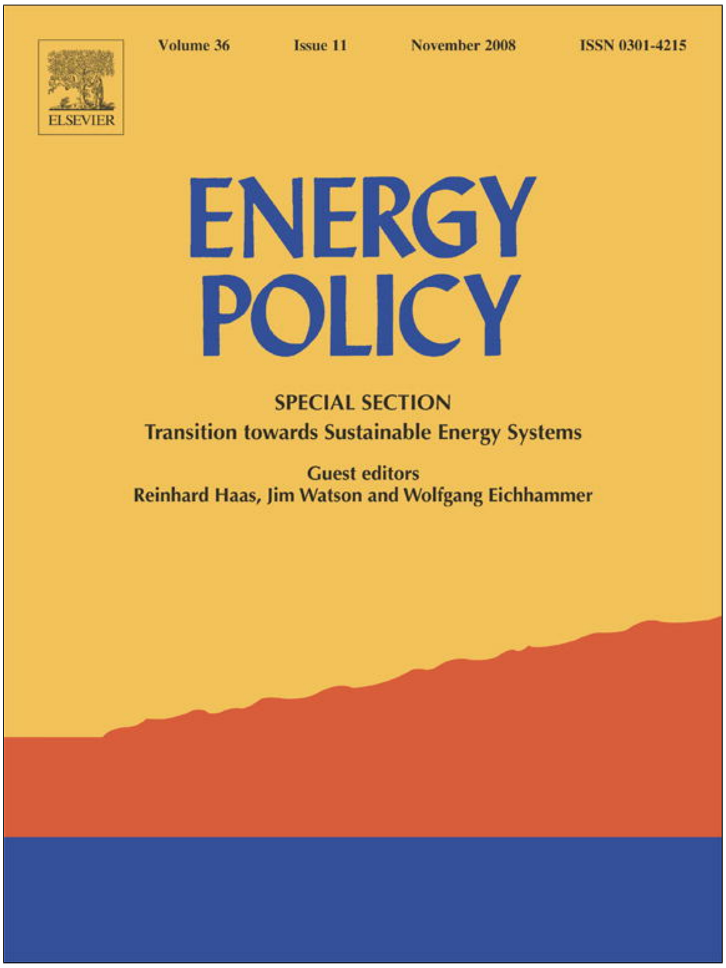
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Renewable and nuclear power: A common future?

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ABSTRACT

Nuclear power and renewable energy are the main options to bring down the carbon intensity of commercial energy supply. What technology is unlimited backstop supply depends on its performance on the sustainability criteria: democratic decided, globally accessible, environmental benign, low risk, affordable.

Renewable power meets all criteria, with affordability under debate. Maximizing energy efficiency as prerequisite, the affordable sustainable option in fact is the twin efficiency/renewable power. Nuclear power falls short on the sustainability criteria and its public acceptance is low. Nuclear proponents now propose nuclear and renewable energy as a suitable couple to address the climate change challenge. The two antagonists however are mutually exclusive on the five major directions of future power systems. First, nuclear power has been architect of the expansive "business-as-usual" energy economy since the 1950s. Second, add-on by fossil-fuelled power plants is bulky and expansive for nuclear power, but is distributed, flexible and contracting over time for renewable power. Third, power grids for spreading bulky nuclear outputs are other than the interconnection between millions of distributed power sources requires. Fourth, risks and externalities and the proper technology itself of nuclear power limit its development perspectives, while efficiency/renewable power are still in their infancy. Fifth, their stalemate for R&D resources and for production capacities will intensify. Nuclear power and renewable power have no common future in safeguarding "Our Common Future".

1. Introduction

The fourth assessment by the Intergovernmental Panel on Climate Change (IPCC, 2007, January, April, May, November) and the Stern Review (Stern, 2006, October) confirmed that climate change is steadily growing into a major threat to the essential life-support systems of our world and of our way of life.

To keep the threatening dynamics of climate change within the human scope of control, it is necessary to slow down the increasing concentration of greenhouse gases in the atmosphe re. Over the last 650,000 years, the CO_2 concentration in the earth's atmosphere never surpassed 300 ppm. Following the exponential growth in fossil fuel use and land clearing, accompanying CO_2 emissions have risen. The built-up concentration climbed from the pre-industrial 280 ppm level to 379 ppm in 2005 (IPCC, 2007). To respect a +2 °C ceiling in temperature increase compared to pre-industrial averages, the EU wants to limit the concentration around 450 ppm. Stern (2006) focuses on a stabilization at 550 ppm CO_2-eq (i.e. including the other greenhouse gases too), which is not very different from the 450 ppm CO_2 target (IPCC 2007, WGIII, Table SPM.5). The 550 ppm CO_2-eq is considered as far too risky by environmental NGOs and by other observers (Baer, 2006). To reach the stated concentration targets, emissions must be reduced urgently and drastically (Stern, 2006, Fig. 3; IPCC 2007, WGIII, Figure SPM7). The emission reduction obligation fuels hope for promoting renewable energy. Others see it as an opportunity to level barriers for a third chance of nuclear power commercialization.

In Section 1 the driving forces of carbon emissions are highlighted, focusing on energy intensity and carbon intensity as the two technical drivers that energy policy can address. In Section 2 the four main contenders for meeting the electric power needs of the future are discussed. Nuclear power and renewable power are assessed on the basis of criteria of a sustainable backstop supply technology. In Section 3 it is shown that the two options are antagonists and mutually exclusive in five major developments of future power systems.

2. Driving forces of carbon emissions

Ehrlich and Holdren (1971) described Impact on the environment as the product of Population × Affluence × Technology. For

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carbon emissions (globally, by continent, by country, etc.) a hybrid identity is used:

Total carbon emissions = Population × Affluence × Energy Intensity × Carbon intensity or

$$\text{Total carbon emissions} = \sum \text{Population} \times \frac{\text{Euros}}{\text{Person}} \times \frac{\text{Joules}}{\text{Euros}} \times \frac{\text{Carbon emission}}{\text{Joule}}$$

Although the assumption of independency among the factors is not evident, the rate of emission changes is written as the sum of the change rates in the four right-hand variables. Fig. 1 shows the impact of the four components on the global energy-related carbon dioxide emissions in the world.

Fig. 1 shows that the emissions of carbon dioxide went up by 16.5% over the period 1975–1980, by 5% over 1980–1985, etc. and were still growing by 4% over 1995–2000. Two factors increased the carbon emissions: the growth in world populations (although declining over the whole period 1975–2000) and the growth in affluence, becoming the factor with the strongest impact during 1995–2000. Discussing population and affluence growth is beyond the scope of this article.

The carbon dioxide emissions are brought down mainly by decreasing energy intensities and to a lesser degree by decreasing the carbon intensity of the energy employed. These more technical driving forces are part of the discussion here. Carbon intensity is a simple variable, but Energy intensity is total primary energy use per unit of GDP (IEA, 2006a, p. 454). GDP is made up of a variety *A* of Activities, expanding the equation

$$\text{Energy intensity} = \frac{\text{Joules}}{\text{Euros}}$$

to

$$\text{Energy intensity} = \sum_A \frac{\text{Joules}}{\text{Activity}} \times \frac{\text{Activity}}{\text{Euros}}$$

Every first factor of the *A* multiplications represents the (inverse) energy efficiency of the activity (almost impossible to observe directly) and every second factor represents the share of activity in the GDP of a country.

The definition of the concept 'energy efficiency' is not settled. It "is a generic term, and there is no one unequivocal quantitative measure of 'energy efficiency'". It "is often broadly defined by the simple ratio (useful output of a process)/(energy input into a process). The issue then becomes how to precisely define the useful output and the energy input" (Patterson, 1996). Because of the difficulty, say impossibility, to define 'useful outputs' in a widely agreed way for more than a handful processes, it is almost impossible to observe energy efficiency directly. The activities that make up the GDP are mostly named 'structure'.

Variations in observed energy intensities of economies can result from differences in energy efficiency and from differences in structure, both very dependent on the state of development (Medlock and Soligo, 2001). For a sample of 11 OECD countries, Geller and Attali (2005) show that the decline in energy intensity during the period 1973–1998 results far more from improved energy efficiency than from structural shifts. On the aggregate, the energy efficiency improvements account for about 80% and the structure effects for about 20% of the total decline.

For bringing carbon emissions to sustainable levels "Energy Efficiency is Top Priority" (IEA, 2006a, p. 31) followed by low-carbon-intensity supply options. Because of the focus on nuclear power as an option, the remainder of the article deals with electricity only.

3. Contenders for the future supply of electricity

The future supply of electricity mainly depends on fossil fuel use, nuclear power, renewable sources and electricity efficiency. In Section 3.1 their interconnections are briefly described. The three supply options are scanned in Section 3.2. The criteria of backstop supply technology are much wider than just the property of being unlimited. Nuclear power (in Section 3.3) and renewable power (in Section 3.4) are evaluated on the broader set of sustainability criteria.

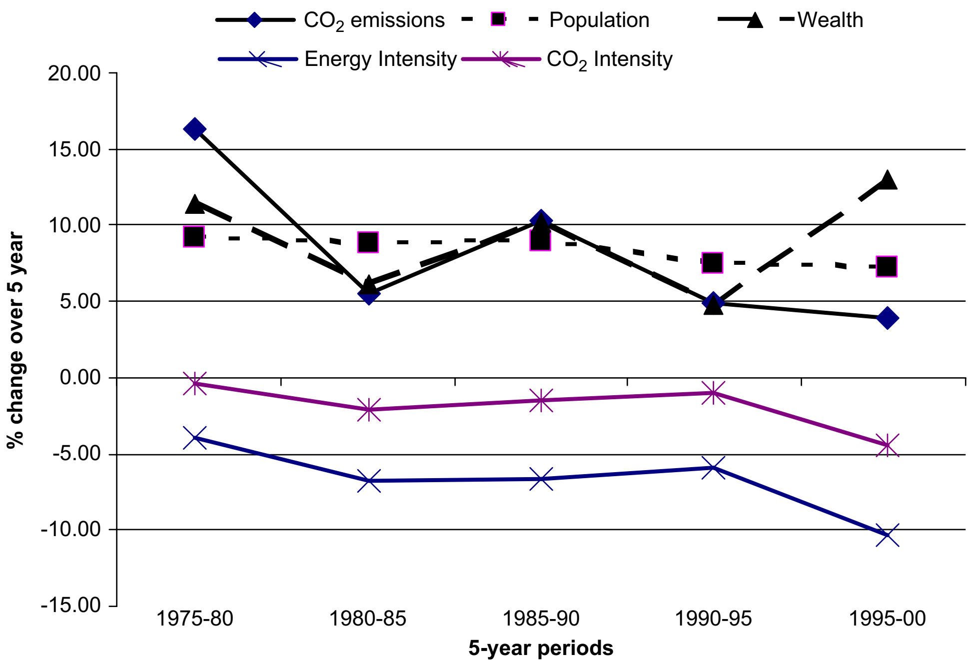

Fig. 1. Decomposition of global energy-related CO_2 emission changes. Changes are given by 5-year periods from 1975 to 2000 (data sources: World Bank, Oak Ridge).

3.1. Four players at the table

Electricity supply in the past decades, at present and in the future is the outcome of market coverage by four main players of a very different kind. Three are supply sources, namely fossil fuels, nuclear heat and renewable energy, and the fourth, 'efficiency', is decisive for the height and structure of the demand for electricity.

Fossil fuels supply more than 85% of all commercial energy in the world and are the source of more than 68% of the commercial electricity (BP, 2005). Although the huge dangers of climate change are caused mainly by fossil fuel combustion, many energy experts expect fossil fuels to remain the dominant energy player during at least the first half of the 21st century. Also in the generation of electricity, fossil fuels may stay in pole position for some time (EU, 2003; IEA, 200X, 2006a).

From fossil fuels, electricity is generated in base-load plants (large coal, but also combined cycle gas turbines (CCGT) that reach their highest efficiencies only under stable full-load conditions) and in flexible plants. Fossil-fired power plants may be conceived as cogeneration (CHP, combined heat and power) units and also can be installed near heat loads (distributed generation). For the large-scale centralized base-load plants, carbon capture and storage (CCS) provides a way out to mitigate the emissions of CO_2 (IPCC, 2005). It is still early to judge the performance of this option, but when successful, the centralized conversion of coal into electricity or into synfuels (including hydrogen) will stay a part of the energy system. Hydrogen could feed fuel cells for combined power and heat supply or power-only applications.

Among fossil fuels, substitution is familiar. After coal had driven out wood as a fuel in the industrializing economies, hydrogen weight in fossil fuel use has steadily progressed. Oil for coal, natural gas for oil, and hydrogen for hydrocarbon gases increase the hydrogen content, thus lowering the carbon/hydrogen ratios. However, the third substitution where the ratio could fall to zero (and solve the emission problem) contains a circular reference because hydrogen is not freely available on earth.

Nuclear power is the second contender. The name power hides that nuclear processes only generate heat (steam). Operational technologies are based on the fission of heavy atoms. There are various competing technologies: pressurized, boiling and water-cooled graphite moderated light water reactors; heavy water reactors; gas-cooled (magnox, advanced gas, high-temperature gas-cooled pebble-bed or prismatic block) reactors, etc. Breeders have been experimented, and again announced as new technology for the future. Fusion of light atoms is demonstrated in the hydrogen bomb, but not mastered as a controlled commercial technology (see the ITER demo project). Existing nuclear plants are very large scale (500, 1000, 1300, 1500 MW), and the future plans (1700 MW) continue this spur. They must run at constant full load in the base load because of technical and economic reasons. They are located at a large distance from urban areas and preferably also from industrial mega-complexes, and the steam conditions of the actual cycles make them unsuitable for cogeneration (the loss in power output is excessive when steam at e.g. 2 bar pressure is extracted).

Renewable power sources are the oldest exploited by mankind to serve his needs (sailing ships, waterwheels, windmills). They cover a wide range of technologies and diverse sources such as hydro (dams, run-of-the-river), wind (aero, wave), solar (photovoltaic, thermal), tidal, biomass, geothermal, etc. (Johansson and Turkenburg, 2004). While the sun delivers massive quantities of energy to earth, it requires good technology and organization to convert this free energy into a useful electricity source to deliver at command for human purposes.[2] Apart from their sustainable appeal and zero or low carbon intensity, renewable energy has few attributes to smoothly fit in the business-as-usual energy structures and habits. Many do not deliver at command but are intermittent, are not centralized but distributed, not concentrated but diffuse, not cheap to mine but expensive to collect. As they stand now, they are technically and economically unresponsive to the exigencies of energy-intensive practices of the industrialized and industrializing societies. But what is today must not be so tomorrow.

End-use efficiency is the main factor of electric intensity. Because no person is fond of the invisible, non-palpable but very dangerous commodity electricity per se, the level of intensity depends on technological and economic variables (Verbruggen, 2006). Increasing efficiencies can have a decisive impact on the electric loads that the supply sources (the three other players) must/can[3] fill.

Step-by-step energy efficiency has received wider acceptance (OECD, 1994; WEC, 2001) and is now seen as "a crucial strategy for sustainable development everywhere. It needs to be recognized as a real resource option" (WBCSD, 2006, p. 12). Facing the growing evidence of climate change, interest groups and companies still obstructing deliberately or objectively the full development and deployment of efficiency solutions have joined the choir praising energy efficiency. On the one hand, the recognition of efficiency as the central piece of every sustainable energy policy everywhere is welcomed. On the other hand, massconfessions entail the danger of dilution, bias and even reversal of essential characteristics of the newly adopted message formally substituted for the yesterday-worshipped idols.

Fig. 2 shows the four options described above with particular links among them. Some aspects of the links are mentioned here and discussed later in the article. The substitutive relationships between fossil fuels and both nuclear and renewable power are not explored in our long-run perspective of transition to backstop solutions. The masonry-filled arrows in Fig. 2 show the complementary and add-on (support, back-up, make-up) relationships between players. In the nearby decades, fossil fuels (mainly natural gas) are expected to deliver add-on services to the contender nuclear power and to the contender renewable power. As discussed in Section 4.2 below, the 'add-ons' are opposite in nature for nuclear and for renewable power, as expressed by the difference in arrows. Renewable power is further crucially dependent on the success of end-use efficiency improvements and thus of intensity reductions (Verbruggen, 2006).

The bullet-filled arrows show opposite positions. Documenting and arguing the positions and relationships is the purpose of this article.

3.2. Main sources of electricity supply

The history of the electricity sector since World War II offers a dynamic picture, where sources and solutions compete in ever-changing positions and conditions. The overall dominance of coal at the beginning of the period has ended, but coal remains a significant source in the generation of power. Although the public, financial and policy support for nuclear energy has been

[2] The largest share of energy people uses is free renewable energy such as daylight, breeze for air and drying, photosynthesis, etc., but these energy flows are not measured (because they are free) and do not show up in our statistics. Once we convert the flows into an energy commodity (e.g. solar hot water for sanitary uses; PV-electric current), the cost of using the flows becomes significant.

[3] The liability of a power supplier is on the one hand providing power when the end-user demands for it (must) and on the other hand shunting power when the end-user is not demanding (can) it.

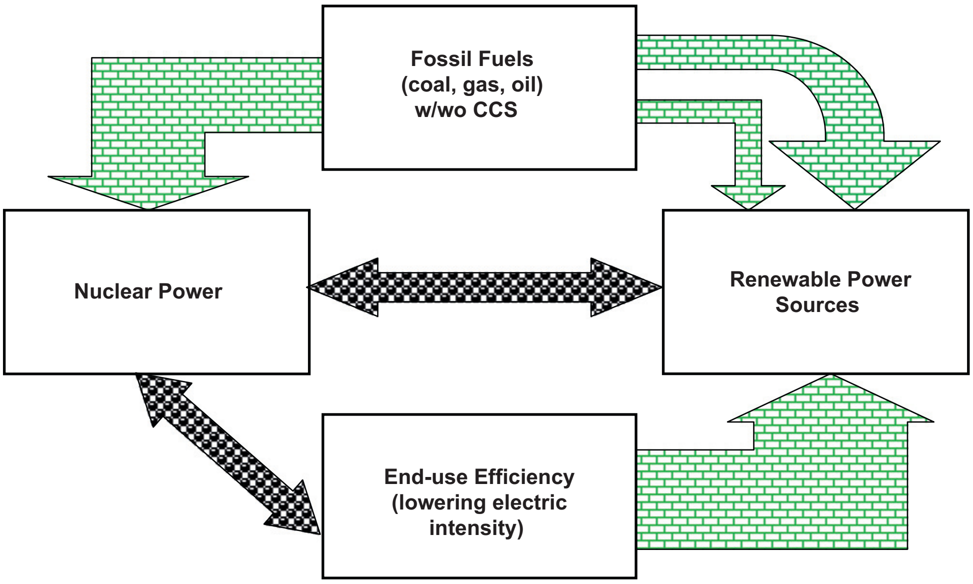

Fig. 2. Four interdependent players contend the supply of electricity.

overwhelming up to 1979 (Three Miles Island)/1986 (Chernobyl), nuclear energy has not succeeded in taking over from coal except for a few countries (e.g. France, Belgium). Oil and gas cover important shares in power generation notwithstanding their exhaustible and premium fuel character. Distributed generation by on-site combined heat and power units and by renewable energy has neither taken over from centralized systems. They struggle with financial return requirements and with, e.g., tariff barriers imposed by incumbent central generators (Verbruggen, 1990; COGEN, 1999).

The future will witness a competition between nuclear and renewable energy for structuring the electricity supply sector as backstop supply options in the long term, and between centralized and distributed solutions (also within the development of renewable technologies), with fossil fuels in a position of add-on supplier (EurEnDel, 2004). Every source scores differently on a set of main characteristics as summarized in Table 1.

From Table 1 it becomes evident why fossil fuels have conquered such a large market share in overall energy supplies and also in the power sector. One may expect fossil fuels to be resilient enough to maintain strong positions in a 'low' carbon emission future. Natural gas is too valuable to be given up, as are premium oil resources, while coal presumably will concentrate on bulk technologies by sequestering the CO_2 in the emissions (IPCC, 2005; IEA, 2006a). All forecast studies foresee an important place for fossil fuels in the coming decades, e.g. EU-WETO (EU, 2003), yearly (IEA World Energy Outlooks, 200X; Dorian et al., 2006). Such scenarios are not sustainable, but they illustrate what business-as-usual may involve.

In the high days of the first oil crisis, Nordhaus (1973) introduced the concept of a "backstop" supply technology. By definition, a backstop supply technology can deliver an unlimited amount of energy at a given (high or very high) cost. In the 1973debate, all focus was on energy exhaustibility, sustainability being at that time the concern of academic and societal minority groups. Nordhaus (1973) describes nuclear power with breeders, followed by fusion, at that time as the evident backstop candidate.

Because today the exhaustibility issue is complemented by the discussion about a sustainable development including democratic, environmental and social concerns next to economic welfare (WCED, 1987, Chapter 2), the 'unlimited' property of backstop supply solutions is completed by 'democratic decided', 'globally accessible', 'environmental benign', 'low-risk' and 'affordable'.[4] These criteria represent the four essential dimensions (or 4P's) of a sustainable development (WCED, 1987, pp. 46, 65; IPCC, 2007, WGIII and Synthesis Report Glossary): (1) political (participation, inclusion, democratic institutions, governance), (2) people (redistribution of global opportunities, access to development and welfare), (3) planet (ecological resilient and sustainable, avoiding irreversible risks), (4) prosperity (rather than profit, i.e. the costs must be reasonable and not wasting valuable economic resources).

3.3. Nuclear power: still a backstop supply?

The performance of nuclear power on the sustainable backstop supply criteria is discussed in Table 2.

Table 2 shows that nuclear power fails on all major criteria of a sustainable backstop supply solution (see also Turkenburg, 2004; Mez et al., 2006). The deliberate phasing-out of the nuclear option (actual plants, RD&D) and ending the investment in further technological mirages are important policies to level the field for sustainable alternatives.

3.4. Renewable power sources as sustainable backstop supply

Renewable electricity sources are arguably the only candidate for passing most of the criteria of the sustainable backstop supply technology (Table 3), except perhaps for the aspect of financial affordability when compared to the present low prices (which is not the same as low costs) of fossil and nuclear power. For example, photovoltaic power from the sunlight is unlimited as long as the earth circles the sun, but is expensive to collect and convert and to bridge intermittent supplies. Several

[4] Affordable is what matches the habits and expectations of the large majority of populations. Applied to electricity use, people expect reliable power at a yearly bill that is not significantly higher than the year before. Keeping the bills stable can be possible either by keeping prices low or by decreasing electric intensities (Verbruggen, 2006).

Table 1
Characteristics of three main future energy options

Properties	Options		
	Nuclear	Fossil fuels	Renewable sources
Energy density	Very dense ($E = mc^2$)	Dense	Mostly diffuse excl. some hydro/bio[a]
Scale	Centralized, gigantic	Divisible, all scales	Distributed excl. some hydro/bio
Control (modulation)	Inflexible (most full load)	At command	Intermittent, (part) non predictable, excl. hydro/bio
Compatible with sustainable options	Bulky and inflexible; intolerant; growth oriented	Sunk costs; expansive investments	Wind and solar need ancillary capacity; hydro/bio independent
Social cost of supply	Very high when all risks are fully incorporated	Very high when all externalities are fully incorporated	Very expensive when full renewable energy supply is due to take over
Market prices	Moderate because risks are not included	Low because externality costs are not included	High because no risks and externalities are rolled of
Technology	Fusion as backstop? Other technological break throughs deem	Wide diversity with innovations Carbon Capture and Storage	Surf on inventions and innovations like micro-electronics, new materials, nanotech, etc.
Acute operational risks	High: nuclear accidents; radioactive releases; weapons proliferation; non-insurable	Manageable although severe accidents can happen (mines, tankers, pipelines)	Tiny and distributed; large-scale hydro dams imply high local risks
Chronic pressures	Nuclear waste; inert gas emissions; landscape: more high-voltage lines	CO_2 emissions; air pollution; leakages; solid waste	Landscape and land-use impact (mainly hydro/bio)
Sustainability	Critical (will fusion deliver? And if yes: how?)	Climate change Exhaustion of premium sources	Global and eternal[*]

[a] Renewable sources concentrated by nature such as rainfall in mountainous areas (hydro) or such as biomass are unevenly distributed and limited in sustainable supply. There is also competition for other end-uses (irrigation; food and fibre production).

Table 2
Evaluation of nuclear power on the criteria of sustainable backstop supply technology

Criteria	Nuclear power performance
Unlimited	Nuclear power on earth can be considered as an unlimited resource only when fusion will be technically, economically and safely possible. The second best unlimited nuclear source (breeders) has failed the practical tests. The once-through use of uranium in fission processes will exhaust the easy recoverable uranium concentrations (IEA, 2006a, pp.134, 242).
Democratic decided	Nuclear technology and the nuclear fuel cycle require secrecy and protection against intruders. Nuclear material can be abused for state or private terrorism (Cornelis and Eggermont, 2006). Decision-making on nuclear projects is mostly of the DAD type (Decide–Announce–Defend). Citizens are considered not to 'understand' such complex technologies and their fortunes. This is opposed to the minimum requirements of procedural fairness where those directly affected by the decisions must have a voice and representation in the process (Brown and Tuana et al., 2006).
Globally accessible	The huge capital and technology intensity of the nuclear option makes this option inaccessible for many developing economies.[a] In addition, proliferation of know-how and nuclear capabilities creates a more dangerous world than the containment and reduction of its spreading, and finally the banning of the nuclear technology in all uses but the medical ones.
Environmental benign	Nuclear fission is a carbon-free process. Other emissions (inert gases) in the air are not as massive and diverse as emissions from fossil fuel combustion. Release of radioactive isotopes is the most significant source of contamination; massive releases happen in case of accidents.
Low risk	Given the probability of accidents, and given the—from a human perspective—eternal lifetime of radioactive waste, nuclear power is not without risks. Some will consider the risks as minor, some as huge. Risk perception and assessment are circumstantial and personal matters that are difficult to define, measure and compare (Shrader-Frechette, 1991). Therefore one could call upon societal risk processing institutions and procedures, i.e. the insurance sector. However, given that the risks of nuclear accidents and the eternal horizon of nuclear waste fall out of the range accepted by experienced professional underwriters, it is false to argue that the societal risks of nuclear power are minor, and should be accepted by the lay people of present and future generations.
Affordable	"Safe" nuclear power is too costly to build and operate. When societies accept particular kinds and levels of risks and the wheel of fortune is benevolent, large amounts of nuclear power can be generated at affordable monetary spending (see France over the last decades). The presented accounts however neglect the externality costs of major accidents and of the eternal concern for the high-level waste. Our instruments to gauge and assess such externality costs fall short. Up to now this is used as a validation that the costs are low, but in fact is an extra argument to adopt a precautionary attitude and policy.

[a] A reviewer pointed to the development of nuclear power in China and India these days. Although this remark is right, a full evaluation of nuclear power development in all developing nations (Brazil, Indonesia, South Africa, Iran, etc.) would require a new paper. Also it may be early days to assess the performance of China's and India's programmes.

other renewable power resources (wave, tidal, wind, small hydro, biomass) experience similar setbacks.

A vast majority of people accept the role of renewable sources as the long-term backstop (Turkenburg, 2004; Eurobarometer, 2007).

However, the backstop property of being unlimited is reserved to only a subclass of the renewable sources. The concentrated renewable sources (hydro, biomass) are limited in supply on this finite earth, and their use is competitive to other ends.

The unlimited sources are provided as flows from the sun (light, heat, wind). These flows are known to be diffuse, fluctuating, intermittent, sometimes non- or badly predictable. Collection and conversion of the flows require significant investments, and because they are not available at command, they need feed-forward control (Twidell and Weir, 2006, pp. 10–15), storage facilities, and make-up and back-up power supplies delivered by other capacities (in the coming decades mostly natural gas-fired). The total system costs of an almost complete renewable power

Table 3
Evaluation of renewable electricity sources on the criteria of sustainable backstop supply technology

Criteria	Renewable electricity sources performance
Unlimited	Renewable energy supplies are global and eternal when derived directly from the available natural flows (solar radiation, light, wind, currents). Hydro and biomass sources for electricity supply are more limited mainly because of competition with other ends (nature conservation, water supply, food production, preserving living areas, conversion to transport fuels, etc.). Because renewable energy can be deployed economically only in an energy economy that is a few times more efficient than the present one, the unlimited character is strengthened.
Democratic decided	More than half of the renewable electricity generation is to be developed in a distributed way. A large part of this can be invested and owned by end-users or by cooperatives of end-users. The power of centralized units will decrease, and so will the nuclear secrecy. The basic principles of procedural fairness are respected (Brown and Tuana et al., 2006).
Globally accessible	Renewable energy is available all over the globe. Some regions have more luck with some sources, and other regions with other sources. The scale, complexity, diversity, security, safety, of renewable energy technologies make them accessible for all people in the world. The poorest areas in the world (Africa, Latin America, Asia) own vast and diverse renewable resources, and they can develop their entire electricity sector based exclusively on renewable technologies, when the industrialized world converts to the efficiency/renewable energy option, and develops the efficiency and renewable technologies of the future.
Environmental benign	Except for large-scale hydro and non-sustainable biomass, the environmental impacts of renewable energy are minor. The additional impact is none or very low when the renewable energy technologies are integrated in other human activities, e.g. rooftop solar, wind turbines in industrial areas.
Low risk	Except for large-scale hydro and non-sustainable biomass (that could be aggravated by genetic modification techniques), the risks of renewable energy are low and manageable by the human species.
Affordable	The wealthy societies of the world can afford the development and full implementation of renewable energy sources. True that people and societies addicted to faulty low-priced fossil fuels and nuclear power (rolling of the high externality costs) are reluctant to start the transition and conversion to a sustainable energy system. The transition is significant because the four basic change processes of a sustainable development are involved (WCED, 1987, p. 46). But this transition is affordable, much more affordable than business-as-usual (Stern review, 2006). Nevertheless, expressed in present references to availability and prices, the affordability of an almost full transition to renewable power sources is subject of concern.

sector are therefore significantly higher than what we are used to since decades. Our societies are now flooded with under-priced non-sustainable energy deliveries with rolling-off the high bill in externalities to the future (and to the poorer areas of the world). The *full phasing-out of cheaply priced fossil fuels* will increase the market prices of investment goods and services in the economy, as also the prices of constructing, placing and operating renewable energy installations.

When, in addition, renewable sources must take care also of ancillary services in a continuous supply of power, the price of the average kWh delivered by a full renewable system will remain at the higher end. The renewable economy will be clean but not cheap, although some studies suggest more optimistic futures (Lovins et al., 2002; EREC and GREENPEACE, 2007; Johansson and Turkenburg, 2004; Wagner and Sathaye, 2006; Uyterlinde et al., 2007).

4. Nuclear and renewable power are opposites

Nuclear advocates today have changed their communication strategy. Presently, the basic position is "nuclear power is but part of the solution; but there is no solution without nuclear power". This is more acceptable to a broader audience than the pre-Chernobyl vantage of nuclear power resolving the energy scarcity. A minority EU citizenship supports nuclear power to be a valid option (Eurobarometer, 2007). People considering nuclear still as an acceptable option state that nuclear has to arrive after the maximum efficiency and deployment of renewable power is accomplished (Turkenburg, 2004). Therefore, it is crucial for nuclear advocates to solicit a marriage with efficiency and renewable power players at the table (Fig. 2), and to argue the compatibility of a joint nuclear and renewable future. Try to forget the past when nuclear power obstructed the path to a sustainable energy future (Lovins, 1976; Hennicke et al., 1985; Hennicke, 2004).

In a sequence of arguments, this section shows that the marriage of efficiency/renewable power with nuclear power can bring neither luck nor healthy offspring. First (Section 4.1) it is highlighted that nuclear development is just "Business-as-usual" that started in the 1950s, and is contrary to the drastic change of course that efficiency/renewable power has to force. Next (Section 4.2) the two antagonists compete for the fossil fuel add-on, but requested plants differ in scale and location. It follows (Section 4.3) that the power grid to accommodate the opposite options has different characteristics. On the sustainability yardstick, nuclear and efficiency/renewable power are extremes (Section 3) and Section 4.4 rephrases that a risk-rational attitude towards nuclear equals the total ban on that technology. Is a technology without future an attractive partner? The full divergence between both options requires also other priorities in research funding and in prioritizing production capacities (Section 4.5). Once the technology, economy and society have made the turn towards a sustainable energy future by giving real and full priority to the sustainable options, it will become obvious with every passing day that there is no empty place for nuclear left over.

4.1. *Nuclear power is part of "business-as-usual"*

Earth's life-support systems (climate, biodiversity, fresh water supplies, clean air, and soil fertility) are endangered by the "business-as-usual" production and consumption systems running on non-sustainable energy supplies (fossil fuels, nuclear power, excessive biomass and hydro harvesting). The damages to the environment and to natural balances caused by the extent and the way of energy use are now the subject of public and political concern. However, the total effects of the energy obesity on the way production and consumption systems have mushroomed are much less documented but reduced to a believer's credo: "more and more commercial energy is needed for well-being".

Since its early days, nuclear power has been intertwined with this credo. The 1950–1960s was the first wave of civil nuclear development with the relentless belief in $E = mc^2$ and the promise of nuclear power—clean and abundant—"too cheap to meter". The dream ended in the conviction of several prominent developers as "too dangerous to go on with it" (David Freeman[5]). The first take-off of nuclear power would not have been flying very high or very far, but was saved by the oil crises in the 1970s. The second wave of civil nuclear expansion pushed the technology to its maximum growth in a few countries such as France, Belgium, Sweden, Japan, USSR, and USA to a lesser degree. The second wave drowned in nuclear accidents (Three Miles Island, USA, 1979, and mainly Chernobyl, USSR, 1986) and in poor competitiveness compared to large-scale, low-priced coal plants and to upcoming more efficient Combined Cycle Gas Turbine plants. More importantly, energy end-users reacted on the higher energy prices (1973, 1979) with a first effort in energy efficiency that curtailed the expansive plans in energy supplies. Nuclear projects in a few developing countries (e.g. Indonesia, Brazil, Iran) led to draws on their balance of payments. The second relief of civil nuclear power was impeded by unresolved major problems such as the management of nuclear waste, the non-delivery of next-generation technologies (breeders, fusion), and the proliferation of nuclear know-how and weaponry.

Climate change is now exploited by nuclear power advocates for organizing a third wave, however, falling back on the same promises—once again—of better technologies and of final solutions to unsolvable problems. Pleas for return to the pre-Chernobyl catastrophe (1986) era are based on the sophist logic:

1. Nuclear power is acceptable because nuclear experts state the risks are minor. "Public acceptance problems related to nuclear weapons proliferation, waste management and safety issues" are considered as "barriers" to overcome (IEA, 2006a, p.134).
2. Because nuclear experts state the risks are negligible, the external costs are low (Externe-E assesses human health-related risks of a hypothetical plant case as representative for nuclear external costs)
3. When the risks and external costs are low, nuclear is competitive.
4. Because the nuclear mirage is cheap, efficiency is not attractive and renewable power is not competitive.
5. For gaining public support, let us spend some lip service to efficiency and renewable energy options, but do away with nuclear phase-out and open the locks for the nuclear third wave (CE2030, 2006).

The myths of nuclear power as cheap and abundant (first wave), as solution for the oil crisis (second wave), as salvation against climate change (third wave, brought in position today), do not stand the test of reality and of the sustainability criteria (Table 2).

On the diagnosis of the life-support system crisis, occasioned mainly by the over-use of commercial energy sources, nuclear and efficiency/renewable power diverge in opinion. As a corollary, their basic prescriptions/remedies for the obese energy patient diverge: nuclear power expansion is the continuation/extension of supplying overdoses, while efficiency/renewable power is the remedy for past and present obesity by a healthy diet with an adapted programme of exercising. I miss the imagination to see what the goal and meaning can be of combining fat and sugar bulk food with a cure of healthy dieting. When such combining takes place, the effects are mostly clear: obesity overcrowds health, because the former is bulky and uncontrolled and the latter requires understanding, self-control and permanent monitoring. The bulky approach of the past is not fitted to develop the slim and lean solutions of the future, efficiency and renewable energy need.

Although nuclear power is advertised as cheap, IEA identifies as the second barrier nuclear plans face, following public acceptance, that 'investment costs based on current technology (including working capital during the construction period, waste treatment and decommissioning) are high' (IEA, 2006a, p. 134). 'Capital cost reduction can be achieved through improved construction methods, reduced construction time, design improvement, standardization, building multiple units on the same site and improving project management' (IEA, 2006a, p. 242). 'Serial production (red.: of the Gen III+1700 MW plants) may enable further cost reductions' (IEA, 2006a, p. 134). "Large scale, serial production, multiple units on the same site" were the success factors of the French nuclear programme of the 1970–1980s that finally jammed in the overcapacity of the 1990s. Every success factor also implies its own risk: the loss of a single large-scale unit is a high loss, serial production often is beset by serial faults and multiple units on the same site can cause domino effects (see the loss of the four units at Chernobyl). But it is not our task to think in nuclear logic. Our point is that this expansive approach is contradictory to the essential attributes the new energy policy must adopt: lean, efficient, flexible and adaptive. The over-supply of commercial energy during the last decades has turned our economies and societies in energy-addicted, obese patients. It has put our development on a non-sustainable track with looming climate change and nuclear risks at the horizon. Continuing this "business-as-usual" is a one-way ticket to catastrophe.

4.2. *Fossil fuel as add-on to nuclear or to renewable power?*

The prominent argument for nuclear power to regain support for a third time is the "saving of fossil fuels" and "reduced carbon dioxide emissions". The argument that a massive nuclear expansion at the end substitutes for fossil fuel consumption needs investigation. When nuclear power is stapling up a massive power base load (60–75% of the load area), the remainder of the loads (25–40%) has to be covered by flexible central power technologies such as fossil fuel or biomass-fired plants or dam hydro. Hydro sites can be adapted or constructed artificially for pumped storage (the two-way conversion of pumping and turbo-generation requires about 30% of the gross power input of the process). The availability of suitable hydro sites and sufficient biomass sources is not guaranteed for an expansive nuclear scenario. The highly capital-intensive hydro plants as ancillary for back-up and make-up services are part of the bill. The high capital costs , however, stimulate hydro operators to maximize their running hours (depending on water availability) and thus compete with nuclear for covering the base load. Less-capital-intensive capacities that are more flexible to locate (for grid balancing, e.g. reactive power) and that are firing fossil fuels being easy to store or convey, mostly supply ancillary services in an integrated power system. When the loads increase, more fossil fuels are required. Burning e.g. natural

[5] David Freeman was CEO of the largest US power utility (Tennessee Valley Authority) in the 1960s, spearheading the development of nuclear power. The Browns Ferry incident (seconds away from a melt-down) made of Freeman a lifetime opponent of nuclear power and an advocate of alternative solutions. He chaired the Ford Foundation project "A Time to Choose" (Freeman, 1974). We met at the advisory panel of scientists to the EBRD, US State Department and EU Commission on the closure of the Chernobyl plants in 1996–1997, under the leadership of J. Surrey (SPRU, UK) (Surrey et al., 1997).

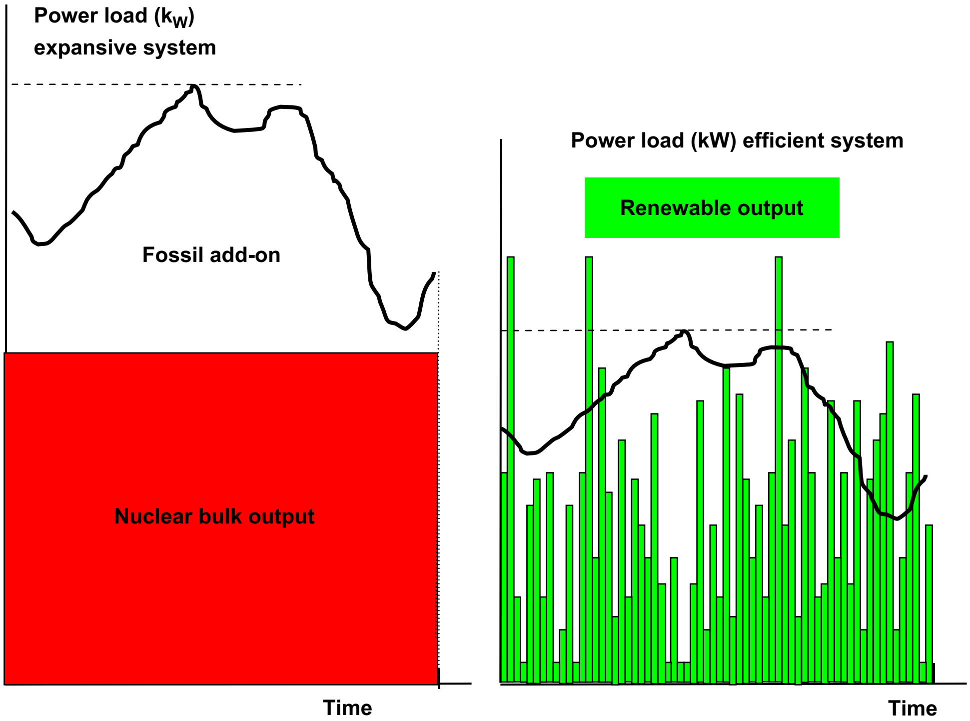

Fig. 3. Fossil add-on to nuclear bulk output versus the fluctuating renewable power.

gas centrally for nuclear power add-on rather than in a distributed cogeneration plant (competing as must-run on heat demand with base-load nuclear generation) results in a higher total CO_2 output.

A more futuristic approach would be the serial construction of nuclear power plants running permanently at full load and directing surplus capacity (what the grid cannot absorb) to hydrogen generation. The direct way of electrolysis is unlikely due to high infrastructure costs and low efficiencies. Obtaining hydrogen by thermo-chemical conversion requires high-temperature reactors not commercially deployed so far. As in the past, the expansion of the nuclear option falls back on the availability of fuel-fired power stations (mostly almost depreciated plants pushed up in the merit order).

A power system that champions the double, threefold, fourfold, … expansion of its sustainable size (because being driven by the large-scale, serial, multiple units nuclear construction gigantism) burns at the end more fossil fuels than a lean and efficient, decentralized system based on maximum efficiency and the maximum recourse to renewable sources.

In the transition to an almost complete renewable electricity sector consisting of a large degree of decentralized intermittent sources, flexible technologies running on command are needed. For a long time to come, fossil fuels (natural gas) will be serving as support, make-up and back-up power suppliers. Although this may sound similar as for nuclear power, the actual implementation is very different. This is shown in Fig. 3. The left panel of Fig. 3 shows the nuclear case that stimulates an expansive power system (almost the present structure in Belgium today). Half or more than half of the power is generated in nuclear base-load stations and the other half (the variable loading) is covered by fossil fuel plants.

A sustainable renewable power-based system is shown in the right panel of Fig. 3. A prerequisite and natural alley[6] of renewable power is efficiency (Verbruggen, 2006). Efficiency reduces demand for electricity by half and more, and although not necessarily in a homothetic way, also capacity demand. Renewable power is offered by nature in a fluctuating and partly unpredictable way. On some occasions the supply exceeds demand, and when export and storage are both unfeasible at that moment, the available power offer is truncated.

At other moments, the shortfall in renewable power must be met by flexible sources. In the medium term, most support will come from fossil fuels. The fossil plants will equal almost the peak capacity of the systems, and consist mainly of flexible technologies that can ramp up and down easily. Their total electric output will be decreasing and hence their fuel consumption. The latter saving is rebounded partly by more ramping that—ceteris paribus—does lower the efficiency (Gross et al., 2006). The fossil power generation technologies for add-on to the fluctuating, varied renewable power technologies should be of a quite different nature (technology, unit sizes, location in the grid) than the fossil plants that add-on to bulk nuclear power. Decentralized cogeneration plants have to contribute too and therefore should be equipped with 'heat rejection' or condensing facilities so they can guarantee their capacity availability.[7]

For the nuclear option the fossil add-on is large and extending (at least never ending), and the more nuclear base-load capacity, the more the fossil add-on has to grow. For the efficiency/renewable power option, the fossil add-on will diminish over time

[6] Reaching high levels of energy efficiency starts with exhausting the opportunities of making use of natural ambient renewable energy (sunlight, ventilation, passive heating and cooling). Minimizing loads paves the way for an affordable renewable energy supply.

[7] Adverse regulations have obstructed the full development of independent, unfettered decentralized cogeneration in various ways (COGEN, 1999). The 2002–2003 draft EU Directives on "promoting" cogeneration had perverse rulings continuing the obstructions, attenuated ultimately in the 2004 version (EU, 2002, 2004; Verbruggen, 2007). Incumbent electric power companies very much engaged in nuclear power were generally most in favour, if not direct inventors, of adverse regulations (Verbruggen, 1990).

because the more the efficiency/renewable power, the lesser fossil fuels are needed. Some estimate that fossil fuels can be phased out as an energy source (it will remain a materials source) by the middle of the century; others forecast a shorter or longer lifetime.

4.3. Electricity grids spread bulk power or interconnect distributed sources?

Related to the different and opposite nature of the power generation aspects of the nuclear and efficiency/renewable power options, comes the discussion of the necessary size and structure of the electricity grids (Lovins et al., 2002; Gallanti, 2007).

A centralized bulky (nuclear and large-fossil expansive) power system has constructed different high- and low-voltage electricity grids than the ones needed for an electric system governed by efficiency, renewable sources and commensurate add-on fossil fuel plants. The bulky system is constructed top-down for pouring out the 1000s MW via 400/360 kV lines to the medium-voltage grids of 20–150 kV, further down the low-voltage distribution grids where consumers are thirsty for ever more. The efficiency/renewable power system starts from the concept that every consumption unit could turn into a production unit (Lovins et al., 2002). In the short run, most consumers will not be ready to adopt such a role, because of lock-in and lack of understanding. In the medium to long run, more efficiency, more use of natural ambient energy and passive technologies, more renewable generation are feasible almost everywhere. Consumers then will become active players, some being also net suppliers of power to the grid during particular moments. Such developments need smart grids that are structured bottom-up with the local markets as components and accommodated for exchanges within and among such local markets, make-up and back-up supplies, storage capacities, etc. This is a significant change in grid development and investment, and it costs billions of € to redesign and overhaul the grids. However, going ahead with energy efficiency will ease some bottlenecks in the existing grids rather soon. More fundamentally, at the watershed between the top-down centralized bulky system on the one hand and the bottom-up, distributed lean system on the other hand, it is important to firmly decide which valley to enter. IEA (2006a, p. 247) states that "Advanced electricity networks and associated technologies will form the backbone of the 21st century energy system", and that "Most of today's systems are based on technology from the 1950s and require substantial upgrading." Investments are due. It is crucial that scarce resources are not invested and locked in an obsolete past but spent on the solutions for tomorrow.

4.4. Risks and externalities of the nuclear option

Studies that try to assess the impact of a nuclear accident in DOEL (a nuclear site in Belgium at 16 km distance from the city centre of Antwerp and within the dense industrial maritime zone of the Port of Antwerp) give up because effects and impacts exceed the circumspection of imagination and the tools for dealing with the conceptual, ethical and measurement issues are lacking.

Notwithstanding the fact that the nuclear spur has consumed the lion's share of energy RD&D resources in the world since WWII (see Section 4.5; Fig. 5), influential lobby's want to continue (and extend) that support. "Continued technology development (Gen IV) and demonstration programmes could help overcome the barriers facing nuclear generation, of which the most important is public acceptance" (IEA, 2006a, p. 134; also pp. 239, 243). On the same page 134 the latter barrier is

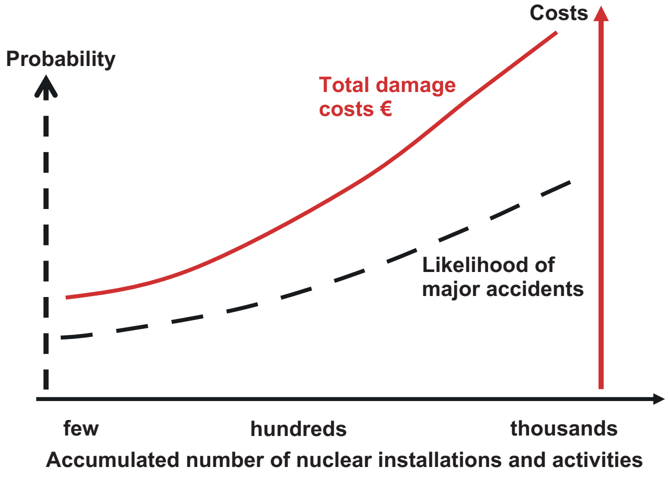

Fig. 4. Likelihood of major accidents and total damage costs of an accident; both are increasing when more nuclear installations and activities proliferate.

defined: "Public acceptance problems related to nuclear weapons proliferation, waste management and safety issues". Or in IEA terms: not the nuclear sector has to prevent or solve the problems but the public has to learn to accept them. This is the world upside-down and it conflicts with basic principles of law and ethics.

For addressing complex, irreversible and uncertain issues, the precautionary principle has been defined (Harremoës et al., 2002). It provides guidance in the field of nuclear decision-making because 'where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to anticipate, prevent and minimize the causes' (UN, 1992, Art.3). In addition no country, nor private company, has the right to take action or to refuse to take action that leads to endanger other's life, health or security (Brown and Tuana et al., 2006, p. 30). The precautionary principle implies the phase-out of nuclear power, the sooner the better, and a fortiori no further spending on new nuclear power.

In the meantime, governments could enforce the 'precautionary polluter pays principle' (Daly, 1999) on the nuclear sector (1) by ending immediately all subsidies (also in RD&D) to the technology (Froggatt, 2005), and (2) by requiring that the ones who undertake nuclear activities create enough funds to offset and mitigate the full cost of the effects and impacts their enterprising can imply. For this, they should call upon the vested private underwriters to insure their nuclear activities at full indemnity. The insurance sector is, since Adam Smith, the most respectable capitalist institute that balances risks for society and for itself properly. When the nuclear advocates speak true that the risks are negligible and should be accepted by the public, the insurance sector certainly will be happy to share in this lucky jackpot by cashing in on a nice premium for a negligible risk. But in reality, the insurance sector is not willing to put their own survival in balance and refuses the full indemnity insurance of nuclear activities.

The externality costs due to climate change are now the subject of extensive study (IPCC, 2007; Stern, 2006) and media focus (Al Gore: The Inconvenient Truth). The externality costs of nuclear power are of a different origin and kind, and are not well studied. The formal assessments of the nuclear externalities (e.g. EXTERNE-E) lack credibility, being not comprehensive, leading to results far below realism, similar as it was (and still is) regarding the costs of climate change damages (Krewitt, 2002; Stirling, 1997).

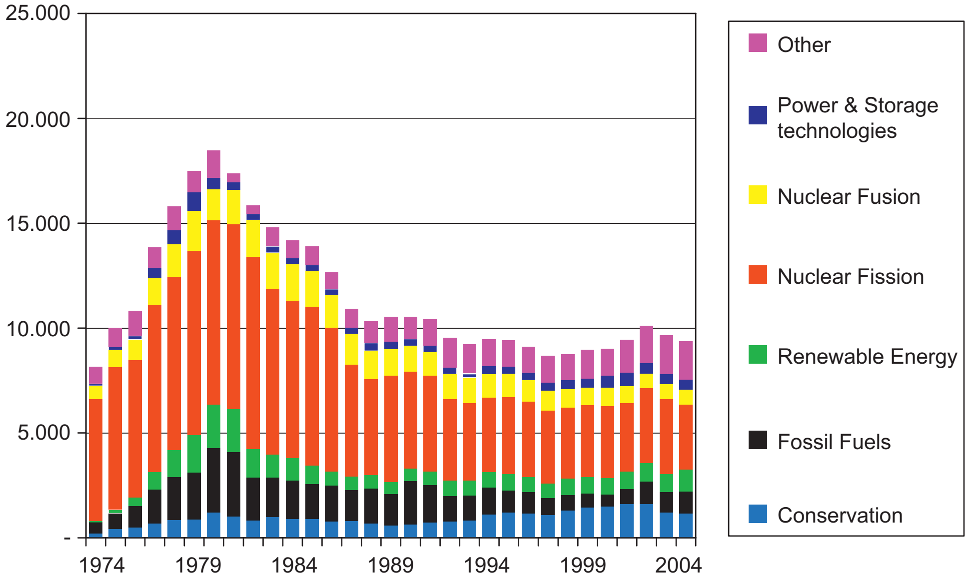

Fig. 5. Public RD&D funding in IEA countries in Mio US 2004 MER prices.

There is no full catalogue from all perspectives (moral, psychological, social, political, economic, financial, military, etc.) of the damaging issues the nuclear option involves. The evaluation of the external costs is centred on a model that assesses the health costs of a theoretical accident on some theoretical site in a theoretical environment. A much fuller catalogue should encompass such issues as the financial-economic costs of a forced immediate shut-down of all nuclear activities when a major accident in a EU member state would develop, over a realistic assessment of the extent and effects of nuclear weapon proliferation when the nuclear technology is given a third chance, up to the bequest value of nuclear waste and waste sites loaded on all generations, also the ones beyond the horizon of human imagination.

Drafting a comprehensive catalogue and in addition assessing the possible effects and impacts, and evaluating all these, require a far broader approach than the narrow engineering-economic publications reveal. Standard tools of cost–benefit analysis and discounting fall short for addressing such issues and for providing useful answers (Stirling, 1997, 1999; Arrow et al., 1996; Portney and Weyant, 1999).

As in the case of climate change, there is evidence about the convex growth of the externality costs even when uncertainty about numbers cannot be resolved. Fig. 4 shows two curves that grow steeply with the expansion of nuclear installations and the number of sites. The bottom curve expresses the likelihood of major nuclear accidents when more and more countries would engage in nuclear activities and the number of installations grows. The probability that somewhere a major accident occurs is increasing faster than linearly, also because less-acquainted countries will enter the nuclear area. The damage costs follow a steeper pattern because of the collateral damage triggered by a single accident on the other nuclear activities.

Combining the two factors (probability and consequences) into a single risk measure (Covello and Merkhofer, 1993), and applying the standards of risk acceptability, the combination of a non-negligible and growing likelihood with the immeasurable high damages of a major nuclear accident or nuclear warfare, will conclude that nuclear power falls into the non-acceptable domain of human enterprising.

While the impacts of nuclear technologies, their failures and abuses, can have devastating consequences of similar size and irreversibility as climate change impacts, there are important differences between both challenges that make public understanding and policy reactions different.

Carbon emission sources are continuous and numerous, globally spread and controlled by billions of decision-makers. Also the various effects are building up continuously, globally spread and fall—although unevenly—yet on all people on earth.

Nuclear technologies and sources are concentrated and controlled by a few (and for security and safety reasons the few should become fewer and preferably zero), and the most harmful effects are punctual in time with effects spreading unpredictably from the point of impact (accidents, nuclear bombs). Risk assessment of the nuclear option is more extreme than risk assessment of climate change damages. The probabilities of particular events are smaller but the consequences of one single event are more catastrophic. One can learn from accidents, near-accidents and incidents that happened and continue to happen. Although the learning processes are not well structured and characterized by opposite interpretations (nuclear advocates versus nuclear critics), a majority of the public evaluates nuclear risks higher than the benefits delivered by the power output of nuclear plants (Turkenburg, 2004; Eurobarometer, 2007). Nuclear advocates call this attitude 'barriers' of public acceptance (IEA, 2006a, p. 134) and the nuclear sector invested and invests lots of money to convince the public and politicians to change their mind and balloting.

But who is the risk irrational?

People are accustomed to assessing and evaluating risks, and with allocating resources for minimizing personal harm risks may occasion to them. The state also helps the overall constituency follows a risk-neutral or risk-averse path (e.g. mandatory car insurance; mandatory contribution for insuring against natural disasters). In underwriting fire/damage insurance for a house or other property, one voluntary accepts a yearly payment to a company and hopes that the company never will have to pay money back (because the psychological loss of losing its home and personal belongings in a fire is much higher than the cash redemption received). The expected monetary value of this risk assessment, risk evaluation and risk management process is negative for all clients of the insurance companies. Yet almost all the clients are willing to pay the risk premium.

The attitude of the citizens rejecting nuclear as a viable option is based on the rational logic of willing to accept a small monetary loss year after year (foregoing nuclear electricity that is cheaply priced[8]) to avoid the harsh consequences of an eventual nuclear catastrophe. This is perfectly rational behaviour where self-declared rationalists who want to remove such barriers (IEA, 2006a, p. 134) should learn from.

When the common good of a society necessitates that all members of the society underwrite insurance, insurance should be mandatory. This occurs when individual members of a community can impose significant risks and actual harm on other members. Undertaking nuclear activities and emitting greenhouse gases are such cases. The mandatory insurance in case of nuclear is most efficiently organized by the stop on new nuclear activities (as e.g. the ban on stratospheric ozone depletion substances—Montreal Protocol). For existing and phasing-out nuclear activities, full indemnity insurance should be paid by the beneficiaries of the financial returns of such activities. In case of greenhouse gas emissions, the insurance premium has to be designed in a way that every emitting activity pays according to its share in total emissions.

Nuclear power is better brought to an end; efficiency/renewable power starts their infancy. Although marriages between such partners exceptionally happen, their long-term future is not bright.

4.5. RD&D and production capacities: urgent and drastic changes needed

The critics on the limited deployment and on the poor performance of renewable energy in the oversized and overweighed today's commercial energy system should take the responsibility of this deplorable situation, because they are the people who absorbed and squandered the RD&D money and who have deformed and occupied the energy technology departments. The other point of criticism, i.e. the shortfall in manufacturing capacities for deploying the renewable energy options in due time, is of an analogous offspring and liability. It is high time to change course and focus on the technologies of the future: efficiency/renewable power. Also, here the nuclear and renewable options are antagonists.

About 50 years ago nuclear was a new technology for boiling water. It became clear that it is a very cumbersome, dangerous and costly way of boiling water (Caldicott, 2006). Today nuclear technology is not innovative, and the pep talk about 'new' nuclear generations III+, IV, V cannot cover the repetitive shortfalls between promised breakthroughs and the actual rusty state of nuclear technological development.

The actual new technologies of today and of the future are of a different nature than nuclear implies: small, mini, micro, nano-scaled, intelligent driven in continuous time, light-weighted, adaptive and flexible. Efficiency and renewable power both surf on and benefit from every step forward in the new technologies. The train is gaining speed and every citizen, organization and country should try not to miss it.

In the first decades after WWII, science and research on energy was devoted almost exclusively on nuclear power development in some industrialized nations, e.g. Belgium (Laes et al., 2004). No single technology in history, other than nuclear, has ever obtained such a quantity of subsidies and of support by the scientific, political, financial, industrial, interests.

The oil crises of the 1970s have added other energy options to the RD&D portfolio but nuclear power continued dominating the absorption of the RD&D funding (Fig. 5) (IEA, 2006b). In the planning of public RD&D budgets for the coming years, nuclear remains the single most funded technology in the energy world, and additional long-range proposals are there to continue to absorb the lion's share of the public energy RD&D money (IEA, 2006a, pp. 233–246). While huge funds spent on nuclear fusion have fallen into oblivion because the research does not deliver except for new promises, the main industrial countries continue to pour money in it. ''Because of the potential benefits of fusion, very high shares of IEA countries' energy R&D budgets are allocated to researching its feasibility and potential. It is not likely to be deployed until at least 2050'' (IEA, 2006a, p. 246). It is high time to better scrutinize the un-hold promises and the allocation of RD&D funds.

5. Conclusion

For realizing a low carbon electricity supply, there are not a thousand options. Only two antagonists are now in the ring: nuclear power and the twin efficiency/renewable power. What could be the ultimate backstop power generation technology? First the 'unlimited source' aspect of the backstop supply technology has to be extended with the criteria of sustainability (WCED, 1987). On the sustainability balance, the performance of nuclear power weighs very light (Table 2), contrary to efficiency/renewable power technologies (Table 3). Therefore it is quite rational that a large majority of the population prefers the latter above the former (Eurobarometer, 2007). For getting a third chance for nuclear power, its advocates want to arrange a marriage with the renewable energy sector.

There are five arguments as to why the efficiency/renewable power option should reject the nuclear advances. First, nuclear power is architect of the business-as-usual that has to be changed urgently and drastically. Second, nuclear and renewable power need a very different add-on by fossil-fuelled power plants; for nuclear the add-on is bulky and expansive, and for renewable power it is distributed, flexible and contracting over time. Third, the power grids for spreading bulky nuclear outputs are of another kind than the interconnection between millions of distributed power sources requires. Fourth, the risks and externalities of nuclear power make this technology non-sustainable and therefore without a future, while efficiency/renewable power are still in their infancy. Fifth, the antagonist options also fight for RD&D resources and for production capacities. Now that the skewed distribution in favour of nuclear starts to be adjusted somewhat, it is time to stop wasting money on the expensive and dangerous water cookers that nuclear reactors are. Better to turn to the real future-oriented technologies that drive efficiency and renewable power.

Summarizing, nuclear and efficiency/renewable power have no common future in safeguarding ''Our Common Future''. The nuclear technology has had two chances of unseen means in human history to prove its validity, and failed. Giving nuclear a third chance will waste the scarce RD&D resources and solidify barriers against its sustainable antagonist: electricity efficiency and renewable power technologies.

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[8] Cheaply priced is not the same as low cost. As with fossil fuel use, the real externality costs are underestimated and rolled of on the future.

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