# EU's Policies for Developing and Deploying Six Green Energy Technologies

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## 1. Introduction

This paper presents an in-depth study on the state and development of the European Union policy related to six green energy technologies:

- Solar Photovoltaic
- Wind Power
- LED Lighting
- Smart Grid
- Nuclear Energy
- Carbon Capture and Storage (CCS)

This paper assumes that the principles of these technologies, their economics, their environmental footprints, and the potential for reducing global greenhouse gas emissions are known. It focuses on the political decision making, regulation, incentives, and experiences in Europe, and discusses the progress as well as the policy shortfalls with respect to the deployment of the six technologies.

Due to the determination of politicians on the European and the national level and based on its engineering and manufacturing capacities, Europe understands itself as the most advanced region towards the development of green and sustainable technologies. A closer look shows however that the decision processes in the European Union are challenging, the coordination among the 27 Member States is time consuming, the appropriate implementation of EU Directives is systematically lacking, and, as a result of national interest group interventions, some efficiency losses are to be observed. But regarding the difficulties EU is facing as a federation of more than two dozen independent states, the momentum in deploying pioneering green technologies is quite remarkable.

The green technologies discussed in this paper are at different stages of development and are addressed by different political instruments. In the subsequent sections the paper discusses from a European perspective how the progress towards the six green technologies and their markets became possible. But before discussing the six individual technologies it is useful to present the general political framework of the European Union decision making towards new energy technologies. In order to keep this part of the paper short, the renewable electricity generation is taken as an example.

## 2. European Framework for Renewable Electricity Policy

Until recently the EU Commission had no direct competence on energy policy. This changed only recently through the Lisbon treaty that became effective in early 2010. While it grants to the EU Commission non exclusive energy competences, Member States have still own energy competences such as the right to determine the national shares of energy technologies and energy sources. Therefore Germany and France can, for example, continue to follow a quite different approach towards the use of nuclear energy.[1]

*Table 1 Timetable of EU renewable electricity policy*

| | |
|---|---|
| Nov. 1997 | EU Commission publishes White Paper setting out a strategy for renewable energy |
| Sept. 2001 | EU adopts Directive on the Promotion of Electricity from Renewable Energy Sources |
| May 2003 | EU adopts the Directive on the promotion of the use of biofuels or other renewable fuels for transport (EU Commission 2003) |
| 10 Jan. 2007 | EU Commission presents Renewable Energy Roadmap as part of its energy and climate change package (EU Commission 2007a) |
| March 2007 | EU summit endorses a binding target to source 20% of energy from renewable sources by 2020 |
| 19 Sept. 2007 | Commission presents its Third Energy Market Package (EurActiv 20/09/07) |
| 22 Nov 2007 | Commission tables a European Strategic Energy Technology Plan (SET-Plan) (EU Commission 2007b) |
| 23 Jan. 2008 | Commission presents a proposal for a new Renewables Directive |
| 13 Nov. 2008 | Commission proposes an Energy Performance of Buildings Directive (EPBD) (EurActiv 14/11/08) |
| 11-12 Dec. 2008 | EU council agrees final version of the Renewables Directive (EU Commission 2009c). |
| 23 March 2009 | Parliament and Czech EU Presidency reach agreement on the Third Energy Market Package (EurActiv 25/03/09) |
| 25 June 2009 | EU Council adopts the Third Energy Market Package (EurActiv 25/03/09). It consists of tree Regulations (cooperation of national energy regulators, cross-border exchanges in electricity, and access to natural gas transmission networks) and two Directives (common rules for the internal markets in electricity and in natural gas) |
| 30 June 2009 | EU issues template for National Renewable Energy Action Plans (NREAPs) (EurActiv 01/07/09) |
| 30 June 2010 | Deadline for EU states to present National Renewable Energy Action Plans |
| 2020 | Target date for EU objective of sourcing 20% of energy from renewable sources |

Source: adapted from several articles supplied by www.euractiv.com

Why then the EU Commission was able to formulate, prior to 2010, European Energy Directives without having explicit competences on energy policy? The answer is based on competences that had been allocated to the EU Council by former European treaties. Particular important are, among others,

[1] Major issues of the EU Commission concerning the use of its new energy competences are shown by recent proposals towards enhancing the solidarity in case of European gas supply disruptions (EU-Commission 2009a) and towards improving the transparency on the infrastructure development in main energy sectors in order to assess the risk of infrastructure gaps (EU-Commission 2009a).

- the Commission's mandate to accomplish the internal European market
- its competence on environmental policy, particularly concerning Greenhouse Gases
- its exclusive rights in determining agricultural policies
- its right in developing rules for European research and development cooperation (r&d) and trans-border infrastructures

The famous 20-20-20-target decided by the European Council in March 2007 is an example showing that these competences allowed the European Union to formulate a strong energy policy without explicit energy competences: The 20-20-20-target claims that, until 2020, the aggregate EU greenhouse gas emissions (GHG) should drop by 20% compared to 1990, the renewable share of EU primary energy consumption should reach 20%, and the energy efficiency should grow by 20%. Each single target is decided on the grounds of at least one of the above non-energy specific EU competences.

*Table 2 EU Member States renewable targets and greenhouse gas emissions*

| | Renewable share in final energy consumption 2006 | Target for renewable shares in final energy consumption 2020 |
|---|---|---|
| Austria | 25.1% | 34% |
| Belgium | 2.6% | 13% |
| Bulgaria | 8.9% | 16% |
| Cyprus | 2.7% | 13% |
| Czech Republic | 6.5% | 13% |
| Denmark | 17.2% | 30% |
| Estonia | 16.6% | 25% |
| Finland | 28.9% | 38% |
| France | 10.5% | 23% |
| Germany | 7.8% | 18% |
| Greece | 7.1% | 18% |
| Hungary | 5.1% | 13% |
| Ireland | 2.9% | 16% |
| Italy | 6.3% | 17% |
| Latvia | 31.4% | 42% |
| Lithuania | 14.6% | 23% |
| Luxembourg | 1.0% | 11% |
| Malta | 0.0% | 10% |
| Netherlands | 2.7% | 14% |
| Poland | 7.5% | 15% |
| Portugal | 21.5% | 31% |
| Romania | 17.0% | 24% |
| Slovakia | 6.8% | 14% |
| Slovenia | 15.5% | 25% |
| Spain | 8.7% | 20% |
| Sweden | 41.3% | 49% |
| United Kingdom | 1.5% | 15% |
| EU | 9.2% | 20% |

Source: ec.europa.eu/energy/renewables/index_en.htm (visited on 20 July 2010)

Any political action of the EU Commission requires a mandate from the EU Council in which the Prime Ministers and Presidents of the Member States decide according to a sophisticated majority rule. In addition, the agreement of the EU Parliament is required.

As part of the 20-20-20 decision process, a breakdown of the aggregate targets to the level of the Member States is required. Concerning renewable electricity generation, the Commission proposed guidelines according to which each Member State should set its targets: In the year 2020, the national targets shall depend on the Member State renewable share in the base year and its per-capita-GDP so that rich countries have to do more than poor countries. The subsequent debate was characterized by political bargaining among the Member States, but on 12 December 2008 the Council reached a conclusion and adopted the country specific renewable energy targets. These targets are laid down in the Renewables Directive 2009/28/EC of 23 April 2009 (EU Commission 2009c).

Another central element of this directive is that the member states are allowed to freely choose their national policy towards achieving the individual targets. EU Member States adopted financial incentives such as grants, loans at privileged rates, and fiscal incentives to encourage the uptake of renewable energies like biomass, geothermal or solar thermal for heating and cooling. Some Member States have also implemented mandatory renewable heating shares for new buildings and for major building renovations.

With respect to renewable electricity generation, most EU Member States adopted mandatory feed-in tariffs for renewable power, which will be discussed further in the next chapter. Other Member States implemented national renewable portfolio standards that set compulsory amounts of renewable electricity to be produced. In both cases the national law considers only renewable investments within the Member State. Investments in other EU Member States are excluded from the feed-in benefit, or are not counted in the renewable portfolio standard, respectively. Thus, according to the present renewable energy support schemes in EU Member States, there is no single market for renewable electricity, but the EU falls apart into 27 different markets. [2] It is paradox that at the same time the EU is working hard to accomplish the Single European Market for Electricity and has put into place an appropriate Directive in 2009 (Third Energy Market Package).

There are attempts to develop an EU wide Renewable Electricity market. The proposed instrument is a Renewable Energy Certificate System (RECS) based on a uniform European renewable portfolio standard. In January 2008 the EU Commission proposed a system along this idea where Member States should issue “guarantees of origin” to producers of electricity coming from renewable energy sources. These Renewable Energy Certificates should be tradable within the European Union. Such a system was favored by electricity traders and large utilities. It would push economic efficiency as it directs renewable investments into those technologies and regions where the renewable energy targets can be met at the lowest possible costs. In theory, the certificate price should be equal to the difference between the marginal cost of producing

[2] The Spanish feed-in law had a clause that installations must be produced at more than 50% of their value added in Spain in order to receive the national support.

renewable electricity in Europe and the wholesale electricity price. With technical progress the price would decrease, with a stricter portfolio standard it would increase.

*Table 3 Feed-in tariffs for renewable electricity in 2009 [Euro/kWh]*

| | Wind power onshore | Wind power offshore | Solar PV | Biomass | Small hydro |
|---|---|---|---|---|---|
| Austria | 0.07 | 0.07 | 0.29 - 0.46 | 0.06 -0.16 | - |
| Belgium | - | - | - | - | - |
| Bulgaria | 0.07 - 0.09 | 0.07 - 0.09 | 0.34 - 0.38 | 0.08 - 0.10 | 0.045 |
| Cyprus | 0.17 | 0.17 | 0.34 | 0.14 | - |
| Czech Republic | 0.11 | 0.11 | 0.46 | 0.08 - 0.10 | 0.08 |
| Denmark | 0.08 | 0.08 | - | 0.04 | - |
| Estonia | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Finland | - | - | - | - | - |
| France | 0.08 | 0.31 - 0.58 | - | 0.13 | 0.06 |
| Germany | 0.05 - 0.09 | 0.13 - 0.15 | 0.29 - 0.55 | 0.08 - 0.12 | 0.04 - 0.13 |
| Greece | 0.07 - 0.09 | 0.07 - 0.09 | 0.55 | 0.07 - 0.08 | 0.07 - 0.08 |
| Hungary | - | - | 0.097 | - | 0.03 - 0.05 |
| Ireland | 0.06 | 0.06 | - | 0.07 | 0.07 |
| Italy | 0.30 | 0.30 | 0.36 - 0.44 | 0.20 - 0.30 | 0.22 |
| Latvia | 0.11 | 0.11 | - | - | - |
| Lithuania | 0.10 | 0.10 | - | 0.08 | 0.07 |
| Luxembourg | 0.08 - 0.10 | 0.08 - 0.10 | 0.28 - 0.56 | 0.103 - 0.128 | 0.089 - 0.10 |
| Malta | - | - | - | - | - |
| Netherlands | 0.12 | 0.17 | 0.46 - 0.58 | 0.13 - 0.18 | 0.07 - 0.13 |
| Poland | - | - | - | 0.04 | - |
| Portugal | 0.07 | 0.07 | 0.31 - 0.45 | 0.10 - 0.11 | 0.08 |
| Romania | - | - | - | - | - |
| Slovakia | 0.05- 0.09 | 0.05- 0.09 | 0.27 | 0.07 - 0.10 | 0.07 - 0.10 |
| Slovenia | 0.09 | 0.09 | 0.27 - 0.41 | 0.07 - 0.22 | 0.08 - 0.11 |
| Spain | 0.07 | 0.07 | 0.32 - 0.34 | 0.11 - 0.16 | 0.08 |
| Sweden | - | - | - | - | - |
| United Kingdom | Tariffs scheduled for 2010 | | | | |

Source: adapted from www.energy.eu/#feedin

But the Commission's proposal was not successful. Member States with unfavorable conditions for renewable energy investments (bad wind and solar radiation conditions, no rivers or mountains suited for hydropower etc.) would not be able to increase their national share of renewables but rather would become net buyers of Renewable Energy Certificates. Therefore the EU Commission concluded that such a harmonization is "premature and would disrupt the market". The RECS was rejected in favor of a voluntary system whereby a Member State can trade excess renewable credits to another Member State based on statistical values. A Member State is only allowed to sell "statistical transfers" if it has already reached its interim renewable targets. As a practical consequence, renewable power production in Europe today develops into the direction of a national industry. It is virtually exempted from the efforts to accomplish a single European Market for Electricity, and it is still unclear how this sector will later be harmonized on a European level.

Returning to the “philosophy” of the EU Renewable Directive2009/28/EC, a typical element for market economies is that quantitative targets on energy technologies should not be legally binding but rather a political guideline. Accordingly no Member State should suffer negative consequences should it miss the national renewable energy target. The EU Commission cannot sanction Member States if they miss their renewable targets, but it can still execute some control: Member States are required to develop national action plans that define individual targets for electricity, heating and transport together with measures to be taken to achieve them. These plans shall also define minimum interim targets. These action plans as well as regular progress reports must be submitted to the EU Commission. If necessary, the Commission will ask Member States to modify their national plans, and the Commission can impose monetary sanctions.

As an interim conclusion, the following economic interpretation of the Renewable Directive is proposed: In a single market, Member States shall not be allowed to subsidize their national industries without explicit agreement of the EU Commission, because these subsidies – like national import tariffs – disturb the functioning of the single market and may lead to unfair competition in those sectors where subsidies are applied. But as the European Union has agreed to mandate Member States t to reach certain national renewable energy targets, the EU Commission must accept national subsidies and other instruments even if they would be incompatible with the concept of the single market.

## 3. The European view of the debate between the feed-in and the quota systems

The concept of feed-in tariffs represents a combination of two incentives in favor of renewable power generation:

- Preferred access to the power grid. In liberalized power markets with third party grid access rights this benefit seems obsolete, because any generator can sell to electricity customers at the market price. The preference to renewable power generators consists in the exemption from the obligation to submit day-ahead schedules to the transmission system operator (as all other grid users are obliged to do). Particularly for intermittent wind and solar generation this privilege is quite valuable
- Price guarantee for up to 20 years, which eliminates marketing and sales risks during this period. Renewable power producers focus their management activities on mitigating technological risks and have easy access to capital markets

In the 1990ies Denmark and Germany pioneered the implementation of mandatory feed-in tariffs which in the mean time became a benchmark for many countries in Europe. Taking the example of Germany, the original minimum feed-in fee of 1990 was set as a percentage of the retail electricity price. As a consequence, the market development of relatively inexpensive renewable technologies such as small hydro and onshore wind was stimulated, but more costly technologies like offshore wind and photovoltaic received practically no impulse. This changed with the Renewable Energy Sources Act (EEG) of the year 2000. Since this amendment, the tariffs cover the calculated costs of renewable electricity generation. They differ according to technologies – expensive technologies like photovoltaics received higher support than cheap technologies. And they decline with the installation year assuming that technical progress would bring the costs of renewable technologies down over time. All regulations of the German EEG are regularly updated to reflect the development of technology costs, investments, and legal problems that occurred during the implementation process.

In recent years it was intensively debated whether or not feed-in systems are more effective than renewable portfolio standards (see for example KLEIN *et al*. 2008). The empirics are clear: Countries applying feed-in tariffs have achieved greater renewable energy penetration rates – at lower costs for consumers than quota-based systems. One of the reasons is that, due to power price fluctuations, renewable portfolio standards entail higher investment risks than systems with fixed feed-in tariffs. Further, renewable portfolio standards tend to favor large electricity utilities, while feed-in tariffs offer opportunities to all market participants, including micro-generation by private households.

Germany is not the only country with growth rates of wind and photovoltaic generation capacities, but a rather successful case as will be explained more in detail in the next chapters (see also figure 1). The growth of wind power and photovoltaic capacities in this country is particularly remarkable because the wind and solar conditions are not rather favorable. Therefore it is not the system as such which determines the growth of renewable power generation, but regulatory details. Several points explain the particular development in Germany:

- First, the budget from which the feed-in fees are paid is not limited, because the funds are paid by grid users, not from the state budget, and in the Renewable Energy Act there is no formal rule that would constrain the annual buildup rates. Accordingly, the growth potential of technology suppliers is virtually not limited, and the respective industries can expand their production capacities without significant risk. Caps, on the other hand, create uncertainties for both technology developers and financing institutions.[3]
- Second, the German system doesn't discriminate foreign technology suppliers against domestic companies. Together with the dynamic decline of feed-in tariffs, a fierce competition among the suppliers is the result, leading to a professional industry sector in a relatively short period of time
- Third, under an unlimited feed-in-system, all relevant economic parameters of wind and PV power generation are publically available and transparent. Investors at economically favorable locations can pay higher prices than those investing at economically weaker locations. Therefore the technology suppliers focus their marketing efforts on countries with economically attractive conditions, thus Germany. The renewable share of other

[3] For Spain, favorable feed-in tariffs in Spain in 2007 led to a surge in installed capacity, forcing the government to cancel the subsidies. The market overheated as companies rushed to install as many solar panels as possible before the end of the scheme. After the market collapse in 2008 the government revamped the policy, increasing tariffs again and introducing caps on the construction of new capacity.

countries cannot develop as long as the global capacities of renewable technology manufacturing are not exceeding the German demand

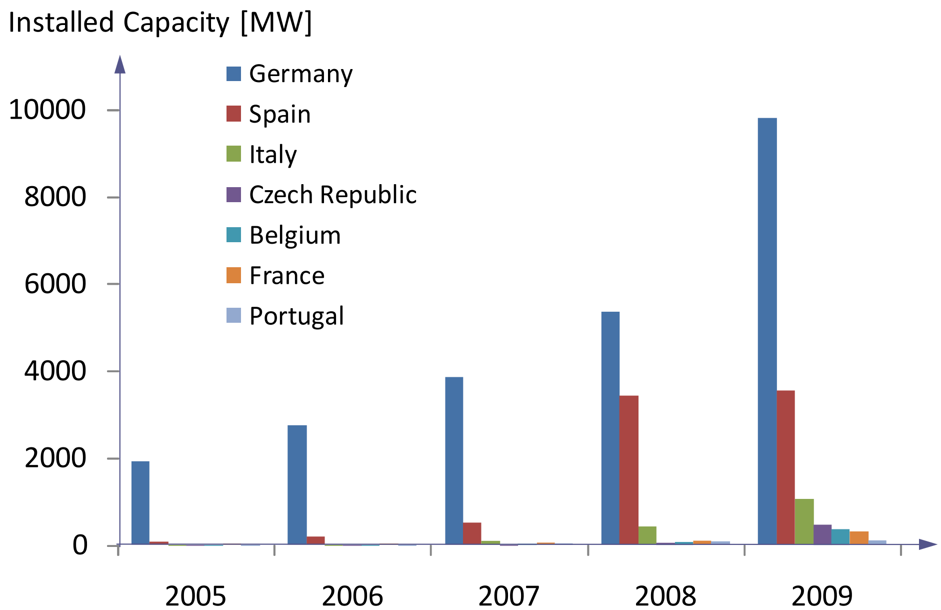


*Figure 1 Installed photovoltaic generation capacity in the EU Member States (Source: calculated from data supplied by the Photovoltaic Energy Barometer)*

The German success story is apparently reaching its limits today. In the near future the cost of the German support scheme is going to exceed 10 bn. USD per year resulting in raising and inacceptable electricity prices. In addition, the growing shares of renewable electricity cannot technically be integrated into the electricity system without transferring some system responsibility to the renewable power producers. Under a mandatory feed-in scheme, renewable power producers don't learn how to use markets to sell electricity. The German government has identified these problems in the "National Energy Plan" of September 2010 and announced a "market bonus system". Under this system the Transmission System Operator will no longer be obliged to purchase all renewable power. Instead the operators of wind mills and PV appliances have to sell to the electricity markets but still receive a bonus payment depending on the technology and the average wholesale power price. Eventually the "market bonus system" could become a strategy towards an Internal European Market for Renewable Electricity which is missing today.

As an interim conclusion of this section, feed-in systems are attractive in the first phase of renewable generation capacity buildup but will have to be modified and/or replaced if the renewable electricity shares become larger.

## 4. Solar Photovoltaic Technology

Today the EU is the uncontested world leader in solar power investments. More than two thirds of all PV capacities worldwide are installed in this region. Until recently, two countries took the lead, Germany and Spain. During 2009 in Germany alone a PV capacity of nearly 4500 MW was invested while the market of PV investments in Spain collapsed due to a cut in feed-in support. While many other countries impose a cap on the PV capacity that benefits from the mandatory feed-in regime, this is not the case in Germany. The unexpected growth imposes a growing surcharge on German electricity customers. In 2010 the surcharge jumped to 20 Euro per MWh electricity consumed, for 2011 it will exceed 30 Euro/MWh. For 2010 additional 7000 MW of PV are expected to be invested in Germany. Assuming a PV generation of 850 MWh per MW installed and a net support of 250 Euro/MWh photovoltaic electricity produced, the PV capacity buildup in 2010 alone will increase the annual cost to German power consumers by at least 1.50 billion Euros, nota bene in each year between 2011 and 2030.

As mentioned above, the German situation is paradoxical in many dimensions. While the annual power generation in Germany doesn't exceed 900 MWh per installed MW photovoltaic capacity, the same capacity installed in southern Europe would produce two to three times that electricity. Second, the high demand for PV systems does not correspond to Germany's production share in the global market for PV modules. Table 4 shows that Asian producers are much more successful than manufacturers from Europe.

*Table 4 Capacity and market share of PV manufacturers in 2009*

| 2009 | Share of PV manufacturing capacity | PV module production |
|---|---|---|
| China | 33% | 29% |
| Germany | 17% | 22% |
| Taiwan | 14% | 15% |
| Japan | 13% | 8% |
| Malaysia | 9% | 12% |
| USA | 5% | 5% |
| ROW | 9% | 9% |

Source: calculated from en.wikipedia.org/wiki/List_of_photovoltaics_companies

Finally cumulated PV capacity in this country may soon exceed 50,000 MW what is significantly more than the minimum power demand during summer weekends. This creates an urgent need to implement smart grid technologies in order to manage PV power, but this as well as electricity storage capacities will not be available in short times.[4] Due to these bottlenecks, the German government may soon be forced to reduce the domestic rate of PV capacity installations. If this will happen, the world market prices for PV modules will tend to fall, and regions with favorable solar radiation conditions will reach PV grid parity (retail power customers can produce electricity at the cost of grid electricity). Thus the PV stimulus program in Europe may turn out to be a rather influential program towards changing the world power system in the direction of more solar electricity.

[4] This view is confirmed by the Solar Europe Industry Initiative – led by the European Photovoltaic Industry Association (EPIA). It proposes three scenarios resulting in three levels of solar share in the electricity market in Europe: 4% for the Baseline scenario, 6% for the accelerated growth scenario and 12% for the paradigm shift scenario. The paradigm shift scenario requires a rapid, widespread adoption of smart grid technologies and power storage.

Another lesson learned is that PV module industry has surpassed national or European boundaries and has become sooner than expected a worldwide business. The consequence is global competition in the growing PV industry. Countries with the most attractive PV support schemes (compared to the solar radiation conditions) will attract PV investments on the account of other countries. As for wind power investments some years ago, few countries will host the large majority of PV investments unless the industry has expanded its capacities beyond levels that can be accommodated by these countries. As the support conditions in individual countries vary, a rather volatile PV expansion path is the result. It is obvious that more international cooperation would improve this situation.

## 5. Wind Power Technology

Unlike photovoltaics, Europe is going to lose its original world leadership position in wind power investments. While Europe's share in worldwide installed wind capacity reached 75% in 2002, it dropped to 49% in 2009. Europe accounted for no more than 26% of the global wind power investments in 2009. Yet the nearly 10,000 MW wind capacity additions in Europe during 2009 are still remarkable. Thanks to their superior technological know-how and experience, European companies still dominate the global wind turbine industry. This is the result of preferred grid access to electricity produced from wind energy in combination with favorable mandatory feed-in fees for wind power in many European countries. According to the EU Renewable Directive, producers of renewable electricity are set to receive preferential access to EU grids. The grid operator is not allowed to reduce the generation of wind turbines except under emergency conditions.


*Figure 2 Annual growth rates of installed wind power*
*(Source: calculated from data supplied by www.thewindpower.net)*

Actually there is an interest towards developing offshore wind farms because capacity factors of wind turbines (ratio of production to the theoretical maximum) are superior and land use and neighborhood conflicts are negligible. Today the leading countries are the United Kingdom and Denmark which each account for one third of Europe's 2009 offshore capacity. Offshore wind – other than onshore wind – is big business. The development requires large-scale industrial structures in turbine manufacturing, offshore construction, and maintenance. This is due to high offshore investment and operation costs, expensive offshore grid infrastructures, and significant financial risks. The leading offshore operating companies in Europe are the German private owned energy company *E.ON* and the Danish state owned *Dong*.

Due to unsolved engineering and financial challenges the offshore wind development in Europe is much slower than expected some years ago. At the end of 2009 the European offshore capacities accounted for only 4.4 GW or 2.5% of the 75 GW wind capacity installed in the EU. But as the technical, financial, and industrial structures are going to be settled, the offshore wind sector will take off the ground.

A big challenge today is the integration of large shares of intermittent wind power generation into the electricity markets. In some European countries wind power exceeds two digit electricity generation shares (Denmark 19%, Portugal 15% and Spain 14%). In Germany the wind share stands at about 9%. In some hours the wind power generation covers already 40-50% of the electricity demand in these countries. To solve the associated power management, two options exist. Well interconnected national power markets can settle excess wind situations by exporting wind power to neighboring countries. The most prominent example is Denmark, which regularly exports a large share of wind power to Norway – a country which has a mainly hydropower based electricity system and virtually no wind capacities.[5] The second option is to reduce or shut-down conventional power plants in excess wind periods. Wind generators face practically no shut-down and start-up costs. Shutting down these installations in case of excess supply would be rather easy. But then wind power plant operators would suffer fewer revenues from feed-in fees. On the other hand, most thermal power plants have shut-down and start-up costs that depend, among others, on the technology, the size of the plant, the type of fuel used, and the (expected) time length of the shutdown period. Even in power systems with high wind capacities thermal power plants are needed to cover electricity demand in windless periods, particularly in badly interconnected power markets.

As a consequence of the wind power privileges, wholesale power prices can become negative. Figure 3 shows the situation on the German wholesale market during a week in December 2009. At the beginning of the week power demand had been high and wind availability low. At the end both changed so that residual power demand became rather small and day-ahead power prices fell below zero during several hours. The economically efficient solution would be to curtail wind power generation so that the wholesale price always remains above zero. Likewise, the grid operator shall pay the wind operators for the non-produced electricity according to the mandatory feed-in fee.

[5] As Norway gets wind electricity for free, the country's electricity producers have little interest to build up own wind capacities in spite of the fact that wind conditions in Norway would be ideal for huge wind power investments.

With negative power prices consumers on the wholesale power market get paid for using power. It is obvious that negative wholesale prices are an obstacle for an efficient use of electricity. Neither the EU Commission nor politicians in EU Member States have taken this situation serious yet, but if the situation worsens, an amendment to the Renewable Directive is likely that should eliminate situations with negative wholesale prices. Meanwhile energy market participants apply more or less intelligent business plans to harvest the economic benefits from occasionally negative prices.

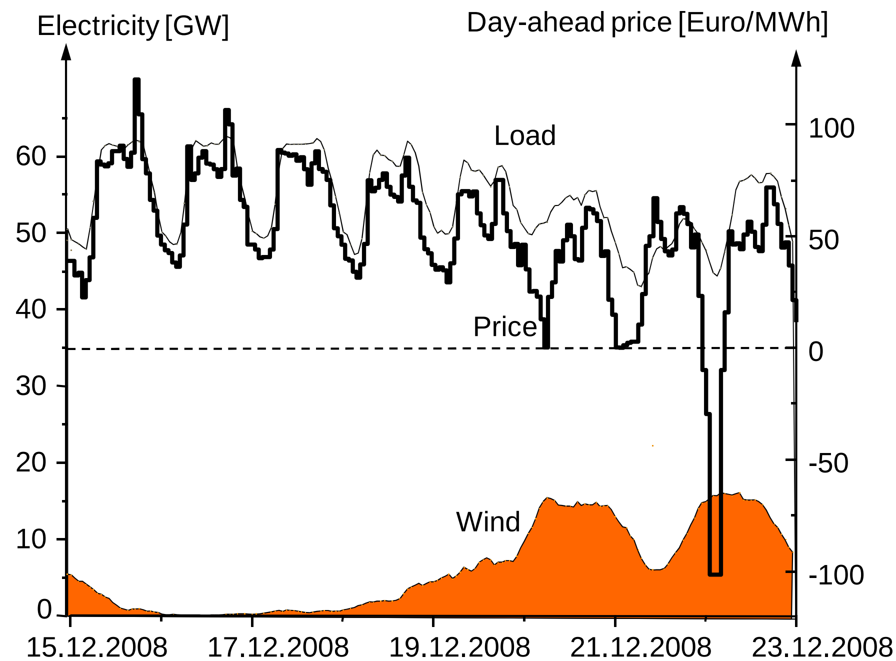


*Figure 3 Negative prices in situations of low demand and high wind generation (source: calculated from ENSYS data bank)*

Many Member States are facing an acute need to repair or even replace their aging power grids. As most European electricity networks are regulated monopolies, regulator incentives will be crucial to develop the technology. The EU Commission argues that market liberalization provides sufficient incentives to upgrade energy infrastructures. The EU Commission has shown its intention to support interconnector capacity extensions, particularly HVDC supergrid connections across the North Sea, as a long-term solution for integrating fluctuating wind power generation into electricity markets. An alternative option discussed on the level of Member States is additional energy storage capacities. The cheapest storage option – pump water hydro reservoirs – is limited in Europe. Only Norway has significant pumped storage hydroelectricity potentials, basically by adding lower reservoirs to the already existing hydropower plants. Other electricity storage options are much more expensive and will probably not be available in capacity and time needed.

Apart from the need to develop instruments for financing these investments into electricity infrastructures, the economic integration of the national European power markets must be improved through Market Coupling. The aim of the EU Commission is to allocate more or less automatically the available interconnector capacities in a way that power is traded from excess regions to the power-short regions.

As an interim conclusion on wind power development in Europe, the present discussion shifts from wind power technologies and investment incentives towards system integration issues. It seems that the present electricity market designs will not generate the economic incentives for the required investments to accommodate growing wind power so that additional European initiatives are likely.

## 6. LED Lighting Technology

The basic European approach towards lighting technology is laid down in the Eco-design Directive 2009/125/EC for Energy-related-Products. This Directive intends to prevent disparate national legislations on the environmental performance of energy using products (except vehicles) that would create new obstacles to the Internal European Market and is the most important EU initiative for reaching the 20% energy efficiency target to be achieved in 2020.

*Table 5 Timetable of EU energy efficiency action plan*

| | |
|---|---|
| July 2005 | The European Parliament and the Council adopt a final text to improve the energy efficiency in the EU on a product-by-product basis under the supervision of a designated panel of EU Member State experts (EUP Directive 2005/32/EC). Priority products include heating, electric motors, lighting and domestic appliances |
| 9 March 2007 | EU summit asks Commission to propose new measures on street lighting and light bulbs (EurActiv 12/03/07) |
| 30 June 2007 | EU Member States begin to submit national energy efficiency action plans to the Commission as part of the Directive on Energy End-use Efficiency and Energy Services (EU Commission 2006) |
| 16 July 2008 | EU Commission adopts a proposal for a Directive to extend the Ecodesign Directive to cover other energy-related as well as energy-using products |
| 26 Sept. 2008 | EU governments endorse two proposals to add lighting and TV 'set-top' boxes to the list of regulated equipment (EurActiv 29/10/08) |
| 21 Oct. 2008 | EU Commission unveils a list of ten priority energy-using product groups for which it wants energy-efficiency standards to be established within the next three years |
| 13 Nov. 2008 | EU Commission proposes efficiency-saving measures as part of the Second Strategic Energy Review |
| 8 Dec. 2008 | EU national representatives vote in favor of phasing out inefficient light bulbs and inefficient halogen bulbs between 2009 and 2012 |
| 18 March 2009 | EU Commission adopts two regulations to improve the energy efficiency of house lamps and office, street and industrial lighting (EurActiv 19/03/09) |
| 24 Apr. 2009 | Parliament approves extension of the Eco-design Directive to cover products with an indirect impact on energy use (EU 2009d) |
| Early 2011 | EU Commission plans to present new Energy Efficiency Action Plan |

Source: adapted from www.euractiv.com

The Directive covers the product's total life cycle. It does not set binding requirements on products by itself but provides a framework (rules and criteria) for setting such requirements through implementing measures. The Commission prepares implementing measures only for products which have significant sales and trade in the EU (indicatively more than 200,000 units a year) and a significant environmental impact and potential for improvement.

In April 2009 two regulations were enacted as implementing measures, which establish specific requirements for electrical lighting:

- Regulation EC 244/2009 for Domestic Lighting sets requirements for acceptable eco-design of consumer-sector lamps with diffuse light. It covers technologies that can generally be used in private households, namely incandescent lamps, halogen lamps, compact fluorescent lamps with integrated ballasts, and LED retrofits

- Regulation EC 245/2009 for Professional Lighting sets requirements for ecological design of products used primarily in highway, industrial, and office lighting, which includes fluorescent lamps, compact fluorescent lamps without integrated ballasts, and high-pressure discharge lamps with E27, 40 and PGZ12 sockets as well as ballasts and luminaries for fluorescent lamps and high-pressure discharge lamps

Based on these regulations, the EU Commission has put into force a multi-year plan that phases out all incandescent lighting: From 1 September 2009 electric bulbs with more than 100 Watt shall no longer be produced or imported into the European Union. From September 2010 on this ban will be extended to bulbs with more than 65 Watt. After September 2011 the limit is extended to 45 Watt, and after September 2012 it covers all traditional light bulbs. The regulation also bans inefficient low and high voltage halogen lamps.

Through the stepwise approach chosen by the EU Commission, the lighting manufacturers should have time to prepare themselves for this change and for offering the consumers a comprehensive range of energy-saving lights as well as halogen and LED lamps. Besides compact fluorescent lamps (CFL), which use up to 75% less energy than traditional light bulbs, the lighting emitting diode or LED-lamp is an attractive alternative to conventional light bulbs since it can produce light in different colors, has an expected lifetime of 15,000 to 25,000 hours of use, does not have a switch delay, does not contain quicksilver, and is expected to pay for itself, due to their 90% energy savings. Thus it can be expected that LED technology will develop as a reasonable replacement for incandescent light technology. Whilst LED products are currently only available for lower ratings, the range is continuously being extended as the luminous efficiency of the semi-conductor components increases. A range of different LED lamp options is going to be available, also in a traditional design as standard, candle or round bulbs with an E14 or E27 screw fitting for common light holders or as reflector lamps with an E27 or a GU10 fitting.

The EU regulation on efficient lighting has no bias in favor of European manufacturers, so that non-European producers may take a LED market share of more than 50 percent in the European Union.[6] For CFLs, domestic production has already today a European market share of only 25%. This is astonishing because Europe applied between 2001 and 2008 anti dumping tariffs of up to

[6] According to www.tagesschau.de/wirtschaft/energiesparlampe100.html published on 11 August 2008, the CFL sales in the EU reached 215 million units in 2006.

66% for CFL imports from China, Vietnam, Pakistan and the Philippines. There were heavy disputes between the German market leader *Osram* (in favor af tariffs) and other European manufacturers (*Phillips*, *Targetti*), environmentalist groups, shopping chains (*Metro*, *Ikea*) and several European governments (against tariffs). The argument was that consumers should not be discouraged from buying energy efficient lighting equipment; the main counterargument was jobs losses within the European Union.

## 7. Smart Grid Technology

The smart grid technology is fundamentally different to supergrid technology. While the supergrid concept is a plan for an overlaying super high voltage transmission grid, smart grids refer to the power distribution grid of low and mid voltage levels. "Smart grid" stands for the introduction of information and communication technologies for Distribution System Operators (DSOs) in order to track electricity flows and to enable the proper operation of distribution grids in situations when large volumes of electricity from decentralized generation plants have to be accommodated (without damaging the equipment of electricity customers connected to the grid). Among others, smart grid technologies should allow private households that produce their own power (via CHP, PV, small hydro etc.) to sell excess electricity back to the grid.

Until now DSOs have no mandatory system service obligations such as voltage control, frequency control, black start capability and re-dispatch of power plants. In the case of the European integrated electricity grid these duties belong to the Transmission System Operators (TSOs). The appropriate regulation and cooperation between European TSOs have evolved in the 1950ies by industry self-regulation, without formal government interventions.

*Table 6 Timetable of EU smart metering actions*

| | |
|---|---|
| April 2006 | EU Directive on Energy End-use Efficiency and Energy Services (EU Commission 2006) lays down foundations for smart meters |
| 13 July 2009 | Third Energy Market Package requires Member States to adopt timetable for rolling out smart meters (EurActiv 25/03/09) |
| 17 Nov. 2009 | Agreement on the Energy Performance of Buildings Directive requires Member States to develop national plans to install smart meters (EurActiv 18/11/09) |
| 2020 | At least 80% of EU consumers to have intelligent metering systems |

Source: adapted from www.euractiv.com

With the growing distributed electricity generation capacities that are connected to the low and mid voltage grid, this historic structure becomes partly obsolete. In the traditional power system electricity flows from the high voltage grid (to which the large power stations are connected) to the low voltage grids. The new system will see situations in which electricity flows from low voltage to higher voltage levels. In order to sustain the reliability and safety of the electricity infrastructure, some system service obligations must be allocated to DSOs, but this is only feasible, if appropriate measurement and control infrastructures are added to the distribution grid.

The Third Energy Market Package of 2009 requires Member States to introduce smart meters that monitor the electricity consumption of all customers in real time. At least 80% of electricity consumers should be equipped with intelligent metering systems by 2020. The recent EU legislation on the Energy Performance of Buildings encourages the introduction of intelligent metering systems when a building is constructed or undergoes major renovation.

There is no standard definition of smart metering, but it usually refers to remote meter reading in conjunction with bidirectional communication systems that allow

- customers to monitor their energy consumption in real time
- power retailers to introduce shorter billing cycles
- TSOs to execute some real time control on the electricity flows across the meters

It is expected that smart metering devices will lead to innovative just-in-time tariffs (based on day-ahead wholesale prices) and perhaps time-of use tariffs (based on the state of regulation power markets). The real-time electricity measurement is also expected to improve the accuracy of electricity bills, to shift electricity consumption from peak periods to off-peak periods, and to lead to electricity savings.[7] A lot of additional ideas about innovative home services offered by power retailers to their customers are discussed (smart homes).

Most Western European countries have set up regulatory frameworks to roll out smart meters. Italy was the first European country to deploy smart meters on a large scale. Sweden was the first country to install smart meters for all its customers by end of June 2009, mandated by government regulation. Debated issues are the following:

- smart meters should be owned by the TSO or by an unbundled entity (that would create benefits from the additional home services)
- the installation of smart meters shall be financed individually through customers or socially through a supplement to the grid access fees[8]
- smart meters should be standardized in order to become interoperable in the future; EU-wide regulation may, for example, avoid that customers have to buy a new meter when switching their energy supplier
- the protection of data security and the privacy of customers
- switching of retail customers may become more difficult so that retail competition will be hindered
- a large number of new tariff options may reduce the transparency of electricity tariffs and costs

[7] *Enel*, an Italian electricity utility, estimates that the introduction of smart meters can reduce consumption peaks by 5% as customers become more aware of their energy use. Moreover, following the introduction of smart meters, the average service interruption per customer and year dropped from 128 minutes to 49 minutes, and the related costs for DSOs decreased from 80 Euros per customer to 49 Euros per customer per year.

[8] In the UK, for example, the government estimated that fitting 26 million homes with smart meters by 2020 would cost more than £8 billion.

Smart meters are thought as a first step toward smart grids. Smart meters by themselves do not constitute smart grids, but they may be a necessary information tool for the intelligent management of distribution grids. With smart grid communication and control systems, the applications of electricity consumers as well as distributed power generators can play an active role in balancing the electricity system, for example by switching on and off the installations according to the level of energy demand. With the anticipated large-scale uptake of electric vehicles smart meters could be used to manage substantial electricity battery storage capacities of parked cars.

The EU Commission has not yet decided whether to launch a new initiative on smart grids. The EU planning document lists four alternatives to be decided until 2011:

- EU executive would do nothing
- EU issues a communication on the roles of the actors involved in smart grid development and table recommendations for them, which would also include a monitoring mechanism on deployment at both national and European level
- EU directly regulates smart grids. The EU Commission would establish a set of guidelines and specific recommendations for Member States on the implementation of smart grids
- EU develops a legislative framework and timetable for the deployment of smart grids

According to communication from the EU Commission, any new initiative and funding at EU level should be based on the experience gained from regional initiatives. If it should turn out that there is some need in terms of European standardization and enforceable rules, the EU Commission will be prepared to act. But the present priority is to convince the investment community that the Third Energy Market Package of 2009 will be properly implemented to make the European internal energy market a reality. The EU Commission expects substantial amounts of private grid investment including smart grids and smart metering, but it recognizes that there may be some need beyond research and development money to financially support the implementation of smart grid projects which involve more risk and long-term view than would have been possible by private companies alone.

The national electricity market regulators have also a significant role to play. Technically it would be possible, for example, to roll out smart meters within a decade. But uncertain returns on investment and a lack of standardization are hindering private investments. The regulators could solve both problems once the political will is there.

## 8. Nuclear Energy Technology

In mid 2010 the EU hosts 143 nuclear reactors with a total capacity of 130 GW. These power plants produced 838,000 GWh in 2009 or about 28% of the EU wide electricity consumption. Four nuclear reactors with a total capacity of 4 GW are under construction. The European Pressurized Reactor (EPR) in Finland (Olkiluoto) with the innovative *Areva* design and a capacity of 1.6 GW is actually three and a half years behind schedule and suffers more than 50% cost overruns. The second EPR project is under construction in France (Flamanville).

Nuclear safety is currently the responsibility of the Member States. But the EU Commission has expressed on several occasions its concerns about the safety of nuclear plants particularly in Eastern Europe where several nuclear power plants are based on the old, less safe, Soviet design. The EU Commission therefore believes that nuclear safety should no longer be considered from a purely national perspective. Therefore the Commission proposed two draft Directives on the Safety of Nuclear Power Plants and the Processing of Radioactive Waste (nuclear package). These proposals would give the EU Commission supervisory power over the nuclear sector in the Member States.

The nuclear package of 2003 consists of different legislative proposals:

- A proposal for a Directive on the Safety of Nuclear Installations, defining the basic obligations and general principles during operation and decommissioning, the requirement for all Member States to have independent safety authorities, and a peer review system to inspect the inspectors. The proposal includes rules for decommissioning funds to ensure that sufficient funds will be available to carry out decommissioning operations of nuclear reactors
- A proposal for a Directive on Radioactive Waste to produce a clear, transparent response in reasonable time to the issue of how to deal with radioactive waste, with the priority to geological burial of waste as the safest method of disposal known at present, the obligation for all Member States to adopt national programs for the disposal of radioactive waste, and on funding for research on waste management

The EU Commission stated that it has no plans to conduct on-the-spot safety inspections at nuclear installations and that there is no intention, under any circumstances, of setting up a corps of European inspectors. Nevertheless the Nuclear Package is one of the most controversial EU initiatives. In spite of the fact that in September 2004 a light draft version had been proposed by the EU Commission, under which the Commission would take a less powerful role on nuclear safety issues than initially envisaged, the dossier is until now stuck in the EU Council. The most contentious issues concern the following questions:

- Should the 'nuclear package' be legally binding?
- Does the package unfairly promote the nuclear sector? This is of particular concern in countries where a nuclear phase-out has been decided
- Does the proposal undermine the subsidiary principle? Member States protect their responsibilities on nuclear safety standards and nuclear waste disposal
- How should decommissioning be financed?
- Should there be a firm time table for decommissioning?

As an interim conclusion, no explicit EU policy progress towards nuclear energy technology exists today. This is in so far paradoxical as one of the origins of the European Union is the European Atomic Energy Community (EAEC or *Euratom*). The organization was founded in 1957 along with the European Economic Community (EEC, today the EU). The EAEC is legally distinct from the European Union (EU), but has the same members, is governed by EU's institutions, and has the purpose to develop the nuclear technologies and the respective industries in Europe as a means for improving the standard of living in the Member States.

## 9. Carbon Capture and Storage Technology (CCS)

If CCS systems will become technically feasible for coal fired power plants, the additional costs per avoided ton of $CO_2$ will probably exceed 60 Euro per ton of $CO_2$. With the present prices below 20 Euro/t $CO_2$, privately financed CCS investments will not occur under the EU emission trading scheme (EU ETS).[9] Therefore the EU has started a discussion about how 10 to 12 large-scale demonstration projects shall be subsidized until 2015.

*Table 7 Timetable of EU actions towards CCS*

| | |
|---|---|
| 10 Jan. 2007 | The Third Energy Market Package proposed by the EU Commission makes new proposals on CCS |
| 22 Nov. 2007 | The Strategic Energy Technology Plan (SET-Plan) highlights CCS as one of the key future energy technologies but lacks a financial component |
| 23 Jan. 2008 | EU Commission issues a Communication on CCS demonstration projects and a proposal for a Directive on the legal framework as part of a larger package on energy and climate change |
| 1 April 2008 | Revised environmental state aid guidelines enter into force, allowing EU Member States to subsidize CCS (EurActiv 28/01/08) |
| 12 Dec. 2008 | EU summit agrees to provide 300 million $CO_2$ allowances from the EU Emissions Trading Scheme (EU ETS) to subsidize the construction of CCS demonstration plants (EurActiv 12/12/08) |
| 17 Dec. 2008 | Adoption of CCS Directive in the EU Parliament (EurActiv 18/12/08) |
| By end 2009 | EU Commission to adopt rules for using up to 300 million tons of allowances from the EU ETS to aid demonstration of CCS |
| 2013 | Revised EU ETS comes into force. Stored $CO_2$ will be considered as “not emitted” |
| By 2015 | 10 to 12 large-scale demonstration projects to be launched for coal and gas-fired power plants |
| By 2020 | All new coal-fired plants should include CCS technology. Existing plants should be retrofitted subsequently |

Source: adapted from www.euractiv.com

Member states rejected the original proposal to match every Euro taken from EU funds with an equal contribution from national budgets due to fears hat poorer Member States of Central and Eastern Europe would not be able to contribute these amounts. In December 2009, the EU Commission proposed that each Member State would be allowed to host a maximum of two projects and that the allowances shall be awarded through two rounds of calls for proposals. After a year of negotiations to fine-tuning of details, the EU Council agreed on 2 February 2010 to use the revenues of 300 million emission allowances from the EU ETS for the period 2013-2020 to subsidize the construction of 12 carbon capture and storage demonstration plants and to support projects on innovative renewable energy technologies. The emission allowances will be sold by the European Investment Bank (EIB) and then distributed to support projects in

[9] For more information about the EU ETS, see Ellerman *et al*. 2010

Member States. At a $CO_2$ price of 20 Euro/t the revenue would amount to about 6 billion Euros or 500 million Euros per project.

As of June 2010 the time schedule of the next steps looked as follows:

- End of June 2010: Decision on 300 million allowances to be formally adopted
- 3rd quarter of 2010: EIB and EU Commission to sign inter-institutional agreement detailing EIB's role in decision
- By end 2010: Member States to submit projects to the EIB
- 2011: EIB assessment of projects
- By end 2011: EU Commission to make final selection

*Table 8 Planned CCS projects in the EU by mid 2010*

| | | |
|---|---|---|
| Belchatow (Poland) | In 2011, *Alstom* and *PGE* will start work on a power plant that will store 0.1 million tons of CO2 per year | Coal |
| Ferrybridge (UK) | *Scottish* and *Southern Energy* will retrofit a coal plant and store 1.7 million tons of CO2 per year starting in 2012 | Retrofit coal |
| Teesside (UK) | *Centrica* will capture and store 5 million tons of CO2 per year from an plant starting in 2012 | IGCC coal, EOR |
| Aalborg (Denmark) | Beginning in 2013, *Vattenfall* will capture and store 1.8 million tons of CO2 per year | Oxyfuel coal |
| Rotterdam (Netherlands) | *C Gen* will capture and store CO2 from a 400-450MW power plant in 2014 | IGCC coal, EOR |
| Longannet (UK) | A 3390 MW plant shall be built in 2014 | Coal |
| Huerth (Germany) | *RWE* plans 400-450MW power capacity for capturing and storing 2.8 million tons of CO2 per year starting in 2014 | IGCC coal |
| Kedzierzyn (Poland) | *PKE* and *ZAK* will capture and store 2.4 million tons of CO2 per year starting in 2014 | Coal |
| Hatfield (UK) | *Powerfue*l will build a 900MW plant in 2014 | IGCC coal |
| Killingholme (UK) | *E.ON* will build a 450MW power plant in 2014 | IGCC coal |
| Onllwyn (UK) | *Valleys Energy* plans to store 2.4 million tons of CO2 per year from an plant beginning in 2014 | IGCC coal |
| Janschwalde (Germany) | *Vattenfall* will store more than 1 million tons of CO2 per year beginning in 2015 | Coal, EOR |
| Lednice (Czech Republic) | Power plant will be retrofitted to capture and store 0.9 million tons of CO2 per year in 2015 | Coal |
| Hodinin (Czech Republic) | A plant will be built in 2015 that will capture and store 0.3 million tons of CO2 per year | Coal/biomass |
| Compostella (Spain) | In 2015 *Endesa* plans to build a coal/biomass plant will that will capture and store 2.75 million tons of CO2 per year | Coal/biomass |
| ??? (Netherlands) | *Nuon* 1200MW plant will be built in 2015 | IGCC coal |
| ??? (Spain) | For 2016 *Union Fenosa* plans a coal plant that will store 1 million tons of CO2 per year | Coal |
| ??? (Italy) | Beginning in 2016, *ENEL* will capture and store more than 1 million tons of CO2 per year | Coal |

Source: adapted from US National Mining Association (www.nma.org/ccs/ccsprojects.asp)

This is obviously a rather ambitious time schedule and major delays have to be expected. One reason is that in order to store $CO_2$ in geological formations, national mining laws have to be adapted. It is quite impossible that the parliaments of the EU Member States are able to decide this within some months only. A further obstacle is the growing opposition of local citizens and environmentalist groups against the underground storage of $CO_2$.

On the other hand, the European industry is preparing projects that shall be submitted to the EIB once the call for tender is open. Table 8 lists 18 European CCS projects. As far as the author knows several of these projects may not be realized due to substantial engineering, financial, legal and licensing problems. Also the lacking social acceptance is a problem in some cases.

The CCS regulation the EU Commission promises for the first time to allocate direct EU subsidies to energy projects and businesses. Until now only EU subsidies had been granted to the agricultural sector, to European r&d projects, and to projects that reduce regional economic disparities in the European Union (cohesion funds). Regarding the difficulties with the discussed CCS pilot projects, it may turn out that a larger share of the budgeted 6 billion Euros will not be allocated to CCS pilot projects but rather to innovative renewable energy projects. Several candidates for large-scale renewable electricity projects already exist. It could turn out that the opening of a new subsidy channel will be, on a long-term scale, harmful for the European industry.

## 10. Conclusions

There are a number of conclusions to be drawn from the European experience with the six technologies. The first and most important one is that if national governments are fully determined to implement convincing and sustainable incentives, the development and market dissemination of green technologies can be much faster than originally anticipated.

Depending on the technologies under concern and the maturity of the market, subsidies, feed-in tariffs, bonus payments, preferential loans, quota rules, mandatory bans and investment tax credits can likewise be successful. Feed-in systems are particularly successful during the early phases of renewable generation capacity buildup but will have to be modified and/or replaced if the renewable electricity shares become larger.

Instruments that create no additional burden to public budgets are particularly attractive to governments. Such instruments are feed-in tariffs and bonus payments for PV and wind power generation. As long as the associated costs for electricity consumers remain limited, the support scheme acceptance and credibility is particularly high which improves success. On the other hand, tax incentives, subsidies and preferential loans have to be financed from national budgets and may be less stable as these instruments are subject to volatile political priorities.

The experience in Europe shows the significance of political risks associated with government intervention in favor of green technologies. Most developers and investors welcome political support and incentives. Europe’s wind power, solar photovoltaic, nuclear energy and CCS industries have all seen phases of strong political backing and ample financial assistance followed by significant reservations and support cuts. As a consequence, green technology companies suffered from unexpected profit drops, employment cuts, and in some cases even default.

An imperfect substitute for volatile political incentives is the early announcement of a long-term gradual phase out of support schemes. This is one reason for EU Directives to require Member States to implement such phase-outs schemes when supporting green technologies. Another reason is that the declining trend of feed-in payments is seen as a quite effective instrument to stimulate the green technology industries towards cost reductions.

An internal coordination of green energy support schemes, for example through international institutions like the new International Renewable Energy Agency (IRENA), would be wishful but probably quite difficult to implement. This is another lesson learned from EU experiences:

- Wind power and nuclear energy technologies are, to a large degree, mature technologies, but their dissemination in EU Member States is quite heterogeneous. While the EU Commission seeks to implement uniform framework conditions, there is an unequal dissemination between Member States due to different national conditions and obstacles. One has to accept that even with international policy harmonization there will always be national and regional differences in energy supply structures
- Two other technologies, solar photovoltaic and LED lighting, are in an early stage of market penetration. While the EU Commission is successful in the case of LED technology to prevent disparate national legislations, it is ineffective in the case of PV. International harmonization is a particularly challenging task if powerful national interest groups would be affected
- The last two technologies, smart grid and CCS, are both in a research and development phase. EU Commission is ambiguous in defining the appropriate approach in terms of procedures, instruments and timing towards the dissemination of these technologies. Smaller legislative units seem to be better suited to regulate and stimulate technologies in an early stage of development. This may be not so bad because decentralized decisions would have less severe consequences in case of political steering errors

Finally I may add a word on early mover advantages: Particularly the PV example shows that in spite of Europe's PV investments leadership its industry is not in the pole position on the global PV market. This result follows from an essential property of feed-in support schemes, bonus, and quota models: usually they have not biased in favor of domestic technology suppliers and generate opportunities for foreign industries that can participate from the very beginning. Direct subsidies, preferred loans and other budget instruments are likely to be used as protectionism measures. The result would be first mover advantages to the domestic industry but an overall much slower global green technological progress and dissemination.

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