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The inability of the Kyoto protocol to significantly curb greenhouse gas emissions and the current economic crisis seem to challenge green policies, shifting attention towards the need to save the economy and job creation. Although several governments are directing their economic recovery efforts towards green jobs and industries, the consequences, in term of unemployment, of the transition period between conventional energy and energy of the future have not been sufficiently assessed. In this context, the author of our tribune, Jean-Pierre SCHAEKEN WILLEMAERS, a specialist of energy resources in the academic as well as the industrial fields and a member of the Advisory Board of the Thomas More Institute, is now addressing the issue of reliability of the sources of energy, starting with electricity generation. The objectives of this analysis is, without any preconceived answer, to assess (and quantify) the strengths and liabilities of nuclear power in comparison with different types of power generation. Such assessment is considering together cost, availability and environment impact. This tribune is part of a larger research program on European energy issues initiated by the Institute over two years ago under de leadership of the author of the present article. This program covers both EU's internal energy matters such as the questions of the security of supply and energy mix, and broader geopolitical energy issues.

Nuclear power, a liability or an asset for Europe?

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1 Introduction

World electricity generation and related emissions will continue to grow rapidly over the next decades in order to meet the needs of an increasing population and of economic growth. From 1995 through beginning 2007 the net power production within UCTE[1] increased at an average pace of about 58 TWh/year from 800 TWh to 2,600 TWh[2] of which:

- 1,360 TWh of conventional thermal;
- 800 TWh of nuclear;
- 305 TWh of hydro;
- 116 TWh of other renewables.

The main contributors of this increase are:

- The users connected to the LV (low voltage) network (domestic customers, professionals, public services and so on: warm water, electricity cooking, electrical devices like TV, DVD, recorders and readers, decoders, phones, game consoles, PC's and the like);
- Small and medium size enterprises.

Power consumption within UCTE is expected to grow annually by more than 1% over the next decade. In 2007 the following European countries were producing more than 50% of their electricity from conventional power plants: Denmark, the Netherlands, Germany, the Czech Republic, Poland, Hungary, Italy, Greece, Luxemburg and Romania.

Within UCTE, the security of electricity supply deteriorated in 2007 with the real margin dropping from 7.6% in 2006 to 5.3% in 2007. Without a significant and vigorous investment programme in electricity and gas infrastructures, Europe's security of energy supply would be threatened[3].

In 2007 investments in renewable capacities grew fast, wind energy being the industry's preference after biomass. However this type of resource is not schedulable and consequently not always available during peak hours. This partially explains the security of supply deterioration.

According to IEA[4], world power production from coal will grow from about 6700 TWh in 2004 to more than 12 000 TWh in 2030 whereas corresponding CO_2 emissions will jump from 7000 t CO_2 to more than 11 000 t CO_2, the bulk of this increase originating from developing countries.

It turns out that by 2030, coal plants in developing countries will produce more CO_2 than the entire power sector in the OECD.

Gas based electricity generation could triple during the same time frame, likely to exceed 9,000 TWh in 2030 (with corresponding CO_2 emissions jumping from 2,000 Mt CO_2 in 2004 to about 4,500 Mt CO_2 in 2030) although coal is expected to remain the dominant fuel for power plants. Renewables without hydro would generate 1,500 TWh by 2030 and hydro by that time would peak at 4,000 TWh.

Wind power accumulated capacity world wide is expected to reach by 2012

	150,000 MW
of which:	30,000 MW in Germany[5]
	55,000 MW in Europe without Germany

[1] 20 European countries: Austria, Bosnia, Belgium, Bulgaria, Czech Republic, Croatia, Denmark, France, Germany, Greece, Hungary, Italy, Luxemburg, Portugal, Poland, Romania, Serbia, Slovenia, Switzerland, Slovak Republic.
[2] TWh : Terawatt/hour = 10^{12} watts per hour.
[3] Capgemini, European Energy Markets Observatory report (10^{th} edition).
[4] International Energy Agency.
[5] Wind power in Germany should not increase significantly onshore, total power stabilizing at about 25 000 MW whereas offshore capacity could attain 20 000 MW by 2020.

65,000 MW worldwide without Europe

At the end of 2006, a total of 435 commercial nuclear reactors were operating with a net generating capacity of about 370 GWe. In 2008, 41 reactors were under construction with a total capacity of 35,000 MWe whereas 108 reactors were planned for 120,000 MWe.

The 2009 credit crunch will very likely slow down renewable power projects and consequently will be raising CO_2 emissions due to an increased output from fossil fuel plants. Hence electricity generation deficit, climate change concerns, security of energy supply, waste disposal, electricity price, limited renewable energy provide decision makers with sufficient basic data to adapt and/or reconsider their energy policy options and **in particular not to reject or neglect any energy resource** like nuclear fuel.

2 Controversy about nuclear power

The purpose of this paper is to address the controversy about nuclear power:

- by comparing, for different types of power generation, some basic data in relation with:
  - security of electrical and fuel supplies;
  - investment costs;
  - electricity price;
  - CO_2 emissions;
- and by considerations about nuclear waste.

1. Considerations about different types of power generation

1.1. Security of electrical and fuel supplies

The main objective of the "second strategic energy review" is securing European energy future at competitive prices while curbing GHG emissions.

In 2007, European electricity consumption still increased by 0.9% and CO_2 emissions stabilized instead of decreasing.

In Germany power demand increased from 524 TWh in 2007 up to 545 TWh in 2008, while in France it grew by 0.4% in 2007 (to 480 TWh) from 2006.

According to Capgemini: "…since the low point of investment in 2005, utilities have started to invest again but have made energy mix choices that are not moving towards a reduction in CO_2 emissions because the majority (58%) of the planned generation capacity will be fossil fuelled."

In 2007, investments in renewable capacity grew fast but this type of source is not schedulable and not always available.

Nuclear power instead provides a stable, secure and permanent production of electricity while meeting to a large extent the climate change concerns.

The nuclear fuel supply is not a cause for concern as explained below, for many decades to come and in any case during the transition period to the energy of the future.

Like coal, uranium mines are well distributed in the world, in rather stable countries, but contrary to coal, as long as sequestration is not mastered, nuclear power plants are little polluting as discussed under the article dedicated to CO_2 emissions.

Security of oil and gas supplies is more questionable (the Russian/Ukraine gas crisis is very significant in that respect) and their price volatility is much higher than those of uranium and coal.

According to NEA and AIEA agencies[6] "red book" the total identified uranium resources increased in 2007 to about 4,456,000 T of uranium metal (U) in the less than USD 80/kg U category and to about 5,469,000 T U in the less than USD 130/kg U category (increase of 17% and 15% respectively compared to their 2005 levels).

The 2007 issue of the above "red book" indicates that " by 2030, world nuclear capacity is projected to grow between 509 GWe net in the low demand and 663 GWe net in the high demand case, from 370 GWe net generating capacity in 2006.

Accordingly world reactor related uranium requirements are projected to rise between 93,775 T U and 121,955 T U by 2030.

How to meet that demand?

First of all it should be noted that the identified[7] nuclear resources are widespread distributed: South America (Brazil), North America (Canada and the USA), the Russian Federation, Central Asia (Kazakhstan and Uzbekistan), Africa (South Africa, Niger and Namibia).

In 2006, two countries, Canada and Australia, accounted for 44% of world production and just 8 countries: Canada (25%), Australia (19%), Kazakhstan (13%), Niger (9%), the Russian Federation (8%), Namibia (8%), Uzbekistan (6%) and the Usa (5%) accounted for 93% of the world production.

Driven by recent uranium price increase, production capacity at existing and committed production centres has increased in 2007.

Significant new production capability is planned for the near term both through the expansion of existing production centres and the opening of new mines mainly in Kazakhstan, Canada, Australia and Russia, in total about 23,000 t U/year within 2013 through re-opening and expansion of existing mines and about 46,500 t U/year within 2013 from new mines.

Total planned additional production capacity would be 69,500 t U/year.

By 2013 the total uranium production is expected to exceed 110,000 t U/year. Such projections are on the low side because they do not take into account:

- Nuclear fuel produced by re-processing spent reactor fuels and surplus weapons related plutonium
- The use of other nuclear fuels such as U238 and thorium thereby expanding the available resource base;
- Unconventional resources from which uranium is only recoverable as a minor by-product such as uranium associated with phosphate rocks non-ferrous ores and so on.

Moreover, it is obvious that uranium demand would drastically decrease when (if?) breeder reactors become operational.

1.2. Investment cost

Turnkey prices of different types of power plants are given below in EUR/kW. It deals with orders of magnitude in 2008. As such costs depend on a number of parameters which vary according to plant location, sources of equipment supply, local legislation, regional and world economic situation and so on, they only serve for comparison purposes.

[6] NEA: for Nuclear Energy Agency (OECD); IAEA: for International Atomic Energy Agency.
[7] Identified means reasonably assured and inferred (based on geologic evidence and projection) resources.

Power plant	Turnkey price, financial cost excluded EUR/kW	
Nuclear	(EPR-3d generation-Flamanville)	2,300÷2,500
Wind	Onshore-2 MW	1,300÷1500
	Offshore-5MW (without connecting cable)	2,000÷3,000
Photovoltaic	(residential with BOS-10 kW)	5,000
Gas fired-combined cycle	500 MW	500÷600
	100 MW	800÷900
Coal fired(pcc)	1000 MW	1,400÷1,700
Hydro	(reservoir)	2,000÷2,500

1.3. Electricity prices (2007)

The figures hereunder serve to give cost estimates of different sources of electrical energy for comparison purposes.

Power plant		**Cost - EUR/MWh** (Second strategic energy review, Commission to European parliament, 2008)
Nuclear		40÷45[8]
Wind	Onshore	75÷110
	Offshore	85÷140
Photovoltaic		520÷ 880
Gas-combined cycle	(Base load)	50÷60
Coal with flue gas treatment (pcc)	(base load)	40÷50

1.4. CO_2 emissions

Contrary to what a number of ecologists claim, nuclear energy is among the energy sources producing the lowest levels of CO_2 emissions during their fuel life cycle.

Said levels are closely comparable with those from renewables such as wind and less than solar. Uranium resources are abundant and the need to access extremely low grade ores is far off.

Although quantification of externalities is complex, it is interesting to compare CO_2 emissions between different types of power generation taking into account upstream and downstream processes. As far as nuclear is concerned, the figures below include: uranium mining and conversion, waste treatment, construction as well as dismantling of the power plant.

[8] Source IEA.

Type of power plant		CO_2 emissions - g CO_2/kWh NEA[9]	Paul Scherrer Institute	EIRE[10]
Coal fired		951	750-1,080	1,114
Gas fired				
	Combined cycle	410	399-544	-
Solar photovoltaic	Grid tied	216	78-217	60-150
	Stand alone	-	-	280-410
Wind		41	10-38	8
Nuclear		20	5-33	39

2. Nuclear waste

Contrary to the common opinion, conditioned nuclear waste does not fill a big space. In Belgium the volume of nuclear waste accumulated since the beginning of nuclear power generation until today is about **22,200 m³,** broken down as follows:

Category of waste		volume (m³)
Category A	Short half life[11] and low, medium activity[12]	17,700
Category B	Long half life, low and medium activity	4,500 (B+C)
Category C	High activity, short and long half time	

It appears thus that long half life time and/or high activity nuclear waste can be lodged in a cube of less than 17 m side which is a rather small volume.

On the basis of data available on January 1, 2001 the quantity of conditioned nuclear waste in Belgium,by 2070 is estimated by ONDRAF (organisme national des déchets radioactifs et des matières fissiles enrichies) at:

Categories	volume m³
category A	70,500
category B	8,900
category C	2,100 to 4,700

[9] NEA (Nuclear Energy Agency) symposium, 2001.
[10] Environmental Imperative for renewable energy.
[11] Half life: time during which radioactivity decreases by 50% in less than 30 years.
[12] Low activity corresponds to a flow at contact of less than 5 millisevert/hour (mSv/h); Medium activity more than 5 mSv/h and less than 2 Sv/h; High activity more than 2 Sv/h.

3 Conclusions

Could we endorse the "Wall Street Journal"[13] when it writes that the current global economic crisis " has demoted green policies to the bottom of the political agenda. Saving economy and creating jobs take priority now" and "disillusionment with the failed Kyoto protocol has turned utopian thinking into sobriety"? From 2000 to 2008 CO_2 emissions have evolved as follows:

EU	+3.5%
USA	+2.0%
OECD	+3.3%
Germany	- 2.7%

In 2004 CO_2 emission level in Europe is back to the 1980 level (thanks to nuclear!). It is a matter of fact that most signatories of the Kyoto protocol failed to reduce their CO_2 emissions during the last 10 years[14].

In Germany, once the most forceful climate supporter, there are signs of a split within the CDU party on climate and energy issues. Amid growing fears of a deepening recession, the German SPD has been arguing that the climate targets should only be accepted if "truly cost effective solutions could be found".

The head of the mining, chemical and energy industrial union, has recently called for a two year postponement of the climate package.

The deepening economic crisis seems to transform the mood of the German people. For instance in December 2008, metal workers and trade unions protested outside the European parliament in Brussels against the EU's climate policy which they fear will increase unemployment.

What about the transition period between conventional energy and the energy of the future?

Already in April 2007, G-7 finance Ministers endorsed nuclear energy as an increasingly attractive source of electricity as governments confront the issues of climate change and over-dependence on fossil fuels. They also recommended diversification of energy sources for both developed and developing countries.

This is all the more true today. Indeed nuclear energy contributes to meet the objectives of the second strategic energy review of securing energy future while curbing GHG emissions.

Nuclear power is schedulable contrary to most renewable energy and provides secure and permanent production.

Its investment cost is significantly less than offshore wind power and much less than photovoltaic and its electricity price is cheaper than any other type of power generation (except pcc coal fired power plant).

Fuel supply is not a cause for concern for many decades to come. The identified nuclear resources are widely distributed and they increased in 2007 to about 4,500,000 T to 5,500,000 T according to uranium market prices. Those quantities do not take into account unconventional resources, fuel reprocessing or alternative fuels such as thorium.

Lifecycle CO_2 emissions from nuclear power plants are closely comparable with those from renewables such as wind power and less than solar power.

The volume of conditioned nuclear waste is rather small. In Belgium, the total volume of long half life and/or high activity waste accumulated until today can be lodged in a cube of 17m side. Testings of safe storage are progressing well.

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[13] December 15, 2008.

[14] It appears however that the warming *trend* of the late 20th century has essentially come to a temporary halt. The data collected by international meteorological offices seem to confirm this.

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