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The author | A Belgian national with a Master's degree in Electrical and Mechanical Engineering, a degree in Physics and Nuclear Chemistry and a baccalaureat in Economics from the Louvain University (Belgium), Jean-Pierre SCHAEKEN WILLEMAERS began his career as a Lecturer at the faculty of applied sciences of this University. He thereafter joined the Tracetebel and Suez-Tracetebel group. Within this group, he was Head of Trade and Marketing and a member of the Tracetebel Engineering Executive Committee. He was thereafter appointed Executive Vice President and member of the executive committee of Suez-Tractebel EGI (Electricity and gas international), and Director of Powerfin. He was in charge of investments in Europe, Russia and the Middle East in the fields of electricity production, transmission and distribution as well as the transportation and distribution of natural gas by acquisition or project development. In this capacity, he was appointed Chairman or Director of several subsidiaries of this group in Europe and Central Asia. He was also Vice President of the Brussels Chamber of Commerce and Judge at the Brussels Commercial Court. In 2000, he founded a centre for high technology start-ups of which he is still a board member. Today, he is a board member of several industrial companies. He is Chairman of the Energy, Climate & Environment Department of the Thomas More Institute a also member of its Advisory Board.

| Introduction

The debate on electrical energy in the EU, more and more emotional, has generated overreactions. Within Europe, a division has emerged between countries rushing for renewable energy and/or phasing out nuclear power (the "Green approach"), and member states promoting a more balanced mix including thermal (with appropriate environmental protection), nuclear and hydro power as well as renewables.

Such a division between energy policies is not experienced at the same scale outside the EU. The experience (good and bad) gained by countries like Germany, that have been and, to some extent, still are investing in "green" energy, will be deciding for pursuing or totally/partially dropping the "green approach". It is worth noting that in the EU member states that experienced scarcity such as the EU Eastern countries, public acceptance of thermal and nuclear power generation is the highest even after Fukushima. Whatever scenario is adopted, a stable legal framework is essential for the required investments. Legislation should obviously take into account recent technological progress.

In any case, in the aftermath of the economic crisis, the priorities of the EU energy policy are to strengthen security of supply and competitiveness in a sustainable way.

This note wants to define the best ways to achieve these goals.

| SECURITY OF SUPPLY

It is for the electrical sector that the security of supply is the more crucial. Because electricity cannot be stored and because demand is little elastic, supply and demand must be permanently balanced on the power market. According to Euroelectric's definition, "Security of supply is the ability of the electric power system to provide electricity to end users with a specific level of continuity and quality in a sustainable manner, relating to existing standards and contractual agreements at the point of delivery". Such reliability involves generation, transmission and distribution (infrastructure adequacy), retail as well as system operation including time scales.[1] Energy supply risks must be considered from both external and internal perspectives.

The external dimension includes import dependency, resource exhaustion and carbon policy. The primary energy carriers such as coal, gas or uranium are partially or totally imported from sometimes remote countries whereas the conversion facilities of these fuels into electricity are located close to consumers. To mitigate the risks associated with those external dimensions, types of power production should be chosen to reduce as much as possible dependency on fuel imports. The internal dimension includes economic, political, financial and technical conditions for power supply security. The most important responsibility of member states is to establish an appropriate legal framework for domestic investments in generation, transmission and distribution of electricity. Regulatory stability, simplified permitting procedures and reduced bureaucracy, fiscal coherence and predictability of environmental policy exempt of ideological considerations, are of the essence.

"Energy market liberalization and privatization have lead 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 – and also in transmission and

1. Medium to long term considerations are particularly important when it deals with regulatory issues. It is the responsibility of governments to ensure through electricity market regulation and additional legislative measures that the market responds to concerns of energy security and environmental challenges.

distribution networks, in some systems- to meet the projected energy demand growth."[2]

The Security of Supply directive or SoS directive on measures to safeguard security of electricity supply and infrastructure investment (EU directive 2005/89/EC) establishes a framework with which member states are supposed to define transparent, stable and non-discriminatory policies on security of electricity supply compatible with the requirements of competitive international market for electricity.

What about the different power resources?

| Nuclear[3]

This section is focused on security of nuclear fuel supply, it being understood that periodic safety reviews are carried out in conformity with Nuclear Safety Authority's criteria and power plants are operated according to best practices. Updating, upgrading and replacement of faulty or worn components as well as appropriate operation should avoid, to a large extent, unexpected outages.

All member states, generating nuclear power, are importing uranium from non-EU countries. However, uranium (U) resources are well distributed worldwide and up to now their supply has not been a cause for concern. The majority of mines are located in politically stable countries such as Australia and Canada. A major geopolitical change regarding U supply comes from Kazakhstan that, in 2008, ranked second (with 8,512 t U) between Canada (9,000 t U) and Australia (8,433 t U).

The known recoverable resources of uranium (U), as of 2013, is 5,902,500 tons to USD 130/kg U.[4] At current demand level (68,000 t U/year for some 375 GW_e capacity), this reserve would be sufficient for operating existing conventional nuclear power plants for about 90 years. Recoverable resources are very dependent on U market prices. Higher prices enable more exploration and the reclassification of resources to the economically recoverable category. For example, at a cost of USD 260/kg U, the global total of identified conventional uranium resources is estimated at 7.1 million tons.[5]

If all conventional resources (U as main product and major by-product) are considered, another 7.3 to 8.4 million tons are added to the 5.9 million tons of known economic resources, which would secure more than 200 year supply at today's rate of consumption. This still ignores the technological factor. It also omits unconventional resources (U recovered as minor by-product) such as phosphate/phosphorite deposits (up to 22 Mt U), black shales (5.2 Mt U) and lignite (0.7 Mt U).[6]

2. Ignacio J. Perez-Arriaga, "Security of electricity supply in Europe in a short, medium and long term perspective", *European Review of Energy Markets*, volume 2, December 2007.
3. Nuclear currently provides 13% of EU's primary energy and 27% of EU's electricity, according to EU Commission Memo, *Questions and answers on security of energy supply in the EU*, May 28, 2014, available on http://europa.eu/rapid/press-release_MEMO-14-379_en.htm.
4. OECD NEA & IAEA (International Atomic Energy Agency), *Uranium 2014: Resources, Production and Demand*, 2014, available on http://www.oecd-nea.org/ndd/pubs/2014/7209-uranium-2014.pdf.
5. *IAEA Annual Report 2013*, available on http://www.iaea.org/publications/reports/annual-report-2013-0.
6. World Nuclear Association, "Supply of Uranium", September 2014, available on http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Uranium-Resources/Supply-of-Uranium/.

"Widespread use of fast breeder reactor could increase the utilization of uranium 50-fold or more […]. Today's reactor fuel requirements are met from primary supply (direct mine output, 78% in 2009) and secondary sources: commercial stockpiles, nuclear weapon stockpiles, recycled plutonium and uranium from reprocessing used fuel, and some from re-enrichment of depleted uranium tails (left over from original enrichment)."[7]

As 72 nuclear reactors were under construction at the end of 2013, out of which 48 in Asia, and as many countries are either expanding or planning to expand their fleet, nuclear fuel demand will increase beyond 100,000 t U by 2030 (actually, according to the World Nuclear Association July 2014 reporting: between 97,450 t U and 119,000 T U).

However, this shouldn't be a cause for concern given the importance of recoverable reserves and because the consumption of nuclear fuel will be considerably reduced when the fourth generation of nuclear reactors will be operational. Moreover, besides uranium that is today the only fuel supplied for nuclear reactors, thorium, not yet commercialized, can also be utilized as a fuel for Candu reactors or in reactors specially designed for this purpose. It is reported to be about three times as abundant in the earth's crust as uranium.

There have been three major initiatives to set up international reserves of low enriched fuel, two of them multilateral ones, with fuel to be available under International Atomic Energy Agency auspices despite any political interruptions which might affect countries needing them. The third is under US auspices, and also to meet needs arising from supply disruptions.[8]

| Power generation from gas

According to EUROSTAT, the EU's energy import dependence has been on the rise since the mid-1990s. Natural gas dependency in the EU-28 is 65.2% in 2013. The Netherlands and Denmark are the only net exporters. In 16 member states energy dependency is higher than 50%. Europe's challenge is that its energy demand will increase by an estimated 27% by 2030 while EU domestic production is falling. Even in the case of solid fuels such as coal, almost half of deliveries come from non-EU countries.

"In total, the EU member states paid about EUR 85 billion to extra-EU suppliers. Six member states of the EU depend on Russia for their entire gas imports: Finland, Slovakia, Bulgaria, Estonia, Latvia and Lithuania. 23% of the EU's energy demand comes from gas which is mainly used for heating and electricity production. Almost 19% of all the electricity generated in the EU comes from gas. The residential and service sectors account for approximately 40% while industry accounts for about 25% of gross inland consumption."[9] Some imports are more risky than others such as the ones from Russia (especially after the Ukrainian crisis) and Algeria that together represent more than half of EU's gas import.

To mitigate such supply risks and uncertainties, diversification of gas sources and transmission vehicles are of the essence. In that respect, domestic gas resources at reasonable costs should be promoted as well diversification of gas routes including Nabucco West for piped gas and LNG to Channel and Mediterranean Sea ports.

7. *Ibid.*
8. IAEA, in cooperation with the government of Kazakhstan, continue to make progress in the establisment of the low enriched uranium bank, the proposed site of which is the ULBA metallurgical plant in UST-Kamenogorsk.
9. EU Commission Memo, *Questions and answers on security of energy supply in the EU*, *op. cit.*

In 2012, LNG met 12% of Europe's gas requirements. The share of LNG in the European gas mix is expected to rise. The oil and gas company Total estimates that LNG will reach 14% of gas demand by 2020 with an import volume of 60 Mt. Since the gas crisis in the winters of 2006 and 2009 and the more recent one in Ukraine, the Commission has done a lot to strengthen the EU's energy security in terms of gas supplies.

Rules of transmission network use has been put in place to avoid congestion at cross-border infrastructures. Another important step to secure uninterrupted supplies in case of external supply disruption, consists of installing reverse flow options that provide a possibility to operate the pipelines in both directions. This requires investments in infrastructure because networks were not designed for such bi-directional flows.

| Intermittent renewables

Electricity generation from wind and solar energy avoids dependency on politically unstable countries. However, as an intermittent source of energy, it cannot guarantee by itself electricity supply at peak consumption and therefore contributes to the lack of reliability of the system. This is confirmed by a study commissioned, in 2006, by the German Energy Agency (DENA). Onshore wind turbines are often installed far from major electricity consumers. Large portions of the electricity produced must therefore be transported over long distances to load centres. This could lead to congestions of existing infrastructure. In Germany, for instance, wind power generation is clustered in the northern part of the country whereas consumers are concentrated in the south and west of the country. Therefore, at high wind power penetration levels, both transmission and distribution grids as well as cross border lines require extensions and upgrading. Power flow needs to be continuously balanced between generation and consumption. Extra thermal reserve capacity to compensate for wind energy intermittency has a high impact on carbon footprint. On the other hand, one should keep in mind that offshore wind power is still an uncertain technology.

A point in case is the Bard 1 wind farm project in the German EEZ (Exclusive Economic Zone) of the North Sea (80 wind turbines totaling 400 MW, 100 km away from shore). The project was to start commercial operation in August 2013 but because of technical problems, it is still not operational in October 2014. This delay generates huge costs on top of the future operation costs due to its remote location. The Bard difficulties are so problematic that they constitute a problem for other offshore projects. For example, because of Bard 1 shortcomings, it was decided to hold the construction of a 200 MW extension of the Trianel Windpark Borkum, the second most important offshore project in Germany, pending the solving of Bard project problems.

Although high on the agenda (for how long?), the penetration of intermittent renewable energy is slowing down in all European countries in spite of the fact that some of them have been at the forefront of the renewable programs. Most EU governments are backtracking on the energy transition. Solar and wind energy industry, a major contributor to European de-carbonization policy and still high on the European roadmap 2050 agenda, is facing hard time. In Germany, "the historically singular simultaneous shut-down of nuclear power plants amounting to 5,000 MW capacity and the long term lack of some 8,500 MW capacity bring the transmission grids to the edge of their resilience."[10] Consequently, there are many hours in which secure network operation is impossible, meaning that it is vulnerable to a single failure.

10. German Federal Network Agency Authority, *Bundesnetzagentur Report*, May 2011.

"As a consequence, the original objective of competitive driven market is replaced by a more or less centrally controlled planning approach. This is dubious in terms of energy economics, economically inefficient and ecologically harmful […]. Also the changed network load pattern due to the shutdown of the 7+1 nuclear power plants has already led to postponements of scheduled service and maintenance works in the transmission grid, because many such works can only be undertaken when there is little or no load."[11] *Bundesnetzagentur* warned of very uncertain supply situations likely over winter, especially in southern Germany, along with increased costs. In case of a permanent shutdown of the 8 nuclear reactors affected by the moratorium, Germany could no longer support security of supply in the European interconnecting grid to the extent it had done so far. Grid stability is the major concern along with generation and transmission capacity.

"In November 2013, the TSOs estimated that peak load for 2014 would be 81.8 GW_e, with capacity margin 9.4 GW_e above this, and rising to 2016. If Germany were to continue with its nuclear phase out policy and maintain carbon reductions, by about 2020, it would need to depend on some 25,000 MW of base load electricity capacity across its borders. The country already has significant interconnection with France, the Netherlands, Denmark, Poland, Czech Republic and Switzerland. This would put Germany in 2020 in much the same situation as Italy, being dependent on neighbours for electricity (which would be mostly nuclear)."[12]

11. *Ibid*.
12. World Nuclear Association, August 2014.

| Competitiveness

"Competitiveness of Nations is a field of economic theory, which analyses the facts and policies that shape the ability of nations to create and maintain an environment that sustains more value creation for its enterprises and more prosperity for its people."[13] The country's national environment is to be the responsibility of the State and the wealth creation process is expected to be assumed by enterprises and individuals. Competitiveness strategies succeed when they balance the economic imperatives imposed by the world markets with the social requirements of a nation formed by history, value systems and tradition.

Cheap energy is a major parameter of competitiveness and electricity is an important component of an energy policy. In particular, the appropriate management of power generation and transmission/distribution in the EU, is essential to sustain its economic development. In this context, the decisions on the power mix are of the essence.

Coal is and will remain economically attractive for power generation, even for EU member states without domestic production, as long as the US keeps on exporting their cheap coal. Indeed, the switch in the US power production from coal to cheap non-conventional gas (thanks to shale gas boom) made US coal available for export, in particular to the EU, at low prices. However, a rebound of the EU carbon market could obviously change the deal.

Gas fired power plants are very competitive, especially the combined cycle ones, if the electricity market is not distorted by political decisions giving the priority of access to the grid to subsidized intermittent energy. Indeed, in the EU countries promoting wind turbines and photovoltaic panels, gas power stations, although essential for compensating intermittency, are no longer profitable because of their very low load factor.

13. IMD World Competitiveness Center, Lausanne, Switzerland.

Nuclear power is very competitive at carbon prices of USD 30/ton and low discount rate.[14] For 5% discount rate, the nuclear electricity generating cost, in cEUR/kWh, is cheaper than any other power production and in particular compared to onshore wind. For a 10% discount rate, the advantage of nuclear is still confirmed.[15]

However, price comparisons are usually made by using levelized costs[16]. The problem is that levelised costs do not take account of the costs of intermittency.

As reported by *The Economist* of July 26, 2014, to get around that problem, Charles Frank of the Brookings Institution, a think tank, uses a cost-benefit analysis to rank various forms of energy. The costs include those of building and running power plants, and those associated with particular technologies, such as balancing the electricity system when wind and solar plants go offline or disposing of nuclear waste. The benefits of renewable energy include the value of the fuel that would have been used if coal- or gas- fired plants had produced the same amount of electricity, and the amount of carbon dioxide emissions that they avoid. It makes wind and solar power look far more expensive than they appear on the basis of levelized costs (Obviously, low and no-carbon power plants do not avoid emissions when they are not working, though they do incur costs). Nuclear power plants, which run at about 90% of capacity, avoid almost four times as much CO_2 per unit of capacity as do onshore wind turbines, which run at about 15 to 25%.

If all costs and benefits are totted up using Mr Frank's calculation, among low carbon power generation, solar power is the most expensive way of reducing carbon emissions. Wind is the next most expensive. Hydropower provides a modest net benefit. But the most cost effective low emission technology is nuclear power.

It is important to note that EU member states with high penetration of solar and wind power production, and/or with nuclear power phasing out, are all facing high electricity prices which, of course, affect the competitiveness of their industry and the purchasing power of households. In Germany, Denmark and Ireland committed to ambitious green growth strategy, even beyond EU targets, the average price of electricity (including all taxes) are the highest in Europe. Conversely, countries with large hydro resources and/or with high stake of nuclear power and relatively low penetration of intermittent renewables, can offer rather low electricity prices.[17]

After having spent vast amounts of public money, placed power utilities in serious difficulty and done little to reduce emissions of carbon dioxide (which was the objective of the renewable energy policy), those countries did not even succeed in building robust renewable industry. On the contrary, a number of solar panels and wind turbines makers went or are about to go bankrupt, or are facing serious financial difficulties.

14. 2010 EECD study, projected cost of generating electricity.
15. World Nuclear Association, "The economics of nuclear power", June 2014.
16. Net present value of all costs (capital and operating) of a generating unit over its life cycle, divided by the number of MWh of electricity it is expected to supply.
17. Jean-Pierre Schaeken Willemaers, *Electricity Prices: The Highest for Households in the EU Countries with the "greenest" Energy Transition Policy*, Institut Thomas More, Tribune 44, September 2014, available on http://www.institut-thomas-more.org/upload/media/tribuneitm44-2.pdf.

| Carbon footprint

A carbon footprint aims to account for the total quantity of greenhouse gas emitted over the whole life cycle of a production process. It is calculated by the method of the life cycle assessment. EU member states that rush for wind and solar power production with significant penetration of their domestic market and/or started to phase out their nuclear power, have not only to face highest electricity prices but also show bad performances regarding the reduction of carbon emissions.

According to the European Environment Agency, the 2011 greenhouse gas emissions per capita of Denmark: about 10 t CO_2/cap, Germany: more than 11 t CO_2/cap and Ireland: more than 12 CO_2/cap are much higher than countries with low penetration of intermittent renewable energy, large stake of hydropower and high nuclear share of power generation such as Sweden: about 6.5 t CO_2/cap or France: about 7.5 t CO_2/cap.

Eurostat estimates that, from 2012 to 2013, CO_2 from fossil fuel combustion increased in Denmark by 6.8% and in Germany,[18] by 2%, this latter country having the highest level (in the EU) of GHG emissions in absolute terms of 760 million tons in 2013. The *Bundesnetzagentur* said, in September 2012, that 25 new power plants totaling 12 GW_e were under construction, 67% powered by black coal and 17% by brown coal, adding to 55 GW already operating and most of it not likely to be shut down before 2020.

Carbon footprint for low carbon generation technologies is dominated by indirect emissions such as these produced during construction and the production of fuels (where applicable). Carbon footprint from wind energy, as with other "low carbon" technologies, occurs during the manufacturing and construction phases, arising from the production of steel for the tower, concrete for the foundations and epoxy/fibre glass for the blades.

18. Two countries higly engaged in green policy.

For nuclear power generation, most emissions occur during uranium mining, fuel enrichment and fabrication. Decommissioning accounts for 35% of the life time CO_2 emissions and includes emissions arising from dismantling of the nuclear power plant and the construction and maintenance of waste storage facilities. The most energy intensive phase of the nuclear cycle is uranium extraction, which accounts for 40% of the total GHG emissions.

Nuclear, wind and river hydro have the lowest footprint, in average, less than 10 g CO_2/kWh. Life cycle solar emissions are higher, well above 50 g CO_2/kWh.[19] Marine technology, based on wave and tidal power, is still an emergency technology.

19. Houses of parliament, *Carbon footprint of electricity generation*, June 2011 Available on http://www.parliament.uk/business/publications/research/briefing-papers/POST-PN-383/carbon-footprint-of-electricity-generation-june-2011.

| Waste

| Nuclear

"The most significant high level waste from nuclear reactor is the used nuclear fuel[20] left after it has spent about three years in the reactor generating heat for the electricity.[21] Low level waste is made up of lightly-contaminated items like tools and work clothing from power plant operation and makes up the bulk of radioactive wastes. Items disposed of as intermediate-level wastes might include used filters, steel components from within the reactor and some effluents from reprocessing. High level wastes make just 3% of the total volume of waste arising from nuclear generation, but they contain 95% of the radioactivity arising from nuclear power. Low level wastes represent 90% of the total volume of radioactive wastes, but contain 1% of the radioactivity."[22]

Spent nuclear fuel[23] can be temporarily stored, under few meters of water or in containers made of dense material such as concrete or steel. There is an international consensus that deep geological disposal is a robust solution for permanent isolation of high level radioactive waste and used nuclear fuel. Internationally, mature safety assessments indicate that granite and clay sites are viable. However, salt sites as well as deep boreholes in crystalline rocks, are also an option.

However, before disposing waste underground, performance and safety assessment of disposal systems must be checked. An important part of checking is to evaluate the impact on repository performance of the coupled effects of mechanical deformation, fluid and gas flow through the repository and thermal loading from decaying waste.

20. As well as other radioactive substances such as minor actinides.
21. Other sources of high level nuclear waste come from research reactors and from the production of isotopes for medical applications.
22. World Nuclear Association, "What are nuclear wastes and how are they managed?", available on http://www.world-nuclear.org/Nuclear-Basics/What-are-nuclear-wastes-/.
23. About 96% of uranium, up to 1% of plutonium and about 3% of high level waste.

To be able to conduct such an evaluation, it is necessary to enhance the theoretical background and to develop models capable of simulating coupled thermo-hydro-mechanical (THM) processes. Chemical processes have also been added to enable study of fully coupled THMC processes in geosystem. The term "coupled processes" implies that each process potentially affects the initiation and program of the other processes.

As of today, France, Russia, Japan, India and China reprocess most of their spent fuel while the US, Canada, Finland and Sweden have currently opted for direct disposal.

In Germany, the federal government is responsible for high activity nuclear waste disposal. Utilities are responsible for interim storage of spent fuel. They have formed joint companies to build and operate off-site surface facilities at Ahaus and Gorleben. However, current policy is for interim storage at reactor sites. In 1977, the State government of Lower Saxony declared the salt dome at Gorleben to be the location for a national center for disposal of radioactive wastes. It is now considered a possible site for geological disposal of high level wastes. It deals with about 5% of total wastes with 99% of the radioactivity. A pilot conditioning plant is there. The site could be available as a final repository from 2025 with a decision to be made about 2019.

The UK's stockpile of nuclear waste which includes more than 100 tons of plutonium and 35,000 tons of depleted uranium, made the country to assess various options on how to deal with it. The plutonium presents a high level of security risk and could cost the country billions of pounds for disposing of, or managing it.

There are three ongoing research programs in the EU: Mount Terri, International Underground research laboratory (URL) in clay, Colloid Formation and Migration project (Switzerland) and Decovalex (International cooperative of nuclear waste organizations, including implementers and regulators as well as associated research and modeling teams).

In a nutshell, a number of underground storage facilities are being tested across Europe and so far, there is no contraindication for using them as repositories for high level radioactive wastes.

| Wind power

According to a study carried out by academics at Edinburg University, based on wind farm performance data from the UK and Denmark, the output from wind farms declines substantially as they get older. By ten years of age, the report found that the contribution of an average wind farm towards meeting electricity demand had declined by a third.

That reduction in performance leads the study team to believe that it will be uneconomic to operate onshore wind farms for more than 12 to 15 years, contrary to industry predictions of a 20 to 25 year lifespan. The study also reports that the decline in performance of Danish offshore wind farms had been greater than that of UK onshore wind farm. Indeed, technical failures during operation are a significant source of risks. Typically, estimates of the cash flows generated by offshore wind farms are based on a technology performance that is uncertain. Marine environment reduces performance and makes maintenance slow and expensive. All this suggests that offshore wind turbine lifespan is significantly lower than expected.

This reduced lifespan not only increases the cost of wind power production but is also a cause for concern because it creates together with the expansion of wind energy generation, a growing waste disposal issue in addition to the problems associated with the decommissioning of wind turbine blades.

Indeed, while some wind turbine components are made of materials that are easily recovered and have good scrap value, such as steel and copper, composite blades are harder to recycle. The world's only industrial enterprise to recycle end-of-life turbine blades is in Melbeck, northern Germany. Zagons Logistik reprocesses blades and other products made from fiber – reinforced plastic for use in cement production.

The responsibility of end-of-life components including blades rests with the wind farm owner or operator, as well as the removal of turbine foundations and service roads.

Before delivering the construction and environment permits to wind farms owners, the Authority is to properly address the responsibilities of these latter in terms of site restoration to pre-wind farm states and recycling of end-of life equipment. Developers should be required to give guarantees for the decommissioning costs.

Denmark and the Netherlands, two of the leading countries in the offshore wind sector, require the owner of an offshore installation to be liable for decommissioning. The Netherlands requires that offshore owners/operators must pay monies into a segregated decommissioning fund for a minimum of 10 years, starting from the 1st year of operation of the project. Such measures are intended to meet people's concern with end-of-life wind turbines which would litter the landscape if not properly dismantled and disposed of, or recycled.

The argument following which there is no problem because old wind turbines will be replaced, most of the time, with more modern, larger and more efficient ones, is not convincing. Even if it is the case, the wind turbine components will still have to be handled, recycled and disposed of. However, replacement could be prevented, for example, because of bankruptcy. In that case, rusting hulks could scar local vistas for decades. On the other hand, operators/developers could be deterred to replace old turbines with new ones because of:

- insufficient lifespan of wind turbines;
- change of legislation resulting in cuts, or even cancellation, of incentives for new turbines, as a consequence of the economic crisis that is not anywhere near finished;
- anti-wind increasing lobbying preventing replacing, all the more so that new turbines will be taller than the previous ones (visual nuisance) and more noisy.

Wind energy is not as clean as claimed by their supporters, in particular, the one generated by synchronous wind turbines. Indeed these latter are provided with alternator having permanent magnet rotor. Those magnets are made of a rare earth alloy[24], neodyme-iron-bore in most cases, with smaller quantities of dysprosium and praseodyme.

The concentration of rare earth in the ore is very low, so it must be separated and purified, using hydro-metallurgical techniques and acid baths. China account for 97% of global output of rare earth, with two-thirds produced in Baotou (Inner Mongolia). Waste water loaded with toxic chemicals used to process ores containing rare earth, are discharged into a pond without treatment. These foul waters not only contain all sorts of toxic chemicals, but also radioactive elements such as thorium which, if ingested, cause cancers of the pancreas and lungs and leukaemia.

24 Rare earth is the name given to a group of 17 chemical elements including 15 lanthanides, scandium and Yttrium.

In the framework of their climate policy, the US and the EU are importing rare earth from China, the production of which is extremely polluting as explained above. This is one more contradiction of the "green" policy.

| Photovoltaic power (pv)

At the end of 2012, the global pv installed capacity, in Europe, was slightly greater than 102 GW, with 31.1 GW accounting for new installations. In 2012, like in 2011, Europe was the leader with the majority of new installed capacities installed on its territory, respectively, 55% and 74% of cumulative installed capacity. With such a market share, the estimation of pv waste volume is becoming an issue. A fixed waste volume already exists, composed of used modules as well as broken and scrap panels.[25] The European Union revised its legislation about waste to take on board this developing technology.

In August 2012, the recast WEEE (Waste Electrical and Electronic Equipment)[26] directive 2012/19/EU provides a legislative framework for extended producers'/sellers' responsibility of pv modules. As from 14 February 2014 at the latest, the collection, transport and treatment (recycling) of photovoltaic panels should have been regulated in every single EU country. Only the UK and Bulgaria have enshrined this directive into their national law before the dead line. Based on the installation capacities in Europe and an average lifespan of 17 years, the volume of photovoltaic waste will exceed 5,500,000 t in 2026 and more than 1 million t of pv waste will need to be collected in 2027 and over 2 million in 2028.[27]

Waste from production scrap varies between 1 and 2%, depending on the manufacturer. In 2012, European manufacturers accounted for approximately 23% of the global pv panel production market (essentially, German manufacturers). PV waste is also produced during installation, about 2% due to breakages.

To date, approximately 10% of potential photovoltaic waste volume have been collected. The most important barrier in recycling pv panels remains the cost. With 10% collection rate, collecting, transporting and treating pv panels are not financially viable. Insufficient attention is currently being paid to the potential risks and consequences of scaling up solar pv cell production and decommissioning.

The two more utilized solar cell materials, Cadmium telluride (CdTe) and crystallized silicon present serious hazards. Cadmium telluride pv is the only thin film technology with costs lower than conventional solar cells made of crystalline silicon (c-Si) in multilayer systems. CdTe is the second most utilized solar cell material in the world. The first one is still silicon.

Either short term or long term exposure to Cd cause serious health problems.

25. Simin Bilimoria, "The evolution of photovoltaic waste in Europe", S&T Consulting, August 5, 2013.
26. This directive as well as RoHS (Restriction of the use of certain Hazardous Substances in electrical and electronic equipment) aim at two goals: to collect electrical and electronic devices, reuse their raw materials and protect people and the environment against dangerous substances.
27. Simin Bilimoria, "The evolution of photovoltaic waste in Europe", *op. cit.*

According to ARL (Analytical Research Laboratory), Cadmium is an extremely toxic metal. Cd toxicity contributes to a large number of health conditions including the major "killer diseases" such as heart disease, cancer and diabetes. The EU has imposed a tighter limit on cadmium. An unrestricted area of applicability includes solar arrays as of 2014.

Silicon based solar pv production also poses hazards because of silane gas SiH_4, an essential material for thin film pv and semiconductors. Silane gas is the most significant hazard in the production of c-SI because it is extremely explosive and presents a potential danger to workers and communities. The production of silane and trichlorosilane results in waste silicon tetrachloride, an extremely toxic substance that reacts violently with water, causes skin burns and is a respiratory, skin and eye irritant.[28]

Moreover, the extremely potent greenhouse gas sulfur hexafluoride is used to clean the reactors used in silicon production. A range of other chemicals are used for cleaning the silicon and cells.

28. Dustin Mulvaney, *Hazardous materials used in silicon pv cell production*, available on http://www.solarindustrymag.com/issues/SI1309/FEAT_05_Hazardous_Materials_Used_In_Silicon_PV_Cell_Production_A_Primer.html.

| Conclusions

What about the electrical energy mix likely to sustain economic and social development? How can an electric power system provide to end users electricity supply continuity, at prices competitive for enterprises and acceptable for households?

The review of the contributions of the different sources of electricity to security of supply, competitiveness and sustainability is likely to put us in the picture about the type of power mix which best suits the EU consumers needs.

| Security of supply

Nuclear power is designed to deliver electricity at a high level of continuity. Uranium resources are well distributed worldwide and the majority of mines are located in politically stable countries.

Uranium reserves are sufficient for operating existing conventional nuclear power plants for about 90 years, and more with 3d generation reactors and many times as much with fourth generation ones. Moreover, thorium, an alternative nuclear fuel, even not yet commercialized, is reported to be three times as abundant in the earth's crust as uranium.

Nuclear power is reliable and will be more and more so in the future thanks to technological progress. In any case, it is more reliable than intermittent energy such as wind and solar power and even, sometimes, more reliable than hydro, given the increasing occurrences of lack of water in summer time.

Wind and solar power, because of their intermittency, cannot secure the supply of electricity. Moreover, it is facing growing opposition, the well known NIMBY effect, and is experiencing shorter lifespan than expected.

Offshore wind power is still an uncertain technology, the Bard 1 wind farm project, in the German EEZ (Exclusive Economic Zone), being a point in case in that respect.

Intermittent energy is bringing the electricity transmission grids to the edge of their resilience and, as a consequence, could not be delivered when operational, if the grid fails.

Coal reserves are abundant and well distributed world wide. Its price is very attractive today.

Although it is a polluting fuel, it is used for compensating the intermittency of wind and solar power because it is cheap and available. Economic considerations eventually prevail over other concerns. Gas becomes more and more abundant and better distributed worldwide thanks to shale gas.

| Competitiveness

Cheap energy is a major parameter of competitiveness and electricity is an important component of an energy policy. In that perspective, it is worth noting that EU member states with high penetration of solar and wind power production, and/or nuclear power phase-out, are all facing high electricity prices which, of course, affect the competitiveness of their industry and the purchasing power of households.

In Germany, Denmark and Ireland, committed to ambitious "green" power strategy, sometimes even beyond EU targets, the electricity prices are the highest in the European Union.

Gas fired power plants, very competitive when the electricity market is not distorted by political decisions giving the priority of access to the grid to subsidized intermittent energy, are no longer profitable in "green countries" because of their low load factor.

Coal remains attractive as long as the US keeps on exporting their cheap coal and in so far the EU carbon market does not change the deal.

Nuclear power is currently very competitive compared to all other sources of electrical energy (still more so with higher carbon prices), when all costs are taken into account, including the costs of intermittency for solar and wind power.

| Carbon footprint

EU member states rushing for wind and solar power production with significant penetration of their domestic market and/or starting to phase out their nuclear power, as part of their low carbon policy, have failed to meet their objective of carbon emissions reduction.

Actually, some of them are increasing their carbon footprint.

Instead of shutting down nuclear power plants, extending the life time of their best units and allowing the construction of new ones (of the most recent generation), would be a more rational approach as their carbon footprint per kWh is of the same order of magnitude as hydro and onshore wind power.

| Waste

All types of power production are facing costs of disposal and recycling, through their life cycle, including wind and solar power.

Volumes of waste could be higher than expected because of reduced life span (wind and solar) or/and low level of recycling (10% for photovoltaic panels).

Wind and solar power is not as "clean" as claimed. The two more utilized solar cell materials, Cadmium telluride (CdTe) and crystallized silicon present serious hazards: silicon based solar panel because of silane gas SiH_4, an essential material for thin film PV and semiconductors and Cd, because of its toxicity. Silane is extremely explosive and its production results in waste silicon tetrachloride, an extremely toxic substance that reacts violently with water, causes skin burns and is a respiratory skin and eye irritant.

Same observation for wind power and, in particular, for synchronous wind turbines which have alternator with a permanent magnet rotor. Such magnets are made of rare earth. To extract rare earth from the ore, toxic substances are used. In China, producing 97% of global output of rare earth, waste water loaded with toxic chemicals are discharged into a pond, without treatment. These foul waters not only contains all sorts of toxic chemicals but also radioactive elements which, if ingested, cause cancer of the pancreas and lungs and leukaemia.

The EU so concerned with the impact on health and nature of imported goodies, should pay more attention to the toxic footprint of PV panels from China.

As far as nuclear waste is concerned, there are ongoing research programs across Europe for high, intermediate and low activity waste.

As of today, France, Russia, Japan, India and China reprocess most of their spent fuel while the US, Canada, Finland and Sweden have currently opted for direct disposal.

There is an international consensus that deep geological disposal could be a robust solution for permanent storage of high level radioactive waste and used nuclear fuel.

The underground facilities being tested across Europe do not show, so far, contraindication for using them as repositories for high level radioactive waste. However, more evaluations and testing are required.

In a nutshell, the analysis conducted in this paper shows that there is no reason to exclude nuclear power production from the electricity supply mix. On the contrary, nuclear power should be part of it with renewables and thermal power as it is a competitive and sustainable source of energy and as it contributes to the security of supply even better than most other types of power generation.