramics	2 x 2 t/km		"
Copper		8 x 19 t/km	"
Lead		8 x 17 t/km	"
Polypropylen		8 x 2.3 t/km	"
Paper		8 x 6 t/km	"
Impregnation		8 x 1 t/km	"

Table 5-6: Parameters for the long-distance transport of 10 GW line capacity /May 2005/.

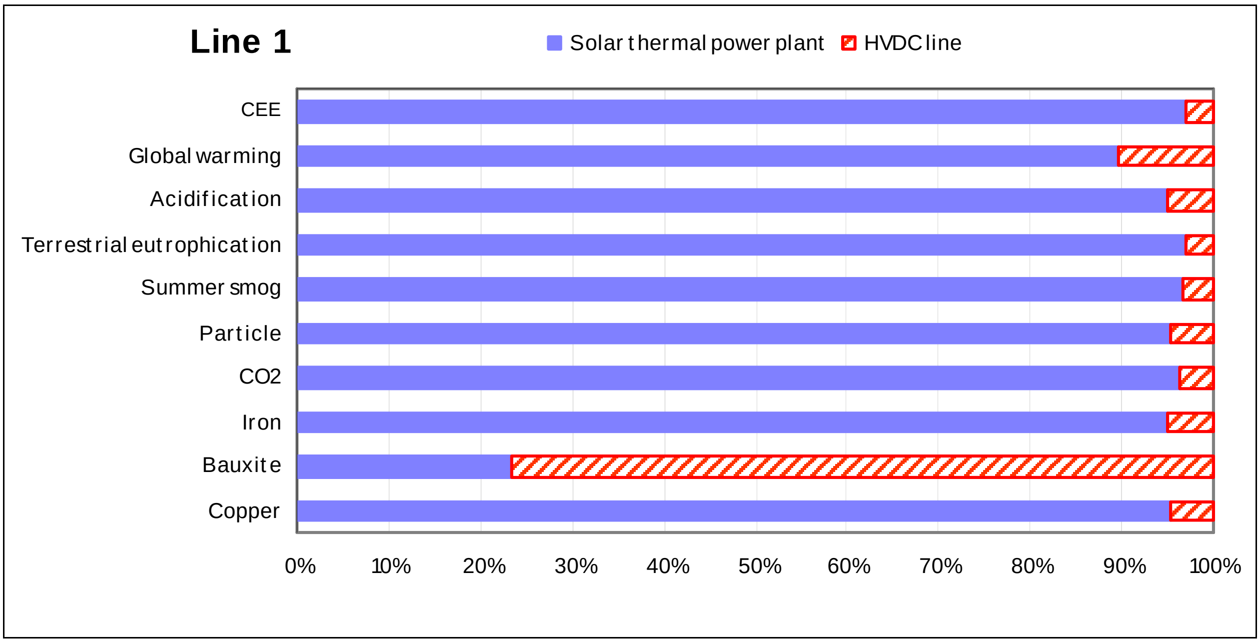


Figure 5-13: Proportional shares of the plant and the line in environmental impacts (line 1, reference year 2030). CEE = cumulated energy expenditure.

The proportional shares of plant and line in the environmental impacts of the entire facility is given in Figure 5-13. It is evident that the impacts are mainly caused by the solar thermal power plant. Only the aluminium demand is significantly higher for the HVDC line. If the submarine cable link is just long enough, approximately 300 km, the need of copper also increases (Figure 5-15).

Solar Thermal Power Plant Impacts

Negative impacts and resource consumptions are mainly caused by the production process of the solar field, which requires a considerable material expenditure because of a size of 15 km x 15 km for a 10 GW installation. Altogether 91 % of the iron flows into the production of the steel girder for the solar field and 97 % of the copper is used for the production of pumps and control lines. About 93 % of the bauxite is meant for the alloy of high-grade steel, which is mostly needed for the absorber tube of the solar heat collecting element. The material expenditure of the residual components of the facility is low in comparison to the solar field (Figure 5-14).

The cumulated energy expenditure (CEE) mainly accounts for 47 % of the construction of the solar field, of that nearly 41 % are used for steel, 30 % for the heat carrier oil phenol and just 15 % for flat glass.

In a high degree also the construction of the thermal storage, the material transport and the plant operation beside the solar field participate in emissions. Thus global warming potential of the solar field comes to 46 % and of the large storage capacity contributes with 27 %.

However, the material transport dominates the terrestrial eutrophication potential with 48 % and the summer smog with 37 %, the transport by trucks due to a large transport capacity.

The acidification potential of the solar field amounts to 43 %. The share of the ship transport is 10 % and is caused by using heavy oil as fuel.

Particle of the size < 10 µm are especially released during the steel production, accordingly high is the share of the solar field (69 %).

During the plant operation impacts arise chiefly in the form of summer smog. Furthermore, a certain need in energy must be met, which follows for the most part from the substitution of phenol. Every year 4 % of it is lost /Viebahn, 2004/.

Besides, the entire facility engineering, the constructional engineering and the steam turbine are not so important in the considered spectrum of impacts and material expenditures.

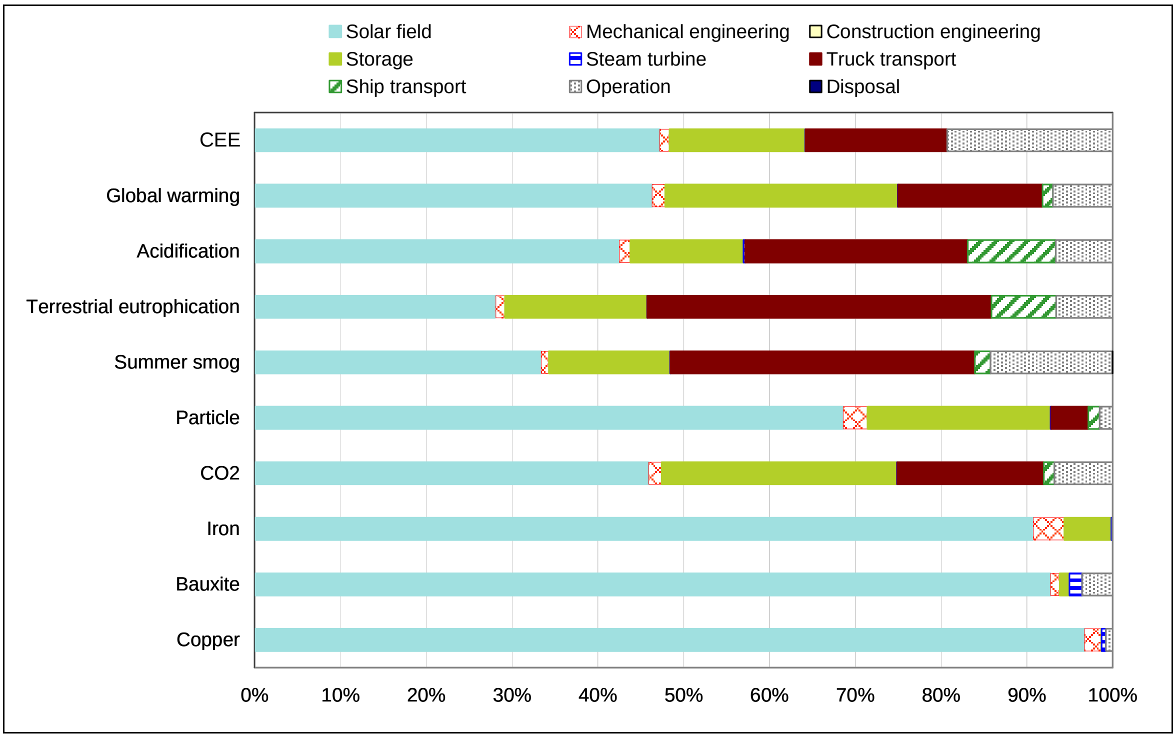


Figure 5-14: Impacts and resource consumptions of single plant components and life cycle phases of the plant respectively (line 1, reference year 2030). CEE = cumulated energy expenditure.

HVDC Transmission Line Impacts

According to the low submarine cable share of 0.6 % in the total line the environmental impacts of the overhead line predominate (Figure 5-15).

About 67 % of the global warming potential is solely caused by the operation of the overhead line. The importance of the ionization of air molecules along the high voltage overhead line for the climate is normally rated as low. Because of the large length of the overhead line a distinct higher influence emerges. First of all it is because of the formation of the laughing gas (N2O), which is a 310 times more effective climate gas than CO_2.

About 75 % of the acidification potential is caused by the manufacture of the overhead line and only 6 % by the submarine cable manufacture. Altogether the transport amounts to 19 %.

The terrestrial eutrophication potential is dominated by the overhead line with 55 %, but the share of transport (43 %) becomes important as well, especially the truck transport with 36 %.

In the category summer smog the influence of the overhead line predominates; it adds 34 % to the steel production and 32 % to the aluminium production. The direct formation of ground near ozone because of ionization processes could not be represented with the underlying evaluation procedure yet.

Associated with the steel production it turns out that the overhead line again dominates the particle formation. Just 16 % go into the production of aluminium and concrete. Iron and bauxite resources are almost exclusively used for the manufacture of conductor wires and pylons, whereas the main portion of the copper consumption is caused by the submarine cable link in spite of its shortness.

About 84 % of the cumulated energy expenditure lies at the overhead line manufacture, of which 59 % go into the steel production and 21 % into the aluminium production. Within the submarine cable manufacture the considered impacts have to be added to the copper and lead production beside the steel production. The share of lead in the eutrophication potential amounts to 43 %, followed by steel (20 %) and the ship transport (19 %). The other components of the submarine cable such as paper, impregnation and synthetic envelopments have a smaller share in impacts. Their share in the cumulated energy expenditure comes to just 12 %, in summer smog due to a higher share of impregnation to 23 %. This picture looks different for the other lines because of a longer transport distance (see Figure 5-16). A detailed description of the complete analysis and the data for the other two lines can be found in /May 2005/.

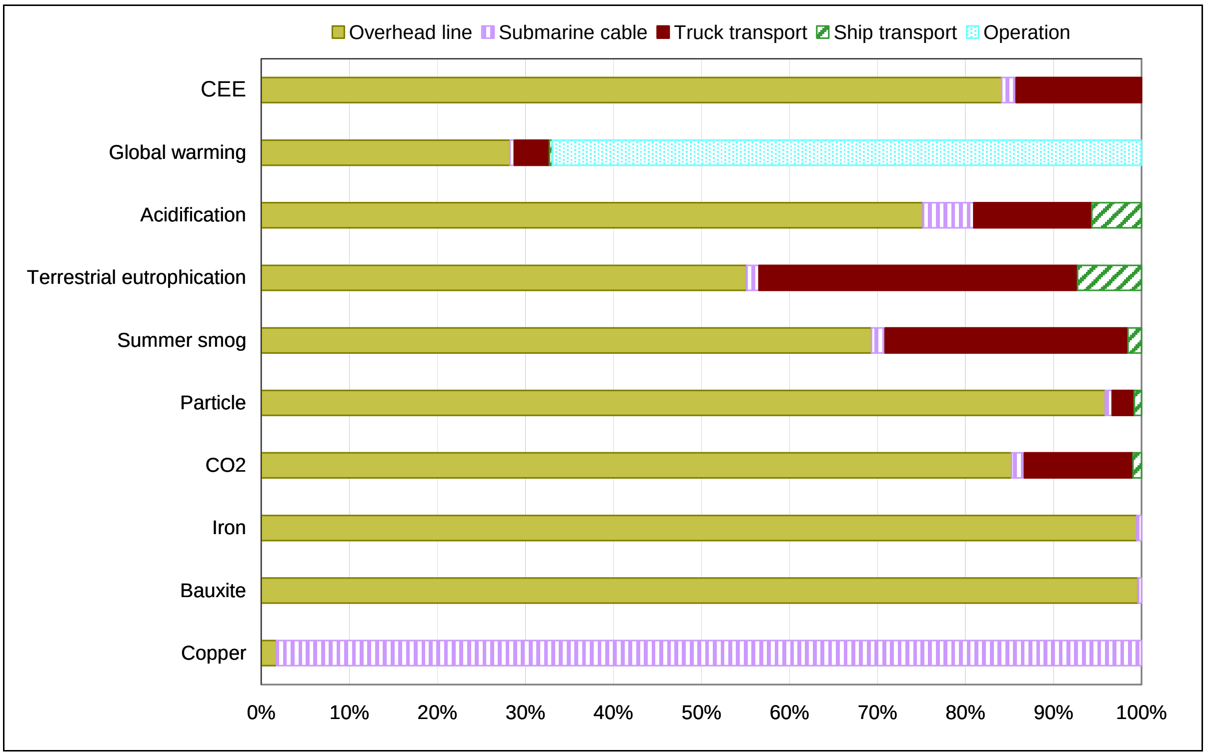


Figure 5-15: Impacts and resource consumptions in the phases of life of the HVDC transmission line (line 1, reference year 2030). CEE = cumulated energy expenditure.

Comparison of the balances of all three lines

The environmental impacts of all three lines are normalized to 1 kWh free network electricity supply and depicted in Figure 5-16 and Table 5-7 for a comparative representation of the impacts categories and the energetic and material resource consumptions respectively.

Line 2 has the highest cumulated energy expenditure with 0.21 MJ/kWh because more energy must be raised for the truck transport. It looks similar for the global warming potential, which is also the highest by line 2. If the emissions arising during the operation of the HVDC transmission lines are considered, the differences in the length of single overhead line sections become clear.

Transport participates considerably in the acidification and eutrophication potential and in summer smog, in case of line 2 even to more than 50 %. The impacts of the ship transport increase according to the distance to North African harbours from line 1 to line 3.

In the acidification potential of line 2 the long submarine cable section turns out. The particle load is the highest in case of line 3. As all values have been normalized to 1 kWh_{el}, the higher losses of line 3 affect the results.

Altogether the impacts of the solar power plant dominate in comparison to the line. This concerns also the iron consumption, only the bauxite consumption is mainly defined by the length of the overhead line section. The share of the line of the copper consumption increases if the submarine cable section is just long enough.

The *cumulated energetic expenditure* for the single HVDC transmission lines depends on the length of the line and the transport capacity. Line 2 requires the highest *cumulated energetic expenditure* regarding plant construction due to a high transportation capacity, particularly in North Africa. The differences in the solar electricity generation also depend on the irradiance on-site.

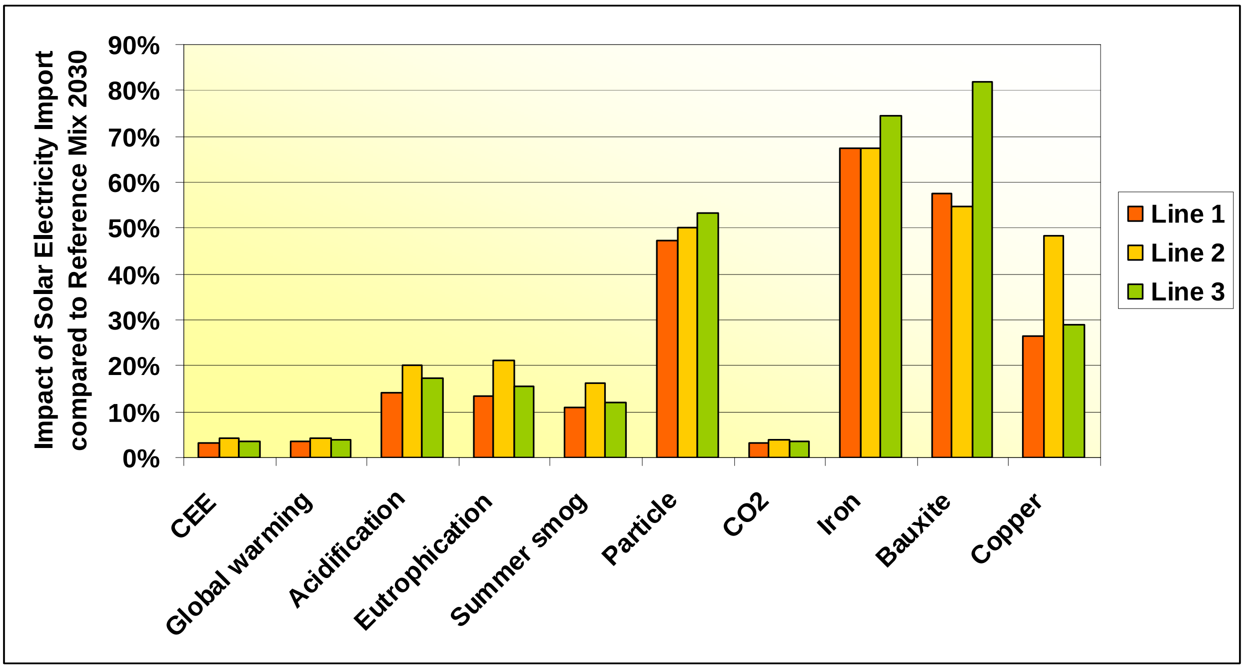


Figure 5-16: Impact of solar electricity transferred from North Africa to Europe compared to the reference electricity mix in the year 2030 /May 2005/

Impact category	Unit per kWh_{el}	Line 1	Line 2	Line 3	Electricity mix 2030	Line 1	Line 2	Line 3
CEE	MJ	0,17	0,21	0,18	5,17	3,3%	4,1%	3,5%
Global warming	g CO_2-Equi.	13,78	16,50	15,00	403,54	3,4%	4,1%	3,7%
Acidification	mg SO_2-Equi.	65,50	93,00	80,00	463,11	14,1%	20,1%	17,3%
Eutrophication	mg SO_2-Equi.	6,87	10,80	8,00	51,32	13,4%	21,0%	15,6%
Summer smog	mg Ethylene	2,57	3,80	2,80	23,26	11,0%	16,3%	12,0%
Particle	mg	22,09	23,50	25,00	46,80	47,2%	50,2%	53,4%
CO_2	kg	0,012	0,015	0,013	0,38	3,2%	3,9%	3,4%
Iron	g	1,50	1,50	1,65	2,22	67,6%	67,6%	74,3%
Bauxite	g	0,019	0,018	0,027	0,033	57,6%	54,5%	81,8%
Copper	g	0,005	0,009	0,006	0,019	26,3%	48,4%	28,9%

Table 5-7: Results of the life cycle assessment of required materials and emissions of solar electricity transferred from North Africa to Europe within the three analysed HVDC lines

The energetic amortization time EAT states how long it takes until all energetic expenditures for the construction of the facility are compensated by the own electricity production. The mathematical equation reads:

$$EAT[a] = \frac{CEE_H}{\left(\frac{E_{net}}{g} - CEE_B\right)}$$

CEE_H	Cumulated energetic expenditure for the facility construction [MJ]
E_{net}	Annual generated net energy amount [MJ/y]
g	mean degree of utilization of the German power plant mix [%]
CEE_B	Cumulated energetic expenditure for the facility operation [MJ/y]

For g a value from literature of 31.4 % is used /Viebahn, 2004/. In Table 5-8 the amortisation times for all three solar thermal power plants including the HVDC transmission lines are listed (reference year 2030). Altogether the energetic expenditure amortizes after 4-6 months.

	Unit	Line 1	Line 2	Line 3
CEE_H	[MJ]	2.76E+11	3.50E+11	3.12E+11
CEE_B	[MJ/y]	2.16E+09	2.20E+09	2.46E+09
E_{net}	[MJ/y]	2.42E+11	2.42E+11	2.63E+11
g	[%]	31.4	31.4	31.4
EAT	[year]	0.36	0.46	0.42
EAT	[month]	**4.3**	**5.5**	**5.1**

Table 5-8: Energetic amortization time (EAT) for the three lines.

One important result of the life cycle assessment and eco-balance is that each installation composed of solar thermal power plant and associated HVDC line causes distinct lower environmental pollution than the reference electricity mix, even taking as reference the enhanced electricity mix of 2030. The energetic expenditure makes up a very small fraction of the reference electricity mix related to one kilowatt-hour. Merely the demand in iron is increased at 40 % due to the erection of the new infrastructure, but this does not represent any limitation regarding the feasibility of such a project.

Differences in performance of the three HVDC lines concerning the share of overhead line and submarine cable hardly influence the result. Only in case of a distinct longer submarine cable section (line 2) or overhead line section (line 3) appears a higher demand in material resources like copper, iron and bauxite.

By means of these results it turns out that, even in an integrated consideration from the provision of original materials over the production and operation of the installation to its disposal, the cumulated environmental impacts are many times lower than the impacts through the conventional energy supply system. Besides, no highly risky waste products are produced, which survive in the long-term such as nuclear waste, whose consequence for the future, anyway, can be hardly estimated.

Besides, it is also a cheap kind of energy supply possible if solar thermal power plants are used in a large scale and all cost reduction potentials are exhausted. Nevertheless, its expansion decisively depends on political framework conditions. At the end of this paper the general statement can be formulated that, from an ecological point of view, nothing is opposed to the expansion of solar thermal energy in North Africa and a transmission of the generated solar electricity to Europe.

Finally it is remarked that the different forms of renewable energy in their great variety show together a major capacity, what does justice to a secured, independent, socially and environmentally compatible and affordable, global energy supply in the long-term.

Bibliography

/ABB 2004/ HVDC References – ABB HVDC Classic and Light Projects, ABB Power Transmission 2004, http://www.abb.com/global/abbzh/abbzh251.nsf!OpenDatabase&db=/global/gad/gad02181.nsf&v=17EA&e=us&c=C1256D71001E0037C1256C330030750D

/ABB 2005/ HVDC References - ABB HVDC Classic and Light Projects. Asea Brown Boveri Ltd, Zurich. URL: http://www.abb.com, 17.07.2005.

/Al-Zubari 2002/ Waleed k. Al-Zubari, Alternative Water Resource Management Policies in West Asia, Industry and Environmental Journal, Issue Theme: Regional Challenges for Sustainability, Volume 25, No. 1, pp. 43-47, UNEP 2002

/APG 2004/ Umweltverträglichkeitsgutachten zur Errichtung der 380 kV-Freileitung in der Steiermark. Verbund Austria Power Grid AG, Wien. URL: http://www.energie.steiermark.at, 6.3.2005.

/Arrillaga 1998/ Arrillaga, J. (1998): High Voltage Direct Current Transmission. 2nd Edition, IEE Power and Energie Series 29, the Institution of Electrical Engineers, London.

/Asplund 2005/ Asplund, G. (2005): Techno-economic feasibility of HVDC systems up to 800 kV. Workshop on 25th February 2005 in Delhi, ABB Power Technologies, Sweden. URL: http://www.abb.com, 20.07.2005.

/Asplund 2004/ Asplund, G. (2004): HVDC Outlook. ABB Power Technologies, Sweden. URL: http://www.abb.com, 14.03.2005.

/Asplund 2002/ Asplund, G. (2002): Sustainable energy systems with HVDC transmission. ABB Power Technologies, Sweden. URL: http://www.abb.com, 11.03.2005.

/Asplund 2004/ Gunnar Asplund, Sustainable energy systems with HVDC transmission, at IEEE PES 2004 General Meeting, Denver, 6-12 June 2004

/Awerbuch and Berger 2003/ Awerbuch, S. and Berger, M., Energy diversity and security in the EU: Applying portfolio theory to EU electricity planning and policymaking, IEA, Report EET/2003/03, February 2003

/Beck 2000/ Beck, H.-P. (2000): Energiesysteme Teil: Elektrische Energieversorgungssysteme. Manuskript zur Vorlesung (W 8804), Institut für Elektrische Energietechnik, Technische Universität Clausthal, Clausthal-Zellerfeld. URL: http://www.iee.tu-clausthal.de, 12.03.2005.

/Bassam 2004/ N. El Bassam and T. Otto, Farming Systems under and around Solar Thermal Power and Desalination (STPD) Plants " Eco-Solar Oasis", Krähenfeld 2004

/BGR 2003/ Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen. Rohstoffwirtschaftliche Länderstudien, Heft XXVIII, Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover

/BGR 1998/ Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen 1998, Hannover/Berlin 1998, ISBN 3-510-95842-X

/BMU 2003-1/ J. Nitsch et. al., Ecologically Optimized Extension of Renewable energy Utilization in Germany, German Federal Ministry for the Environment, Stuttgart April 2004

/BMU 2003-2/ U. Bruchmann, Umweltpolitik - Geothermie - Energie der Zukunft, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin Sept. 2004

/BMU 2004-1/ J. Nitsch, S. Gärtner, K. Barthel et.al., Umweltpolitik - ökologisch optimierter Ausbau der Nutzung erneuerbarer Energien in Deutschland, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin April 2004

/BMU 2004-2/ F. Trieb et. al., Concentrating Solar Power, German Federal Ministry for the Environment, Stuttgart 2003

/BMU 2004-3/ W. Dürrschmidt, G. Zimmermann, Eds., Renewable Energies - Innovation for the future, German Federal Ministry for the Environment, Berlin 2004, http://www.bmu.de

/BMU 2005/ Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Erneuerbare Energien in Zahlen - nationale und internationale EntwicklungArtikel in Notizzettel legen. Berlin 2005 http://www.erneuerbare-energien.de/inhalt/2720/5466/

/Bossel 2005/ Ulf Bossel, On the Way to a Sustainable Energy Future, International Conference "Intelec '05" Berlin, September 18 -22, 2005, http://www.efcf.com/reports/

/Brower 1992/ Michael Brower, Cool Energy: Renewable Solutions to Environmental Problems, UNION OF CONCERNED SCIENTISTS, MIT Press, 1992, http://www.portaec.net/library/energy/environmental_impacts_of_renewab.html

/Brischke 2004/ Modell einer zukünftigen Stromversorgung Deutschlands mit hohen Anteilen regenerativer Energien auf der Basis eines Mehrknoten-Netzes, Doctoral Thesis, University of Stuttgart, 2004

/Brockhaus 2005/ Brockhaus Multimedial Atlas 2005

/Brundtland 1987/ Brundtland, G.H., Our Common Future, World Commission on Environment and Development, Report 1987

/Cameco 2006/ URL: http://www.cameco.com/investor_relations/ux_history/historical_ux.php

/Czisch 2005/ G. Czisch, Szenarien zur zukünftigen Stromversorgung bei optimaler Nutzung von Fusionskraftwerken und regenerativen Energien, Doctoral Thesis, Univ. Kassel 2005

Debus, L. (1998): Elektrosmog im Meer durch gleichstromerzeugte elektrische und magnetische Felder - eine Literaturstudie. Deutsche Hydrographische Zeitschrift, Supplement 8, S. 167-180, Bundesamt Hamburg.

/DENA 2005/ DEWI / E.ON Netz / EWI / RWE Net / VE Transmission, Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020, Abschlussbericht zur DENA Netzstudie, Deutsche Energieagentur, Köln 2005

/DPG 2005/ Deutsche Physikalische Gesellschaft, Klimaschutz und Energieversorgung in Deutschland 1990 – 2020, Bad Honnef 2005

/EcoInvent 2003/ EcoInvent Database for Life-Cycle Analysis of Emissions and Materials, Vers. 2003

/ECOSTAR 2004/ R. Pitz-Paal, Project Presentation: Integrating and strengthening the ERA, European Concentrated Solar Thermal Road-Mapping, Cologne 2004

/EEA 2004/ European Environment Agency, Energy subsidies in the European Union EEA Technical Report 1/2004, Copenhagen 2004

/ENERDATA 2004/ GasElecStat 2004 databases, ENERDATA S.A.

/ESA 2004/ C. Hendriks, N. Geuder, P. Viebahn, F. Steinsiek, J. Spies, Solar Power from Space: European Strategy in the Light of Sustainable Development. Phase 1: Earth and Spaced based power generation systems., by order of the European Space Agency (ESA), Collaboration of Ecofys Netherlands, DLR Germany and EADS Germany.

/etso 2004/ European Transmission System Operators, Net Transfer Capacities in Europe for the year 2004, http://www.vdn-berlin.de/ntc_.asp

/EU 2003/ L. Mantzos et. al., European Energy and Transport trends ton 2030, The European Commission, Brussels 2003

/EU 2004/ The share of renewable energy in the EU, Commission of the European Communities, Brüssel Mai 2004

/EU 2006/ Commission of the European Communities, GREEN PAPER - A European Strategy for Sustainable, Competitive and Secure Energy, COM(2006) 105 final, Brussels, 8.3.2006 http://europa.eu.int/comm/energy/green-paper-energy/index_en.htm

/EURELECTRIC 2003/ Systmed Report, Manzoni et. al., Mediterranean Interconnection: State of the Art 2003, Union of the Electricity Industry: State of the Art, December 2003

/EurEnDel 2004/ Delphi Project Team: IZT, EC, IEFE, Risoe, Technology and Social Visions for Europe's Energy Future – A Europe-wide Delphi Study, Contract ENG1-CT2002-00676, Brussels 2004, www.eurendel.net

/EWEA 2002/ P. Gardner, et. al., Wind Energy - The Facts, European Wind Energy Association, Berlin 2002, http://www.ewea.org/06projects_events/proj_WEfacts.htm

/Externee 2003/ European Commission, External Costs - Research results on socio-economic damages due to electricity and transport, Brussels 2003, http://www.externe.info/

/EXTOOL 2003/ Lena Neijj et al., Experience Curves: A Tool for Energy Policy Assessment, Lund University, European Commission, Lund 2003

/FAO 2003/ Review of World Water Resources by Country, Food and Agriculture Organization of the United Nations, Rome 2003

/FAO 2004/ FAO Database Collections FAOSTAT 2004, last updated February 2004

http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0

/Fischer et al. 2004/ P. Fischer, G.Asplund, E. Jansson, Aspects on infeed of multiple HVDC into one ac network, Paper presented at CEPSI 2004, Shanghai, China, October 17 - 22, 2004

/GEA 2004/ Gawell, K., Reed, M., Wright, M., Geothermal Energy: The Potential for Clean Power from the Earth, Geothermal Energy Association, Washington 2004, http://www.geo-energy.org/PotentialReport.htm

/GGA 2000/ S. Hurter et. al., Atlas of Geothermal Resources in Europe: Planning Exploration and Investments, Geowissenschaftliche Gemeinschaftsaufgaben, Hannover 2000

/Goldberg 2000/ Goldberg, M., Federal Energy Subsidies: Not all technologies are created, Equal, REPP, July 2000

/Greenpeace 2005/ Greenpeace International, Energy Revolution: A Sustainable Pathway to a Clean Energy Future in Europe, A European Energy Scenario for EU-25, Amsterdam 2005

/Hafner 2005/ Hafner, M. (2005): Mediterranean Energy Markets and the Mediterranean Electricity Ring: Status and Perspektives for a Clean Power Market. Observatoire Méditerranéen de l'Energie (OME), Presentation on the Menarec 2 Conference in Amman, 9.5.2005.

/HGF 2001/ Hearing on Nuclear Fusion before the Bundestag Committee for Education, Research and Technology Assessment, Berlin, 28. March 2001, http://fire.pppl.gov/eu_bundestag_english.pdf

/Horlacher 2003/ Prof. Dr.-Ing. habil. H. Horlacher, Globale Potenziale der Wasserkraft, Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen, Berlin, Heidelberg 2003

/HWWA 2005/ Strategie 2030 - Vermögen und Leben in der nächsten Generation, Teil 3 - Energierohstoffe, Berenberg Bank und Hamburgisches Weltwirtschaftsinstitut, Hamburg 2005

/IEA 2001/: Competition in electricity markets, Paris.

/IEA 2002/ IEA (2002): World Energy Outlook 2002, Paris.

/IEA/UNEP 2002/ International Energy Agency, United Nations Environment Programme, Reforming Energy Subsidies, Paris 2002

/IEA 2003/ Renewables – Information 2003, International Energy Agency

/IEA 2003-1/ K. Kurokowa, Energy from the Desert - Feasibility of Very Large Scale Photovoltaik Power Generation (VLS-PV) Systems, Photovoltaik Power Systems Executive Committee of the International Energy Agency, London 2003

/IEA 2003-2/ Electricity Information 2003, International Energy Agency

/IEA 2003-3/ Energy Statistics of OECD Countries 1960 – 2001, International Energy Agency

2003 Edition

/IEA 2004/ International Energy Agency, Analysis of the Impact of High Oil Prices on the Global Economy, International Energy Agency, Paris, 2004

IEA 2005/ World Energy Outlook 2005, Middle East and North Africa Insights, Paris 2005

/IEA/NEA 2005/ P. Fraser, (IEA), E. Bertel (NEA) et. al., Projected Costs of Generating Electricity Update 2005, International Energy Agency/Nuclear Energy Agency, Paris 2005

/IEA 2006-1/ International Energy Agency, Renewable Energy: RD&D Priorities, Paris 2006

/IEA 2006-2/ IEA Web Data Server, Beyond 20/20, http://www.iea.org/rdd/eng/TableViewer/wdsview/dispviewp.asp

/IFEU, IFU 2005/: Umberto - Software für das innerbetriebliche Stoffstrommanagement. Benutzerhandbuch, Umberto Version 5, Institut für Energie- und Umweltforschung Heidelberg GmbH (ifeu), Institut für Umweltinformatik Hamburg GmbH (ifu).

/IGA 2004/ Mary H. Dickson, Mario Fanelli, What is geothermal energy?, International Geothermal Association, Pisa 2004

/IPCC (ed.) 2001/ Climate Change 2001: The Scientific Basis. IPCC Third Assessment Report. Summary for Policy Makers, Cambridge, New York, Cambridge University Press

/IPCC 2002/ Climate Change 2001; Report 2; T. Morita, J. Robinson (Lead authors): Greenhouse gas emissions mitigation scenarios and implications. Intergovernmental Panel of Climate Change 2002 (also: Special Report on Emission Scenarios. Working Group III: Mitigation of Climate Change, April 1999)

/ISO 2005/: DIN EN ISO 14040: Umweltmanagement - Produkt-Ökobilanz - Prinzipien und allgemeine Anforderungen. Deutsches Kompetenzzentrum für Nachhaltiges Wirtschaften (DKNW) der privaten Universität Witten/Herdecke, Lehrstuhl für Umweltmanagement der Universität Hohenheim. URL: http://www.oekoradar.de/de/gesetzte/norm/01993/index.html, 07.06.2005.

/IUCN 2006/ http://www.iucn.org/themes/spg/Files/opor/opor2_3.html

/Kiesling et al. 2001/ Kießling, F., Nefzger, P., Kaintzyk, U. (2001): Freileitungen: Planung, Berechnung, Ausführung. 5. Auflage, Springer-Verlag, Berlin.

/Knies et al. 1999/ G.Knies, G.Czisch, H.G. Brauch, Eds., Regenerativer Strom für Europa durch fernübertragung elektrischer Energie, AFES Press Report 67, Mosbach 1999

/Knies 2006/ Personal Communication

/Knoepfel 1995/ Knoepfel, I. (1995): Indikatorensystem für die ökologische Bewertung des Transports von Energie. Forschungsbericht Nr. 20, Laboratorium für Energiesysteme, ETH Zürich, Juris Druck + Verlag Dietikon.

/Krewitt and Sclomann 2006/ Krewitt, W., Schlomann, B., External costs of electricity generation from renewable energies compared to electricity generation from fossil energy sources, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin 2006, http://www.erneuerbare-energien.de/inhalt/37085

/Kulnick & Marhold 2000/ Kullnick, U., Marhold, S. (2000): Elektrokabel im Meer. In: Technische Eingriffe in marine Lebensräume, BfN-Skripten 29, Seite 4-30. Workshop des Bundesamtes für Naturschutz, Internationale Naturschutzakademie Insel Vilm, 27.-29.10.1999. Bundesamt für Naturschutz, Bonn-Bad Godesberg.

/Laures 2003/ Laures, W. (2003): Untersuchungen zum Einsatz von Höchstspannungskabeln großer Längen in der 400-kV-Ebene. Dissertation an der Universität Duisburg-Essen.

/Lehner et al. 2005/ Lehner, B., Czisch, G., Vassolo, S, The impact of global change on the hydropower potential of Europe: a model-based analysis. Energy Policy, Vol. 33/7: 839-855 based on Alcamo et al. (2003), Döll et al. (2003), Umweltsystemforschungszentrum an der Gesamthochschule Kassel, Kassel 2005

/Leuschner 2005/ Leuschner, U. (2005): Energie - Wissen. Heidelberg. URL: http://www.udo-leuschner.de/basiswissen/index.htm, 1.3.2005.

/Marquina, Brauch 2000/ A. Marquina, H.G. Brauch, Political Stability and Energy Cooperation in the Mediterranean, AFES Press, Mosbach 2000

/Martinot 2006/ URL: http://www.martinot.info/policies.htm

/May 2005/ Eco-Balance of a Solar Electricity Transmission from North Africa to Europe, Diploma Thesis, University of Braunschweig, 2005

/MED-CSP 2005/ MED-CSP Study Team, Concentrating Solar Power for the Mediterranean Region, Study commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Stuttgart 2005, www.dlr.de/tt/med-csp

/Meteonorm 2004/ Global Meteorological database for Applied Climatology Meteornorm Version 5.0, Meteotest, Bern 2004, http://www.meteotest.com

/Michaelowa et. al. 2004/, A,. Michaelowa, Clean Development Mechanism and Joint Implementation - New instruments for Financing renewable Energy Technologies, International Conference for Renewable Energies, Bonn 2004

/NDA 2002/ Managing the Nuclear Legacy - A strategy for action, Whitepaper of the UK Nuclear Decommissioning Authority, London 2002, www.nda.gov.uk

/Normark 2005/ Normark, B. (2005): Persönliche Mitteilung am 23.07.2005, ABB, Schweden.

/NREL 2003/ H. Price, Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts, National Renewable Energy Laboratory, Chicago Oct. 2003

/NREL 2004/ Pamela L. Spath, Margaret K. Mann, Biomass Power and Conventional Fossil Systems with and without CO2 Sequestration - Comparing the Energy Balance, Greenhouse Gas Emissions and Economics, National Renewable Energy Laboratory, NREL/TP-510-32575, January 2004, http://www.osti.gov/bridge

/OECD 2004/, K. Neuhoff, Large Scale Deployment of Renewables for Electricity Generation, Round Table on Sustainable Development, Organisation for Economic Co-operation and Development, Paris 2004, http://www.oecd.org/dataoecd/16/59/34358441.pdf

/oilnergy 2006/ URL: http://www.oilnergy.com/

/OME 2003/: Electricity Interconnections in the Mediterranean Countries. Observatoire Méditerranéen de l'Energie, Paper for the Conference in Tripoli, 17.-18.03.2003.

/ORNL 2003/ LandScan Global Population 200x Database Release. Documentation, Oak Ridge National Laboratory, Oak Ridge, Tennessee. URL: http://www.ornl.gov/ sci/gist/, 01.05.2005.

/Peschke, Ohlshausen 1998/ Peschke E., v. Olshausen, R. (1998): Kabelanlagen für Hoch- und Höchstspannung. Entwicklung, Herstellung, Prüfung, Montage und Betrieb von Kabeln und deren Garnituren. Siemens AG, Berlin und München. Publicis MCD Verlag, Erlangen und München.

/Platts 2004/ UDI World Electric Power Plants Data Base, Platts, a divison of The McGraw-Hill Companies, Inc., Washington 2004

/Quaschning 2000/, Systemtechnik einer klimaverträglichen Elektrizitätsversorgung in Deutschland für das 21. Jahrhundert, Verband Deutscher Ingenieure, Düsseldorf 2000

/REN 2005/ Eric Martinote, Worldwatch Institute, Renewables 2005 – Global Status Report, Washington DC, 2005, http://www.ren21.net/

/Risoe 1998/ URL: http://www.windatlas.dk/Europe/About.html

/RIVM 2001/ A. de Moor, Towards a Grand Deal on subsides and climate change, RIVM Netherlands Institut of Public Health and the Environment, May 2001

/Rudervall et al. 2000/ Rudervall, R., Charpentier, J. P., Sharma, R. (2000): High Voltage Direct Current (HVDC) Transmission Systems. Paper presented at Energy Week 2000 in Washington D.C. on March 7-8, 2000. ABB Power Systems Sweden, World Bank United States, ABB Financial Services Sweden. URL: http://www.abb.com, 17.03.2005.

/Schlabbach 2003/ Schlabbach, J., Elektroenergieversorgung. VDE Verlag GmbH, Berlin und Offenbach 2003.

/Schumacher 2002/ Schumacher, A. (2002): Die Berücksichtigung des Vogelschutzes an Energiefreileitungen im novellierten Bundesnaturschutzgesetz. In: Naturschutz in Recht und Praxis - Online, Heft 1. URL: http://www.naturschutzrecht.net/ online-zeitschrift/NRPO_Heft1.pdf, 22.02.05.

/Schymroch 1985/ Schymroch, H. D. (1985): Hochspannungs-Gleichstrom-Übertragung. Teubner Studienskripten Elektrotechnik 109, B. G. Teubner, Stuttgart.

/SEP 1997/ Umweltverträglichkeitsstudie der Hochspannungsverbindung Norwegen-Niederlande. NV Sammwerkende Elektriciteitc-Produkticbedrijven, Arnheim.

/Söderberg, Abrahamsson 2001/ Söderberg, L., Abrahamsson, B. (2001): SwePol Link sets new environmental standard for HVDC transmission. ABB Review 4/2001. URL: http://www.abb.com, 18.07.2005.

/SOLEMI 2004/ Solar Energy Mining, http://www.solemi.de

/SolWater 2006/ URL: http://www.kernenergien.de/projekte

/SBA 2003/ Statistisches Bundesamt, Statistisches Jahrbuch für das Ausland 2003, Wiesbaden

/Thomson 2006/ URL: http://www.datastream.com/

/TREC 2006/ URL: http://www.trecers.net/

/UBA 1999/ Bewertung in Ökobilanzen. UBA-Texte 92/99, Berlin.

/UBA 2004/ Institut für Energetik und Umwelt GmbH, Entwicklung einer Gesamtstrategie zur Einführung alternativer Kraftstoffe, insbesondere regenerativ erzeugtem Wasserstoff als Kraftstoff für den mobilen Bereich - Biogene Kraftstoffe, UFOPLAN FKZ 203 45 118, Leipzig 2004

/UCTE 2005-1/ http://www.ucte.org/statistics/exchange/e_default.asp

/UCTE 2005-2/ http://www.ucte.org/publications/order/e_default.asp

/UCTE 2005a/ URL: http://www.ucte.org/publications/library/e_default_2005.asp, 16.08.2005.

/UCTE 2005b/ URL: http://www.ucte.org/statistics/production/e_default.asp, 16.08.2005.

/VDEW 2001/ Kabelhandbuch. 6. Auflage, Verband der Elektrizitätswirtschaft e.V., VDEW-Verlag, Frankfurt am Main.

/Viehbahn 2004/ Viebahn, P. (2004): Solarthermische Kraftwerkstechnologie für den Schutz des Erdklimas - SOKRATES-Projekt. Projektbericht, Deutsches Zentrum für Luft- und Raumfahrt Stuttgart.

/VDE 2006/ Personal communication, VDE-ETG Workshop, Frankfurt, March 2006

/vIEM 2006/ URL: http://www.viem.de/

/WBGU 2003/ H. Graßl et. al., Welt im Wandel - Energiewende zur Nachaltigkeit, Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen, Berlin März 2003

/WDC 2006/ http://wdc.dlr.de/data_products/SURFACE/NPP/wisski_egu_280405.pdf

/WEC 2004/ World Energy Council, http://www.worldenergy.org/wec-geis/publications/reports/ser/overview.asp

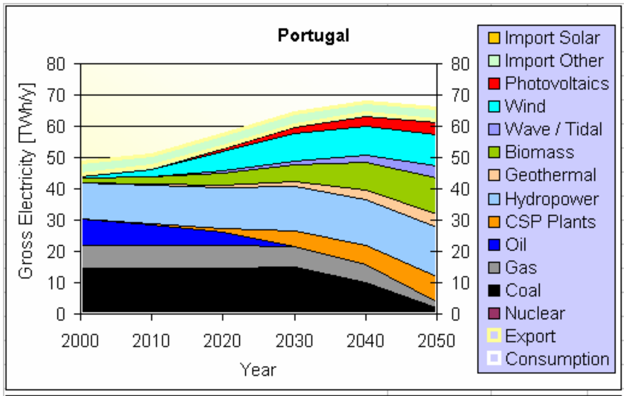
/WETO 2003/ EC DG Research, World Energy, Technology and Climate Policy Outlook, European Comission, Luxembourg 2003

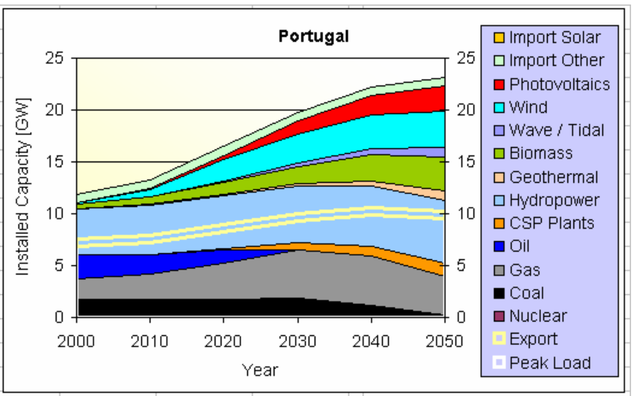
/Wirtz, Schuchardt 2003/ Wirtz, K. W., Schuchardt, B. (2003): Auswirkungen von Rohrleitungen und Stromkabeln. In: Warnsignale aus Nordsee und Wattenmeer – Ein aktuelle Umweltbilanz. J. L. Lozán, Seite 154-156. Wissenschaftliche Auswertungen, Hamburg.

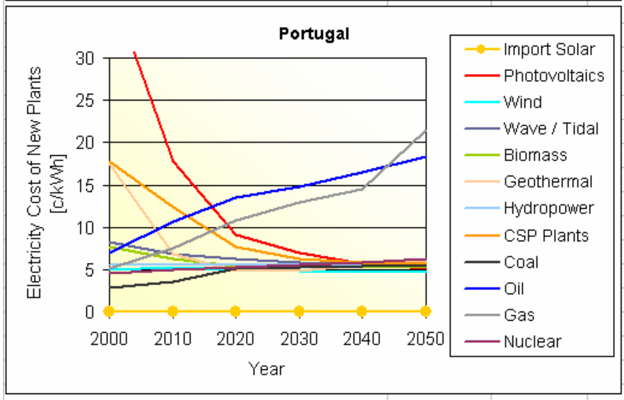
/WISE 2006/ WISE Website: http://www10.antenna.nl/wise/index.html?http://www10.antenna.nl/wise/485/4813.html

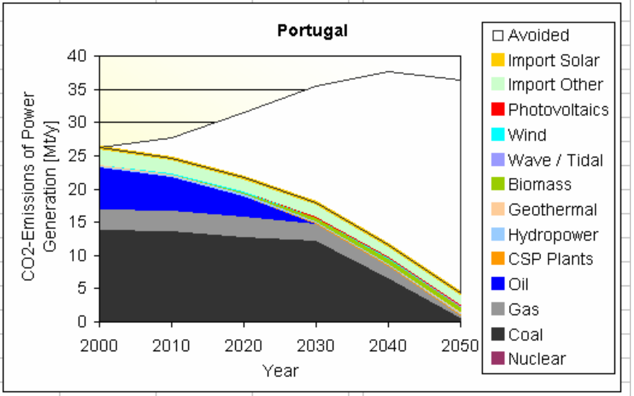
/WWA 2004/ World Wind Atlas 2004, Meteotest, Bern 2004, http://www.meteotest.com

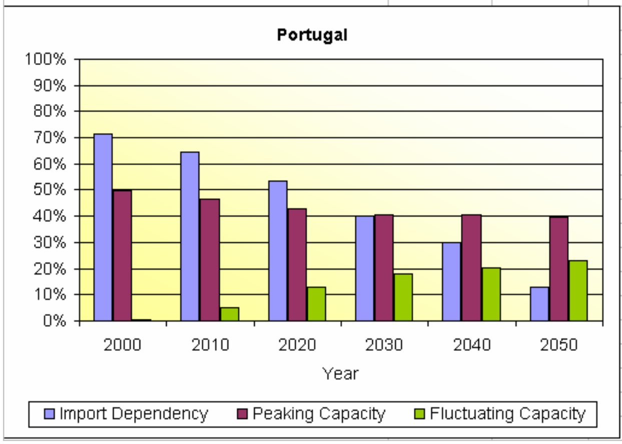
Portugal

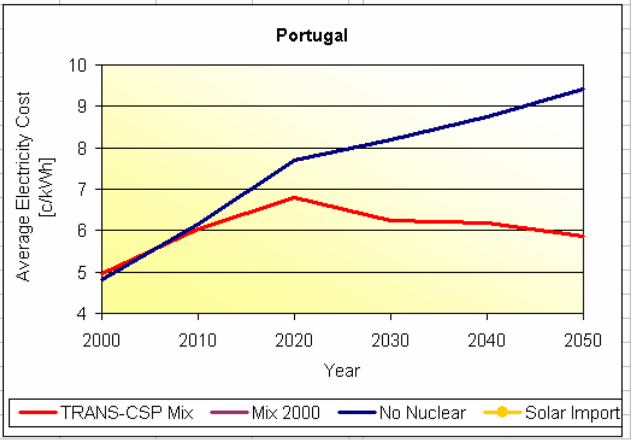

Portugal
Gross Electricity [TWh/y]
80
70
60
50
40
30
20
10
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Portugal
Installed Capacity [GW]
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

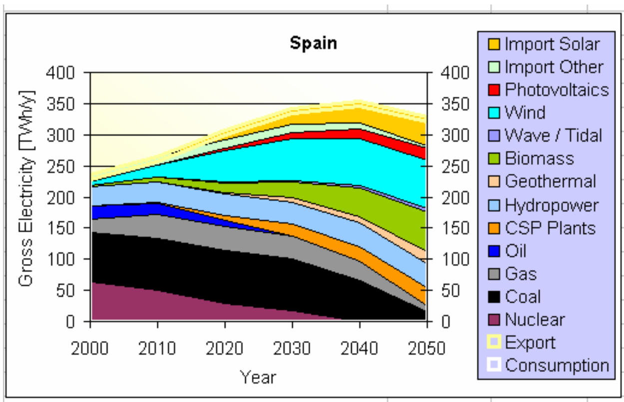

Portugal
Electricity Cost of New Plants [c/kWh]
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

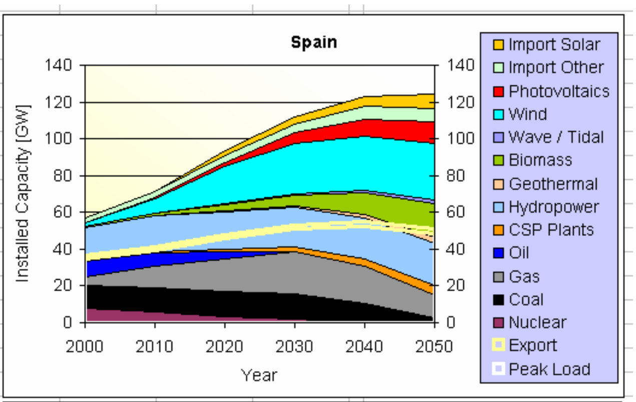

Portugal
CO2-Emissions of Power Generation [Mt/y]
40
35
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

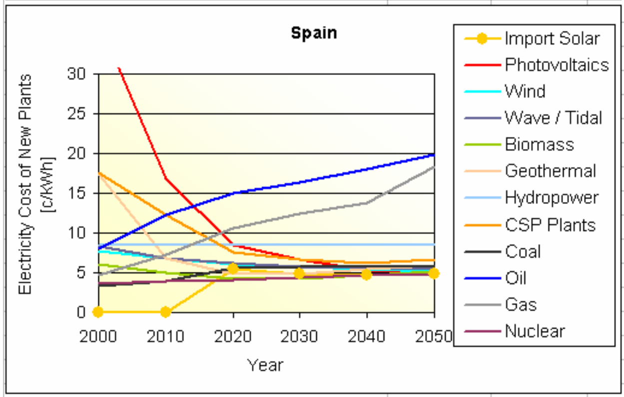

Portugal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

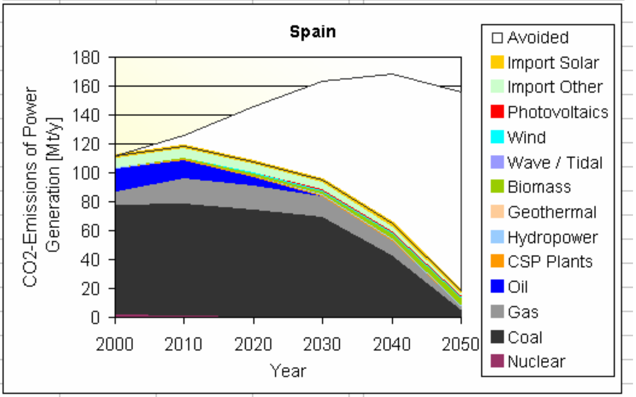

Portugal
Average Electricity Cost [c/kWh]
10
9
8
7
6
5
4
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

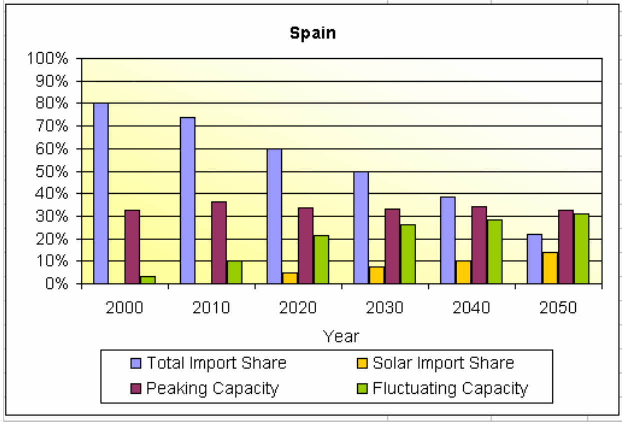
Spain

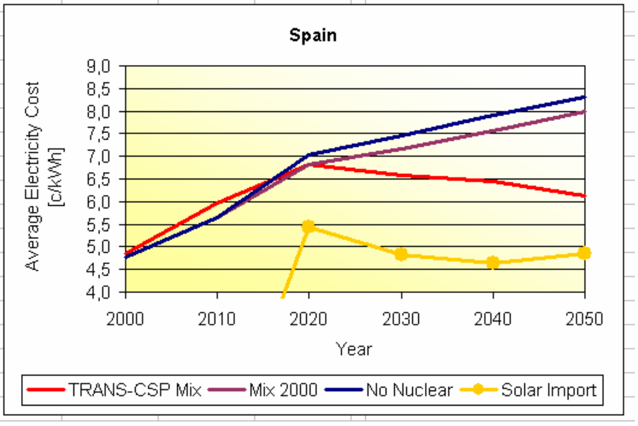

Spain
Gross Electricity [TWh/y]
0
50
100
150
200
250
300
350
400
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Spain
Installed Capacity [GW]
0
20
40
60
80
100
120
140
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

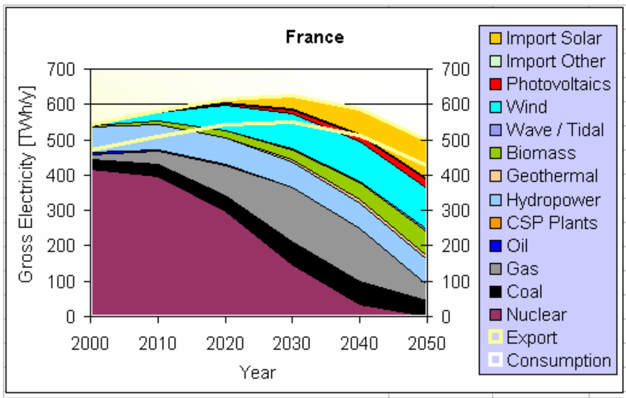

Spain
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

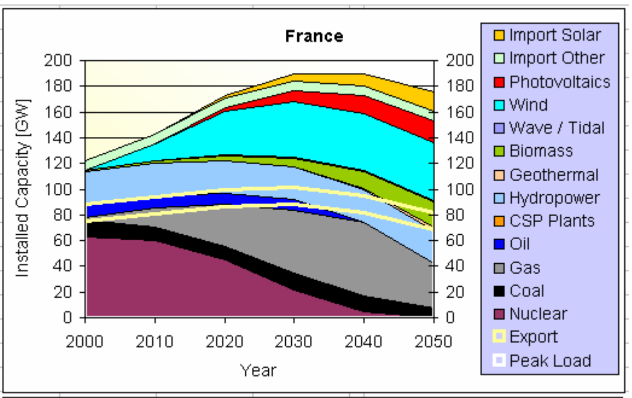

Spain
CO2-Emissions of Power Generation [Mt/y]
0
20
40
60
80
100
120
140
160
180
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

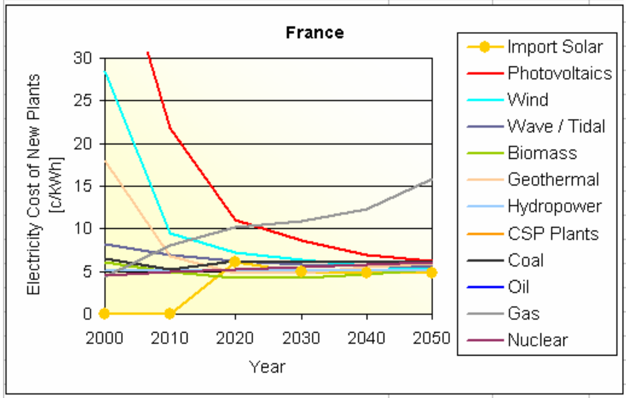

Spain
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

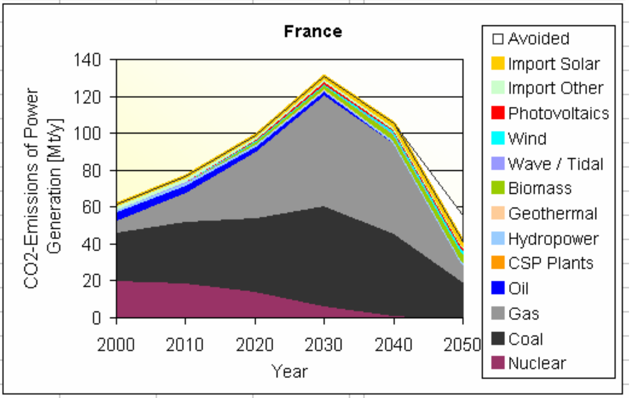

Spain
Average Electricity Cost [c/kWh]
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

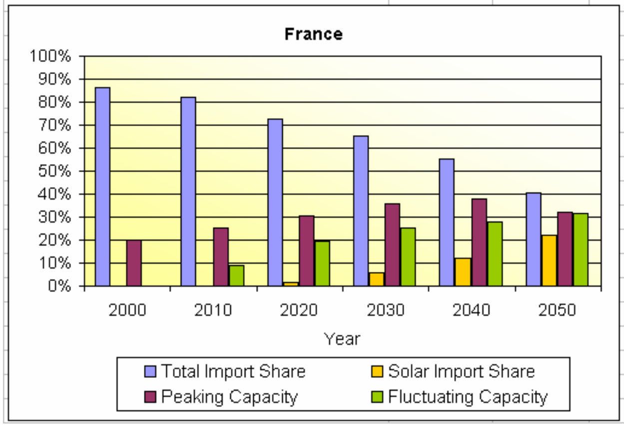
France

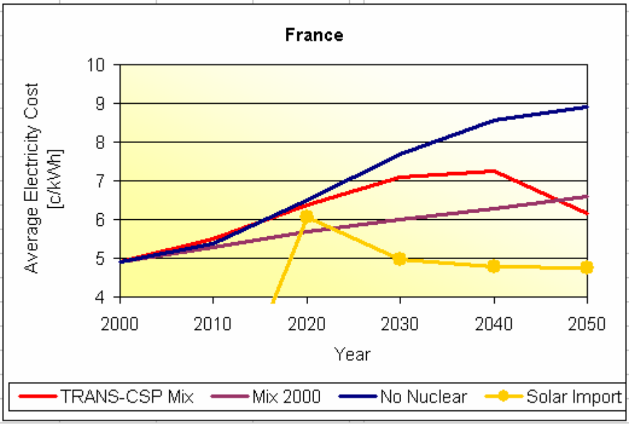

France
Gross Electricity [TWh/y]
0
100
200
300
400
500
600
700
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


France
Installed Capacity [GW]
0
20
40
60
80
100
120
140
160
180
200
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

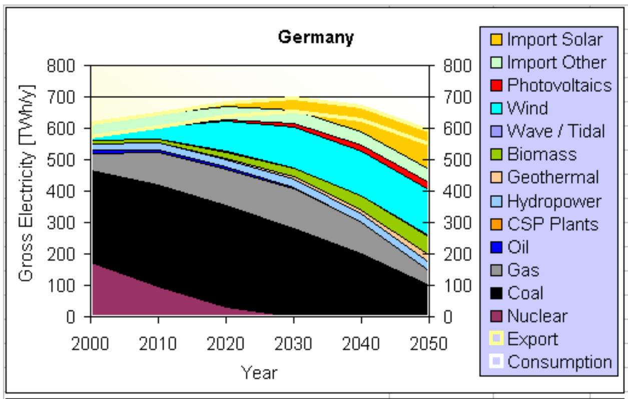

France
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

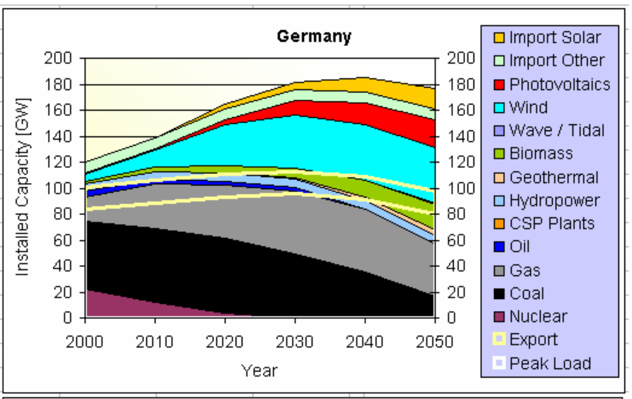

France
CO2-Emissions of Power Generation [Mt/y]
0
20
40
60
80
100
120
140
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

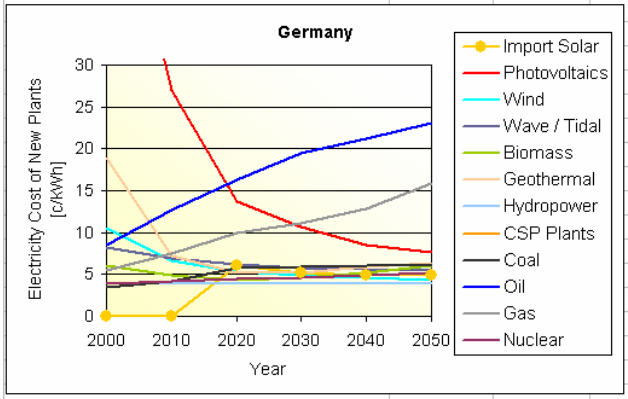

France
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

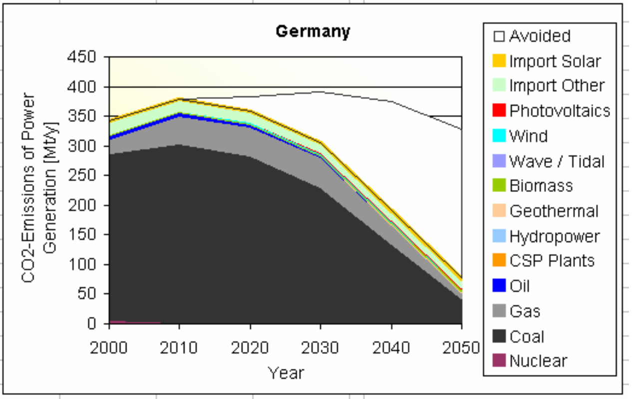

France
Average Electricity Cost [c/kWh]
4
5
6
7
8
9
10
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

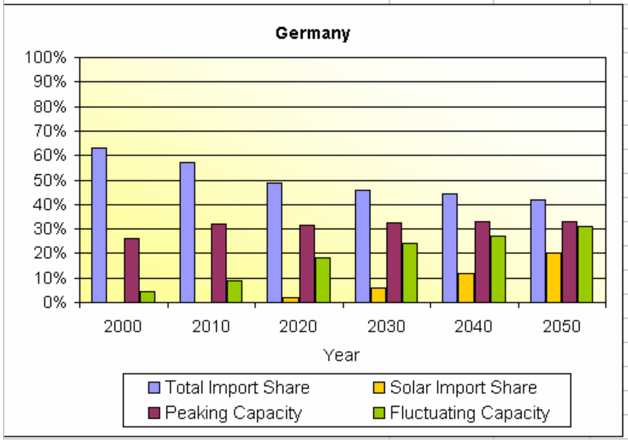
Germany

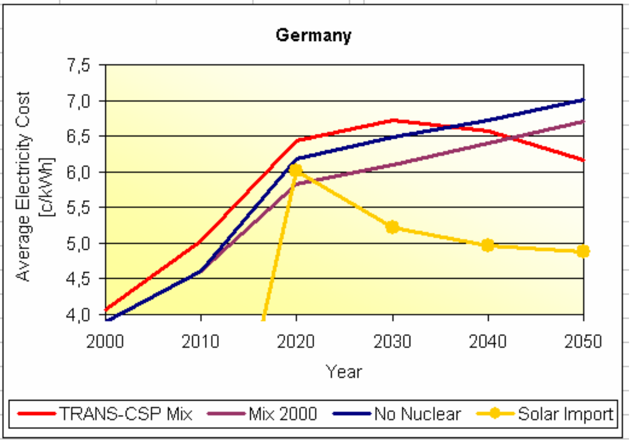

Germany
Gross Electricity [TWh/y]
0
100
200
300
400
500
600
700
800
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Germany
Installed Capacity [GW]
0
20
40
60
80
100
120
140
160
180
200
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

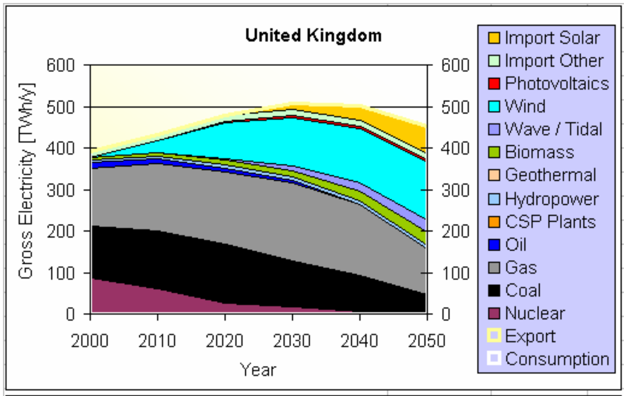

Germany
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

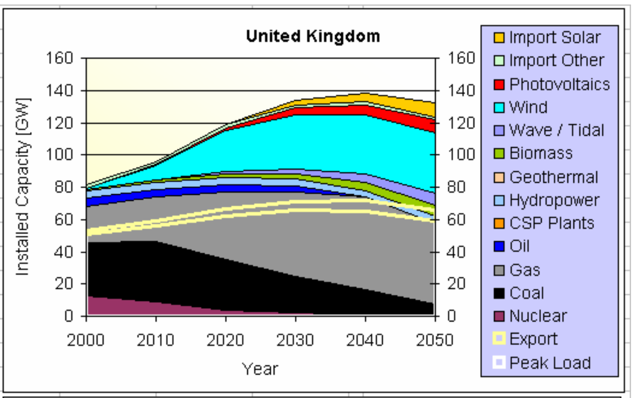

Germany
CO2-Emissions of Power Generation [Mt/y]
0
50
100
150
200
250
300
350
400
450
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

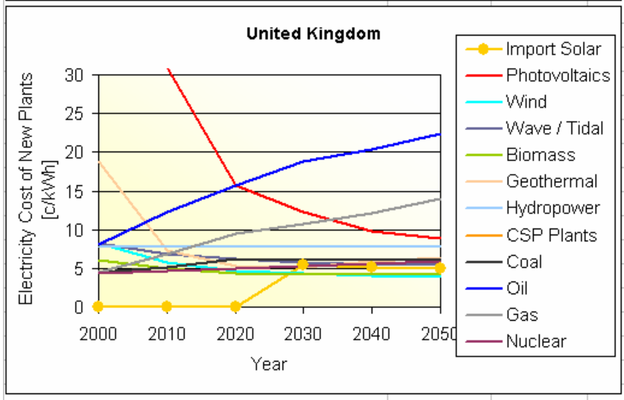

Germany
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

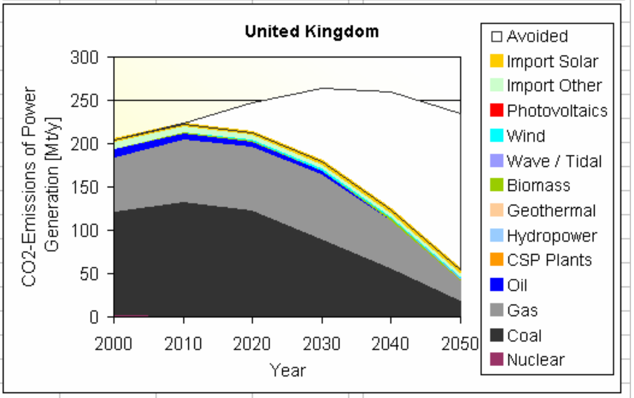

Germany
Average Electricity Cost [c/kWh]
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

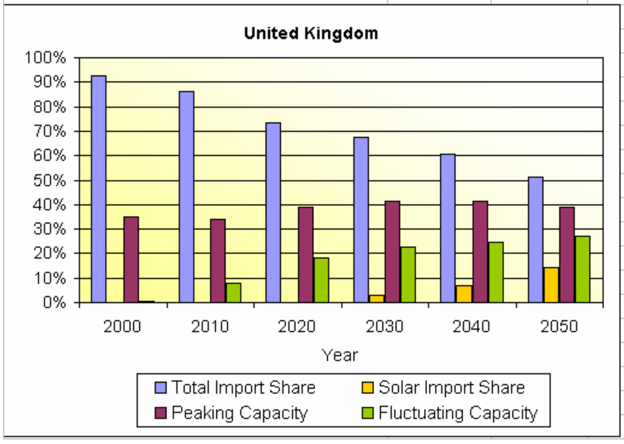
United Kingdom

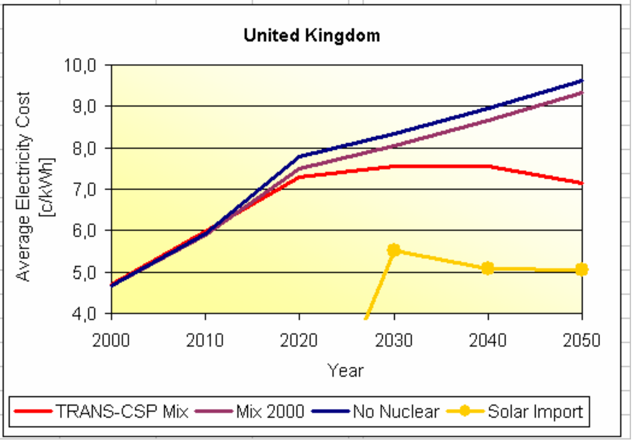




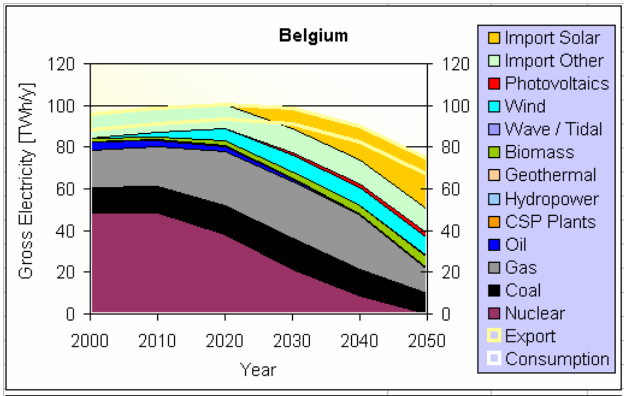


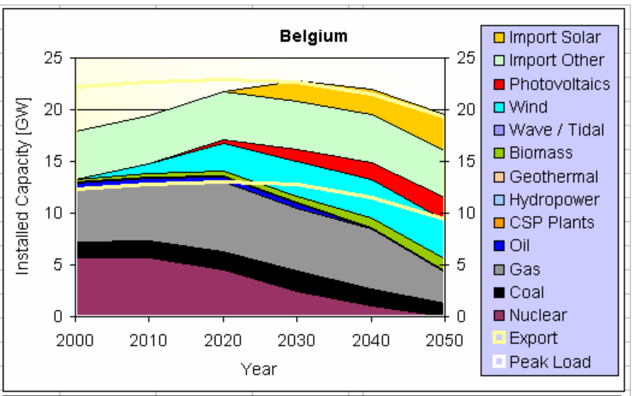


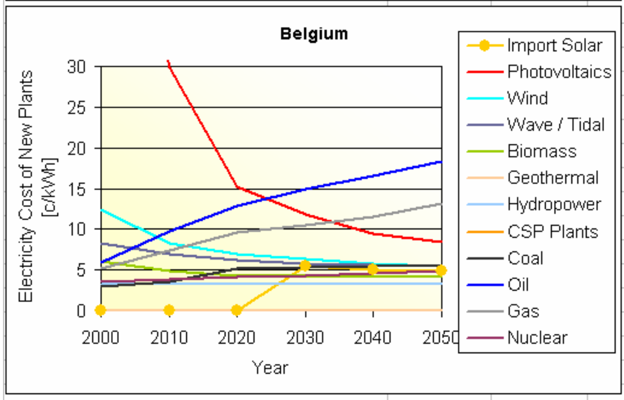


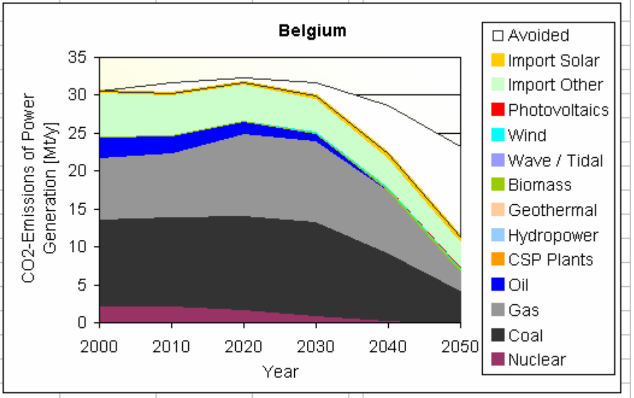


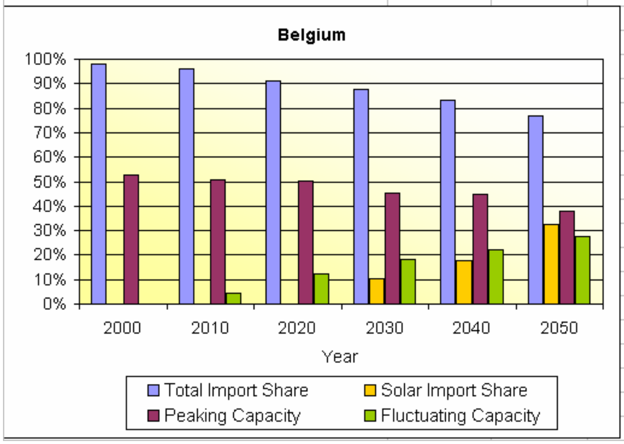
Belgium

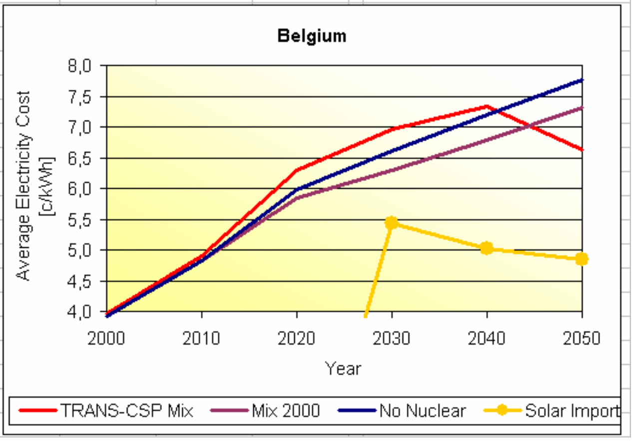

Belgium
Gross Electricity [TWh/y]
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Belgium
Installed Capacity [GW]
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

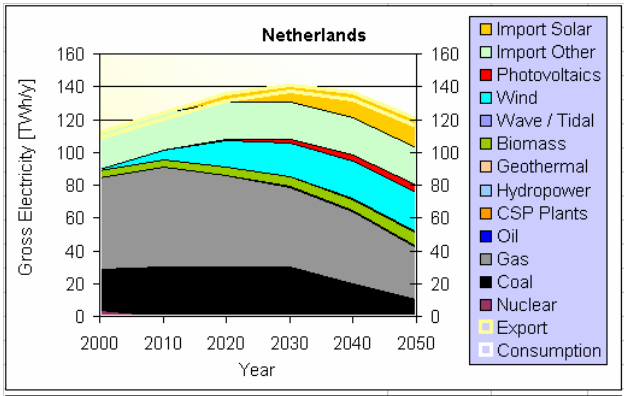

Belgium
Electricity Cost of New Plants [c/kWh]
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

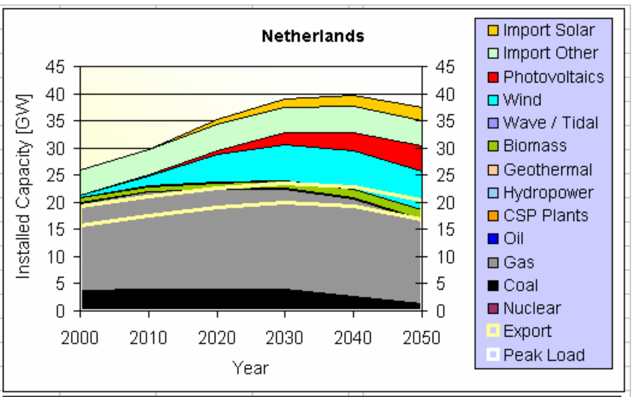

Belgium
CO2-Emissions of Power Generation [Mt/y]
35
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

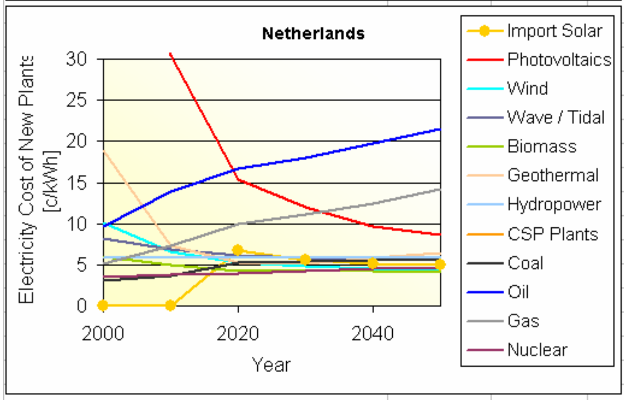

Belgium
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

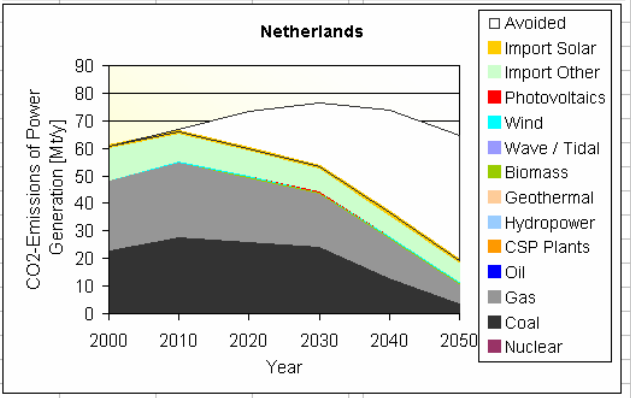

Belgium
Average Electricity Cost [c/kWh]
8,0
7,5
7,0
6,5
6,0
5,5
5,0
4,5
4,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

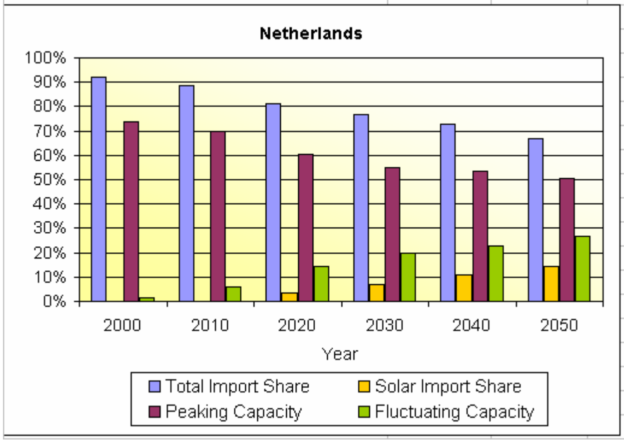
Netherlands

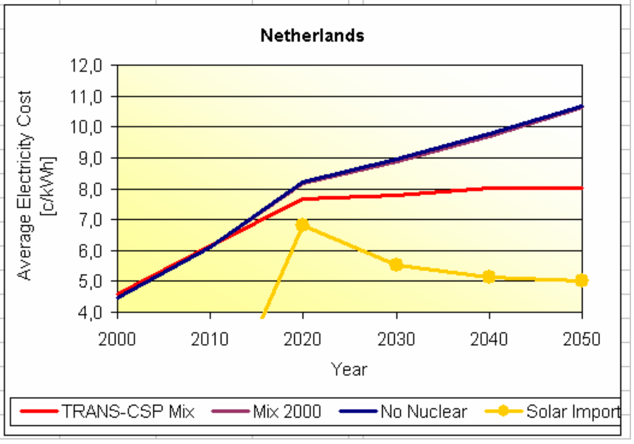




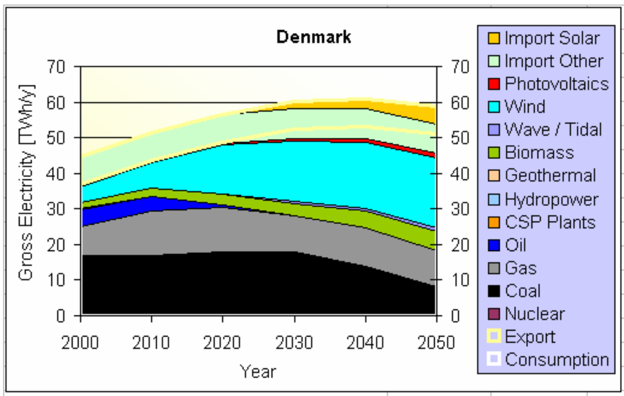


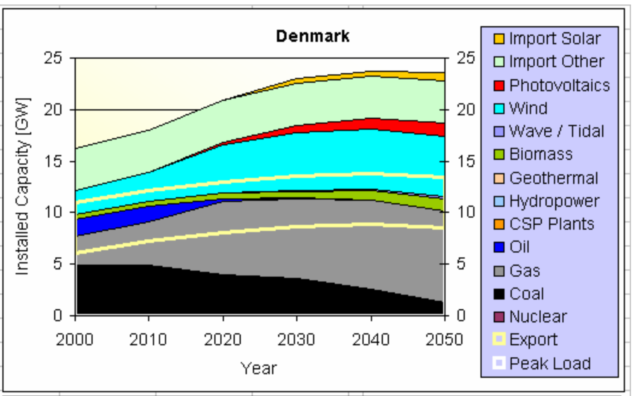


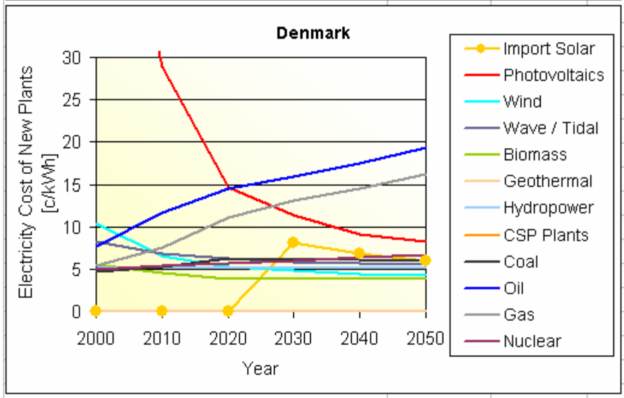


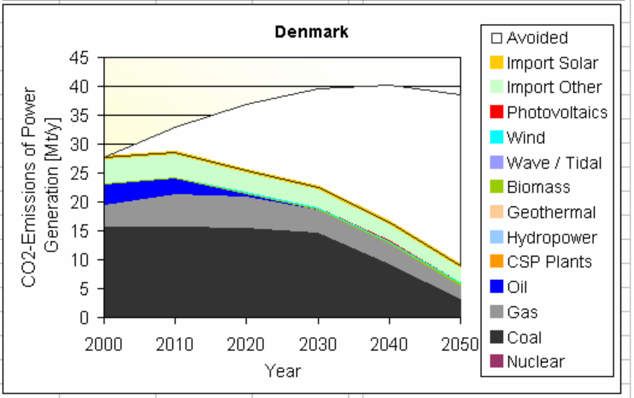


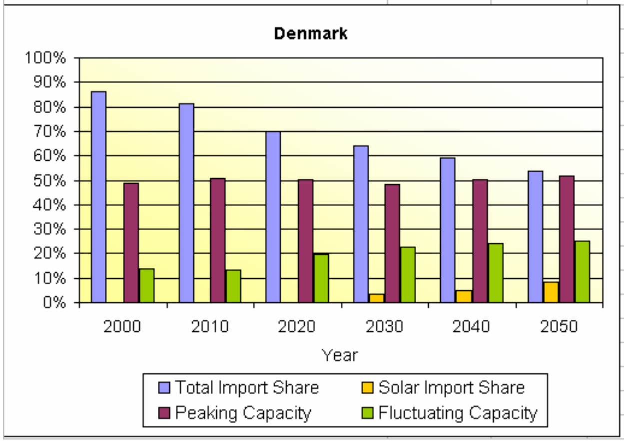
Denmark

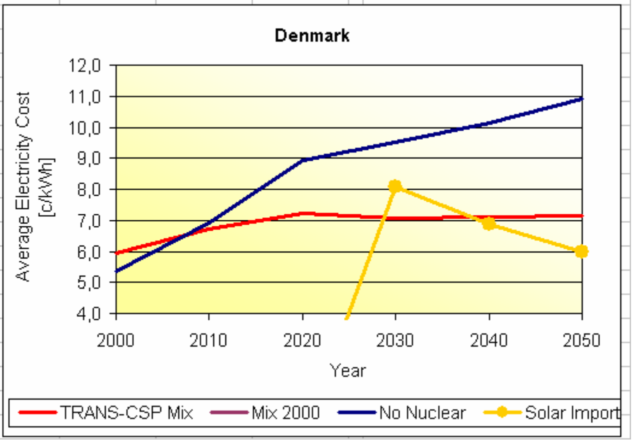

Denmark
Gross Electricity [TWh/y]
0
10
20
30
40
50
60
70
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Denmark
Installed Capacity [GW]
0
5
10
15
20
25
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

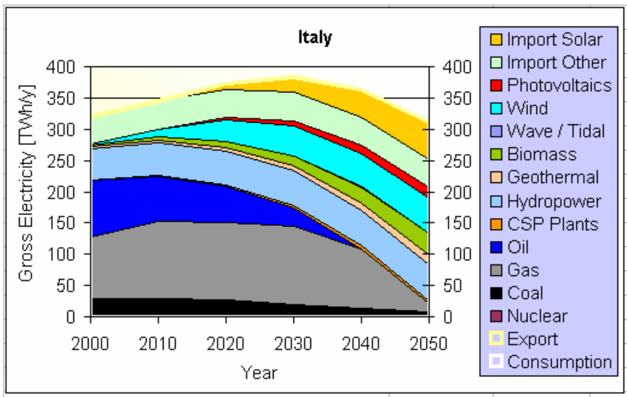

Denmark
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

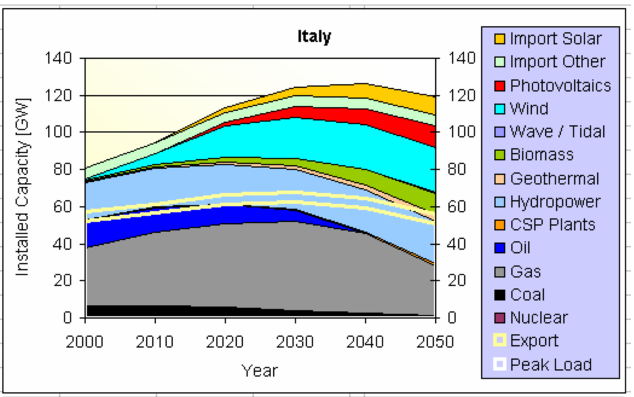

Denmark
CO2-Emissions of Power Generation [Mt/y]
0
5
10
15
20
25
30
35
40
45
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

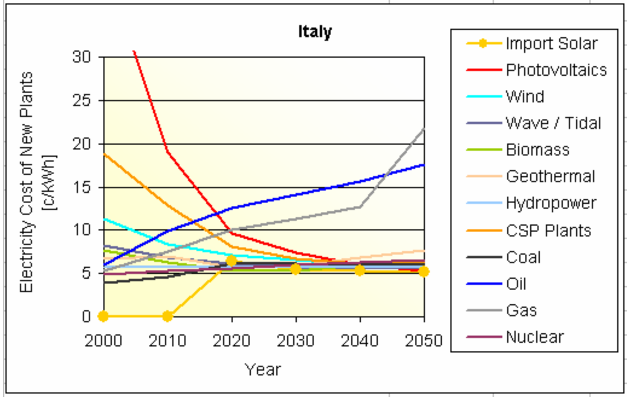

Denmark
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

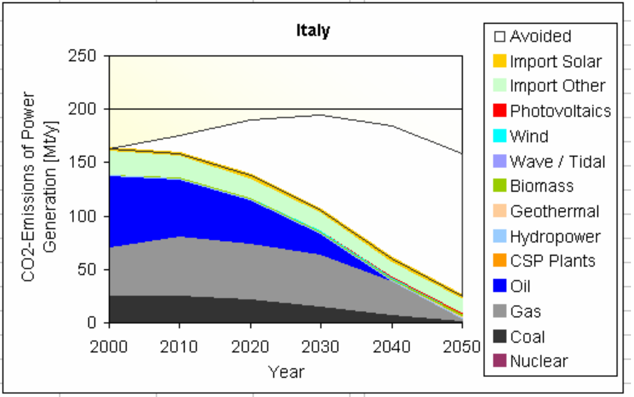

Denmark
Average Electricity Cost [c/kWh]
4,0
5,0
6,0
7,0
8,0
9,0
10,0
11,0
12,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

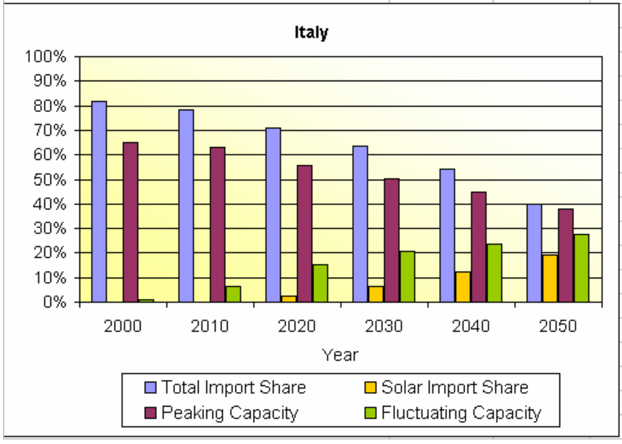
Italy

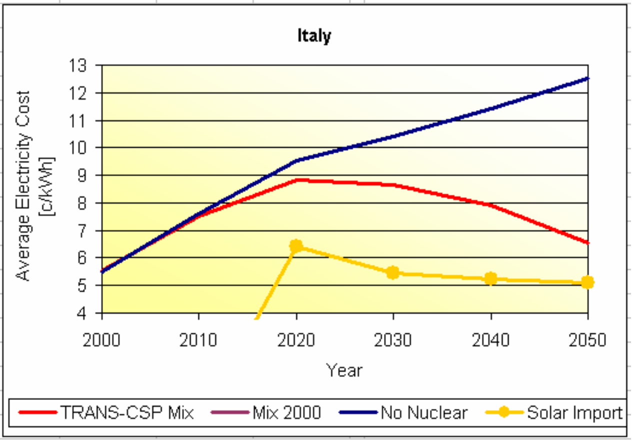

Italy
Gross Electricity [TWh/y]
0
50
100
150
200
250
300
350
400
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Italy
Installed Capacity [GW]
0
20
40
60
80
100
120
140
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

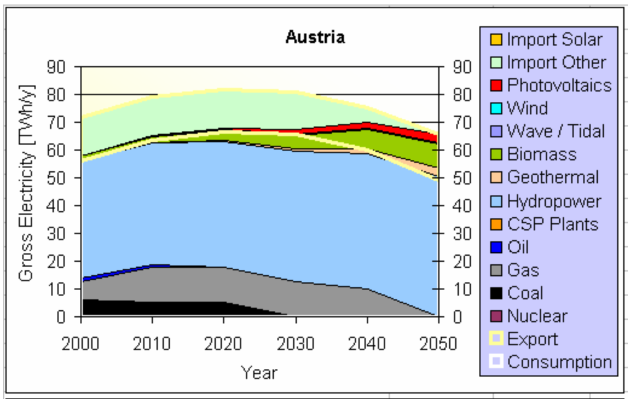

Italy
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

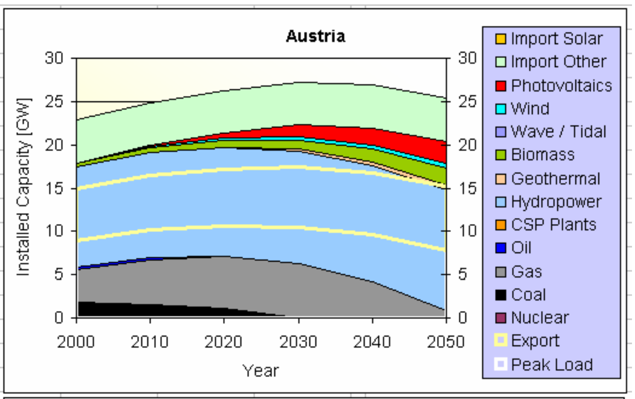

Italy
CO2-Emissions of Power Generation [Mt/y]
0
50
100
150
200
250
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

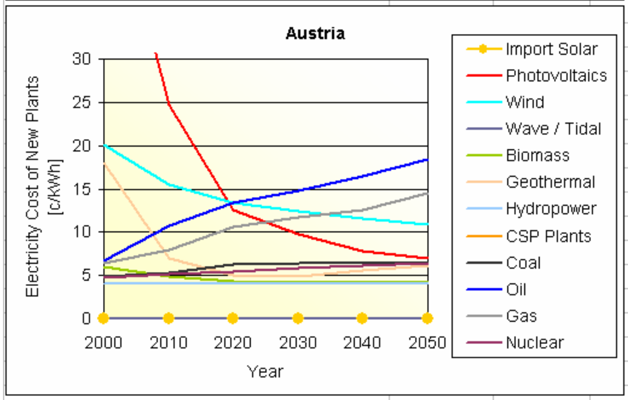

Italy
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

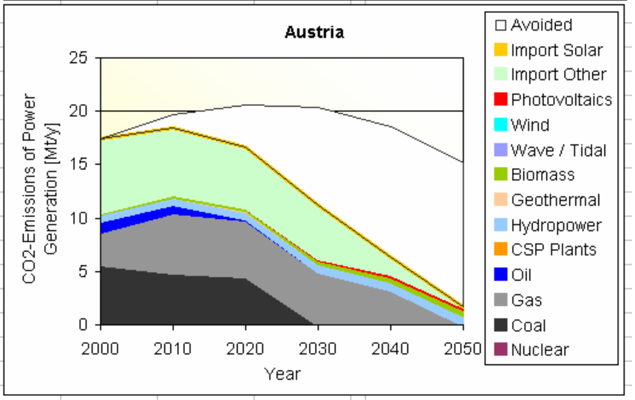

Italy
Average Electricity Cost [c/kWh]
4
5
6
7
8
9
10
11
12
13
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

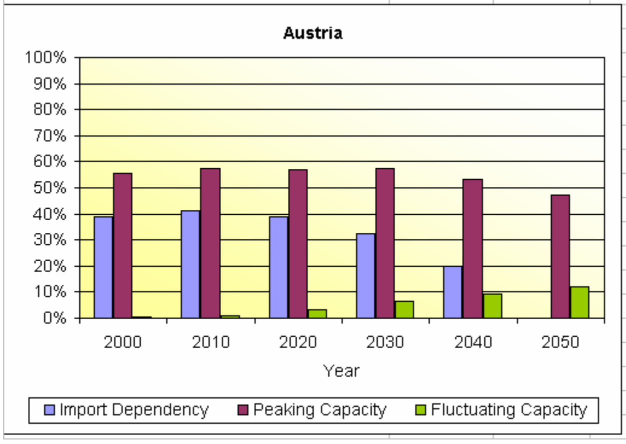
Austria

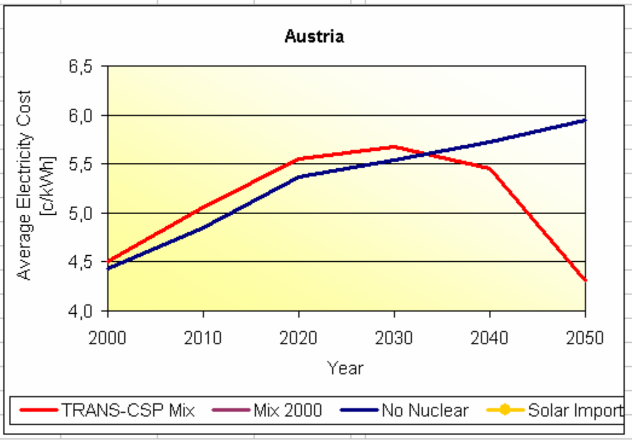

Austria
Gross Electricity [TWh/y]
0
10
20
30
40
50
60
70
80
90
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Austria
Installed Capacity [GW]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

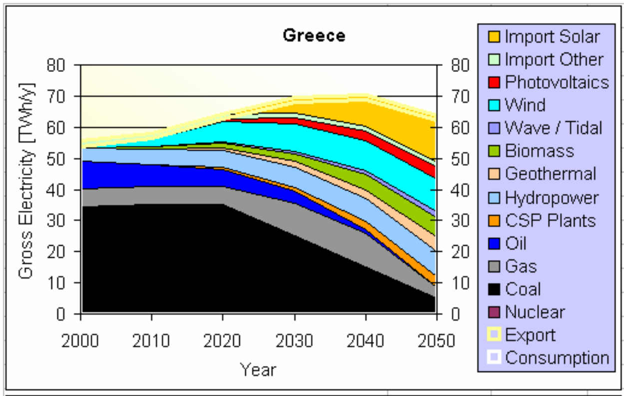

Austria
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

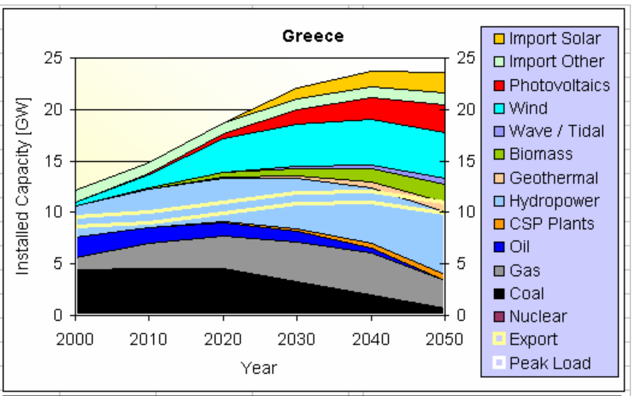

Austria
CO2-Emissions of Power Generation [Mt/y]
0
5
10
15
20
25
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

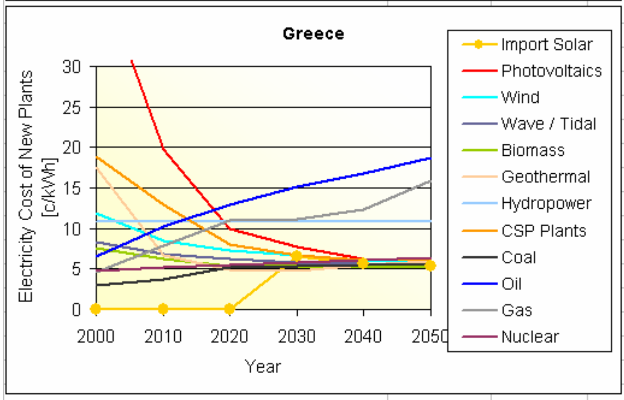

Austria
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

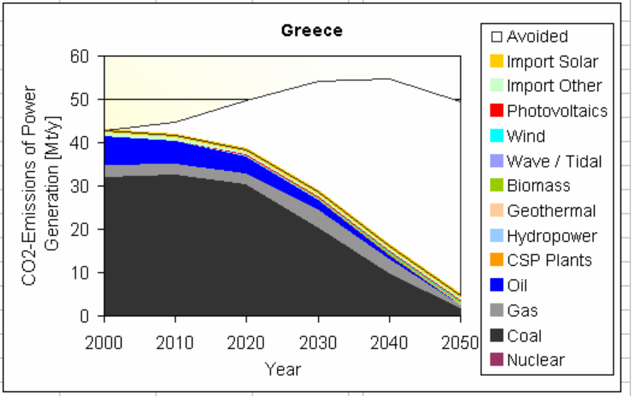

Austria
Average Electricity Cost [c/kWh]
4,0
4,5
5,0
5,5
6,0
6,5
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

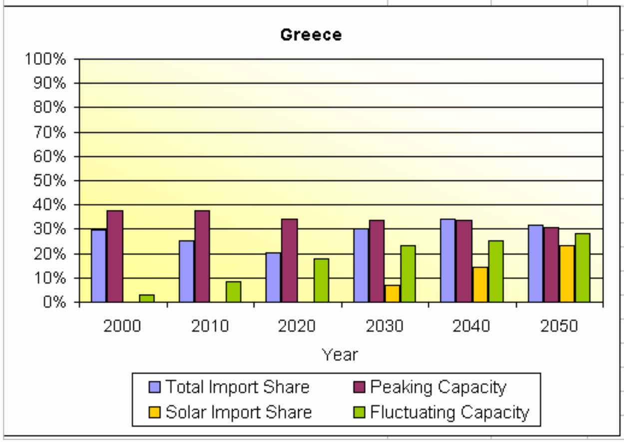
Greece

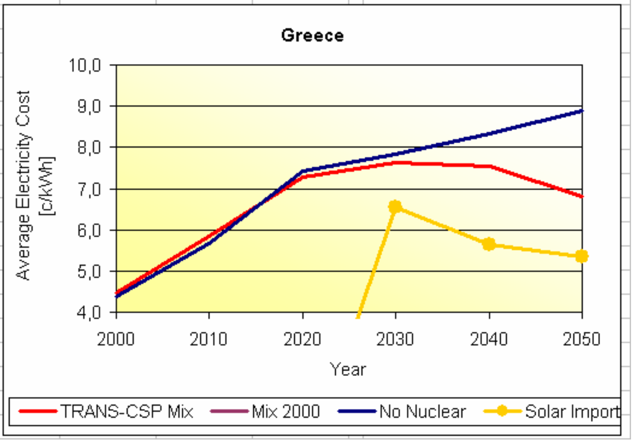

Greece
Gross Electricity [TWh/y]
0
10
20
30
40
50
60
70
80
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Greece
Installed Capacity [GW]
0
5
10
15
20
25
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

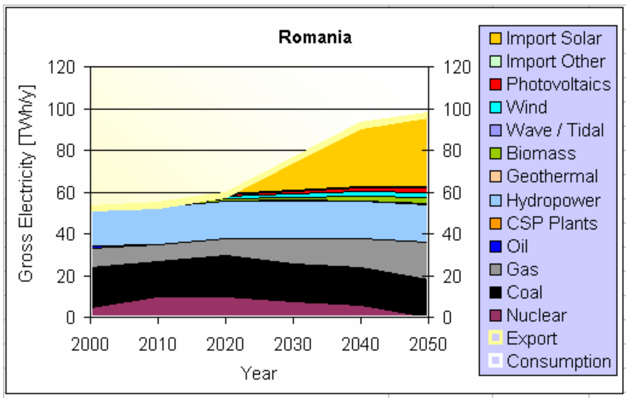

Greece
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

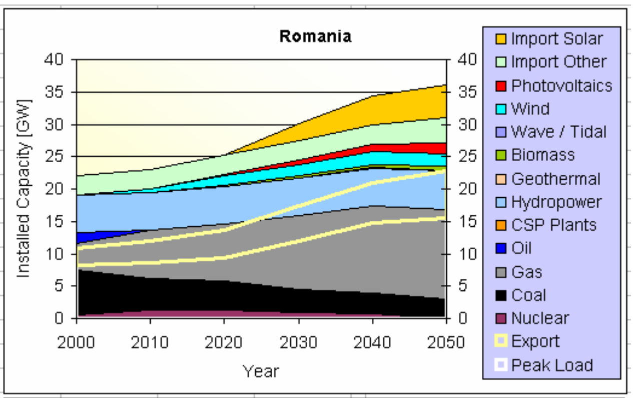

Greece
CO2-Emissions of Power Generation [Mt/y]
0
10
20
30
40
50
60
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

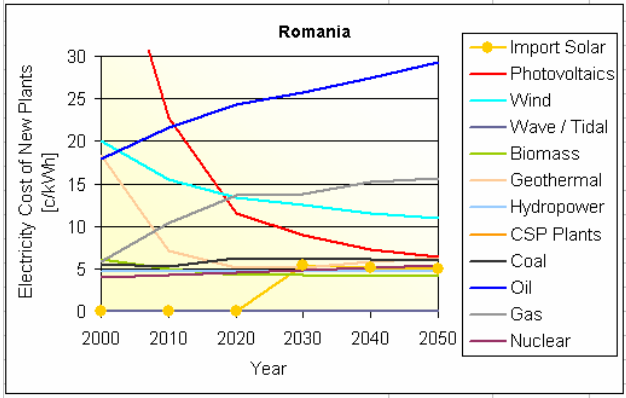

Greece
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Peaking Capacity
Solar Import Share
Fluctuating Capacity

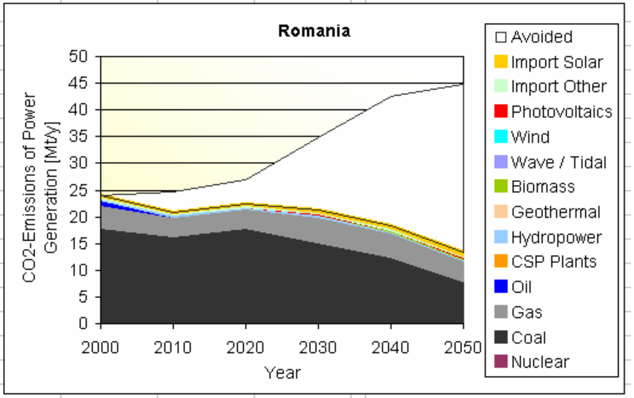

Greece
Average Electricity Cost [c/kWh]
4,0
5,0
6,0
7,0
8,0
9,0
10,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

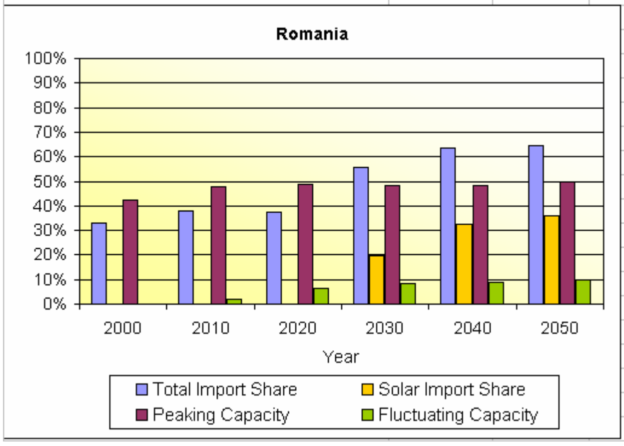
Romania

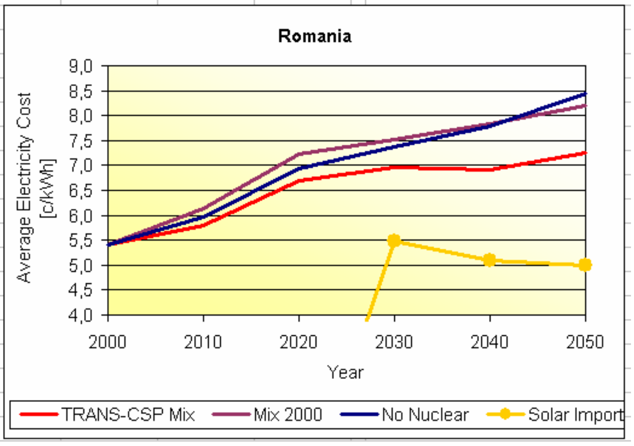

Romania
Gross Electricity [TWh/y]
0
20
40
60
80
100
120
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Romania
Installed Capacity [GW]
0
5
10
15
20
25
30
35
40
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

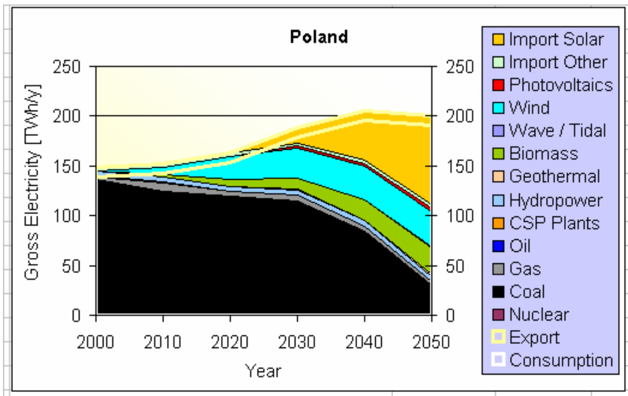

Romania
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

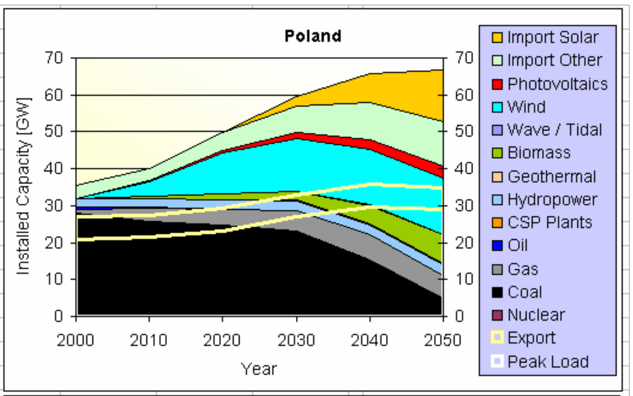

Romania
CO2-Emissions of Power Generation [Mt/y]
0
5
10
15
20
25
30
35
40
45
50
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

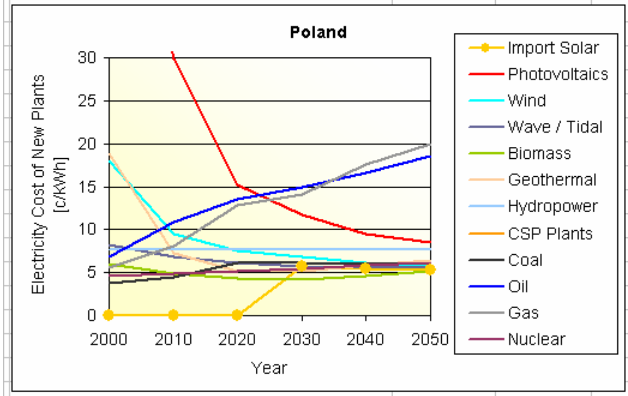

Romania
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

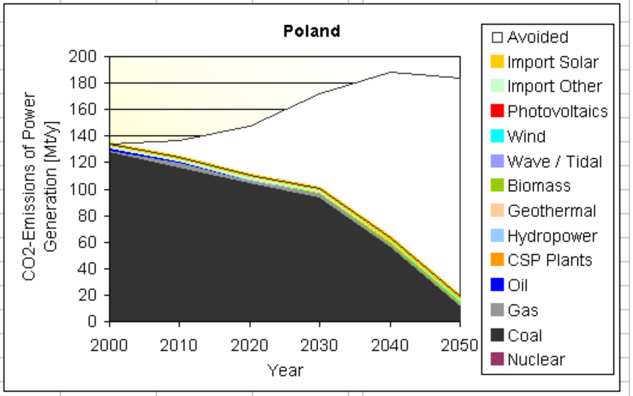

Romania
Average Electricity Cost [c/kWh]
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

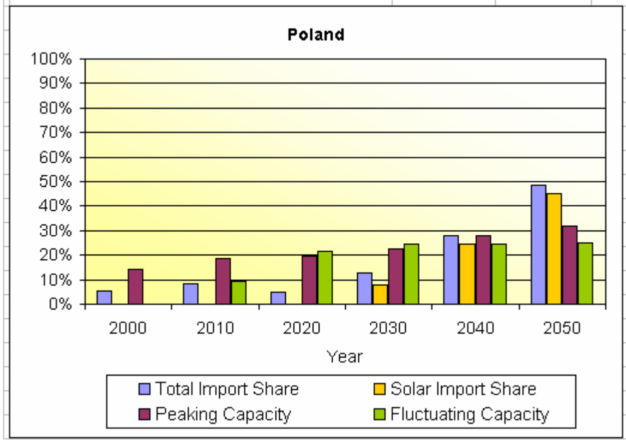
Poland

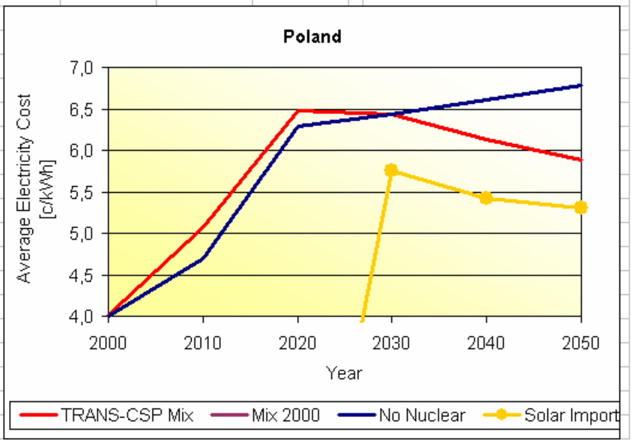

Poland
Gross Electricity [TWh/y]
250
200
150
100
50
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Poland
Installed Capacity [GW]
70
60
50
40
30
20
10
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

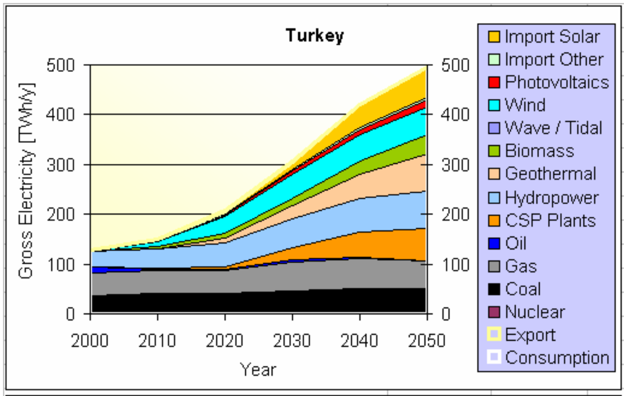

Poland
Electricity Cost of New Plants [c/kWh]
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

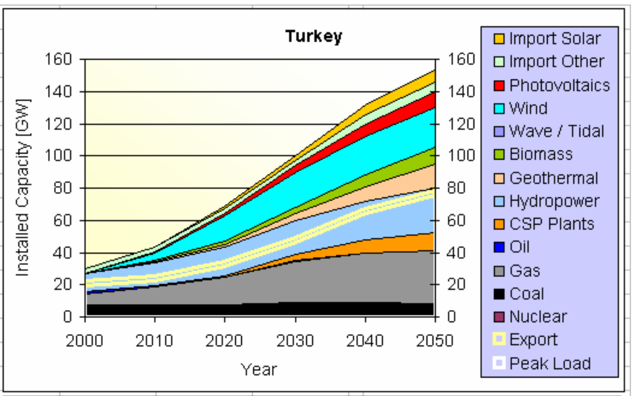

Poland
CO2-Emissions of Power Generation [Mt/y]
200
180
160
140
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

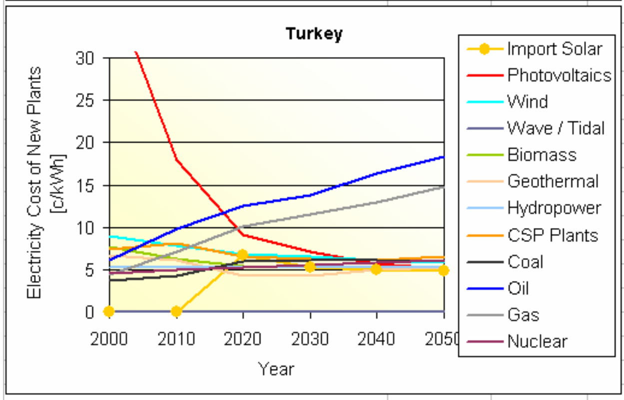

Poland
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

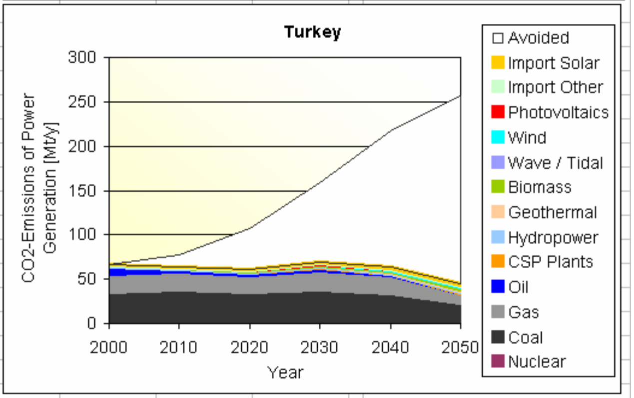

Poland
Average Electricity Cost [c/kWh]
7,0
6,5
6,0
5,5
5,0
4,5
4,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

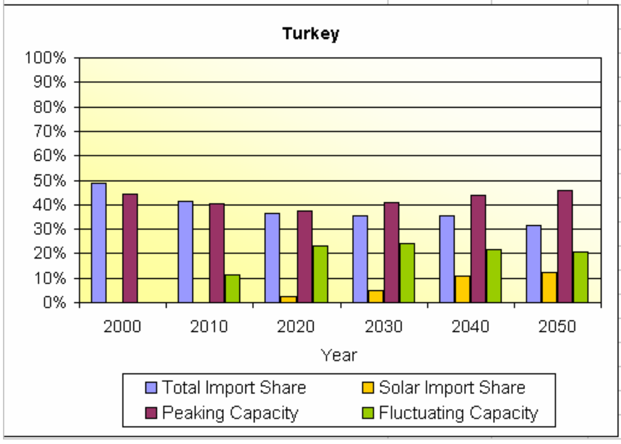
Turkey

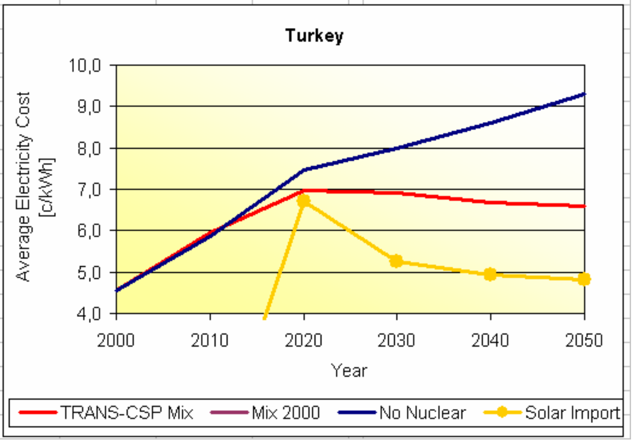

Turkey
Gross Electricity [TWh/y]
0
100
200
300
400
500
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Turkey
Installed Capacity [GW]
0
20
40
60
80
100
120
140
160
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

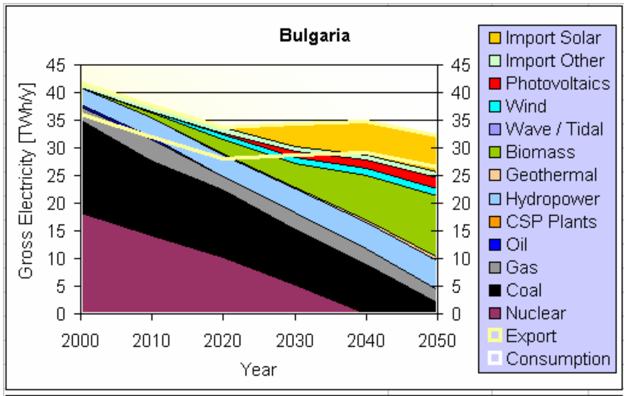

Turkey
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

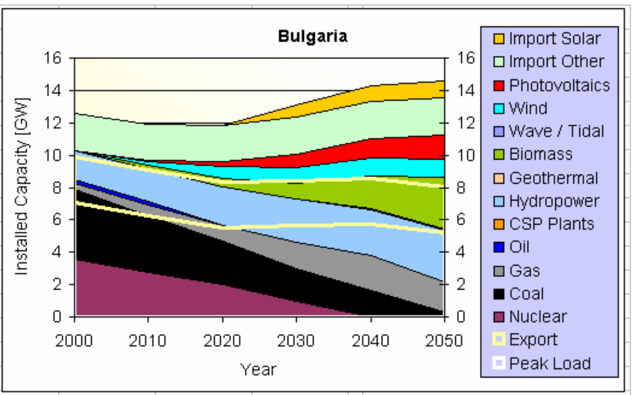

Turkey
CO2-Emissions of Power Generation [Mt/y]
0
50
100
150
200
250
300
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

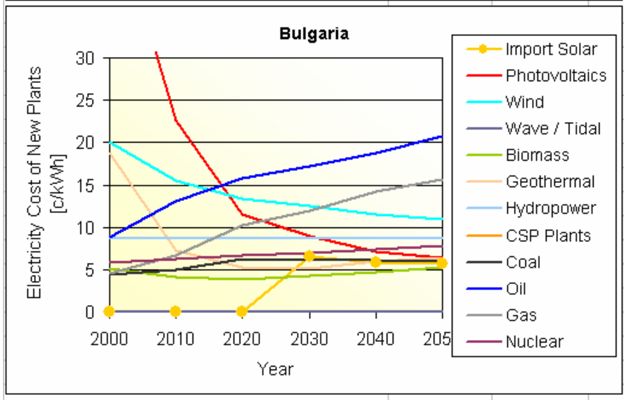

Turkey
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

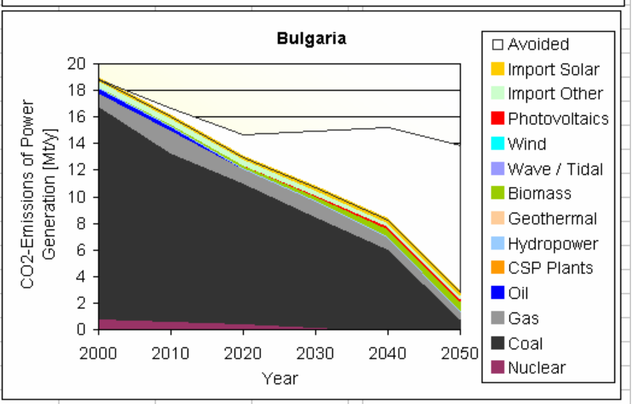

Turkey
Average Electricity Cost [c/kWh]
4,0
5,0
6,0
7,0
8,0
9,0
10,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

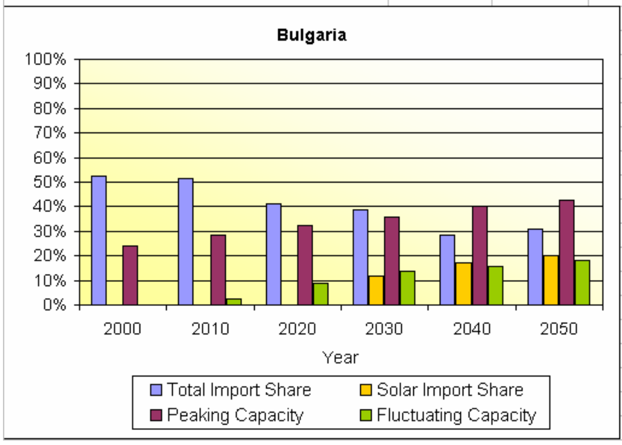
Bulgaria

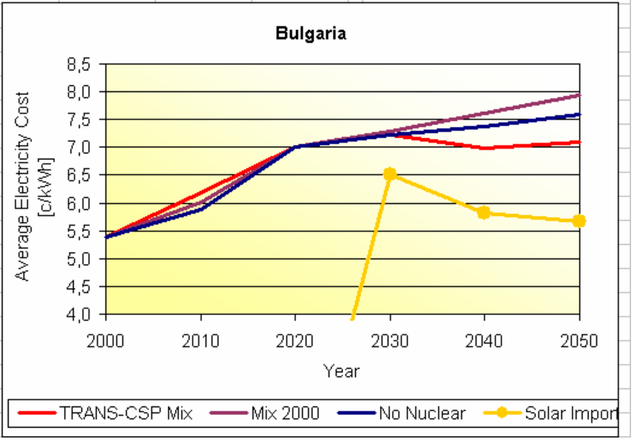

Bulgaria
Gross Electricity [TWh/y]
0
5
10
15
20
25
30
35
40
45
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Bulgaria
Installed Capacity [GW]
0
2
4
6
8
10
12
14
16
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

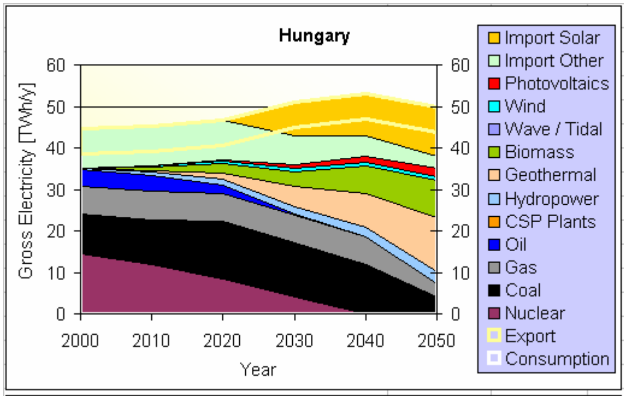

Bulgaria
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
205
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

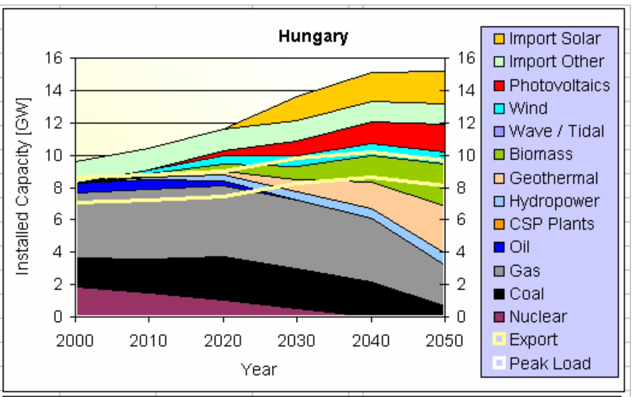

Bulgaria
CO2-Emissions of Power Generation [Mt/y]
0
2
4
6
8
10
12
14
16
18
20
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

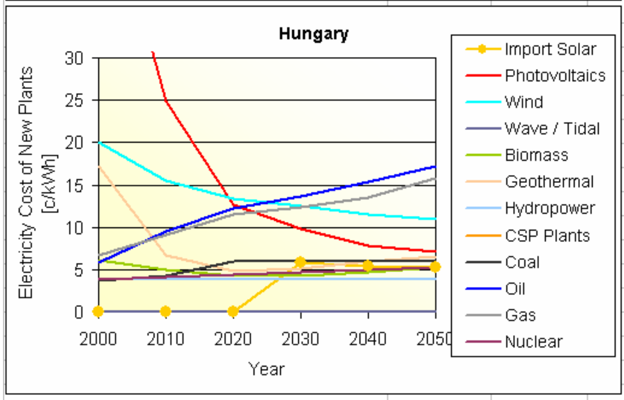

Bulgaria
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

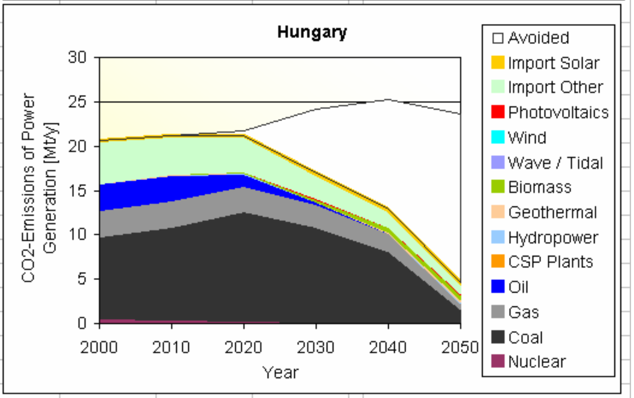

Bulgaria
Average Electricity Cost [c/kWh]
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

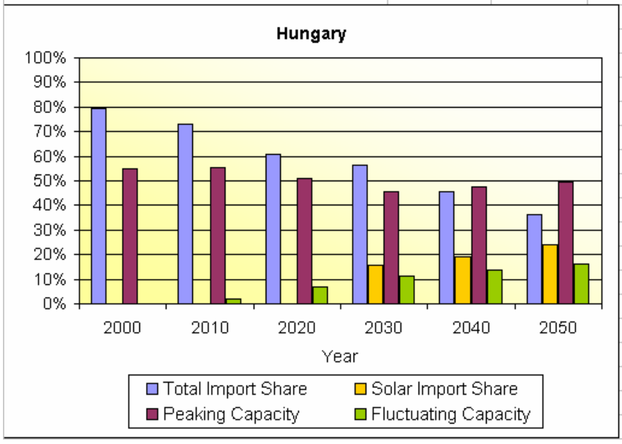
Hungary

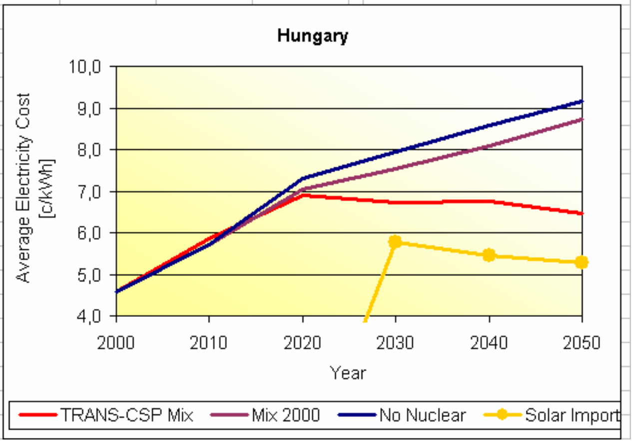

Hungary
Gross Electricity [TWh/y]
0
10
20
30
40
50
60
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Hungary
Installed Capacity [GW]
0
2
4
6
8
10
12
14
16
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

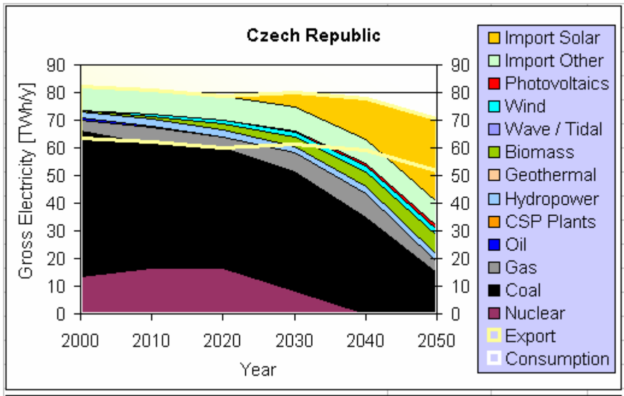

Hungary
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

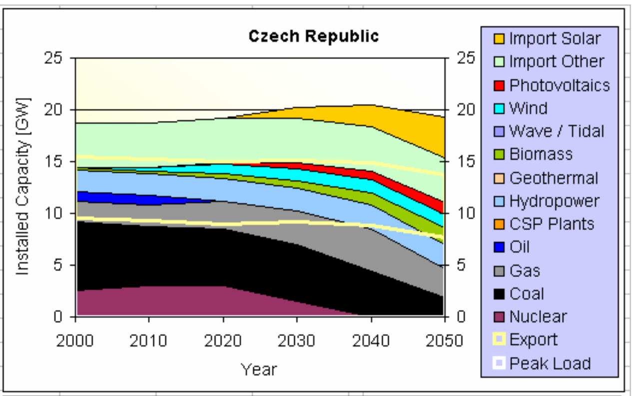

Hungary
CO2-Emissions of Power Generation [Mt/y]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

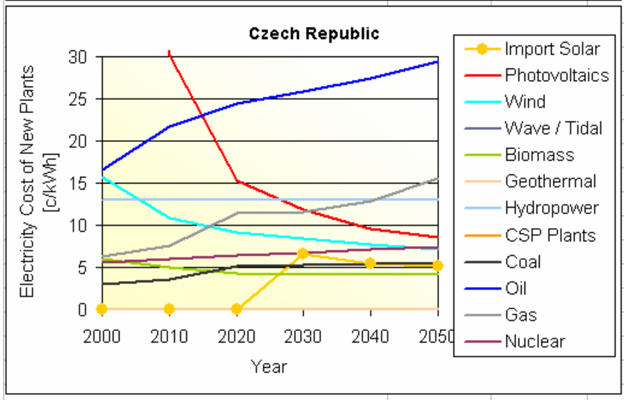

Hungary
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Total Import Share
Solar Import Share
Peaking Capacity
Fluctuating Capacity

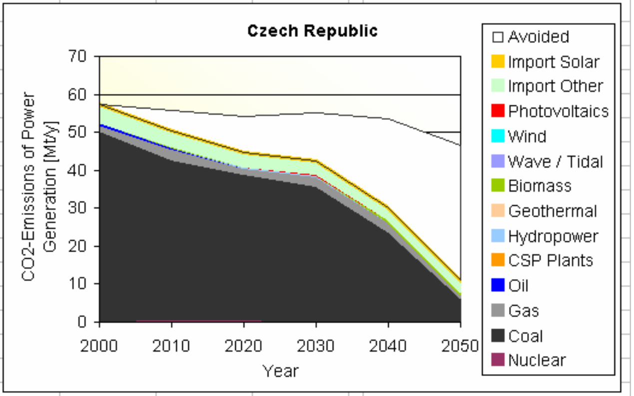

Hungary
Average Electricity Cost [c/kWh]
4,0
5,0
6,0
7,0
8,0
9,0
10,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

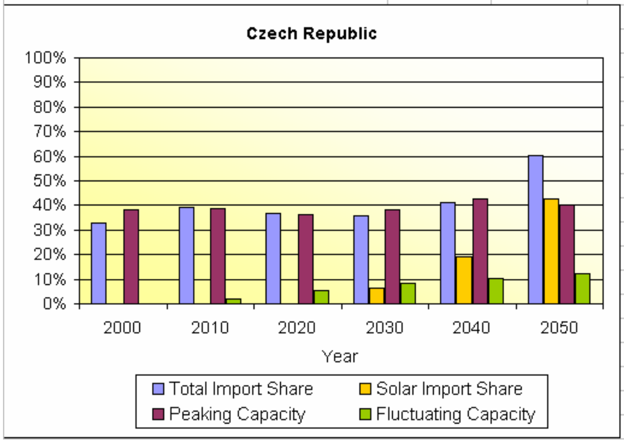
Czech Republic

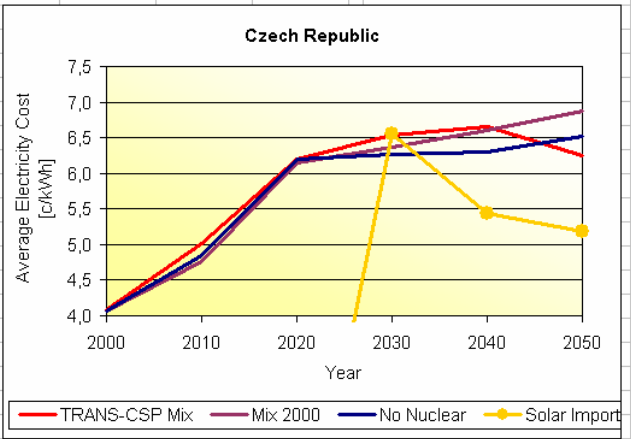




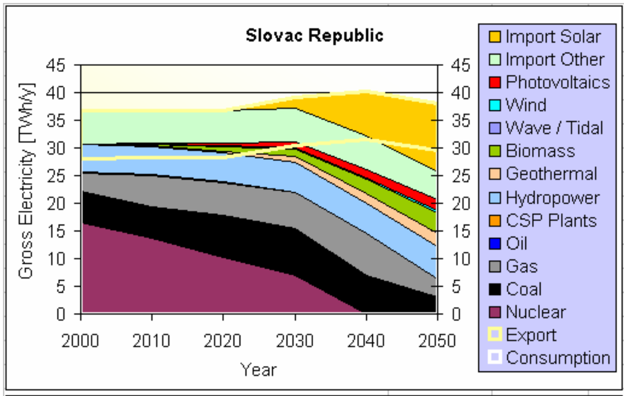


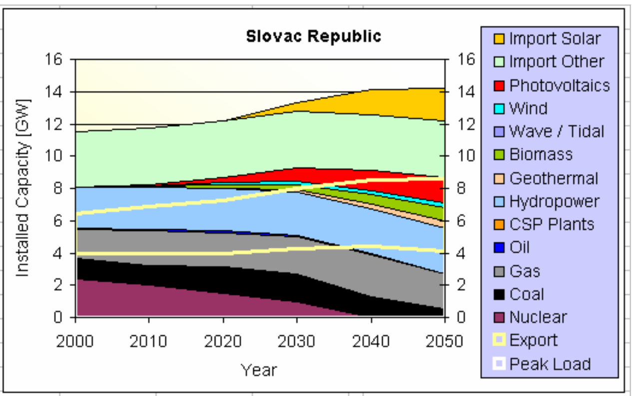


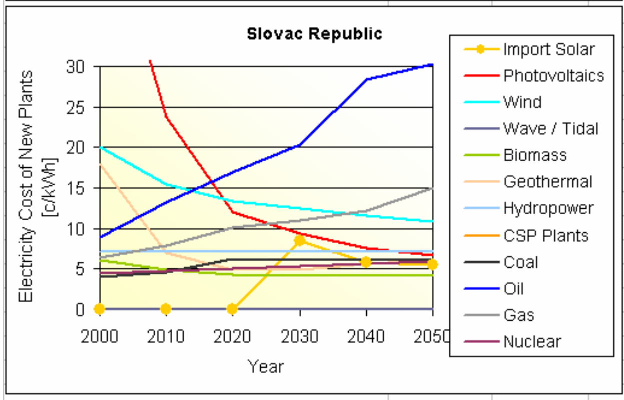


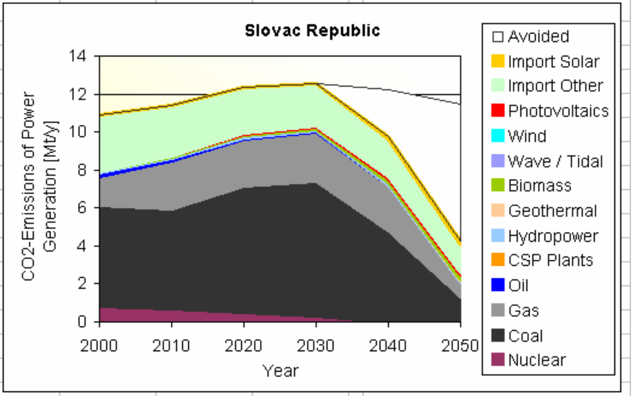


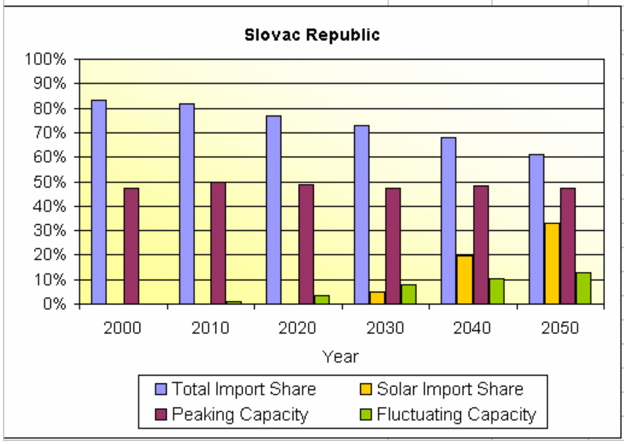
Slovac Republic

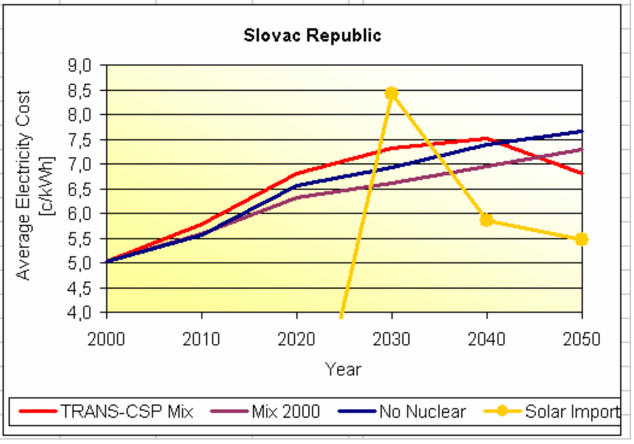




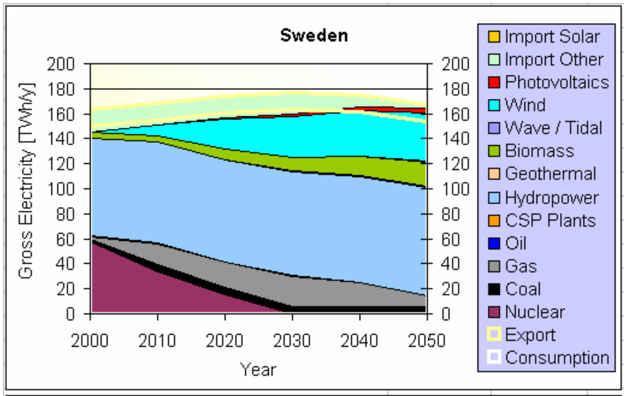


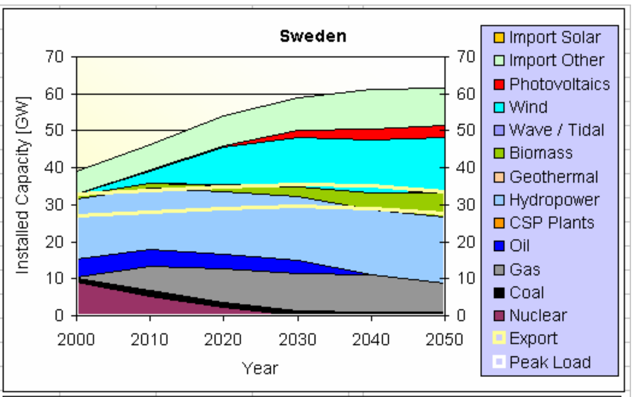


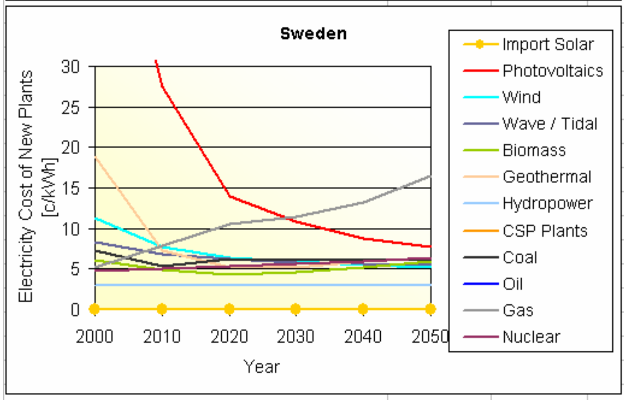


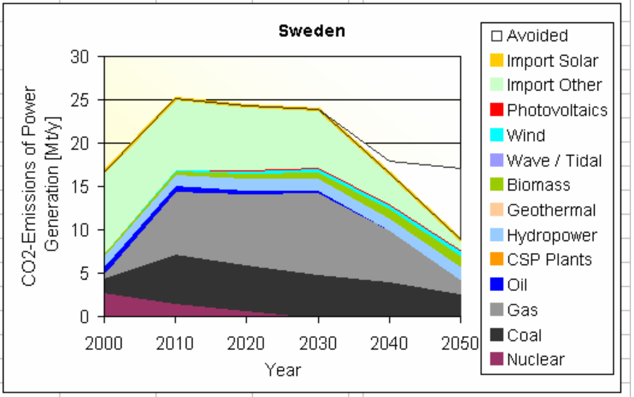


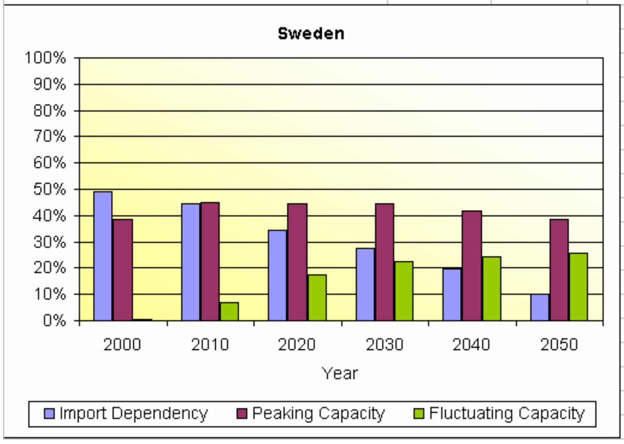
Sweden

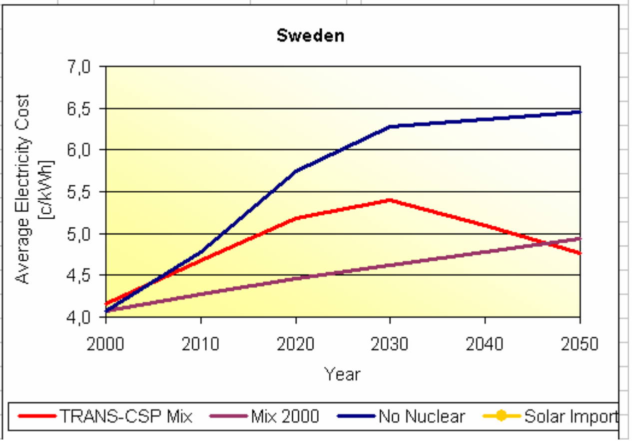

Sweden
Gross Electricity [TWh/y]
200
180
160
140
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Sweden
Installed Capacity [GW]
70
60
50
40
30
20
10
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

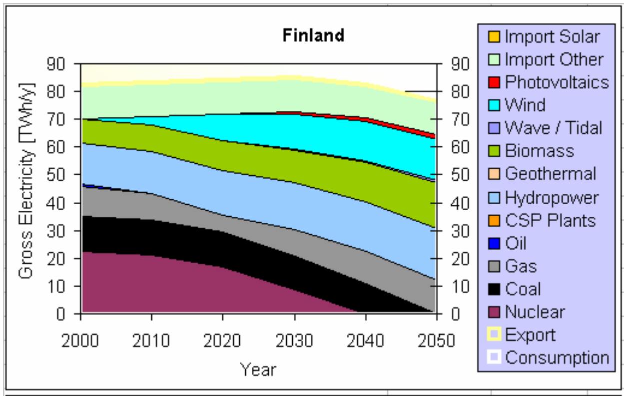

Sweden
Electricity Cost of New Plants [c/kWh]
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

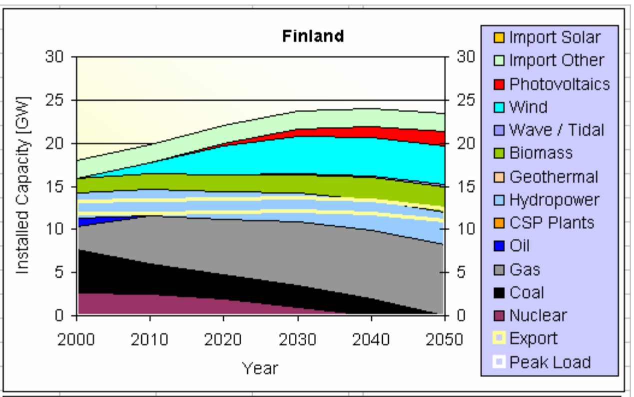

Sweden
CO2-Emissions of Power Generation [Mt/y]
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

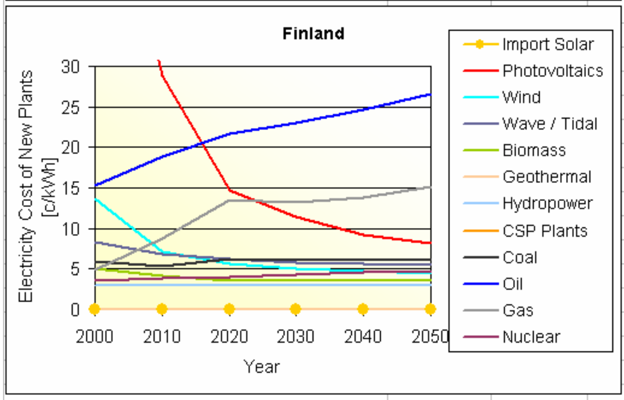

Sweden
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

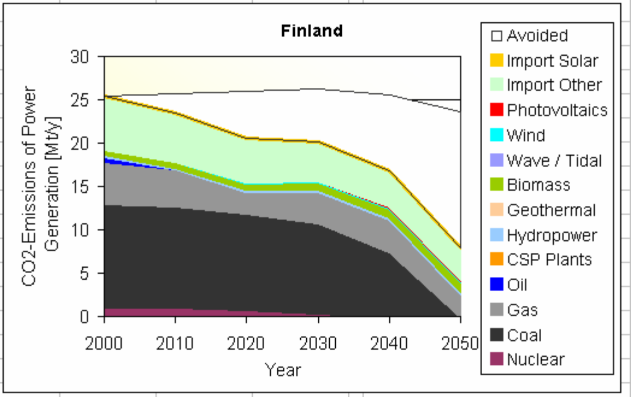

Sweden
Average Electricity Cost [c/kWh]
7,0
6,5
6,0
5,5
5,0
4,5
4,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

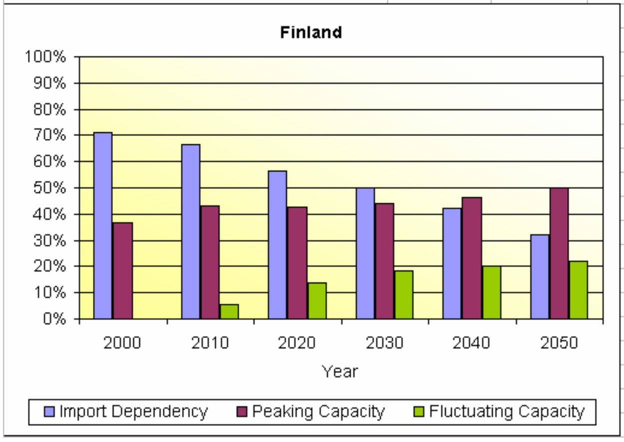
Finland

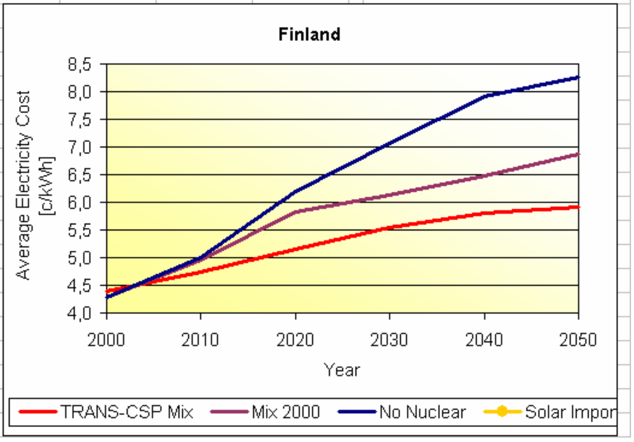

Finland
Gross Electricity [TWh/y]
0
10
20
30
40
50
60
70
80
90
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Finland
Installed Capacity [GW]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

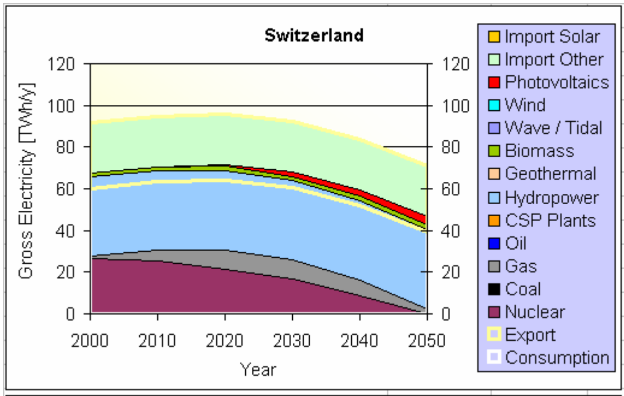

Finland
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

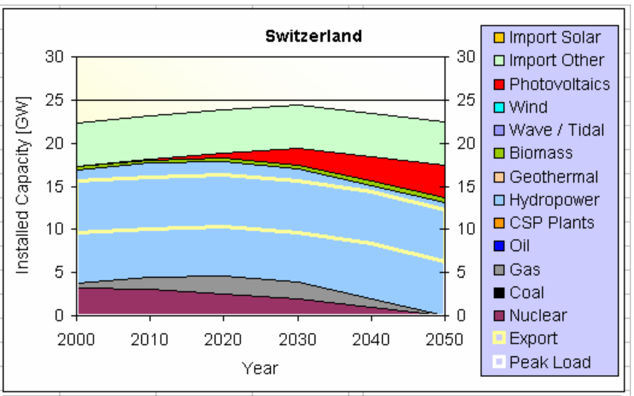

Finland
CO2-Emissions of Power Generation [Mt/y]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

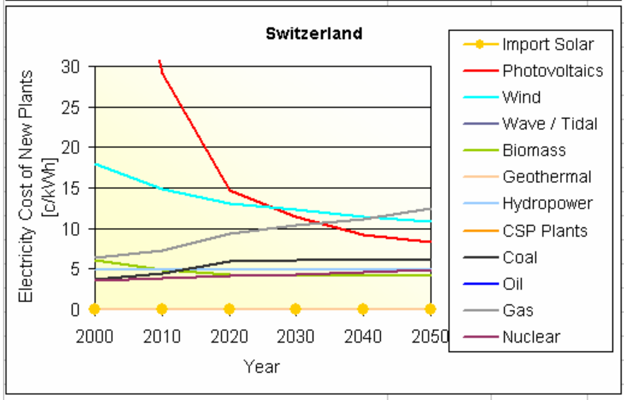

Finland
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

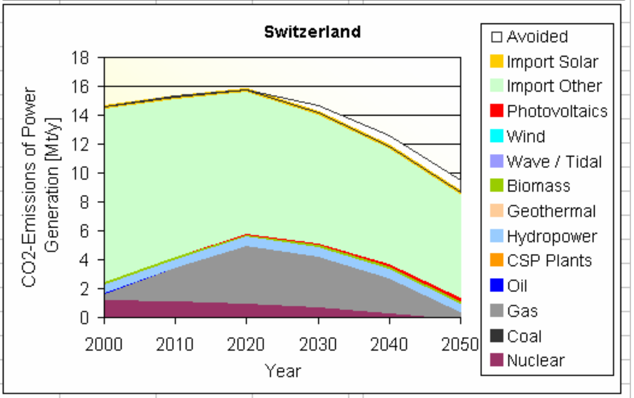

Finland
Average Electricity Cost [c/kWh]
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Impor

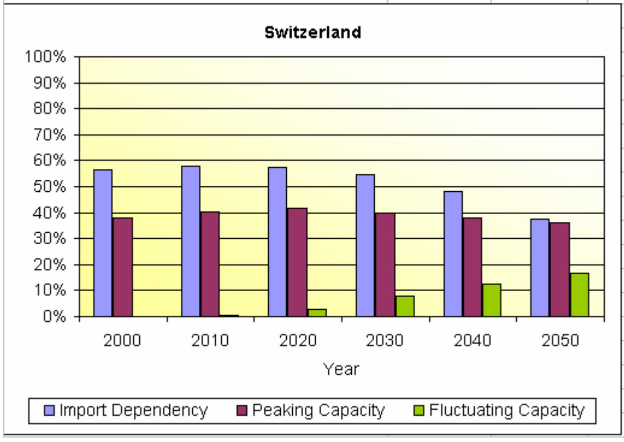
Switzerland

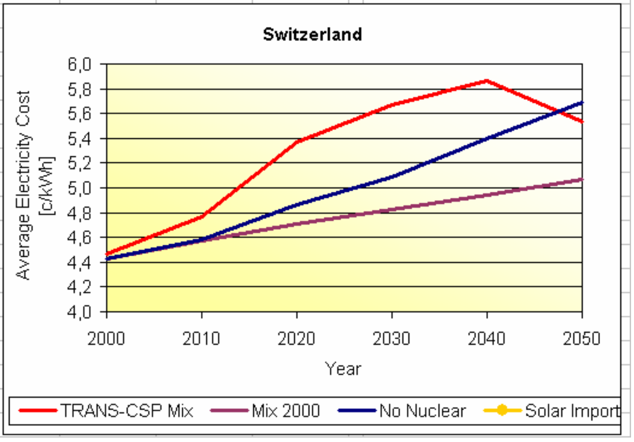




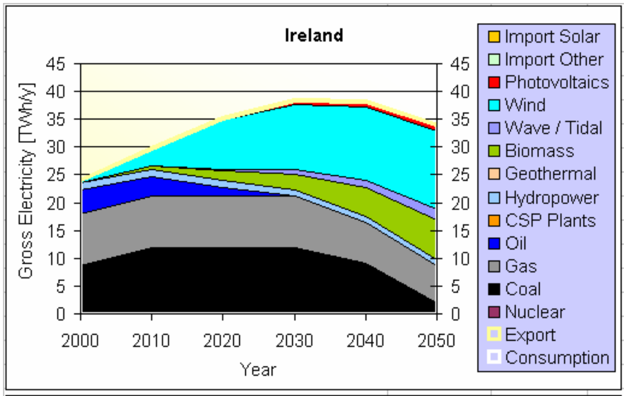


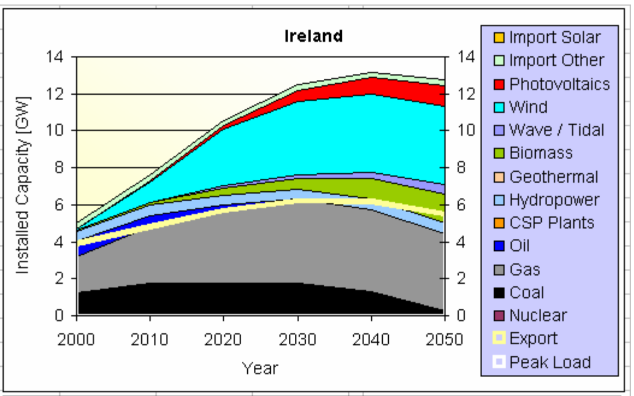


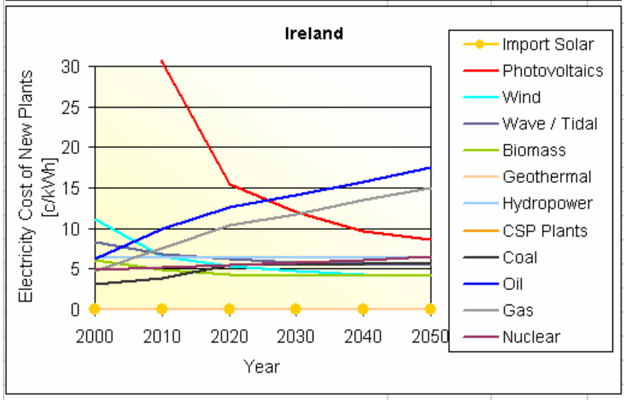


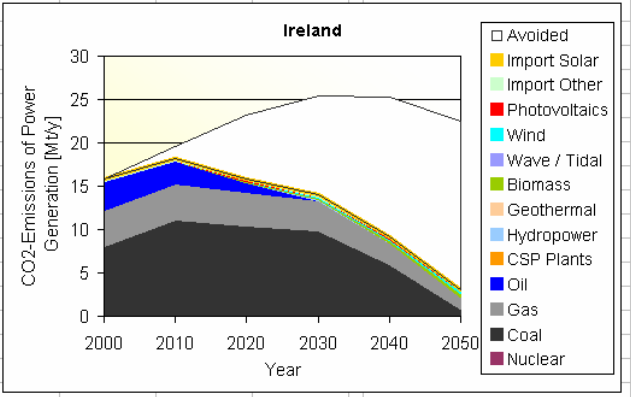


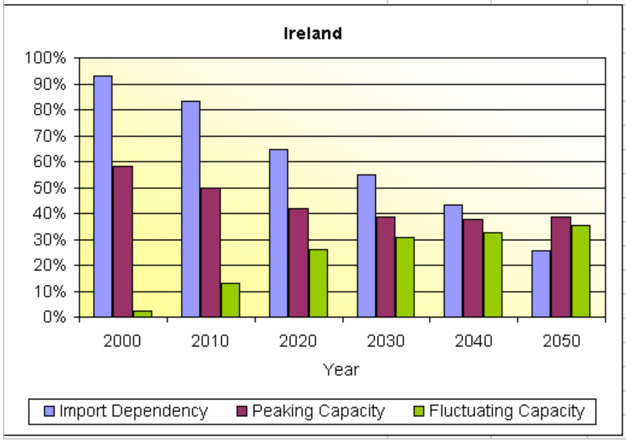
Ireland

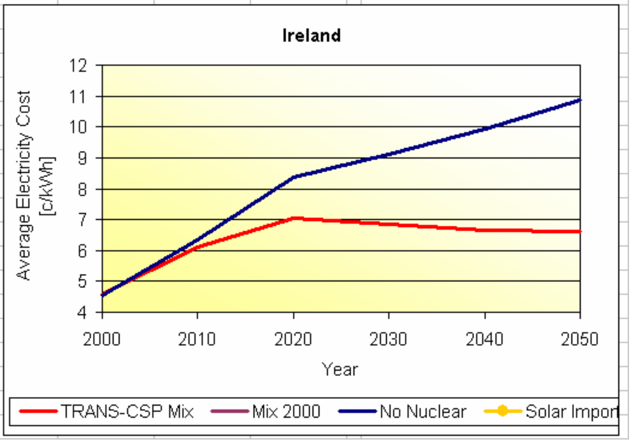

Ireland
Gross Electricity [TWh/y]
0
5
10
15
20
25
30
35
40
45
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Ireland
Installed Capacity [GW]
0
2
4
6
8
10
12
14
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

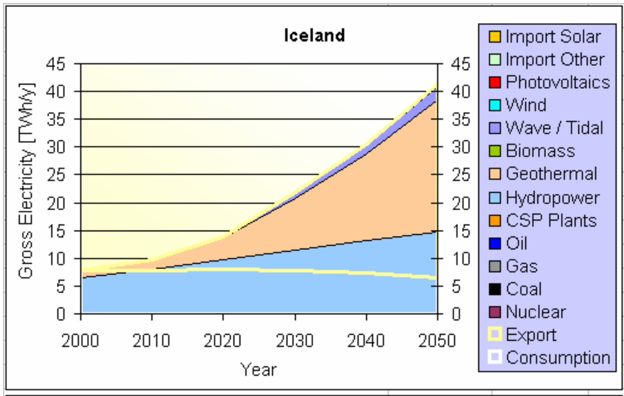

Ireland
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

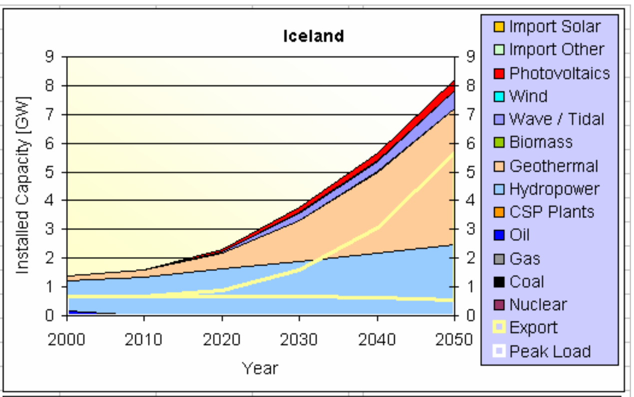

Ireland
CO2-Emissions of Power Generation [Mt/y]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

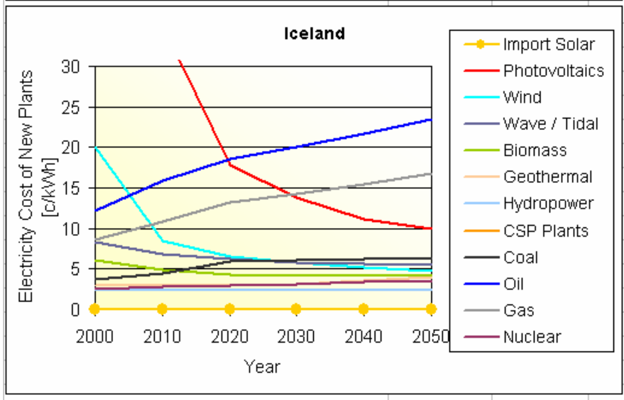

Ireland
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

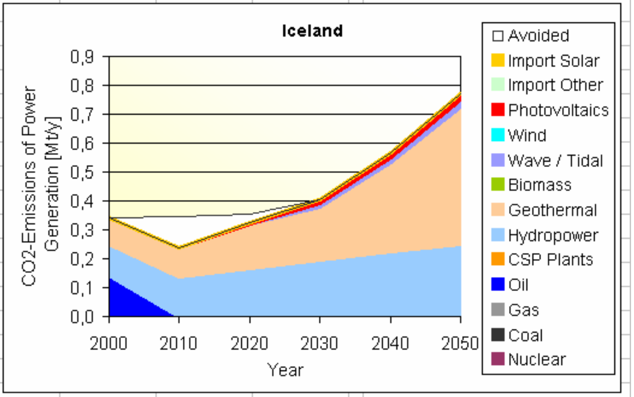

Ireland
Average Electricity Cost [c/kWh]
4
5
6
7
8
9
10
11
12
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

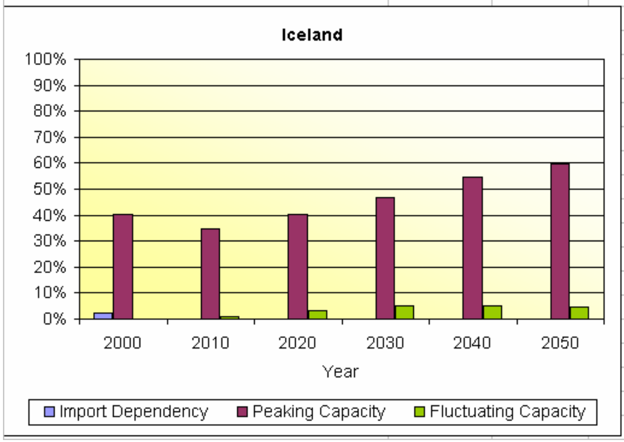
Iceland

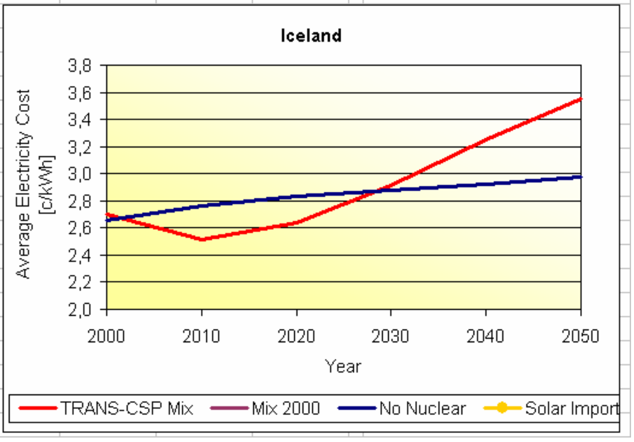

Iceland
Gross Electricity [TWh/y]
0
5
10
15
20
25
30
35
40
45
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Iceland
Installed Capacity [GW]
0
1
2
3
4
5
6
7
8
9
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

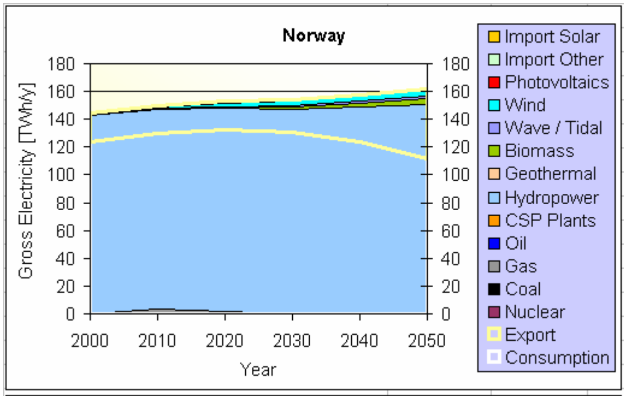

Iceland
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

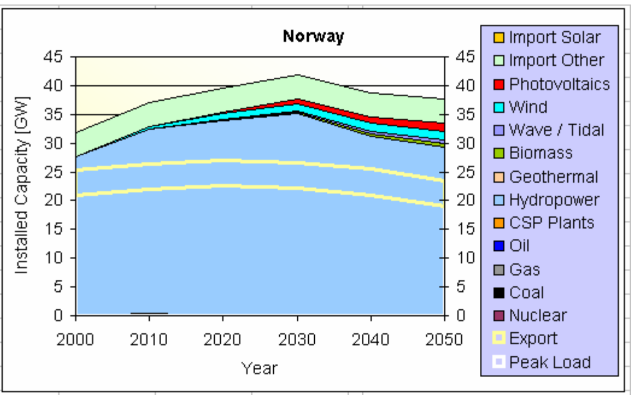

Iceland
CO2-Emissions of Power Generation [Mt/y]
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

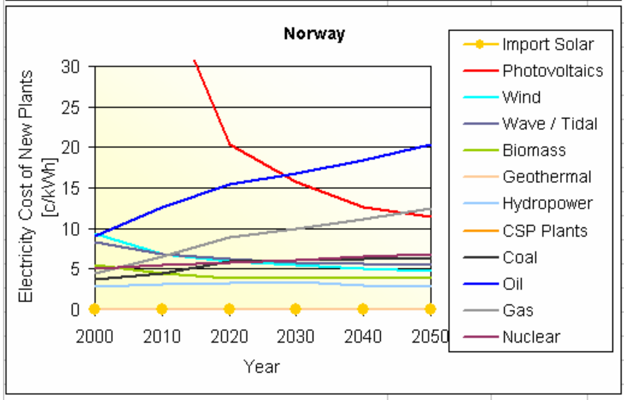

Iceland
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

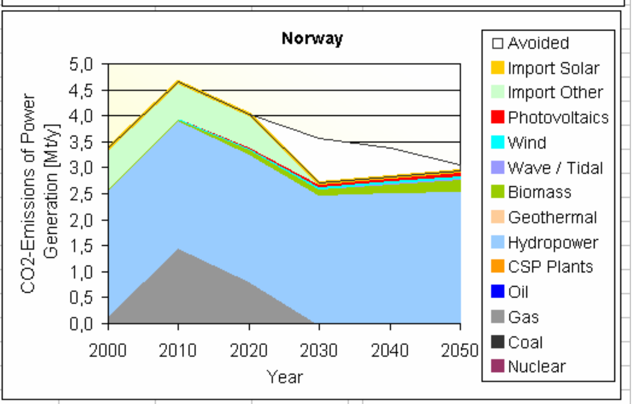

Iceland
Average Electricity Cost [c/kWh]
2,0
2,2
2,4
2,6
2,8
3,0
3,2
3,4
3,6
3,8
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

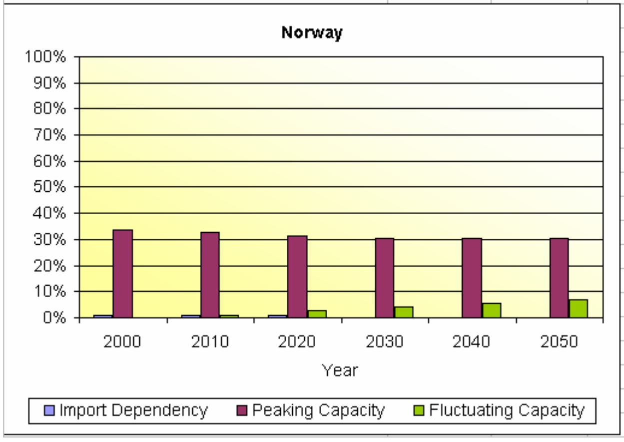
Norway

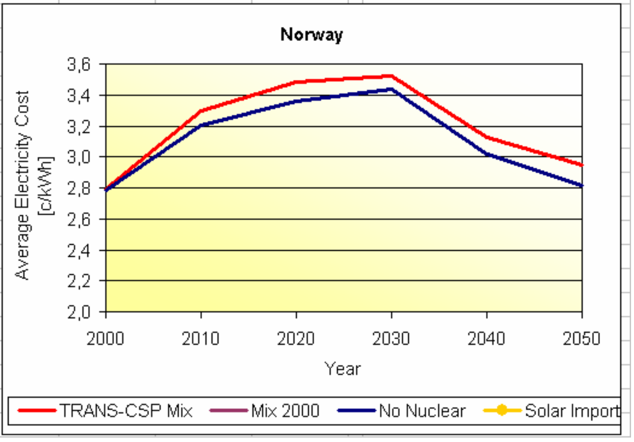

Norway
Gross Electricity [TWh/y]
180
160
140
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Norway
Installed Capacity [GW]
45
40
35
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

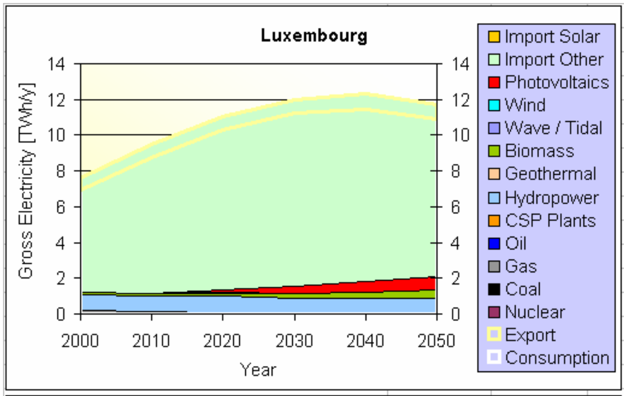

Norway
Electricity Cost of New Plants [c/kWh]
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

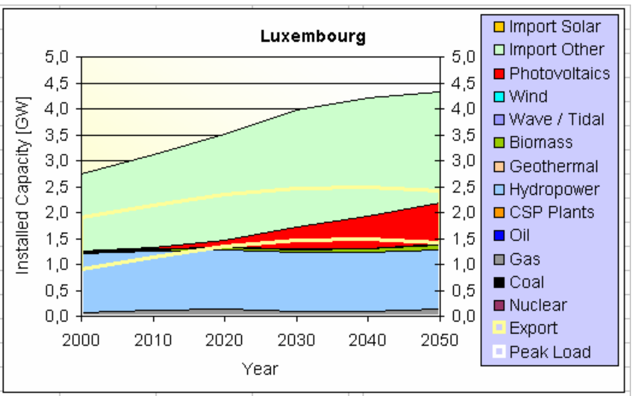

Norway
CO2-Emissions of Power Generation [Mt/y]
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

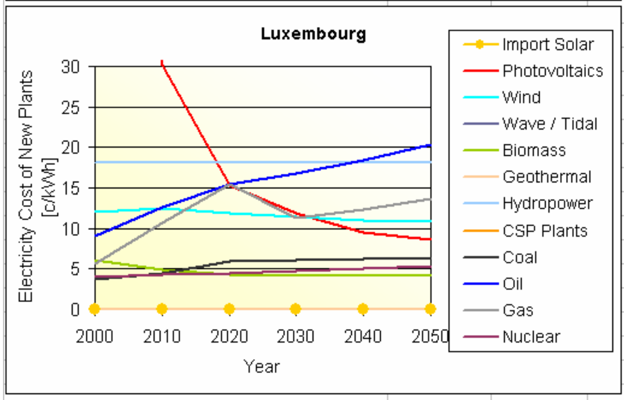

Norway
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

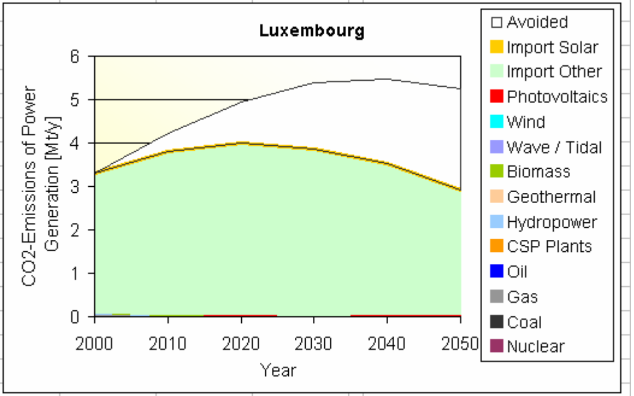

Norway
Average Electricity Cost [c/kWh]
3,6
3,4
3,2
3,0
2,8
2,6
2,4
2,2
2,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

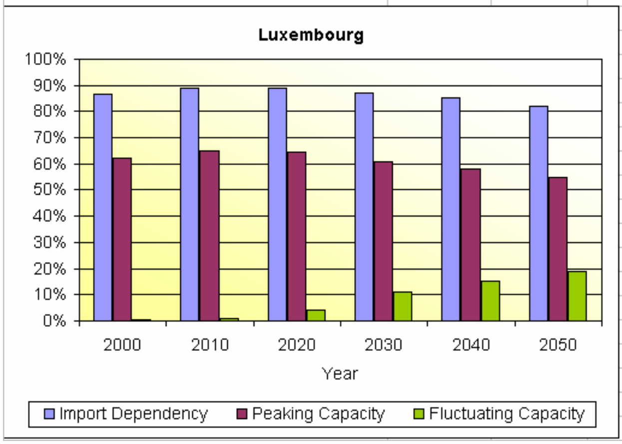
Luxembourg

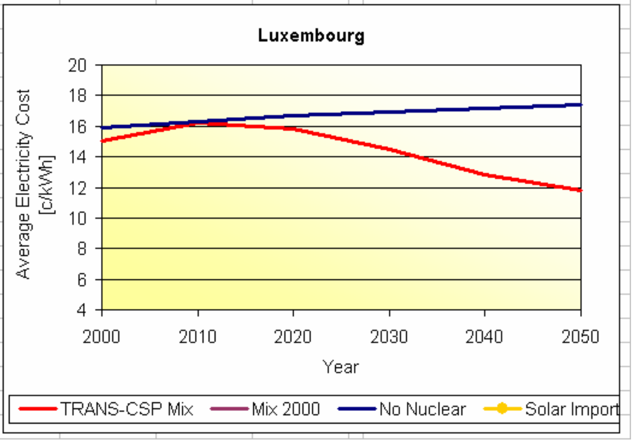

Luxembourg
Gross Electricity [TWh/y]
0
2
4
6
8
10
12
14
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Luxembourg
Installed Capacity [GW]
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

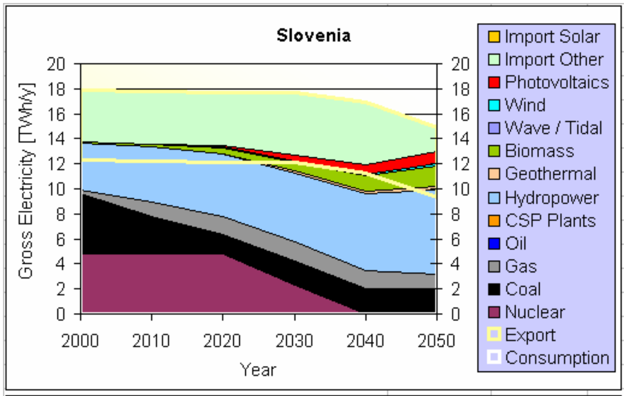

Luxembourg
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

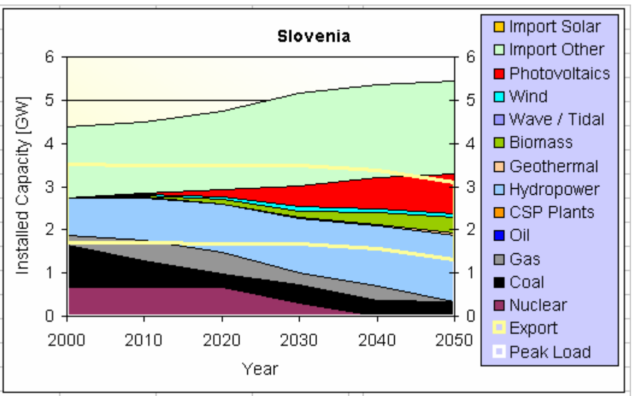

Luxembourg
CO2-Emissions of Power Generation [Mt/y]
0
1
2
3
4
5
6
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

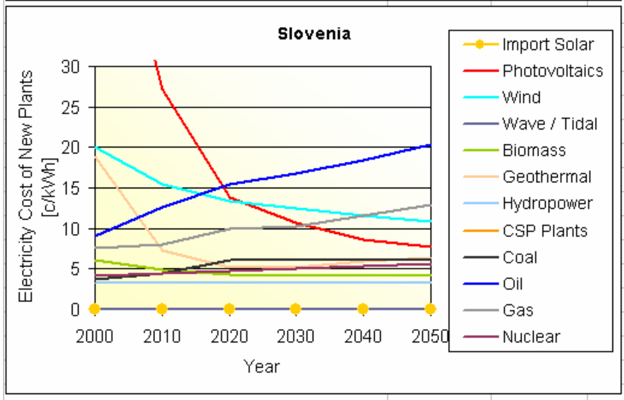

Luxembourg
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

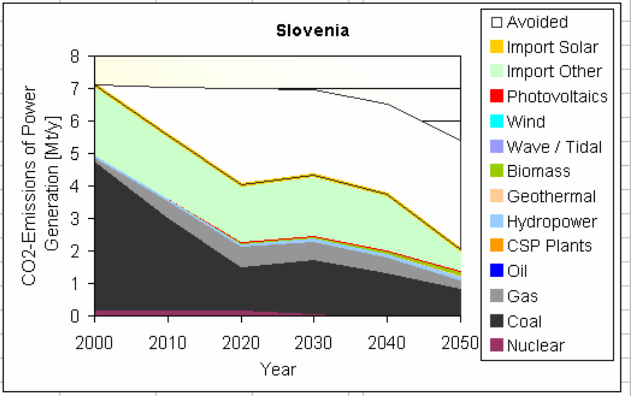

Luxembourg
Average Electricity Cost [c/kWh]
4
6
8
10
12
14
16
18
20
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

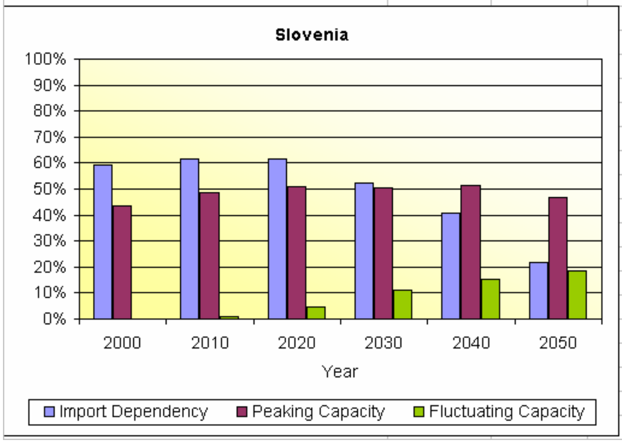
Slovenia

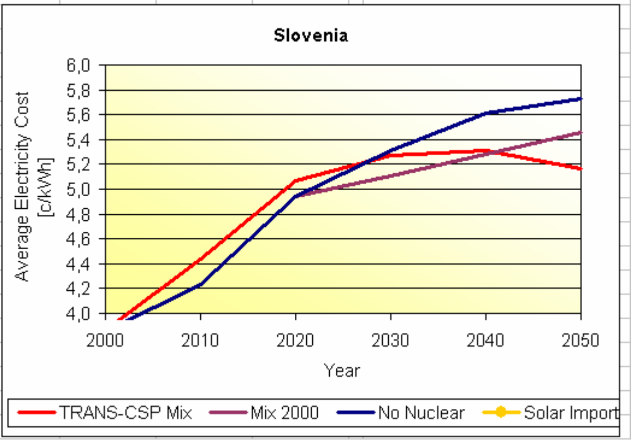

Slovenia
Gross Electricity [TWh/y]
0
2
4
6
8
10
12
14
16
18
20
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Slovenia
Installed Capacity [GW]
0
1
2
3
4
5
6
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

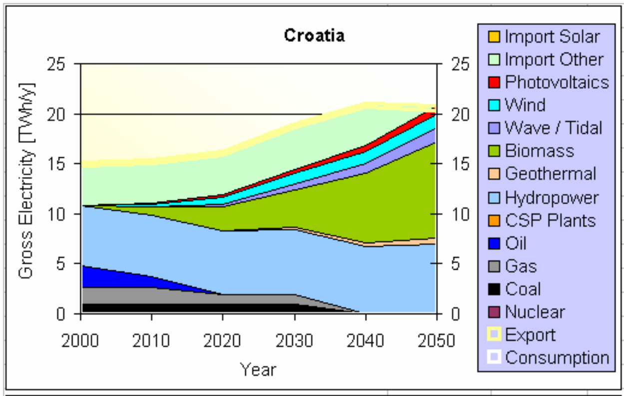

Slovenia
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

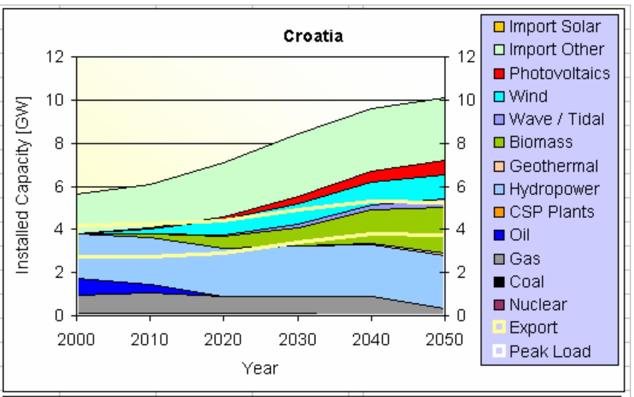

Slovenia
CO2-Emissions of Power Generation [Mt/y]
0
1
2
3
4
5
6
7
8
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

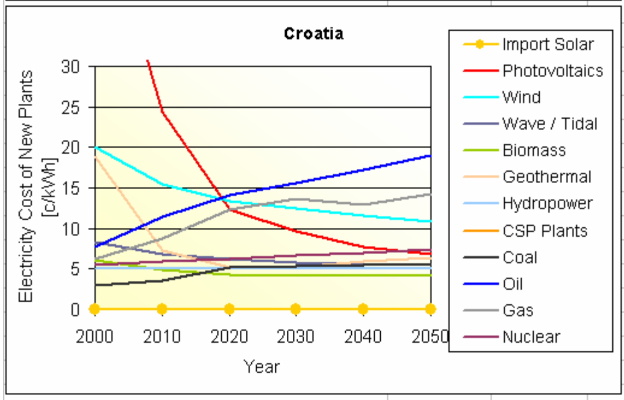

Slovenia
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

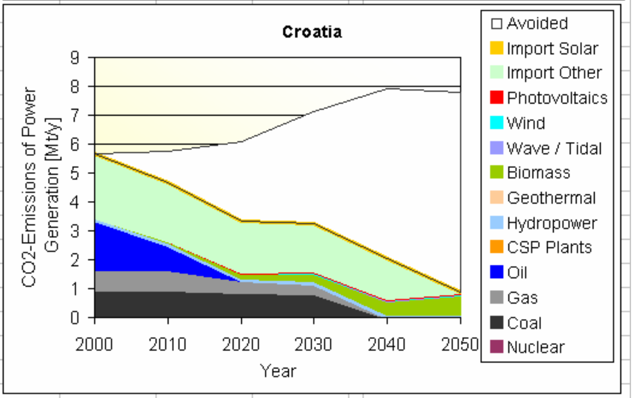

Slovenia
Average Electricity Cost [c/kWh]
4,0
4,2
4,4
4,6
4,8
5,0
5,2
5,4
5,6
5,8
6,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

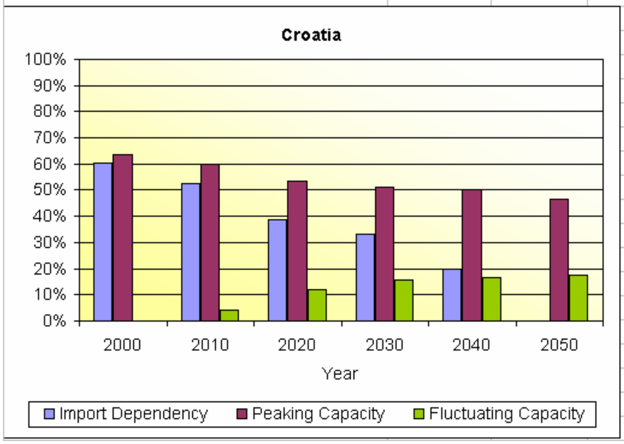
Croatia

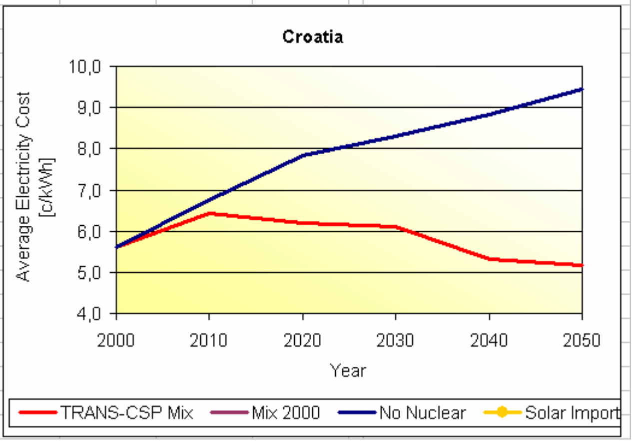

Croatia
Gross Electricity [TWh/y]
0
5
10
15
20
25
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Croatia
Installed Capacity [GW]
0
2
4
6
8
10
12
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load

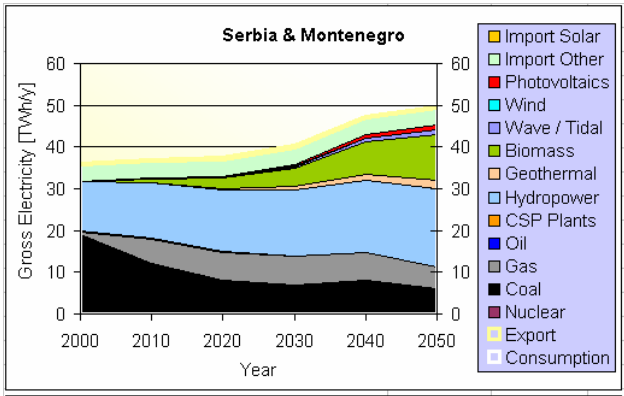

Croatia
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear

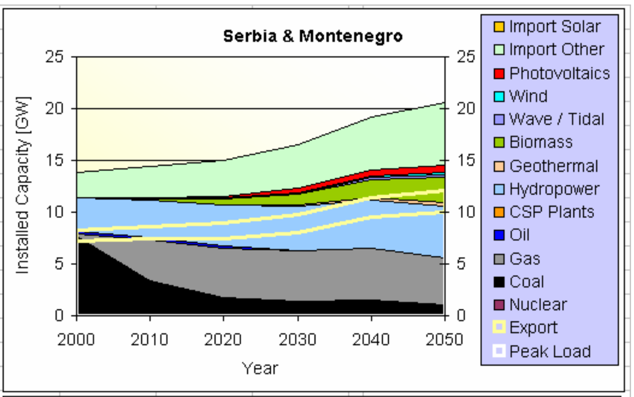

Croatia
CO2-Emissions of Power Generation [Mt/y]
0
1
2
3
4
5
6
7
8
9
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear

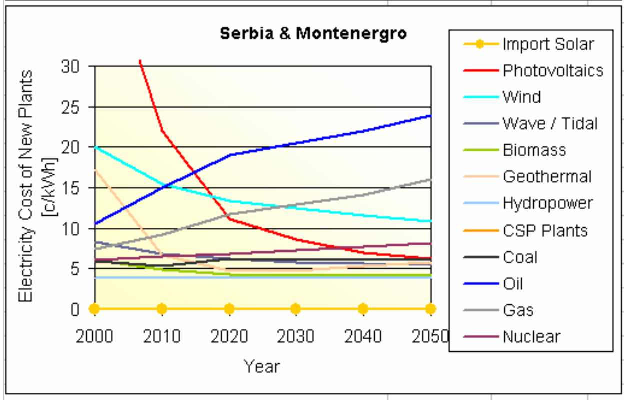

Croatia
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity

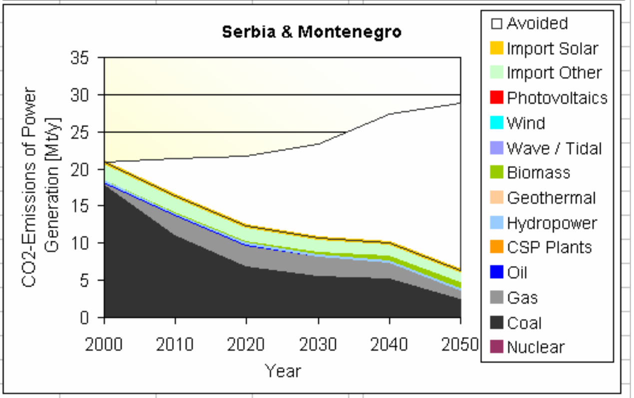

Croatia
Average Electricity Cost [c/kWh]
4,0
5,0
6,0
7,0
8,0
9,0
10,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

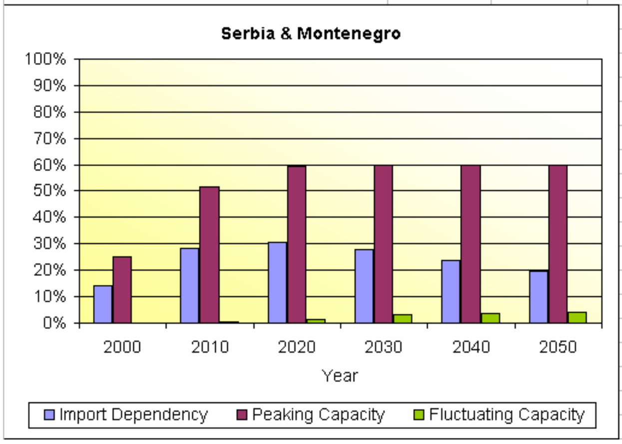
Serbia & Montenegro

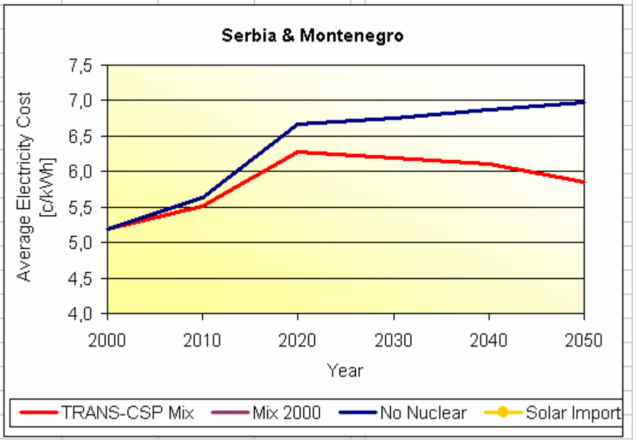




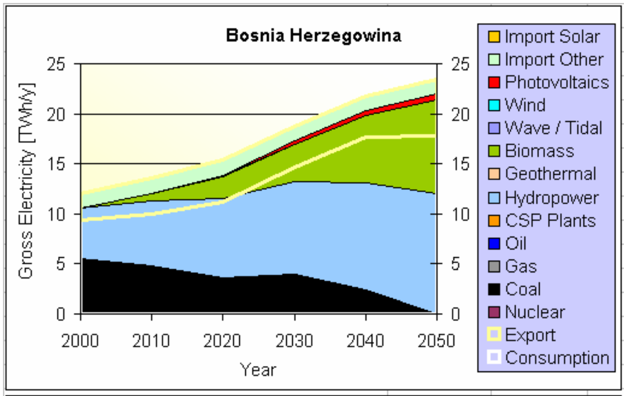


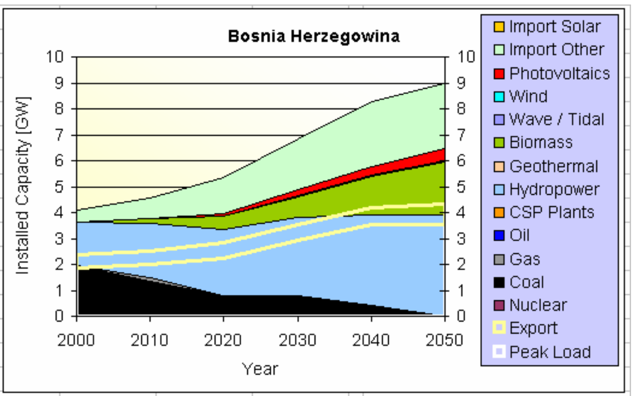


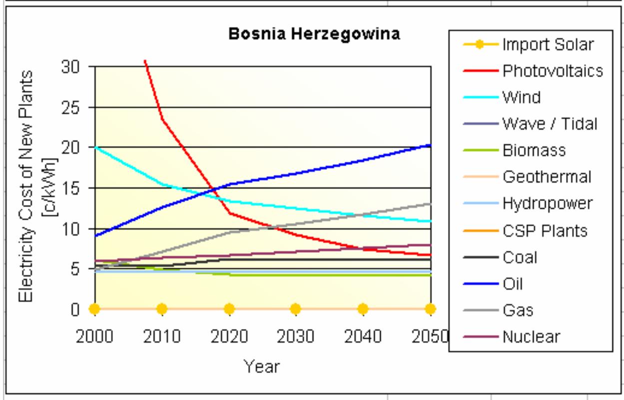


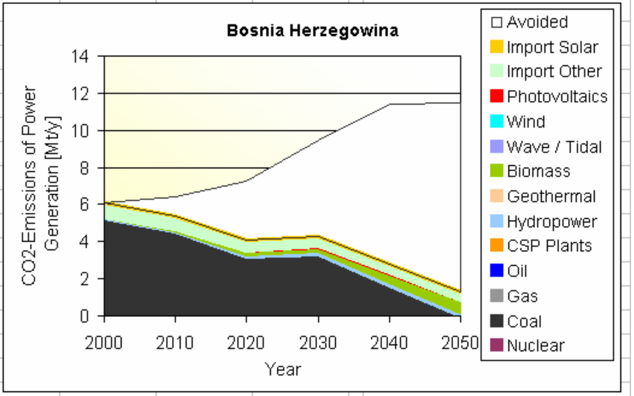


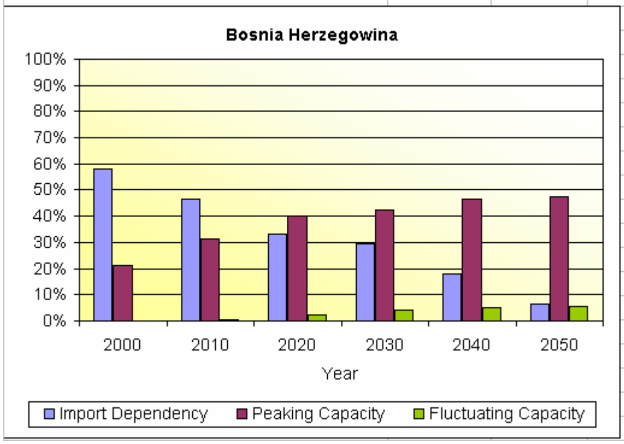
Bosnia & Herzegowina

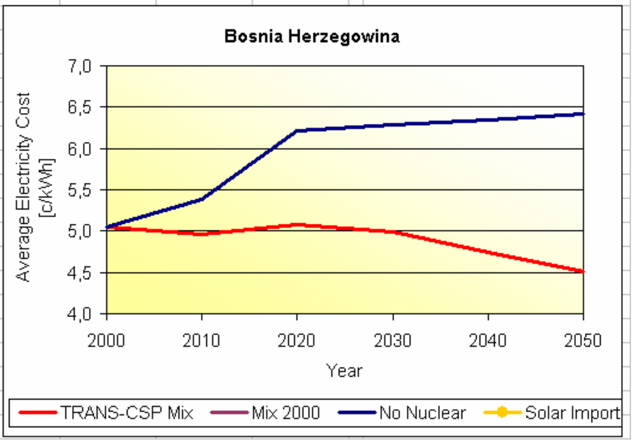




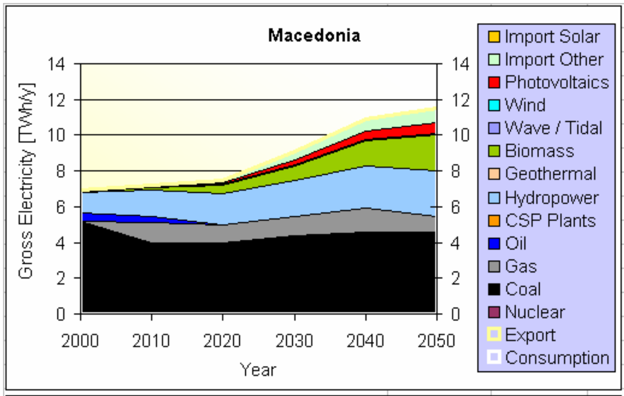


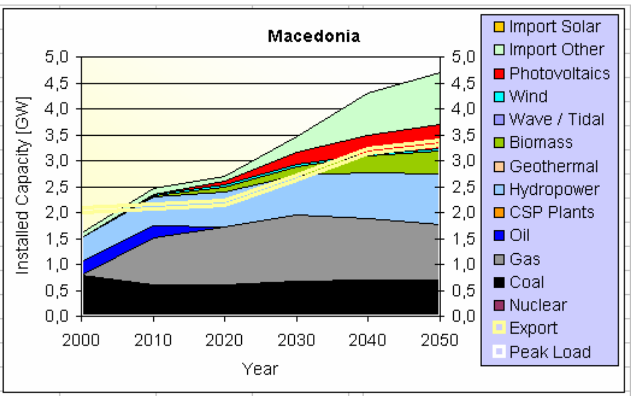


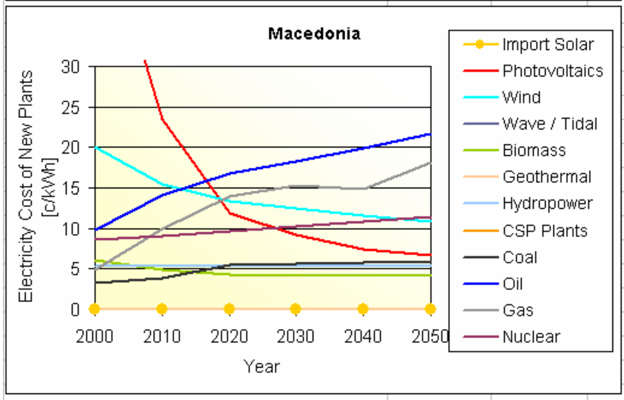


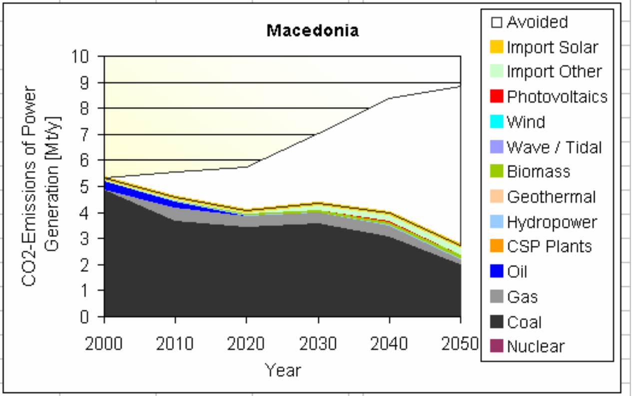


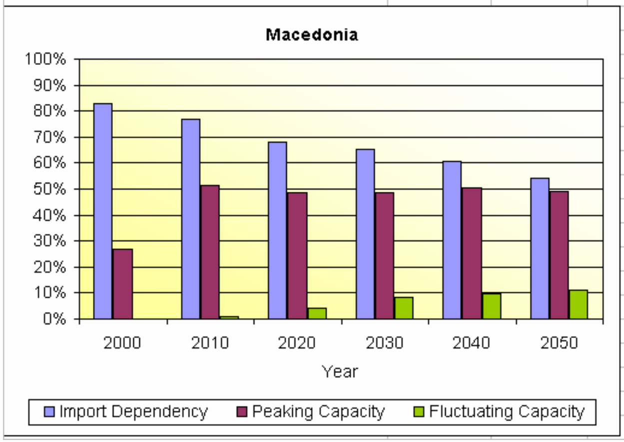
Macedonia

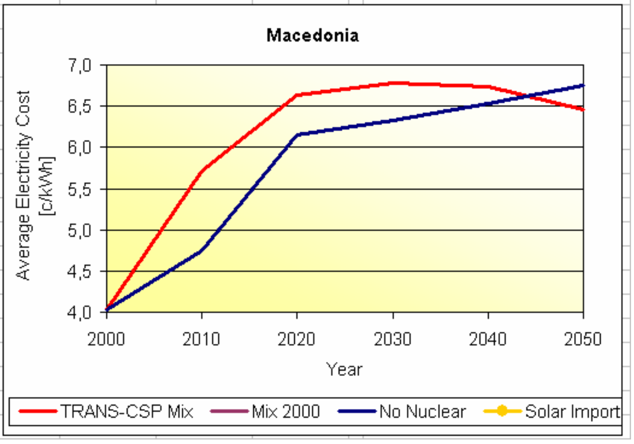

Macedonia
Gross Electricity [TWh/y]
0
2
4
6
8
10
12
14
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Consumption


Macedonia
Installed Capacity [GW]
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
2000
2010
2020
2030
2040
2050
Year
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear
Export
Peak Load


Macedonia
Electricity Cost of New Plants [c/kWh]
0
5
10
15
20
25
30
2000
2010
2020
2030
2040
2050
Year
Import Solar
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Coal
Oil
Gas
Nuclear


Macedonia
CO2-Emissions of Power Generation [Mt/y]
0
1
2
3
4
5
6
7
8
9
10
2000
2010
2020
2030
2040
2050
Year
Avoided
Import Solar
Import Other
Photovoltaics
Wind
Wave / Tidal
Biomass
Geothermal
Hydropower
CSP Plants
Oil
Gas
Coal
Nuclear


Macedonia
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2000
2010
2020
2030
2040
2050
Year
Import Dependency
Peaking Capacity
Fluctuating Capacity


Macedonia
Average Electricity Cost [c/kWh]
4,0
4,5
5,0
5,5
6,0
6,5
7,0
2000
2010
2020
2030
2040
2050
Year
TRANS-CSP Mix
Mix 2000
No Nuclear
Solar Import

Annex 2: Abbreviations

AC	Alternating Current
bbl	barrel of crude oil
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
cap	per capita
CDM	Clean development Mechanism
CEE	Cumulated Energy Expenditure
CF	Capacity Factor
CSP	Concentrating Solar Thermal Power Stations
CHP	Combined Heat and Power
CO_2	Carbon Dioxide (greenhouse gas)
DC	Direct Current
DNI	Direct Normal Irradiance (solar beam radiation on ideal sun-tracking collectors)
DPG	Deutsche Physikalische Gesellschaft
€	Euro
EU	Europe
EUMENA	Europe, Middle East, North Africa
EMFTA	European Mediterranean Free Trade Area
Flh	full load hours per year
Fresnel	Inventor of a facetted concentrating mirror assembly
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GHG	Greenhouse Gases (emissions responsible for climate change)
GIS	Geographic Information System (electronic geographic data base)
GW	million kilowatt (capacity unit)
GWh	1 million kWh (energy unit)
HDR	geothermal power from hot dry rocks in several thousand meters depth
H.R.H.	His Royal Highness
HVAC	High Voltage Alternating Current Transmission of Electricity
HVDC	High Voltage Direct Current Transmission of Electricity
Hybrid	Mixture of solar and fossil primary energy in a concentrating solar power plant
IEA	International Energy Agency
IPCC	International Panel on Climate Change
kV	kilovolt = 1000 Volt (unit of tension)
kW	kilowatt (unit of power)
kWh	kilowatt-hour (unit of energy)
LCA	Life Cycle Assessment of Emissions, Materials and Energy Consumption (Eco-Balance)
LEC	Levelised Electricity Cost
ME	Middle East
Med	Mediterranean Region
MED	Multi-Effect-Desalination
MENA	Middle East & North Africa
m	meter
mm	milimeter
MSF	Multi-Stage-Flash Desalination
MTSA	Multi-Tower Solar Array

MVA	Mega (million) Volt Ampere
MW	million Watt
MWh	1000 kWh
NA	North Africa
NPV	Net Present Value
Ώ	Ohm, measure of electric resistance of materials
OECD	Organisation for Economic Co-operation and Development
O&M	Operation and Maintenance
OME	Observatoire Mediterraneen de l'Energie
RE	Renewable Energy
PPA	Power Purchase Agreement
PRR	Project Rate of Return
PSA	Test Centre Plataforma Solar de Almeria, Southern Spain
R&D	Research and Development
RD&D	Research, Development and Demonstration
REA	Renewable Energy Act
RES	Renewable Energy System
RO	Reverse Osmosis Membrane Desalination
SBP	Schlaich, Bergermann and Partner
SEGS	Solar Electricity Generating System
SEMC	South Eastern Mediterranean Countries
Stirling	Inventor of an external combustion piston engine
THDR	temperature of hot dry rocks
TREC	Trans-Mediterranean Renewable Energy Cooperation
TWh	1 billion kWh
UCTE	Union for the Coordination of the Transmission of Electricity
UHVDC	Ultra-High Voltage Direct Current
WBGU	Wissenschaftlicher Beirat für Globale Umweltveränderungen, German Scientific Council for Global Environmental Affairs
WEC	World Energy Council
W	Watt
y	Year

Annex 3: Solar Thermal Electricity Imports by Country

Total HVDC Solar Import Electricity in TWh/y

Year	2000	2010	2020	2030	2040	2050
Austria	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0
Denmark	0	0	0	2	3	5
Finland	0	0	0	0	0	0
France	0	0	10	35	70	110
Czech Republic	0	0	0	5	15	30
Belgium	0	0	0	10	16	24
Ireland	0	0	0	0	0	0
Luxembourg	0	0	0	0	0	0
Netherlands	0	0	5	10	15	17,5
Sweden	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0
United Kingdom	0	0	0	15	35	65
Poland	0	0	0	15	50	90
Bulgaria	0	0	0	4	6	6,5
Slowac Republic	0	0	0	2	8	12,5
Slowenia	0	0	0	0	0	0
Germany	0	0	15	40	80	120
Hungary	0	0	0	8	10	12
Greece	0	0	0	5	10	15
Italy	0	0	10	25	45	60
Malta	0	0	0	0	0	0
Portugal	0	0	0	0	0	0
Spain	0	0	15	25	35	45
Turkey	0	0	5	15	45	60
Macedonia	0	0	0	0	0	0
Croatia	0	0	0	0	0	0
Romania	0	0	0	15	30	35
Serbia & Montenegro	0	0	0	0	0	0
Bosnia-Herzegowina	0	0	0	0	0	0
Iceland	0	0	0	0	0	0
Norway	0	0	0	0	0	0
Total	**0**	**0**	**60**	**231**	**473**	**707,5**

Total HVDC Solar Import Capacity in GW

Year	2000	2010	2020	2030	2040	2050
Austria	0,00	0,00	0,00	0,00	0,00	0,00
Cyprus	0	0	0	0	0	0
Denmark	0	0	0	0,4	0,5	0,75
Finland	0	0	0	0	0	0
France	0	0	2	5	9	15
Czech Republic	0	0	0	1	2	4
Belgium	0	0	0	2	2,5	3,5
Ireland	0	0	0	0	0	0
Luxembourg	0	0	0	0	0	0
Netherlands	0	0	1	1,5	2	2,4
Sweden	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0
United Kingdom	0	0	0	2,5	5	9
Poland	0	0	0	2,5	8	14
Bulgaria	0	0	0	0,75	1	1
Slowac Republic	0	0	0	0,5	1,5	2
Slowenia	0	0	0	0	0	0
Germany	0	0	3	6	11	16
Hungary	0	0	0	1,5	1,75	2
Greece	0	0	0	1	1,5	2
Italy	0	0	2	5	8	10
Malta	0	0	0	0	0	0
Portugal	0	0	0	0	0	0
Spain	0	0	2,5	4	5	8
Turkey	0	0	1	2,5	6	7,5
Macedonia	0	0	0	0	0	0
Croatia	0	0	0	0	0	0
Romania	0	0	0	3	5	5
Serbia & Montenegro	0	0	0	0	0	0
Bosnia-Herzegowina	0	0	0	0	0	0
Iceland	0	0	0	0	0	0
Norway	0	0	0	0	0	0
Total	**0**	**0**	**11,5**	**38,65**	**69,25**	**102,15**