# Security of electricity supply in Europe in a short, medium and long-term perspective

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# Abstract

Security of electricity supply is a broad concept that comprises different activities and time frames and whose ultimate objective is to provide electricity to the end consumers within prescribed quality standards. This paper examines the impact that the activities of system operation, transmission, distribution and generation have on the security of supply of a power system in the four time dimensions that contribute to security of electricity supply: security, firmness, adequacy and strategic energy policy. The paper reviews and evaluates the regulatory instruments that are available within the Internal Electricity Market (IEM) of the European Union (EU) to achieve an appropriate level of security of electricity supply and focuses on the Energy Policy for Europe that has been put forward by the European Council and the indispensable and broader context of sustainability of the global energy model.

## 1. Introduction

As EURELECTRIC –the Union of the Electricity Industry at pan-European level- defines it, "security of electricity supply is the ability of the electric power system to provide electricity to end-users with a specified level of continuity and quality in a sustainable manner, relating to the existing standards and contractual agreements at the points of delivery", see [1]. In this definition one has to notice that what really matters is that the end consumers receive the electricity that they demand from the system, with at least a prescribed level of continuity and quality (i.e. low in harmonics, micro-interruptions or other distortions in the voltage waveform), which cannot be 100% perfect since perfection has an infinite cost. The supply contract or some regulated standards typically specify the minimum required level of continuity and service quality.

Security of supply also requires that the provision of electricity happens in a sustainable manner. It is noteworthy that the definition includes sustainability as one of the elements of security of supply. Sustainability links the need to provide electricity to the present end users with caring for the provision to future generations. This is not a minor requirement, since the present model of electricity supply –and the entire energy model, for that matter- is not sustainable[2].

This paper examines the topic of security of electricity supply from a broad perspective, which includes the different activities –generation, transmission, distribution, retail, system operation- that are needed to take the electric energy to the end consumers, as well as the time scales –from real time to strategic decisions that are made many years before they have an impact on the actual supply of electricity-. Although all relevant topics will be considered, the emphasis of the paper will be on those areas that appear to be more critical or insufficiently addressed at the present time: the activity of electricity from a medium to long-term time perspective, in particular when contemplated from a regulatory viewpoint. Although the

[2] Sustainable development, as defined in the well-known Brundtland report at the UN World Conference on Environment and Development, in Rio de Janeiro 1992, is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." Multiple statements from every authoritative institution confirm that the present energy model is not sustainable. A sustainable energy model must include some essential features: lasting and dependable access to primary energy sources, adequate infrastructures to produce and deliver the required amount of energy reliably, non irreparable environmental consequences, compatibility with an adequate economic development and equitable universal access to modern forms of energy supply.

paper addresses security of *supply*, the active role of the demand itself in contributing to a more satisfactory provision of electricity-related services is becoming increasingly important and has to be explicitly considered.

The response of electricity markets to security of supply considerations is presently a matter of preoccupation. Unlike governments, individual generation companies carry little or no explicit obligation to address energy security or environmental challenges. It is the responsibility of governments to ensure, through orthodox electricity market regulation and additional legislative measures, that the market responds to these concerns. Besides letting market prices send correct economic signals, most of the additional mechanisms of response that have been proposed typically consist of regulatory instruments to provide additional incentives or limitations to the behaviour of market agents. These are generally necessary, since markets rarely internalize long-term public policy objectives and they miss most environmental externalities associated to electricity production or consumption. Energy market liberalization and privatization have led to a more efficient power sector, but also to greater price volatility and increased commercial risk for new capacity investment across all fuel types. In a significant number of systems, energy planners have begun to voice concerns over current limited levels of private sector investment in new generation –also in transmission and distribution networks, in some systems- to meet the projected energy demand growth. This is of particular importance now that a very significant volume of investment in electricity infrastructure –generation in particular- will be needed in Europe for the next 25 years and that there is an urgent necessity to move towards a low carbon economy, see [2, 3].

These concerns, among others, were partly addressed by the EU Directive 2005/89/EC on measures to safeguard security of electricity supply and infrastructure investment (hereafter the *Security of Supply Directive or SoS Directive*). The purpose of the SoS Directive is to establish a framework within which Member States are supposed to define transparent, stable and non-discriminatory policies on security of electricity supply compatible with the requirements of a competitive internal market for electricity. Jointly with the EU Directive 2003/54/EC (the *IEM Directive*), the SoS Directive provides a toolbox of regulatory instruments aimed at safeguarding security of supply in the Internal Electricity Market by ensuring an adequate level of generation capacity, an adequate balance between supply an demand and an appropriate level of interconnection between Member States (MS). This set

of instruments include the consideration of security of electricity supply as a public good, with the ensuing legal implications; the authorization procedure for new generation capacity may be supplemented by tendering procedures to be implemented by the MS; the MS are also required to provide a stable investment climate and to define and publish roles and responsibilities of security of supply policies and of all relevant market actors; the ongoing process of defining minimum operational rules and obligations on network security must be reinforced; diverse recommendations concerning maintaining the balance between supply and demand, regarding reserve network capacity, generation operating reserves, interruptible contracts or network investment signals; finally, the regular publication of reports that monitor the different aspects of security of electricity supply is ensured.

The philosophy behind the IEM and the SoS Directives is to provide safeguard measures in case the electricity market fails. Undoubtedly most of these measures are useful. However, as it is customary with the EU regulation of the IEM, so much is left to the interpretation by the Member States that there is not much guidance on how to implement critical aspects –such as coordination among system operators, preventive measures against market power abuse, cross-border balancing mechanisms or congestion management-[3]. Furthermore, there is no enforcement of some essential elements –information transparency or the provision of sufficient interconnection capacity- and Member States end up by implementing a patchwork of regulatory measures that create a barrier to the implementation of a true IEM, see [4]. The SoS Directive adds some safeguards to the IEM Directive, while supporting its principles of market driven investment. The scope of both Directives is strictly limited to the functioning of the IEM, and therefore they ignore the broader strategic context of security of electricity supply and, even more, energy supply in general.

Other relevant EU Directives concern the implementation of the Internal Gas Market, the creation of the EU Emission Trading Scheme, setting indicative targets for penetration of renewables and energy efficiency (these targets are binding in the more recent European Energy Policy package) and establishing standards for air pollution from large combustion plants. All

[3] The EU Commission has published notes that help to interpret aspects of the electricity Directives, see http://ec.europa.eu/energy/electricity/legislation/notes_for_implementation_en.htm. However, these notes do not cover all issues in need of clarification and may not dispel all uncertainties.

these regulatory measures have had a large impact on the development of the European electricity sector (generation investments in particular) and indirectly on the security of electricity supply.

## 2. Taxonomy of the different areas of concern

"Security of electricity supply" is a commonly used expression in the regulatory context, but it lacks precision, since it encompasses too many concepts at the same time. One has to realize that the actual physical supply of electricity to the end-consumers at a given moment in time is the outcome of a complex and interlinked set of actions, some of which were performed many years before, which jointly make possible that the right technologies and infrastructures of generation and networks have been developed and installed, provision of fuels have been contracted, hydro reservoirs have been properly managed, networks and power plants have been maintained correctly and at an adequate time, generators have been started-up and connected to the grid so that they were ready to function when needed, margins of operating reserves have been kept, and metering, control and system protections were functioning correctly.

In the more precise world of engineering, the broad all-encompassing term of "security of supply" is replaced by "reliability", which is defined by the National Electric Reliability Council in the U.S.A. as "the degree to which the performance of the elements of the electrical system results in power being delivered to consumers within accepted standards and in the amount desired"[4]. Although the quality of the delivery of electricity only materializes in real time, as indicated before, its provision comprises a multiplicity of actions and measures that have to be performed in different time ranges -from many years to seconds-, by different agents –from investors to regulators or system operators- and involving different types of technologies and equipment –generators of a diversity of technologies, transmission and distribution networks, control centers or the means of provision of primary fuels-. Therefore "reliability" has been precisely broken down into its major components, in order to facilitate its understanding and to design proper technical procedures and regulatory measures. The "time" and the "activity"

[4] A similar definition and a complete review of the allocation of responsibilities, the functions of each stakeholder and the security criteria in the EU Member States can be found in a report by the Council of European Energy Regulators (CEER), see [5].

dimensions of reliability will be described next.

From the "time" perspective one can distinguish four dimensions of reliability of electricity supply:

- **Security**, which is the readiness of existing and functioning generation and network capacity to respond in real time when they are needed to meet the actual demand. This is a short-term issue. Caring for system security is the main function of the System Operator, who sets at every moment the most adequate reserve margins for generation and network.

- **Firmness**, which is the provision of the generation and network availability that partly results from operation planning activities of the already installed capacity. This is a short to mid-term issue. Firmness depends on the short and medium term management of generator and network maintenance, fuel supply contracts, reservoir management, start-up schedules, etc. A flawed management of firmness may result in poor system security, even if there is abundant installed capacity of generation and network.

- **Adequacy**, which means the existence of enough available capacity of generation and network, both installed and/or expected to be installed, to meet demand. This is a long-term issue.

- **Strategic energy policy**, which concerns the long-term availability of energy resources and infrastructures: long-term diversification of the fuel provision and the technology mix of generation, geopolitical considerations, future price evolution of fuels, potential environmental constraints, expected development of interconnections, etc. This is a long to very long term issue.

The main "activities" involved in the provision of electricity are system operation, generation, transmission and distribution; but here one should also include retail and the demand itself:

- **System Operation:** The System Operator (SO) is responsible for the security of the power system operation. At wholesale level (large generation and transmission) there is typically one SO for the entire power system of a country –like in Italy, France or Spain-; other

countries, like Germany, have several SOs. In addition, each distribution utility needs a Distribution Network Operator (DNO), who is responsible for managing the distribution network and facilitating any connected distributed generation, also with the ultimate goal of providing a secure supply to the end-consumers connected to its network.

In most EU countries the SO is also the owner of transmission assets (either the totality or an important fraction of them) and it is named Transmission System Operator (TSO). "Active" TSOs –as the one in the UK- are responsible for the development of the grid (in the same way that DNOs are responsible to develop distribution grids) while "passive" TSOs just propose the plan of transmission network reinforcement, which has to be approved by the regulatory authorities; then, the authorized investments are performed by the "passive" TSO or their construction may be auctioned. In all cases SOs are responsible for the secure joint operation of the complete transmission network and the generation connected to it.

System Operation is a monopolistic activity that has to be regulated as such, that is, its remuneration should be mostly based on cost-of-service considerations. In addition, it is possible to design economic incentives associated to the performance of the SO, although it is a complex matter to define incentives that do not have other undesirable implications. For instance, economic incentives could be associated to the reduction (with respect to a prescribed target) of the extra costs of dispatch derived from the management of network constraints. Incentives can also be applied in relation with the reduction of the costs of provision of ancillary services or network losses. The National Grid in the UK has had a quite successful experience in implementing these incentives. The concern here is how to gauge the magnitude of the incentives so that they may not result in a reduction of security margins in operation. In several EU countries, TSOs also run *ad hoc* markets to provide operating reserves and other ancillary services, all of them directly related to security of electricity supply.

- **Transmission** is a separate activity from system operation, and it consists of the construction, maintenance and direct physical maneuvering of the transmission network facilities. Transmission is another natural monopoly and therefore it must be regulated as such.

The simplest and more robust regulation of transmission starts with a transmission network expansion plan being proposed by the SO (a "passive TSO in this case"), with the participation (via specific proposals) of the network users, and approved by the regulator. Once a facility is authorized, its construction, operation and maintenance could be allocated by competitive bidding and its remuneration should then be based on the outcome of the competitive bidding process. The owner of any transmission facility should be subject to economic penalties (or incentives) based on its actual availability. Transmission costs should be fully allocated to the network users using cost reflective methods. This simple scheme guarantees –except for other difficulties in line construction, such as the NIMBY ("not in my back yard") syndrome- that all transmission facilities that are needed for a reliable supply and that are economically justified will be built.

However, even under this robust regulatory scheme, the transmission activity is much more difficult to perform under a competitive regime: the transmission network becomes the meeting point of the wholesale market agents, who are free to install new facilities and to ask for connection at any point of the grid. This introduces much uncertainty in network planning, reliability margins become tighter and there is an urgent need to send sound economic signals and to facilitate useful information on future network conditions so that the users make sound location decisions. Despite much discussion, European regulators have been unable to come up with any EU-wide scheme of locational signals and very few countries have implemented a domestic one.

A true EU-wide approach to security of electricity supply obviously requires sufficient interconnection capacity among the transmission networks of the different Member States. This is another issue waiting to be solved, since the EU actually consists of several subsystems with weak –and sometimes inexistent- connections among them, despite persistent attempts for many years by some of the involved parties and hollow formal declarations[5]. Recently the EU Commission has decided to appoint high level facilitators to help find a solution to the most stubborn cases.

[5] At the Barcelona European Council of 2002 it was agreed a minimum level of interconnection capacity among neighbouring Member States of at least 10% of their peak demand.

- **Distribution**: By comparison with transmission, distribution -which is also a natural monopoly- cannot be regulated on the basis of the individual facilities –since there are too many of them-, but on the basis of global performance. The regulator should set targets of quality of service and energy losses, with geographical differentiation. Network expansion, as well as network operation and maintenance, are left to the distribution utility. The remuneration of the distribution network must be based on an efficient level of investment that is commensurate with a prescribed minimum level of quality of service and penalties or credits that depend on indicators of actual performance, with respect to losses and quality of service. Stressing quality of service at distribution level is essential, since most failures of supply have its origin in distribution. A comparison of the different incentive schemes that have been implemented in EU Member States can be found in [6].

  A high penetration level of distributed generation (DG) is the major current challenge –and opportunity- for the distribution activity. Article 14/7 of the IEM Directive stipulates that DG should be considered by DNOs when planning the development of the distribution network. The European research project DG-GRID -see in [7]- has issued recommendations in this regard. The revision of the planning and security criteria used by DNOs in order to include the potential benefits of DG deferring or reducing network investments is recommended. The potential advantages of having DG as a new control source should become a DNO opportunity instead being considered a threat. DG can help to improve reliability indices working in islanding mode in case of global network outages. DG can provide ancillary services such as voltage control, frequency reserve, or black start to improve voltage quality. To achieve this aim, it is recommended to implement performance based regulation that provides explicit incentives to DNOs for improving quality of service levels and for introducing a deep transformation from passive to active management, increasing DG participation in network control and DG contribution in case of network disturbances.

- **Generation** is the most complex activity under a regulatory perspective, when security of supply is concerned. In principle no intervention should be needed since, under EU electricity regulation, the activity of generation is freely performed in a competitive manner. However, the single major question concerning reliability in generation is whether an

energy-only market can provide sufficient investment for attaining a satisfactory level of reliability, or if some form of regulatory action will be required. While some consensus exists regarding security in generation –with the use of ad hoc markets to provide operating reserves, for instance-, adequacy and firmness in generation is still a very open issue, even conceptually. And very little progress has been made on strategic energy policy so far. The remaining sections of this paper will mostly concentrate on the generation-related aspects of security of electricity supply.

- **Demand and retail:** Demand cannot be considered anymore as an inflexible sink of electricity that is not responsive to prices or other incentives and signals. Markets are meant to be the meeting point of supply and demand, with prices bringing efficient responses from both sides. Advances in metering and communications make it possible two-way interaction between companies and consumers, which increasingly will have the possibility of reacting on-line to the actual conditions in the power system. Retailers may also help in providing innovative choices to end consumers. Whenever energy prices are insufficient to include externalities, or if more drastic measures are needed in emergency situations, other types of measures can be implemented, such as interruptibility contracts, economic incentives or mandatory measures to promote energy saving and efficiency, and consumer education programs. In future power systems, where a massive penetration of intermittent renewable energy sources is expected, demand response should be an essential component of the overall reliability strategy.

## 3. Security

The regulatory changes that started in the nineties and introduced unbundling and competition in the mostly vertically integrated and traditionally and nationally regulated electric utilities, also resulted in important changes in the hierarchical organizations and systematic operation procedures of the utility associations, both domestic, European and international, UCPTE, UKTSOA and NORDEL being the largest ones in Europe. The unbundling of activities was key in the creation of a

European organization of transmission system operators, ETSO. Meanwhile generators, distributors and also some TSOs had assembled in EURELECTRIC. The changes in the structure of the power sector, the increased and much less predictable trading activity that has resulted from the introduction of the market, the strong penetration of intermittent generation sources in several Member States, and some recent blackouts have forced an in-depth revision of the handbook of rules that had been governing electricity exchanges in Europe for a long time and the entire trading philosophy itself. The Union for the Coordination of Transmission of Electricity (UCTE) has undertaken the revision of its Operation Handbook, while the EU Commission and the Council of European Energy Regulators (CEER) have issued recommendations to guide the process, see [8, 9]. Major topics addressed in these guidelines include coordinated congestion management in the IEM, computation of interconnection capacities, common definition of the N-1 operational security criteria, the legally binding nature of the rules and the corresponding enforcement measures, system restoration, rules at the borders between synchronous areas and harmonization of the procedures of the power exchanges.

Important lessons can be learned from the several large-scale blackouts that have taken place in the EU during the last years –most notably in Italy and Scandinavia in 2003 and the large disturbance that spread over most of Europe on November 4, 2006- and also elsewhere as the USA in 2003. All of these blackouts were security-related and lack of generation capacity was not the cause in any of them[6]. Numerous organizations have examined these blackouts. Here the conclusions and recommendations of the European Regulators Group for Electricity and Gas (ERGEG) will be briefly summarized, see [10].

The main lesson that has been drawn is the need for more integrated and harmonized operational rules. This issue was raised by the EU regulators after the Italian blackout in September 2003, but has not yet been properly tackled. Recommendations included a call for an immediate and comprehensive response from the European institutions and from the

[6] Lack of generation capacity has not been the cause of any of these system *security* problems, but this should not be interpreted as saying that shortages of generation capacity have not created any difficulties in the European electricity system. France, as well as Italy, during the hot summer of 2004; Spain in several short instances during the winters of 2003 and 2004 where interruptibility contracts had to be activated, or Norway during the winter of 2002, among other examples, all experienced very tight reliability margins, or unusually and sustained high electricity prices or were forced to shed some load because of insufficient generation.

TSOs together with the national energy regulators and CEER/ERGEG at European level in order to help prevent similar incidents in the future or if disturbances occur to improve efficiency of remedial actions and restoration. Meanwhile, the United States responded by taking numerous measures to reinforce the regulatory framework within the Energy Policy Act 2005, and today reliability criteria are legally enforced.

ERGEG concludes that "The events of November 4 uncover a legal and regulatory gap in Europe's electricity market. The operational security rules of the interconnected electricity network are not embedded within a Europe-wide operational and legal framework. The current framework depends on voluntary measures, mostly to be taken by TSOs. However, interconnected electricity networks of Europe – "EU Grid" - require a legally binding framework based on fully effective compliance, monitoring and collaboration … A need particularly exists for detailed and specific obligations placed on TSOs in relation to the coordinated operation of the electric power networks across the Internal Energy Market and to provide for information exchange between TSOs … The application of such a framework including the legally binding operational security rules is vital for the emergence of a fully integrated electricity market." However, such a legal framework can only partially be achieved under current EU regulation –the SoS Directive and the IEM Directive with its Regulation (EC) 1228/2003-. In a comprehensive package of regulatory recommendations[7], ERGEG has advocated for a tighter and more integrated institutional framework, with two upgraded institutions, some ERGEG*plus* –from the regulatory side- and ETSO*plus* –from the systems operation side-, which could properly address the challenge of an IEM with 27 countries, when Norway and Switzerland are included.

Regarding the contents of the operation rules themselves, ERGEG recommends more precisely defined rules for coordinated real time security assessment and control, to facilitate secure network operation in synchronous areas; more effective communication and information exchange between TSOs will allow more effective operational planning, thereby enhancing the coordination of operational system security within the synchronous areas; exchange of standardized real-time data among neighbouring TSOs must be precisely defined and duly implemented; joint operator training programs; and real time information exchange and coordination between TSOs and DNOs as well about generators connected

[7] See the Energy Regulators' advice in a "six pack" in www.ergeg.org

to the distribution network. Coordination in the contribution to the restoration of supply, automatic load-shedding, and frequency control is deemed of critical importance.

Considering now the normal operation of the power system, a basic security requirement is that, at all times, sufficient short-term reserve margins should be available to the TSO for system operation. These margins should be clearly defined, with special attention to the system's characteristics, such as the mix of generating technologies or the volume of interconnection with neighbouring systems. Most Member States have implemented a wide variety of *ad hoc* market mechanisms to provide the several kinds of operating generation reserves. The quantities are typically mandated by the TSO and the markets determine the prices. Although the scheme is working satisfactorily at domestic level, the actual challenge for the IEM is to coordinate the "balancing markets" of several neighbouring Member States. At present, cross-border trade for real time balancing is almost non existent in most parts of Europe. Without cross-border balancing, the specific requirements of each local market create an effective entry barrier to the agents from external systems, see [16, 4]. Besides, with the projected strong increase in wind power, with shifting exporting areas, improved coordination of cross-border trade will be indispensable.

## 4. Firmness

Most regulations and procedures do not distinguish between firmness and adequacy. However, the difference is palpable. Even with abundant installed generation and network capacity, if a significant part of this capacity is not readily available when needed to meet the actual demand, because of a variety of reasons –lack of water in the reservoirs or of fuel in the tanks, lines with flows beyond their physical capacity, power system exceeding its security limits, units out of service for maintenance or because of a forced outage- then there is a shortage of supply and all demand cannot be met. This is a firmness, not an adequacy problem.

Does firmness need regulatory intervention? Think of generation. Here it is not a question of promoting new investment, but of incentivating the existing generation capacity to make a special effort to be available at those times when there is a significant risk that supply will not be able to meet all

demand (it is immaterial if they are available or not when there is an ample generation surplus). One can think that energy market prices will suffice, since they will raise sharply whenever supply risks not being able to meet the entire demand, therefore encouraging all available generation to produce. There is a major reason in favour of regulatory intervention and this is coupled to the issue of generation adequacy. If the regulator considers that there is a market failure in generation investment and that somehow a certain margin of firm capacity over peak demand has to be guaranteed (see the next section), then it should issue a complementary firmness measure to ensure that this nominal firm capacity is actually available at the time of crisis.

The simplest way to accomplish this in a market environment is to pay the generators in proportion to the amount of firm capacity that they can offer to the system (this would be an adequacy payment) and to penalize them heavily if they fail to meet this commitment when required to do so, and only then (this penalty is the firmness component). This scheme to promote firmness has two advantages. First, it avoids micromanagement and strict supervision of the generation units by the regulator (for example by supervising the level of hydro reservoirs, checking the firmness of gas supply contracts or inspecting non dispatched units to verify if they are available as declared). Second, the scheme correctly discriminates against unreliable generators, since they will voluntarily declare lower values of firm capacity –or they will request a very high payment for it- thus reducing their competitiveness, if they fear being frequently unavailable when needed and therefore penalized.

A crucial issue for the reliability of electricity supply in the EU context is the firmness that is to be expected in the supply of the demand in country A from firm contracts with generators that are located in another country B. There are two issues here that have an impact on the firmness that these contracts provide to country A: One has to do with the capacity of the interconnection capacity between countries A and B. In order to be really firm, the contract must be accompanied by another firm contract of the corresponding amount of transmission capacity between the specified nodes where buyer and seller are located. And this firmness may be diminished if there is some finite probability that this transmission capacity might not be available when import from B is needed to meet demand in A.

The second, and more important issue, has to do with the possibility that country B may call back the contract in case there is a supply crisis in this

country. Obviously the problem with firmness only arises when both countries have a supply crisis, since only then the contracted generation in B cannot be replaced by anything else. What should prevail in this case: the contract or the potential request of the regulator in B to suspend any exports while demand in B cannot be totally met? It is clear to the author of this paper that a true security of supply for electricity at EU level will only happen when firm import and export contracts have priority over any domestic demand without such contracts. This seems to be the direct interpretation of article 4.3 in the SoS Directive: "In taking the measures referred to in Article 24 of Directive 2003/54/EC *(it refers to measures to be adopted in emergency situations)* and in Article 6 of Regulation (EC) No 1228/2003, Member States shall not discriminate between cross-border contracts and national contracts". Unfortunately, most electricity laws of the Member States have explicit clauses maintaining that exports to other countries will be interrupted in case of a domestic emergency of supply. And these provisions have been applied whenever there has been the occasion for it.

The role of demand in contributing to alleviate a potential or actual power shortage should not be underestimated. Reference [11] shows how diverse countries in the world –including Norway and Sweden, for instance- have been able to reduce demand significantly and sustain it until the crisis has subsided; market prices reflecting the actual marginal cost of electricity were of essence here. Also automatic load-shedding worked correctly during the November 4, 2006, European-wide blackout. This report presents a package of measures to "save electricity in a hurry" that can be adopted in emergency situations, rather than suffer power curtailments or indiscriminating blackouts. There are basically three types of strategies: a) make electricity prices reflect the actual system marginal costs; b) encourage behavioral changes of consumers; c) introduce more energy efficient technologies. The specific measures to be adopted depend on the particular system and the anticipated duration of the crisis and the time of preparation. Some of these demand-side measures may be considered under "firmness", while others rather belong to "adequacy".

## 5. Adequacy

Development of installed capacity has kept pace with the increase in the IEM peak load from 1991 to 2004, as the relatively constant ratio between

these two magnitudes shows, see [3]. However, much of the new installed capacity is wind and, therefore, the actual security ratios have decreased[8]. Most EU countries had very high capacity margins when the liberalization process started and they have shrunk, as it is typical when competition is introduced.

According to [3], about 160 GW of coal, oil, gas and nuclear capacity in OECD Europe is more than 30 years old. This represents 20% of total installed capacity in 2004. More than half of European coal capacity is more than 30 years old. More than 90% of nuclear capacity in OECD Europe is still less than 30 years old, but 60% is older than 20 years.

In the 2006 World Energy Outlook report, see [2], the International Energy Agency describes the projections to 2030 for a "reference scenario" that extrapolates the current energy policies at domestic and EU levels. By 2015 in this reference scenario 294 GW of new capacity will have to be built in OECD Europe. 106 GW of this capacity will replace retired plants and 188 GW will meet the growth in demand. For 2030, 928 GW of new capacity will be needed for OECD Europe, 435 GW of which (more that half of the currently installed capacity) will replace the decommissioned plants. It is important to know that the IEA report considers this reference path to be "expensive, dirty and insecure."

Will this large need of future investment be met? According to the last annual report by the association of European Transmission System Operators (ETSO), see [12], the period 2008-2010 shows a decrease of margins as load growth is only partly compensated by generation development. Nevertheless the foreseen commissioned power plants cover a sufficient part of the load increase to ensure that Remaining Capacity[9] remains significantly higher than what is considered as a reasonable security margin in 2010. It may also be underlined that between 2008 and 2010, the part of renewable energy sources will increase from 8% to 10% of the generating capacity. For the 2010–2015 period, the situation is more tightened. Most of the increase of generating capacity relies on renewable

[8] This should not be understood as a negative statement regarding wind generation. There are excellent reasons to promote a massive penetration of renewable energy sources for electricity production in Europe and elsewhere. The most relevant of these sources –wind and solar- have an intermittent nature. Therefore the operation of the system and the response of demand have to be adapted to cope with this new feature in the power systems of the future.

[9] "Remaining capacity" is the margin of "reliably available generation capacity" over peak load, plus a safety margin; where "reliably available generation capacity" is computed by deducting estimated unavailable capacity from installed capacity.

energy sources, mainly wind power. As the availability of this type of generation is only partly guaranteed, depending on wind regimes, it is not sufficient to prevent the global Remaining Capacity from continuing a regular decrease.

If it is assumed (conservatively) that only new generation projects known as firm will happen, these confirmed investment decisions seem sufficient, at ETSO level, to allow a reasonable level of adequacy from now to 2012. After 2012, if further investments are not decided in due time, the reliability of the whole system cannot be considered as achieved. By 2015, it will be necessary to commission a total of 20 GW of new generation capacity (approximately 3% of installed capacity), in addition to plants already under construction. Therefore, important final decisions on additional investment must be made in the next few years to ensure that a sufficiently large share of planned plants actually materializes. The important uncertainty regarding future plant retirement, which is affected by the CO2 trading prices and regulation and the implementation of the Large Combustion Plant EU Directive, has to be taken into account. Besides, the study assumes unlimited exchange capacity among countries. Local analyses are also available in this ETSO report and some of them are more worrisome than for ETSO as a whole, because of the diversity of technology mixes and the weakness of some interconnections.

Energy dependence has been voiced as a major threat to security of electricity supply in the EU. It currently amounts to 50% and it is estimated to grow until 70% by 2050, see [13]. This dependence can only be alleviated by energy efficiency and saving measures, an increased penetration of domestic renewable energy sources and (where public acceptance allows it) nuclear expansion. As far as security of supply is concerned, the key factor is not dependence but diversity of fuels, fuel sources, technologies and suppliers, so that risks can be managed, see [1]. This approach will yield a flexible energy system well suited to reconcile energy dependence with EU competitiveness. It also reduces the incentive for politically motivated interruptions.

Overall, installed generation capacity in Europe is well diversified. But this is not true at country level. So, it is only well diversified if EU countries are able to increase the volume of trade. However, current trends in investment may reduce the level of diversification in the future, since most of the investment during the last 15 years has been in natural gas based CCGTs,

combined heat and power (CHPs) and wind, see [3]. According to the Platts database, more than 35 GW of new capacity (coal, oil, gas, nuclear and hydro) was under construction in OECD Europe in 2005. Most of these were CCGTs (some 20 GW). In 2006 alone, 7.5 GW of wind power capacity were added in the EU. It may be argued that lack of diversification is the consequence of a market failure, which has to be corrected with higher level energy policy measures.

As with firmness, the role of demand in the provision of security of supply should be very substantial. In the WEO 2006 alternative policy scenario [2] perhaps the most important package of alternative policies is the one with measures to improve energy efficiency. These measures could significantly reduce the need for new capacity: from 294 to 225 GW by 2015 and from 928 to 713 GW by 2030. The energy efficiency targets expressed in the recent EC Green Paper on Energy Efficiency [13] call for even larger and faster improvements in energy efficiency.

There has been much discussion on the convenience of introducing regulatory measures to facilitate that electricity markets provide a reliability level that the regulator feels comfortable with. See [14] for a discussion on the existence of a market failure and a review of proposed regulatory schemes. Some countries, like the UK or Australia, have opted for the "**leave-it-to-the-market**" approach, where it is expected that an energy-only market will be able to attract all the necessary investment. However, an increasing number of countries have opted for any of the following methods to attain adequate reserve margins:

- **Auctions**: The IEM and SOS Directives allow Member States to run auctions for new generation capacity that is not obtained otherwise and to assign long-term contracts to the winning bidders. The Brazilian energy auctions are becoming a reference design, at least in Latin America.

- **Capacity payments** were first used in Chile in 1982 and later adopted in Argentina, Colombia, Peru and some other Latin American Countries, under various formats, and also in Spain. In essence the method consists of awarding to each generating unit a daily payment (only when it is available) which is computed by multiplying the firm capacity of each generating unit times a per unit capacity payment (€/MW) that may be uniform or may vary with

the season. Each country has chosen a different approach to determine the firm capacity of the generating units, but the basic idea is that the firm capacity is a measure of the contribution of each generating unit to the reliability of the power system.

- **Capacity markets**, which impose consumers –or their representatives- the obligation to purchase in the market a firm capacity equal to their demand plus a certain reserve margin. At the same time, the firm capacity of each generating unit is determined administratively, so it can bring its bids to the market. This approach has been applied in some U.S. markets, like New England or PJM.

- **Reserve markets**: On behalf of consumers, the system operator acquires in advance a band of generation capacity –or a set of peaking units- with the commitment that it will be available when the remaining system capacity has been used, thus ensuring a certain supplementary reserve. They have been recently implemented in Sweden and The Netherlands.

- **Reliability options**: This method establishes an organized market where the regulator requires the Market or the System Operator to buy in a public auction a prescribed volume of contracts from generators on behalf of the consumers. The commitment of a generating unit winning the auction is as follows: the generating unit sells, in exchange for a premium a call option for all the energy that its firm capacity can produce, at the strike price of the option, and it is subject to a prescribed penalty if the power is not delivered when required. The approach is presently being considered by Spain and Italy and versions of it have been implemented in Colombia, Panama and Greece.

In a market with 27 Member States who have adopted different regulations concerning generation adequacy it will be inevitable to suffer a certain level of economic distortion and free riding. Some degree of harmonization is therefore needed, at least at regional market level.

## 6. Strategy

### 6.1. The broader context

A recent report by Oxford University [15] warns against a direct pursuit of energy security –trying to control the world energy resources and using them in the least expensive way without considering any side effects-, since this would have unfortunate consequences on climate change and the worsening of poverty in some of the poorest parts of the world: "The wrong energy policy, misaligned with goals on climate change and global poverty, risks creating new enemies for Europe, new threats to energy supply, greater damage from climate change, and worse poverty in the poorest parts of the world". The report argues that these three objectives – energy security, climate security and world energy poverty can be addressed simultaneously, but that it takes an explicit effort of coherence across all three goals. The same conclusion, and a useful set of recommendations, were the outcome of the recent European project SESSA, see [16] for details.

Security of electricity supply can only be rightly addressed within the broader context of the complete energy model. Prospective studies provide highly valuable insights into the workings and the future of the European energy model. A worrying reference situation is depicted in [17], which has been later updated in [18]. This is a "Business As Usual" scenario -which is a continuation of current trends and policies into the future-, characterized by the expected demand growth, without especial measures of energy savings and efficiency, inequitable world distribution of energy resources, inadequate effort in R&D in energy, continued rate of depletion of fossil fuel resources, risk of insufficient investment in generation and network capacity and no major effort to curb climate change. Despite all this, the scenario results in an increased decoupling between economic growth and energy consumption, because of improvements in energy efficiency (both on the demand and the supply sides), changes in the structure of EU industry, saturation in demand for some important energy needs, and the policies already in place. However, in this reference scenario the total energy consumption in the EU is expected to grow at about 0.7% per year and renewable energy sources would only expand at a moderate rate. No pressing energy resources limitation during the next 20 years is forecasted in the model, although, in the specific case of oil, peak production forecasts

range from roughly now to 2030 or even beyond that date. Most of the consumption growth will be met by increasing imports from outside the EU. Therefore, energy dependence will increase from about 47% in 2000 to a forecasted value of 67% in 2030. Electricity demand is forecasted to grow about twice as fast as the average energy demand. So, massive investments in new generation capacity will be needed (about 500-600 GW in EU-25 during the next 30 years, in order to reach a generation capacity twice as large as today's). In the reference scenario, most of the new investments will take place as gas-fuelled plants, which will contribute to increased import dependence, especially when taking into account the decline in domestic EU gas production. British, Dutch and Norwegian gas will be also unable to meet the required demand increase, so growing gas imports from Russia, Northern Africa and other regions are anticipated. Most environmental pressures show an improving trend, with the important exception of carbon emissions. In this case, transportation and electricity generation are the critical sectors. Carbon intensity –i.e., CO2 emissions over GDP- is expected to decrease until 2015 and to rise afterwards, mainly because of the end of carbon intensity improvements by fuel switching (i.e., substitution of coal by gas), and because of the electricity generation gap caused by the forecasted phase-out of nuclear stations, that would be mostly filled by advanced technology coal plants (carbon capture and sequestration is not used in this reference scenario). Therefore, total EU-25 carbon emissions are expected to rise at a short-term rate of 0.3% per year, accelerating from 2015 onwards to a long-term rate of 0.5% per year. These studies confirm the previously cited figures in the adequacy section and help identifying the main challenges of EU energy policy:

- Security of energy supply, in relation both to dependence on imports of natural gas and oil (high volumes of imports from unstable regions) and to the required investment in infrastructures to ensure adequacy of electricity supply, see [19].

- Increasing carbon emissions, in contrast with climate change policy objectives.

- Poor performance of uncoordinated policies supporting penetration of renewable energies.

- Continuous growth of road and air transport, and the need to improve energy efficiency in the transport and buildings sectors.

- High uncertainty about the future of nuclear energy after 2020, and the concomitant lack of a strategic choice on a sustainable base-load generation of electricity.

Obviously, alternative scenarios can be devised by assuming implementation of measures related to further promotion of renewable energy sources, higher efficiency in final uses, increased availability and public acceptance of nuclear energy, higher taxation on carbon, increased carbon trading, support to specific transportation technologies or development of new technologies (such as carbon sequestration or a economic and technically viable scheme of production and utilization of hydrogen), see [18]. In any case, given the very large inertia of any energy system, most of the actions in this policy package must be simultaneously and strongly pursued in order to have a significant effect.

Radical technology changes will be needed to attain a low carbon economy in the long-term. Despite the attractiveness of market mechanisms –such as the EU Emission Trading Scheme-, it has to be acknowledged that they will not achieve much in terms of emission reductions and structural technology changes unless the prescribed emission targets are sufficiently stringent and apply to most relevant countries and/or users. Then, for the time being at least, additional *ad hoc* policies will be needed for low carbon technology development.

## 6.2. An Energy Policy for Europe

Finally, the EU has responded to this challenge with a package of measures that, jointly considered, can be seen as a significant component of a future and comprehensive EU energy policy. These are statements taken from the Presidency Conclusions of the European Council of March 2007: "Given that energy production and use are the main sources for greenhouse gas emissions, an integrated approach to climate and energy policy is needed to realize this objective. Integration should be achieved in a mutually supportive way. With this in mind, the Energy Policy for Europe (EPE) will pursue the following three objectives, fully respecting Member States' choice of energy mix and sovereignty over primary energy sources and underpinned by a spirit of solidarity amongst Member States: a) increasing security of supply; b) ensuring the competitiveness of European economies and the availability of affordable energy and c) promoting environmental

sustainability and combating climate change. … As a milestone in the creation of an Energy Policy for Europe (EPE) and a spring board for further action, the European Council adopts a comprehensive energy Action Plan for the period 2007-2009. … The Action Plan sets out the way in which significant progress in the efficient operation and completion of the EU's internal market for gas and electricity and a more interconnected and integrated market can be achieved. … It also addresses the crucial issue of security of energy supply and the response to potential crises. As regards security of supply the European Council stresses the importance of making full use of the instruments available to improve the EU's bilateral cooperation with all suppliers and ensure reliable energy flows into the Union. … (The Action Plan) … develops clear orientations for an effective European international energy policy speaking with a common voice. It fixes highly ambitious quantified targets on energy efficiency, renewable energies and the use of biofuels and calls for a European Strategic Energy Technology plan, including environmentally safe Carbon Capture and Sequestration, to be examined at the Spring 2008 European Council meeting." With these measures, or with additional ones, the EU is committed to reduce the emissions of greenhouse gases by 20% by 2020 unilaterally and in 30%, "provided that other developed countries commit themselves to comparable emission reductions and economically more advanced developing countries to contributing adequately according to their responsibilities and respective capabilities … with a view to collectively reducing their emissions by 60% to 80% by 2050 compared to 1990." These measures certainly have a much longer-term perspective than the IEM or the Security of Supply Directives, and they will imply massive investments and technological changes in electricity generation, transmission grids and system operation.

EPE has avoided entering into the nuclear debate: "EPE will fully respect Member States' choice of energy mix … confirms that it is for each and every Member State to decide whether or not to rely on nuclear energy … suggests that broad discussion takes place among all relevant stakeholders on the opportunities and risks of nuclear energy".

Note that the EPE package has a clear favorable impact on security of electricity supply, since it will reduce the demand, it will facilitate the generation of electricity with fossil power plants (coal in particular) and it will force an important deployment of renewable energy sources, most of which will be used to produce electricity. This will probably reduce the present concern on security of electricity supply and the attention will be

more focused on climate change and competitiveness issues.

### 6.3. Other issues of concern

Other strategic issues that are relevant to security of electricity supply and that have not been included in the Energy Policy for Europe package are:

- The relevance of the existence and encouragement of national champions on security of electricity supply. Consolidation developments that increase the efficiency of the firms and their capacity to invest have to be seen favourably, as far as they do not impair competition. Most fears of loss of security of supply appear to be unfounded and, therefore, nationally motivated interference in these consolidation processes is not justified.

- Climate change policies, until they stabilize, will create more uncertainty on investment, which is not good for security of supply. Carbon markets, for the time being, do not seem to be able to decisively promote any desired technology changes towards a low carbon production of electricity.

- New schemes of TSO coordination and a revision of the philosophy of system operation will be needed to cope with the expected massive penetration of intermittent renewable generation of electricity in the EU networks. Smart new forms of integration of supply and demand of electricity will be required because of efficiency and also security reasons, see [18].

## 7. Conclusions

The paper has reviewed the major aspects concerning security of electricity supply. It has been realized that essential aspects of security of supply have to be addressed at EU level and with a view to the wider context of the sustainability of the world energy model. Excellent reviews of these issues and comprehensive sets of recommendations can be found elsewhere, see [1, 9, 10, 16 and 18], for instance. The European Council has initiated

building an ambitious Energy Policy for Europe that takes into consideration the indispensable broad context, although still some elements are missing. Tighter schemes of organization and coordination of regulators and system operators, as the ETSO-plus and ERGEG-plus, are certainly needed. This is expected to facilitate the agreement on a revised set of security rules and their implementation. The existing Directives have to be enforced so that security of electricity supply is truly addressed at EU-wide level. Long-term security of supply has to be addressed with some audacity and an open mind: all technology options must, in principle, be considered; the large potential of energy efficiency and savings should not be underestimated; massive penetration of intermittent renewable energy sources has to be met by innovative schemes of system operation and advanced forms of integration of supply and demand. Power system models and advanced computation methods of probabilistic security measures will have to be developed. Security of electricity supply will be again a fascinating topic in a richer and much more complex environment.

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