The SuperSmart Grid

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The energy and climate challenges

The energy system of today is heavily based on fossil energy resources. This system was developed during a time of low and constant energy prices, when it seemed reasonable to expect prices to remain low and constant, and fossil energy to be abundant. Since the oil crises in the 1970s we know that this is not true, and the recent strong increase of demand – driven by the economic boom in the emerging markets – has once again shown that the energy system of today must change. The competition for energy resources is becoming tougher as countries like China and India become more aggressive on the increasingly instable and volatile energy market. The world demand for energy is expected to increase with 60% by 2030. Since about 1980, the oil production is larger than the oil field discovery rate leading to increasing fears of “peak oil” (IEA 2004:57ff; Zittel, Schindler 2007:33). After the oil crises, during the 1980s and 1990s, the oil price decreased again, and the oil import dependency of the EU continued to increase (Eurostat 2008a). Today, we are experiencing oil prices at unprecedented levels - the increase from 1998 to 2008 was about 800% (see Figure 1) – which is a considerable strain to the European economy and a heavy burden for developing economies. The price of natural gas is linked to the oil price and has shown a similar development; the world market coal price has also increased in the last years, though not as strongly as the oil and gas prices (EIA 2008; VdS 2008). This limits the economic possibilities for a fuel switch from oil to coal or gas. Even if the energy markets are likely to relax somewhat in future, it seems clear that the age of cheap and abundant fossil energy is coming to an end.

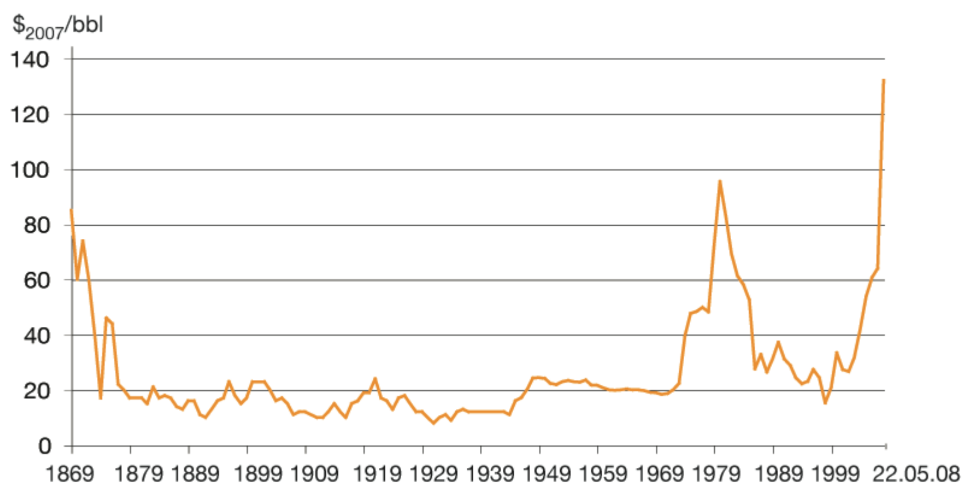

Figure 1: Yearly average oil prices (WTI) in real terms [$\$_{2007}$/bbl] 1869-2008. The value for 2008 is the WTI spot price in New York on May 22 2008. Sources: Inflationdata 2008; WTRG 2008; Bloomberg 2008

Most of the fossil energy resources are imported to the EU (in 2005 52,4%), and the import shares are expected to increase to about 2/3 by 2030 (Eurostat 2008b:13; DG TREN 2008:97). These imports mainly come from instable countries, such as Russia, Algeria or South Africa (see Table 1). The increasing competition on the world energy market makes this an increasingly risky situation, and powerful measures to diversify the energy mix, increase the spread of supply countries and reduce the import dependency should be considered.

Table 1: Energy import dependency 2005, EU27, by country of origin [in % of total imports]

	Oil	Gas	Coal
Russia	30	45	21
Norway	16	24	
Saudi Arabia	10		
Algeria	4	21	
Nigeria		4	
Libya	8	2	
South Africa			23
Australia			12
Import dependency	82	58	40

Quelle: Eurostat (2008b:14f)

At the same time, the climate problem becomes more urgent. Projected impacts of climate change are estimated to cost the economy in the range between 5% and 20% of global GDP per year if action is not taken (Stern 2006). BAU scenarios project extreme temperature rise in the range of 4-7°C by the end of the century. Already with a global average temperature increase of 2°C over preindustrial level, an increase widely considered just enough to avoid "dangerous climate change", major changes in precipitations patterns are to be expected. Reduced access to fresh water will pose major challenges for vulnerable communities with severe implication for agriculture, food security, ecosystems services, health and security. There is an urgent need to come up with effective measures which take into account the long-term dimension of climate change and the short-term requirements of economic growth, business profitability and national energy security. Energy is a critical driver for economic growth but it is also a key-driver for climate change. We face the dilemma of having to meet growing energy demands, keep the energy price down and at the same time prevent dangerous climate change. Given the rapid economic growth of emerging economies and the time horizon of global investment decisions in the energy system, decisions taken in the next few years will determine future technology for many decades to come.

The fossil fuel-based energy system of today needs to go through a dramatic transformation. The challenges posed by the surge in energy use, the difficulty to access traditional energy sources due to either geological or political reasons and the rising threat of climate change, cannot be addressed by old means. Business as usual is not longer possible.

In order to prevent dangerous climate change, in Heiligendamm leaders of the G8 nations agreed to seek "substantial" cuts in emissions at least of 50% by the year 2050. It is expected that a firmer agreement will be reached at the upcoming G8 summit in Japan. However, there is no credible plan - neither from politics nor from business – on how to reach this target. This is clearly weaker than the EU commitment to keep the world average temperature increase within 2ºC from pre-industrial levels, by reducing the global emissions by at least 50% by 2050 – the industrialised countries, however, should reduce by at least 60-80% (European Commission 2007:2).

Since 1990, the EU27 emissions have decreased by some 6%[1], or about 300 Mt CO_{2eq}. The EU15 has increased GHG emissions by 1%[2] from 1990 to 2005 (Eurostat 2008c:3). In 2050,

[1] Energy industries, industry and "others-sector" have each reduced emission by some 200 Mt since 1990, whereas Transports have increased emissions with about 300 Mt. Most of the EU27 reduction has occurred in the former communist countries, as a result of the economic turmoil.

[2] Excluding LULUCF emissions.

the total EU emissions must be reduced by about 5 500 Mt, to about 1 000 Mt CO_{2eq}. This is an enormous challenge that requires the restructuring of all economic and societal sectors.

A new energy system needs to be created to provide energy security as well as climate security. In this paper we discuss about the need to put in place an electricity infrastructure capable of meeting the electricity needs of the next 50 years and support a transition towards a decarbonised economy. To reach the EU target on emissions reduction of 80% by 2050, the European electricity system and its infrastructure need to be reinvented with the aim of reaching 100% renewable electricity by 2050.

The renewable option for climate and energy security

A variety of technology options are on the table to mitigate emissions from the electricity system in the coming decades. Among the most discussed at the moment there are CCS (carbon capture and storage), nuclear and an increasing variety of renewables energy sources such as wind, solar, biomass, waves, hydro and geothermal power.

Considering that coal is abundant and often available within national borders, it is difficult to imagine a future without it. However, the burning of coal strongly interferes with the commitment to combat climate change. In the past years lot of emphasis has been put on clean coal and considerable efforts have been made to design and test the technologies for capturing and storing the CO_2. Despite that, several of the plans have been either cancelled or delayed. The US most spectacular plan for clean coal, FutureGen has been put on hold, with the government pulling out of the consortium due to costs reasons. The UK lead initiative for reaching a European agreement to finance and build the first commercial CCS plant in China is, as of today, not operational and there are no clear signs on when a binding agreement could be reached. Only few pilot projects are being implemented, with Norway, Germany and Australia leading the way (see for example OED 2008; GFZ 2008). It remains unclear whether large-scale CCS is a technically and economically feasible option, and when it will deliver. At least until 2020, no significant deployment of CCS can be expected.

It seems unrealistic that the nuclear sector can be expanded fast and massively enough to contribute significantly to climate change mitigation; the capacities of constructing new nuclear power plants are limited. Furthermore, nuclear remains highly controversial and due to the inherent technological, proliferation and political risks, it should be considered very cautiously in the debate.

As an alternative, renewable energy resources offer clean alternatives to fossil fuels. They produce little or no pollution or greenhouse gases, are widely available and will never run out. Therefore, one of the key objectives of European energy policy is a substantial increase in the use of renewable energy sources, coupled with a massive increase in energy efficiency. Long distance direct current energy transmission, distributed power generation and smart grid systems could become key elements for fulfilling this objective. However, a massive deployment of renewable energy sources poses completely new technological and organisational challenges for the existing energy systems.

Limits of the existing grid

The European high-voltage grid is to a large extent some 50 years old. It is based on a hierarchical, top-down flow and distribution of power flow and was build in the 70's and 80's to connect lower voltage networks and serve as backup system to cover potential breakdown of power plants. The methods of operating the power grid have not changed. It has remained substantially the same despite the fact that the number of customers has increased and their needs have changed dramatically over time

Following the deregulation and liberalisation of the power markets, the transmission grid and the access to it have become increasingly important. Moreover, the rapid expansion of wind power in many regions in weak load areas (e.g. in northern and eastern Germany) drives the grid to its capacity limits[3] and creates a need for new power lines from the production sites to the load centres (Arzt 2008). The expected expansion of offshore wind will increase the need for new connections. The fluctuating nature of renewable energies cause further strain on the grid infrastructure. A further stress to the grid is caused by the increasing number of new power stations being built close to harbours or pipelines instead of close to demand centres. The increasing production of renewable electricity and the geographical restructuring of the conventional power generation combined with the expected increase in electricity demand, lead to a situation where the current transmission grid will not suffice to satisfy future electricity needs.

The future grid

Regardless of the context – solving the climate change problem, or securing the electricity supply - the grid has become one of the key conditions to satisfy both. In the field of renewables, two main approaches are disputed: 1.) The wide-area supply of electricity, and 2.) decentralised generation.

1.) The concept of large-scale transmission of renewable electricity over very long distances is generally known as the *SuperGrid*. In Europe, the potentials for renewable electricity are large, possibly even large enough for an electricity supply from exclusively renewable sources, but they are very unevenly distributed across the continent (see for example DLR 2006:58). The prerequisite for an electricity system completely based on these sources is a massive expansion of an efficient, long-distance transmission grid in a wide-area supply system. In a larger perspective, the potentials for wind and solar energy in the deserts of North Africa would be enough to satisfy the world energy demand many times over, and may therefore hold many low-hanging fruit also for supplying the wider European region with electricity. The wide-area supply of electricity is dependent on a structure which allows transmitting renewably generated electricity from sites of favourable generation to places of high demand, if necessary over very long distances. The technology for transmitting electricity over long distances (high voltage direct current lines (HVDC) has been in use for several decades. One such SuperGrid vision is the DESERTEC concept of the Club of Rome, which combines the resources of North Africa (*desert*s with enormous potentials for renewable electricity) with the assets of Europe (*tec*hnology) (see DESERTEC 2007, 2008).

[3] Another increasingly urgent problem affects the mid-voltage level (mainly 110 kV), which brings the decentrally produced electricity to the high-voltage grid: Also regions where the high-voltage grid would be sufficient, experience increasing difficulties with connecting new wind turbines (see Arzt 2008).

2.) The decentralised approach is based on a cluster of distributed generation (DG) installations, (e.g. gas turbines, microturbines, fuels cells (FCs), photovoltaic (PV), small wind turbines (WTs), biogas digestors etc.), which are connected by a *Smart Grid*.. These clusters, or Virtual Power Plants, are collectively run by a central control entity which controls the electricity output from the entire cluster by regulating the different power plants. The clustering of a number of different renewable technologies, of which some should be technologies able to produce electricity on-demand like hydro or biomass power plants, effectively smoothes the stochastic, supply-controlled feed-in of wind and PV. This way, the total feed-in from the Virtual Power Plant can be controlled and kept at a constant level. With this approach, the renewable power plant cluster is as controllable and as reliable as a conventional thermal power plant (see for example www.kombikraftwerk.de or RWE 2007). The Smart Grid is equipped with ICT-based optimisation technology in order to communicate with demand side loads that offer a variety of options to make the grid load and the production more predictable, and adapt the production to the demand accordingly. Using Smart technologies would allow a massively increased share of renewable, intermittent electricity in the grid, since it enables a controlled flow management and shiftable, interruptible and scheduled feed-in. Without a substantial upgrade of the current grid and the implementation of Smart technologies, an electricity supply from 100% renewable sources will be not possible.

The SuperSmart Grid

The large-scale centralised SuperGrid and the small-scale decentralised SmartGrid approaches are often perceived as being mutually exclusive alternatives. However, we argue on the fact that the two concepts are complementary and can and must coexist in order to guarantee a transition to a decarbonised economy. What is required is therefore a SuperSmart Grid[4]: The infrastructure to transmit renewably generated electricity from a variety of small and large generation sites scattered over wide areas with the ability to manage both fluctuating supply and loads.

The concepts of energy storage and load management will become increasingly important with increasing shares of intermittent power in the system. Whereas it is difficult to store electricity itself, it is convenient to store energy using pump storage hydro power plants – the SuperSmart Grid would make it possible to power Swiss pump storage plants with North African solar power. More importantly, the SmartGrid allows the power flow to be redirected and controlled and enables the targeted grid management using stochastic smoothing, it accentuates another benefit of the SuperGrid concept: the stochastic smoothing of feed-in of the supply-controlled wind and solar power. In a very large-scale system, the wind always blows somewhere, which would flatten feed-in peaks and fill the feed-in valleys in the regional grid sections, thus increasing the stability of the system and reducing the need for back-up power or energy storage (see for example Czisch 2006).. ,

A dense grid of HVDC lines in Europe would set up the precondition for integrating the today only loosely coupled national markets into a European common electricity market. Moreover, HVDC lines would open the way to connect and integrate North African countries into the European power system, thus creating a double benefit: Europe could make use of the vast

[4] The word SuperSmart Grid (SSG) was invented by Antonella Battaglini and used the first time in the PIK position paper for the energy conference in Lund in 2007

potential of wind and solar power in its vicinity to decarbonise its electricity system; the neighbour regions would be supported in the build-up of a renewables-based power system and benefit from the financial streams that would come along with integrating them into the SuperSmart Grid.

From a technical point of view, the construction of first point-to-point HVDC lines could start today. However, the techniques to couple numerous HVDC lines into an actual SuperSmart Grid do not yet exist and must be developed in the light of experiences made in the course of building up the SuperSmart Grid. The SuperSmart Grid will, as the existing grid has been in the past, only gradually come into existence while technological learning will continuously reduce the technological uncertainties. A recent survey has shown that almost all informed stakeholders (99%) expect the technological uncertainties to be surmountable (see Barras, Gordon 2008). Instead, there are several other uncertainties and risks, mainly of political and financial nature, that must be addressed.

Similarly, the technologies for a decentralised energy system are available already today. They are being successfully tested in a multitude of pilot projects among which the microgrid pilots in the Island of Kythnos in Greece and the ecological city of Mannheim-Wallstadt in Germany and the ambitious 100 million $ "smart grid" project in Boulder, Colorado, which should be completed in 2009[5]. However, despite the fact that it is already possible the application of small distributed energy resources (DERs), "controlling a potentially huge number of DERs creates a daunting new challenge for operating and controlling the network safely and efficiently" (Hatziargyriou 2007)

Risks and open questions

The literature on visions similar to the SuperSmart Grid vision clearly states the potential macroeconomic benefits of massive renewable electricity imports from North Africa (see for example Czisch 1999, 2006; Czisch, Giebel 2007; DLR 2005, 2006, 2007; DESERTEC 2007, 2008) and/or a decentralised energy system (see for example ABB 2008; SmartGrids 2006; Buchholz et al. 2006; Chebbo 2007) They all state that implementing a SuperSmart Grid vision is technologically and economically challenging but realistic. Actually implementing the idea is, according to the same sources, a political problem, and as a consequence a financial problem. This statement correlates well with the PIK/ECF preliminary stakeholder survey results (Barras, Gordon 2008).

Regarding these political and financial problems, there are a number of issues and open questions that must be thoroughly investigated. Most of these have to do with investment risks, often triggered by political uncertainties. Below, 6 of the most important aspects to address are discussed from the perspective of investors and questions are defined.

- **Sheer magnitude of investment.** Compared to alternative options, a SuperSmart Grid would be highly capital intensive and have significant economies of scale. Individual projects combining generation and HVDC transmission and capable of delivering 5 GW of power from North Africa to Central Europe would with today's costs require investments of 10 – 25 billion €, depending on which generation technology is chosen. This is the same range as the officially stated cost of constructing the 23 GW Three Gorges Dam in China, the actual cost may have been considerably higher, or the cost of building the Channel Tunnel, which is the world's largest infrastructure project financed

[5] See www.rockymountainnews.com

with private funds (BBC 2006; CCM 2008; Anderson, Roskrow 1994; Glancey 2005). It is about ten to fifteen times the cost of building a 1 GW coal-fired power plant. Considering the European[6] peak load of about 400 GW (UCTE 2007:121) it becomes clear that the SuperSmart Grid would be an infrastructure project of an unprecedented, but not singular scale: the IEA expects China to build more than 700 GW of coal power plants between 2005 and 2015 (Platts 2008), which is approximately the same amount of generation capacity that was built in the entire EU since World War II. Important questions to answer include how large investments serving a public purpose have been financed in the past, and how current stakeholders in the industry envision such financing taking place.

- **Poorly defined financial uncertainties**. While many projects within a SuperSmart Grid vision appear economically attractive, there are some uncertainties that could significantly influence their profitability. These include both uncertainties concerning competitiveness and political uncertainties (see below). Most analysts state the costs of renewable electricity from North Africa at a feed-in point to the AC grid in central Europe are between 5 and 20 €c/kWh, depending on generation technology and assumptions regarding risks and learning effects (see Lilliestam 2008). Whether a specific technology is profitable depends on the development of both other renewable technologies (i.e. wind competes against CSP, a sudden cost fall for one influences the profitability of the other) and other generation technologies (most significantly technical breakthroughs in CCS or nuclear). Similarly for a fully decentralised energy system massive investments would be required. The future carbon price is a significant risk of the same category. These uncertainties must be analysed and, as far as possible, quantified. The risk that a non-European government at some point nationalises the power production is real, however low, and is a deterring factor that includes the total loss of the invested capital. The risk of terrorism against power plants or power lines cannot be eliminated but it has to be compared with the same risk for other options (e.g. nuclear) and the existing grid. Risk impacts the specific generation cost; the question of cost increase due to risk bonuses should be explicitly answered and a clear framework for investors in Europe and abroad should be put in place to guarantee "an acceptable" rate of return.

- **Policy uncertainty.** At present, there is considerable uncertainty about the future energy and climate policy of Europe, and the long-term predictability of these are close to zero. Whereas the EU long term climate targets are somewhat defined, and seem quite ambitious, the future energy policy is totally unknown. After the Irish referendum, it is unclear, whether there will be a new Lissabon treaty with more clarity to the foreign energy policy and also the design of the future internal energy market. The long term frame of the Emissions Trading Scheme (ETS) is uncertain, but it is clear that it will be reformed. This uncertainty affects expectations of the future carbon price, which will have a large impact on the profitability of renewable energy projects. However, by the end of this year there should be more certainty regarding the ETS. In the short to middle term, the renewable technologies will be dependent on support schemes to be competitive with the conventional energy sources; the amount and form of such support scheme(s) are not at all clear. Possible future support schemes for other, competing technologies (for example CCS or nuclear) add to the policy uncertainty. The uncertainty for investors in

[6] Number valid for the UCTE, which consists of continental EU and former Yugoslavia
[8] Except smaller land-based stretches of submarine links, such as the Baltic cable.

renewable power outside the EU for export to the EU is even larger: the climate policy of the non-EU countries is unclear, as is the question whether such energy can be accounted for the EU country's renewable energy target compliance. However, the EU Directive on renewables is expected to be decided by the end of the year, bringing clarity and hopefully long term directions and confidence for investors. The questions of the potentially suitable range of policy instruments should be answered, and the costs, benefits and risks of different instruments thoroughly investigated. Potential conflicts between these policies and other existing or planned policy frameworks must be explicitly addressed.

- **Local political obstacles to transmission**. Obtaining rights of way to build long-distance transmission lines in Europe has until now been a challenge: there are examples of permission processes which have taken more than 10 years from application to permission. This could explain some of the reluctance of the EU Transmission System Operators to invest in new high-voltage grids. To transmit power from the Mediterranean to the heart of Europe would require rights of way crossing several national, and hundreds of local jurisdictions. Therefore, the proposal of constructing a large-scale HVDC grid through all of Europe is not very promising with the current legislative situation, although HVDC power lines have a higher capacity for the same number of lines compared to HVAC, and hence narrower rights of way. There is a great need for accelerating permission processes and coordinating these at a European, or at least a national, level. Today, there is not a single HVDC line on land[8] in Europe, and so to governments this would be a novelty. Questions to answer include the question of what legal frameworks dictate the acquisition of public rights of way through Europe, and of the potential for a European directive on transmission rights of way.

- **Import dependency**. In an increasingly integrated European Union, electricity transfer via a SuperSmart Grid from one Member State to another can hardly be seen as electricity import. Instead, the EU can be seen as one block, where only electricity transfer from non-EU countries are regarded as imports. The possibility of bulk electricity transmission across Europe from one EU country to another therefore rather decreases the EU energy import dependency, since it reduces the need for gas, coal and nuclear power, for which most of the fuel is imported. Electricity imports from North Africa increases the EU import dependency, but this electricity import dependency is of a different nature than the "normal" energy import dependency. The renewable electricity produced for Europe in North Africa cannot be sold on a world market, but is either sold within the EU-NA market or not at all, whereas the flows of oil and coal, and to some extent also gas, can be redirected to other countries and regions than the EU. Moreover by combining HVDC lines with DG options we could expect a decrease in the overall energy import dependence. However, it must be investigated how the European energy import dependency is influenced by a SuperSmart Grid scheme, and especially how it affects the security of electricity supply.

- **Lack of political lobbying**. Despite the conceptual simplicity of the SuperSmart Grid idea, there does not appear to be much political pressure on governments to engage in any action at all. Thus, there has been significantly less public investment, and less expenditure of political capital, to promote investment in extra-European renewable power generation coupled with transmission, compared to other technical options to achieve European climate protection goals. Historically, the most public expenditure has been for nuclear power. More recently, there have been large demonstration projects for carbon capture and storage, and more projects are being planned. In Germany and Spain, there have been very efficient and effective feed-in tariff support systems for wind and PV. We suspect that one explanation for this lack of support for the SuperSmart Grid vision is the absence of a politically powerful coalition standing behind such investment opportunities. The major existing power producers, such as RWE and E.On, would clearly benefit were carbon capture and storage to become feasible and cost-competitive, and yet would not clearly be the ones to benefit from African-based solar or wind power. A central question concerns how to generate enough political support for policies promoting investments in extra-European power generation and transmission. The question of how to raise political support in the North African countries is especially important.

Looking ahead

In the past years Europe has been leading climate policy and the ETS has been the main motor for driving emissions down in Europe and abroad. The world will be looking at Europe very carefully in the coming years to see if and how Europe will meet the targets it has chosen for itself.

The EU directive on renewable due to be published at the end of the year set the boundaries for Member States to meet the agreed 20% of energy demand by renewable supplies by 2020. For this to happen, the period between now and 2020 will need to see substantial structural changes. In the draft Renewables Directive, the possibility of physically importing electricity from outside the European borders and to count towards the national targets is being considered. If this option is confirmed the vision of linking Northern Africa to Europe may become a reality. This would be a very important step towards a decarbonised future. This option would imply the possibility of developing a renewable based economy in Northern Africa with positive implications not only for climate security but also a substantial contribution for local development, jobs creation and sea water desalination facilities and increased social stability. In Europe a link to North Africa through HVDC lines combined with Smart technologies would generate innovation in the electricity and engineering sectors and have long lasting repercussion on the way we "invent" our decarbonised future.

For the ongoing negotiations for an UN-post 2012 agreement it could be an important break through if the EU together with partners would come up with a plan, which combines

1. a realistic sharp increase of renewable energy for the EU,
2. a co-operative approach with a developing country region to secure energy security and greenhouse gas reduction in both regions and.
3. a break trough for important technologies which can play an important role world wide.

The EU Directives on renewable will also contribute in creating positive dynamics for the further development of DG in many regions. Experience built around the world will contribute in clarifying technological and commercial uncertainties. However, for a substantial contribution to the 2020 renewable target it is essential that a political framework is put in place as soon as possible and that adequate public private partnerships are fostered to carry out large scale projects. Energy companies need to be involved in the process as they will play a key role in finding commercially acceptable solutions. The NGO communities also need to be involved at an early stage to guarantee that the process is acceptable for civil societies and the outcomes long lasting. Moreover the financial markets will need to be mobilised to come up with mechanisms capable of favouring capital mobilisation at large scale.

Achievements in the renewable energy fields until 2020 will be determinant to define further steps towards the 80% emissions reduction target and shape the future energy system.
It is clear that the development of a SuperSmart Grid still require considerable efforts to better understand the economic, commercial and technical challenges. This will only be gained through practical experience. For this a strong and clear political framework needs to be put in place to provide long term directions and securities for investors.

Sources

ABB (2008): *The corporate technical journal of the ABB Group*, ABB, Zürich, www.abb.com/abbreview, 2008-06-16.

Arzt, I. (2008): Gesetz versäumter Chancen, in: *Neue Energie 06/2008*, pp. 26-28. Bundesverband Windenergie e.V., Berlin.

Barras, L., Gordon, R. (2008): *Stakeholder perceptions of a SuperSmart Grid. Preliminary results of the survey*, Potsdam Institute for Climate Impact Research, European Climate Forum, Potsdam.

Buchholz, B., Engler, A., Hatziargyriou, N., Scholtes, Schluecking, U., Furones Fartos, I. (2006): *Lessons learned: European pilot installations for distributed generation. An overview by the IRED cluster*, CIGRE 2006, paper C6-302.

Bloomberg (2008): *Energy prices*, Bloomberg.com, London, http://www.bloomberg.com/markets/commodities/energyprices.html, 22.05.2008.

Chebbo, M (2207): *Electricity networks of the future 2020 and beyond*, Power Engineering Society General Meeting, IEEE.

Czisch, G (1999): *Potentiale der regenerativen Stromerzeugung in Nordafrika*, Universität Kassel, Kassel.

Czisch, G. (2006): *Szenarien zur zukünftigen Stromversorgung. Kostenoptimierte Variationen zur Versorgung Europas und seiner Nachbarn mit Strom aus erneuerbaren Energien*, Universität Kassel, Kassel.

Czisch, G., Giebel, G. (2007): *Realisable scenarios for a future electricity supply based 100% on renewable energies*, Universität Kassel, Risø National Laboratory, Kassel, Roskilde.

DESERTEC (2007): *Clean power from deserts*, The Club of Rome, Hamburg.

DESERTEC (2008): *Our vision of the Union for the Mediterranean: The DESERTEC Concept. Deserts + technology for energy, water and climate security*, The Club of Rome, Hamburg.

DG TREN (2008): *European energy and transport trends to 2030 – update 2007*, Directorate-General Transport and Energy (DG TREN), European Commission, Brussels.

DLR (2005): *Concentrating solar power for the Mediterranean region*, German Aerospace Center (DLR), Berlin, Stuttgart.

DLR (2006): *Trans-Mediterranean interconnection for concentrating solar power*, German Aerospace Center (DLR), Berlin, Stuttgart.

DLR (2007): *Concentrating solar power for seawater desalination*, German Aerospace Center (DLR), Berlin, Stuttgart.

EIA (2008): *Natural gas prices*, Energy Information Administration (EIA), Washington D.C., http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm, 17.05.2008.

European Commission (2007): *Limiting global climate change to 2 degrees Celsius. The way ahead for 2020 and beyond. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions*, European Commission, Brussels.

Eurostat (2008a): *Energy statistics – Quantities. Import by country of origin*, Eurostat, European Commission, Brussels, http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,45323734&_dad=portal&_schema=PORTAL&screen=welcomeref&open=/&product=EU_MASTER_energy&depth=2, 28.05.2008.

Eurostat (2008b): *Energy and transport in figures. Part 2 Energy*, Eurostat, European Commission, Brussels.

Eurostat (2008c): *Energy and transport in figures. Part 4 Environment*, Eurostat, European Commission, Brussels.

GFZ (2008): *CO2SINK*, GeoForschungsZentrum Potsdam (GFZ), Potsdam, http://www.co2sink.org/, 2008-06-16.

Hatziargyriou, N.et al (2007) Microgrids. An overview of ongoing research, development and demostration projects, IEEE power & energy magazine 78

Inflationdata (2008): *Historical crude oil prices*, Inflation Data, Richmond, http://www.inflationdata.com/inflation/inflation_rate/Historical_Oil_Prices_Table.asp, 17.05.2008.

Lilliestam, J. (2008): *Findings from the SuperSmart Grid conferences, Nov. 2007-April 2008*, Potsdam Institute for Climate Impact Research, Potsdam. (Comes during summer 2008).

OED (2008): *Carbon capture and storage*, Norwegian Ministry of petroleum and energy (OED), Oslo, http://www.regjeringen.no/en/dep/oed/Subject/Carbon-capture-and-storage.html?id=86982, 2008-06-16.

Platts (2008): *Global energy mix to become more reliant on coal: IEA's Birol*, Platts.com, London, http://www.platts.com/Coal/News/6883905.xml, 03.06.2008.

RWE (2007): *Siemens und RWE Energy entwickeln gemeinsam virtuelles Kraftwerk*, RWE AG, Dortmund, http://www.rwe.com/generator.aspx/presse/language=de/id=76858?pmid=4001753, 2008-06-13.

SmartGrids (2006): *European SmartGrids technology platform. Vision and strategy for Europe's electricity networks of the future*, DG Research, European Commission, Brussels.

Stern, N. (2006): *Stern Review on the economics of climate change*, Her Majesty's treasury, London.

VdS (2008): *Preise für Steinkohlen*, Verein der Steinkohleimporteure (VdS), Hamburg, http://www.verein-kohlenimporteure.de/deutsch/preise/inhalt.htm, 26.05.2008.

WTRG (2007): *Oil price history and analysis (updating)*, WTRG Economics, London, http://wtrg.com/prices.htm, 17.05.2008.