

## The overall energy issue; a bird's eye view

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### 1. Introduction; the importance of a sound energy provision

Although we do not seem to bother too much about it in our daily activities, a *reliable, clean and affordable* energy provision will be one of the major challenges of the 21-st century. Without being too pessimistic, we have to point out that simple “solutions” are not evident, because there are sometimes quite opposing desires, requirements and boundary conditions to be fulfilled. The energy issue has its impact all over the world; in some locations it seems somewhat better because those regions possess “easy” (read, fossil) energy sources, but globally speaking, it will be difficult for everybody. Since in Europe, we do not have any energy sources to speak of at our disposal, the challenge will be considerable. However, because of other constraints, the challenge for other regions will also be non-negligible.

Almost any activity requires energy. *Energy* is the life blood of every economy, whether already developed or still developing. Everything is “permeated” by energy: humans, the fauna, the flora, society. There is nothing that moves or changes, that grows or decays, without using energy. We use energy for all kinds of physico-chemical thermal processes, for heating and cooling, to have lighting, for drive power for industrial applications and for transport, to use modern communication means, and much more. To give an idea of the importance of energy for society, it suffices to turn back the clock by a few hundred years. That “good old time” was characterized by a questionable standard of living: many labor activities were based on human muscular strength, often even resulting in slave labor; much time was spent on finding wood for heating and cooking. Transport and communication were, measured by today's standards, very limited or even non-existing. All this was changed in a revolutionary way

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thanks to the discovery of coal and oil, the invention of the thermal engines and electrification.

In this limited contribution, it is not possible to treat all the ins and outs of the entire energy issue. We shall try to reduce it to the most basic essentials by illuminating the different aspects, and thereby displaying the global picture. We shall blow cold and warm at the same time. Indeed, if one takes into account all the complexities of the energy issue, the energy world is seldom black or white. It is indeed the objective to find, within the by nature imposed boundary conditions, the optimal compromise from an energetic-technical, economical and ecological viewpoint.

The present paper will not dwell on numerical “guestimates” or on scenarios for future energy demand, nor on the different sorts of potentials of energy stocks, renewable power flows, etc. Those and related figures can be found in the literature; e.g., (Nakicenovic, 1998 [29]), (Watson, 1996 [35]), (Houghton, 2001 [19]), (McCarty, 2001 [27]), (UNDP, 2000 en 2004 [34]), (IEA, 2001 [20] en 2004 [21]), (CEU, 1996 [5], 2001 [6], 2003 [7] & [8] en 2004 [9]), (BP, 2005 [2]), (IPCC SRES, 2000 [24]). Rather, a credible qualitative case will be made to address the most important elements of the energy issue, not without pointing out the difficulties that must be overcome.

## **2. Present-day perception of the energy issue**

The present-day attitude towards “the importance of energy” is somewhat difficult to pinpoint. The recent past (1970 till now) has shown mixed levels of attention.

After the oil shocks of 1973 and 1979, the word “energy crisis” was in everybody's mind, from the policy makers up to the people at large. Energy conservation was not only preached, but actually implemented; for electric generation purposes, there was a shift from oil to coal and nuclear power.

At the end of the eighties and mostly throughout the nineties of the previous century, oil and gas became so cheap that energy was no longer an issue; it disappeared from the scene. This was the case for the private citizen, for most companies and for effectively all policy makers. Energy conservation measures were not worth the effort; the potential pay-back times were just too long.

Things changed again at the end of 1999. At that time, OPEC spoke again with one voice and imposed oil-production constraints which in turn made the oil prices rise to over 30 \$ a barrel, awakening people from their “hibernation” and making them realize that cheap energy provision should not be taken for granted. Although the economic slowdown at the end of 2000 and the first half of 2001 decreased the pressure somewhat on the demand side, and kept oil and gas prices “reasonable”, the California electricity debacle, the September 11 2001 attacks in New York and Washington, the ENRON scandal, and the blackouts in North America and Italy in 2003 (in August and September 2003, respectively), made many people around the globe aware of the fact that energy security is not guaranteed. Electricity and gasoline or petrol do not automatically come out of the outlet or the pump!

Furthermore, because of all kinds of reasons such as the continuing tensions in the Middle East, with the current “climax” the (second) war in Iraq, the social unrest in Venezuela and Nigeria, the economic boom in countries such as China and India amongst others, the oil prices in 2004-2005 have increased even more, such that many large and small consumers start to feel it in their wallet<sup>10</sup>. Albeit that in this regard, Europe is kind of lucky because it does not feel the whole effect of the price increases due to the rate of exchange between the Euro and the Dollar. Drawing heavily on an oil and gas supply which originates from rather dubious geo-political regions such as the Middle East and the former Soviet Union is now considered as a risky energy policy. The tone towards future energy security is now different; countries are striving more and more for a reduction of imported primary-energy dependence.

The question to ask, however, is how long the present feeling and “alertness” will prevail. Given the fact that humans have a short memory and tend to ignore the lessons from the past, it should not be surprising if, given the absence of major upsets over the next couple of years, we were to become again more sloppy in our energy considerations.

Without any doubt, major “perturbations” are to be expected in the long run. With a large brush, the situation can be painted as follows. As will be demonstrated below, and as is clear from all respectable energy projections,

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<sup>10</sup> Per 10 \$ increase in oil price (during a continued period of time), during the first two years following the price increase, the loss in GDP for the European part of the OECD, will be roughly 0.5%. Inflation would rise by about 0.5% and the unemployment would increase as well. (IEA WEO 2004 [21] en IEA 2004 [22].)

it is expected that world-energy consumption will grow considerably over the next 50 to 100 years. In all probability, the finiteness of oil and gas, and the imbalance between supply and demand as soon as the (Hubbert) peak production will have been reached, may lead to even higher prices. The alleged enhanced greenhouse effect, from its side, puts pressure on the use of fossil sources, and—in a first instance— pushes towards more hydrogenated fuels such as natural gas. The drive towards increased gas use (known as the “dash for gas”) may further increase the prices. On the other hand, there are massive reserves of coal worldwide, so that one can bet on it that these stocks of coal will be used. The possible threat for climate change, then, will require that measures such as carbon capture and sequestration be implemented to avoid carbon-dioxide emissions. These elements will be discussed in detail below.

To curb the demand, on the one hand, and to help supply the required energy, on the other hand, society should emphasize more the use of energy-efficient measures and technologies on the demand side, and develop affordable “alternative”<sup>11</sup> energy-conversion technologies on the supply side. As will be argued below, however, there are many *uncertainties* as to the degree of contribution each of these approaches could offer. After going through all possibilities, it will be clear that society will still need big centralized working horses for base-load electricity generation and will continue to rely for a long time to come on fossil and nuclear sources. As a matter of fact, the massive use of intermittent sources will be helped by a considerable fraction of continuously operating and robust base-load plants, fuelled by more steady sources. Also, the presence of a strongly interconnected electric grid will still be needed for quite some time.

For non-electric carriers, a similar logic holds. Large facilities for resource recovery, transformation (such as refining etc), transport and distribution will still be needed for a long time to come. Although, on the one hand, decentralized energy-conversion technologies (such as boilers for space heating and CHP<sup>12</sup>) will establish or even amplify their position, the supply of fuel will need even larger fuel-transport infrastructures. Special attention is needed here for pipe-line based carriers such as natural gas and hydrogen in the future. In this *decentralized* versus *centralized* “area of tension”, CHP technologies constitute an interesting case in that CHP is usually utilized (and often promoted) for *decentralized electricity* generation, whereas that same

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<sup>11</sup> “Alternative” here simply means other than the “usual” energy technologies. The adjective “alternative” is not necessarily related to “renewable” or “sustainable”, etc.

<sup>12</sup> CHP stands for “Combined Heat and Power”

type of CHP is then often promoted as a *centralized heat source* for district heating.

### **3. Future energy consumption; long-term scenarios**

By means of some very simple considerations, based on the increase of the world population, on the one hand, and on the expected increase of energy demand per capita in the largest part of the world, on the other hand, it is possible to estimate that in the second half of this century, the global energy consumption will be higher by a factor of about ...3...than it is today.

It must be recalled that scenarios are not a prediction of the future; they are merely self-consistent thought exercises (run by a computer) to be able to trace the evolution of certain developments. Scenarios allow the evaluation of the consequences of a set of *hypotheses*. The results are clearly dependent on the hypotheses and if the results of the exercise are unacceptable according to some criteria, then the hypotheses need to be adjusted – and perhaps be turned into rigid boundary conditions. E.g., the fossil-fuel prices for the consumer could be increased through CO<sub>2</sub> - or energy taxes, the Kyoto targets can be imposed on the system, etc. In other words, the future projections made by the different scenarios give us the opportunity to take corrective action now, such that the “predicted” outcome can be avoided or optimized.

It is instructive to consider the basic tendency of two very simple scenarios by SHELL (Shell, 1996 [31]). They give a simple argument to roughly estimate the future energy needs and the challenges to be faced. In a slightly adapted version, we consider the period between 2050 and 2100. (The Shell scenarios take 2060 as focal point). Two different scenarios are dealt with. The first scenario, called “continuing growth” (more or less “business as usual”) *postulates* that the world primary-energy consumption per capita would double by that time. Furthermore, the world population would be roughly double of what it was in 1996. As a consequence, the primary-energy consumption would increase by a factor of four. The second scenario, called “dematerialization” takes an opposite point of view in that it *postulates* a constant world energy consumption per capita. Given the still doubling of the world population, the overall primary-energy consumption would increase by a factor of two. The “postulated” consumption in both cases is in fact a *hypothesis*. Given the present “underdevelopment” of the developing world, an increase of world energy consumption per capita seems justified. A doubling on a world scale is perhaps too bullish. But a

constant consumption per capita is probably likewise unrealistic: indeed, if developing countries get the increase they deserve, that would mean that the industrialized world will have to squeeze the belt quite substantially. Whatever it may be, the fact that primary-energy consumption will probably reach levels of the order of ...3... times the current level, means a serious challenge on the energy-supply side. The dematerialization scenario remains challenging on the supply side, but is in addition very demanding on the demand side. In any case, towards the end of this century, the world will require considerably more primary energy than today.

The scenarios of the IEA in their newest World Energy Outlook (IEA, 2004 [21]), already give a taste of what is out there. In their so-called reference scenario, all policy measures currently on the books have been taken into account; the time horizon is 2030. In the period till 2030, the world primary energy consumption would increase by about 60%. It is also interesting to mention that the global energy intensity (defined as the primary energy consumption per unit gross domestic product) is projected to decrease with 1.4%, while the CO<sub>2</sub> emissions in a world-wide scale would increase by 62% compared to the overall emission level of 2002.

Especially the influence of the developing countries, and then notably China and India, which together make up about one third of the world population and which are currently going through a massive economic expansion, draws attention. *China's* primary energy share would rise from 12% in 2002 to 16% in 2030. With that increase, China alone will be responsible for 1/5 of the increase of primary energy demand. The primary energy demand in *India* is likewise projected to grow substantially, albeit slightly slower than in China. In 2002, the primary energy consumption in India was about 43% of that in China; in 2030, and even with the massive Chinese growth projection, it will still be about 40% of that in China. These two countries will thus be responsible for about 1/3 of the worldwide growth of primary energy by 2030 (effectively in step with their proportion in the world population).

In a so-called “alternative” scenario, planned, expected and “plausible” policy measures have been taken into account. That exercise reflects the likely situation that over the coming 25 years, policy measures will be adapted. According to that more strict scenario, the world primary energy consumption would increase by a “mere” 43% compared to 60% in the base case. The CO<sub>2</sub> emissions would only increase by about 37% between 2002 and 2030 and the global energy intensity would decrease by 1.8%

compared to the 1.5% in the reference scenario. The IEA World Energy Outlook (IEA, 2004 [21]) contains a wealth of information. It is discussed in more detail in the paper by Fatih Birol, further in this issue.

## 4. The challenge for a sound energy provision

### 4.1. Sustainable development

The concept of *sustainable development*, which became well known through the publication of the so-called Brundtland report “Our Common Future” (Brundtlandt, 1987 [3]), actually has many facets and is material for a variety of subtle in-depth considerations by a multitude of human-sciences researchers. (See e.g., Laes, 2005 [26].) In this contribution, we limit ourselves to a rather pragmatic, but therefore not less valuable —because in any case concretely applicable— approach of the concept.

In simple terms, the Brundtland report “defines” sustainable development as “[development that] meets the needs of the present without compromising the ability of future generations to meet their own needs”. Furthermore, the book states a bit further that “[this] requires meeting the basic needs of all and extending to all the opportunity to fulfill their aspirations for a better life”. One therefore notices that this concept has two dimensions, a temporal dimension and a geographic one, the latter addressing the inequality on earth, i.e., especially poverty.

The concept of *sustainable development* can be “filled-in” in several ways. A first route is what one could call the interpretation *in the “narrow sense”*. According to this line of thought, every generation would have to pass on to the next generation as many primary energy resources as they inherited from the previous generation. It should be clear that for every source considered separately, attaining this goal is effectively impossible. It is inevitable that our present generation will exhaust, or at least seriously deplete, the oil and gas resources. It is also clear that our generation will not be able to leave the environment unchanged due to our energy consumption. Further increase of atmospheric CO<sub>2</sub> concentration seems to be inevitable and very likely, some temperature increase will occur, since global warming has probably already started. It seems reasonable to accept that our society will not be able to prevent this global climate change and that we will have to adapt, to try to mitigate and learn to live with the consequences.

However, there is no fundamental reason why *sustainable development*

should be interpreted in the narrow sense. It seems to be more reasonable to advocate a **“broad interpretation”** in the following sense. We therefore refer to the sentences of the Brundtland report quoted earlier. The point is that although sustainable development should offer the same chances and an acceptable level of prosperity and wellbeing to all countries and not just to a select club of the OECD, and that one should “conserve” the environment, now and in the future, that does not mean that everything has to remain status quo. Quite the contrary! It is perfectly well acceptable to incorporate economic and technological development into the concept; sustainable development should not be considered as a static but as a *dynamic* concept. We have to strive for an optimal exploitation of *all* resources (not only the energetic ones), whereby scientific & technical progress and new technological options are being utilized. In that sense, our current generations are allowed to exhaust the existing energy resources as long as we guarantee that the overall prosperity of the next generations has increased and that they no longer need those same resources, because we leave them with a better substitute.

#### **4.2. External cost as a means to sustainability**

In principle, it seems simple to “force” a sustainable energy provision. If one were to succeed in computing the cost of all adverse effects of the energy provision system and one would manage to incorporate those additional costs into the market price, then one could expect that society would “automatically” converge to a sustainable energy provision. This is the issue of ***internalizing the external costs***.

Put quite generally, *external costs* (sometimes called costs “for third parties”) are those “costs” which are made when making available economic goods or services and which are not paid for by the market parties (i.e., the consumers and the producers) and are referred to “third parties”. Often, it concerns costs which are related to environmental degradation and which are being borne by the society at large. Other examples of external costs can be found in the transportation sector through traffic jams and hence a lack of mobility. Still other examples are the so-called back-up costs if a particular electricity generator has to fill in the gap that has been left by a different “producer” when non-controllable generation such as wind energy or solar energy does not deliver. In this last case, it is often said that the European grid has an enormous absorption capacity and that it can easily deal with those fluctuations. This is, however, a misleading way of portraying the situation. It is indeed the case that those fluctuations can be

handled (at least if one does not exaggerate), but it does equally imply that somebody somewhere connected to the grid must increase electricity generation, since otherwise the frequency of the grid would decrease. This is thus an external cost that should actually be borne by that agent who is responsible for it.

The total cost, after the external costs have been appropriately evaluated and incorporated - the latter being called the “internalization” of the external costs - is called the social cost

$$\textit{Social cost} = \textit{private cost} + \textit{external cost}$$

The private cost is the cost component that is usually borne by the market players and that is incorporated in the usual market prices. Internalizing external costs makes goods and services more expensive than thought at first; hence, the market equilibrium will change, and the amount of goods traded will decrease.

To internalize the external costs and to “enforce” them onto the producers and the consumers, one could introduce an external-cost tax which equals the marginal external cost. This tax which would in a first instance be paid by the producers, who would in turn pass it on to the consumers, will in the end benefit society. The biggest part of this tax will be borne by the consumers; the producers can “recover” part of the tax burden via a higher market-equilibrium price.

The computation of the external costs due to emissions or discharges of “pollutants” (such as CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>, radioactive isotopes, etc) is actually - at least in principle - equivalent with the determination of the *Marginal Damage cost, represented by MD*. This marginal damage cost is the extra cost per unit extra discharge of the pollutant. This curve *MD* is usually an increasing function of the amount of emissions; the larger the emission, the bigger the rise in damage. See the curve labeled *MD* in Figure 1.

To decrease the environmental damage cost, one can take measures to diminish the emissions. This could be done by substituting the type of fuel - e.g. from coal to natural gas for electricity generation - or by implementing technological fixes or by using a completely different technology (e.g., more efficient conversion- or production technologies, environmental-technical measures such as exhaust cleaning facilities). In general, these measures are not without cost, and usually these costs increase the further one wants to

reduce the environmental damage. To characterize these costs, one uses the so-called Marginal Abatement cost curve, abbreviated as *MAC*.

As is evident from Figure 1, there are costs related to the emission of undesirable substances, but also to the reduction of them. Economically seen, the most efficient level of emissions is given by the point  $e^*$ , where the marginal damage cost (MD) equals the marginal abatement cost (MAC), equal to  $s$ . Only for that point, the area under the two “triangular” surfaces  $b + c$  is minimal. It is clear that one must look for a compromise between emission and abatement of it. For an emission level larger than  $e^*$ , there is a too large a damage cost for the environment; for an emission level smaller than  $e^*$ , the environmental damage cost is lower, but society (globally seen) has spent too many resources, that could have been allocated more efficiently somewhere else.

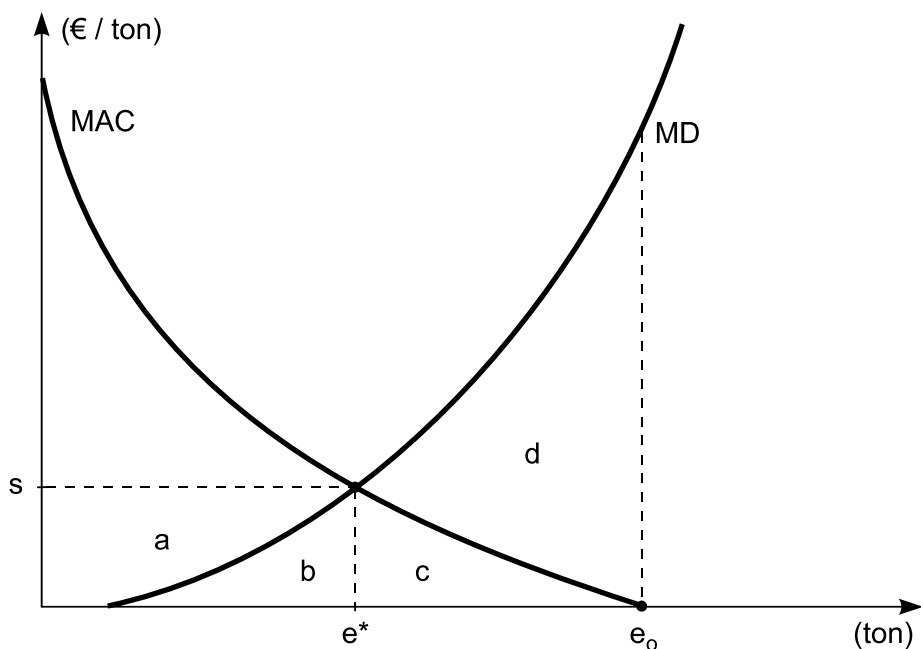
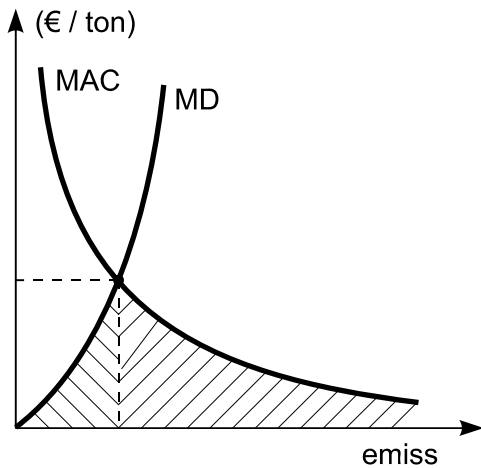
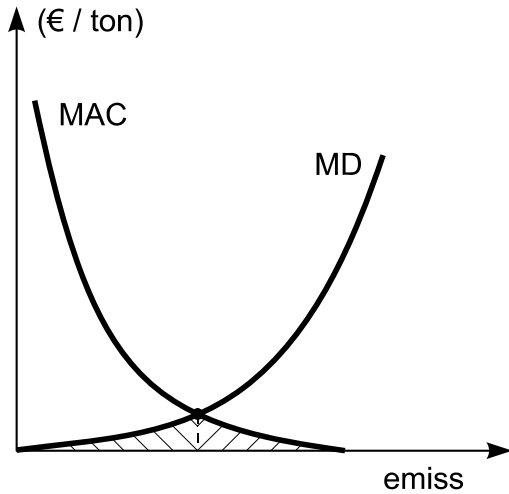


Figure 1. The marginal damage function (MD) and the marginal abatement cost function (MAC) as a function of the emission level of a particular pollutant, expressed in ton. The point  $e^*$  is the most “optimal” emission point, where the marginal abatement cost equals the marginal damage cost, equal to  $s$ . The total cost for society equals the area of the triangular surfaces  $b + c$ .

Both the “optimal” emission level and the total cost strongly depend on the

form of the curves *MD* en *MAC*, which depend in turn on the type of emissions in question. The following examples, borrowed from Field & Field (2002, [14]) and depicted in Figure 2 clearly illustrate this.



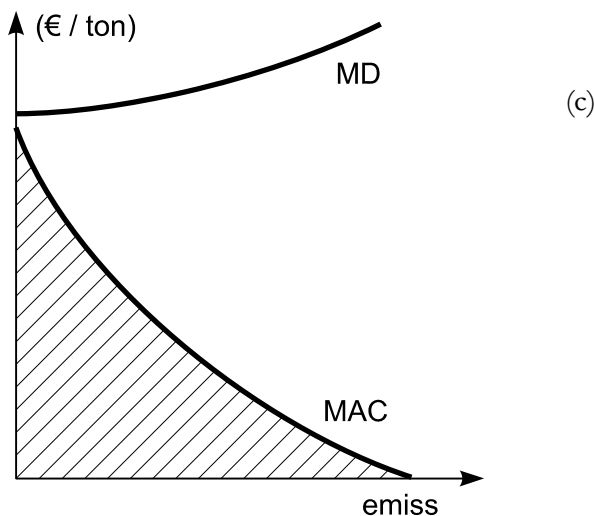


Figure 2. Different (hypothetical) examples of MAC and MD curves and their efficient level of emission. In example (a) the marginal cost (as well as the total cost) is rather small, but the emission level is relatively high. In example (b) on the other hand, the costs are higher, but the emission level is rather small. In example (c), the curves MAC and MD do not intersect such that the optimal level of emissions equals zero, while the total cost equals the total area under the MAC-curve.

The importance of a correct determination of the external costs, and thus the marginal damage cost function *MD* is also evident from the effect of **environmental or emission taxes** (or levies). If only the abatement cost function were known, then the emission level will be determined by the intersection of the *MAC* curve and the height of the tax imposed, as shown in Figure 3.

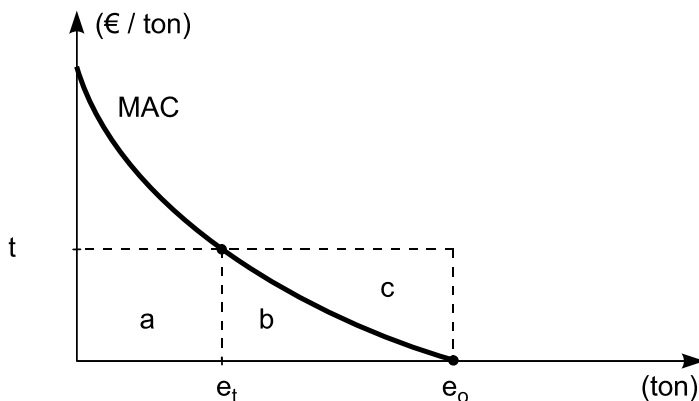


Figure 3. Determination of the emission level *e*, as a consequence of an emission tax, labeled as “*t*”.

For all emission levels  $e > e_t$ , the “polluting” actor (company, sector,...) will take measures to reduce the emissions because the marginal abatement cost is lower than the tax  $t$ . By reducing his emission level from  $e_0$  to  $e_t$ , the actor avoids a total levy cost equal the area (c); the area (b) is the total abatement cost that the actor will spend to reduce his emissions to reach the level  $e_t$ . With the remaining emission level  $e_t$ , the actor will still have to pay a tax equal to the area (a). For this actor, with this MAC curve, it is cheaper to pay the tax rather than to reduce the emissions to a value  $e < e_t$ .

The problem with the situation as depicted in Figure 3 is that it is unknown what is the “optimal” emission level  $e^*$  as determined in Figure 1, and that it is therefore impossible to set the “correct” tax. If the authorities wish to use a levy or tax as an instrument, it is fundamentally important to know the environmental damage function MD and thus the external costs as a function of the emission level.

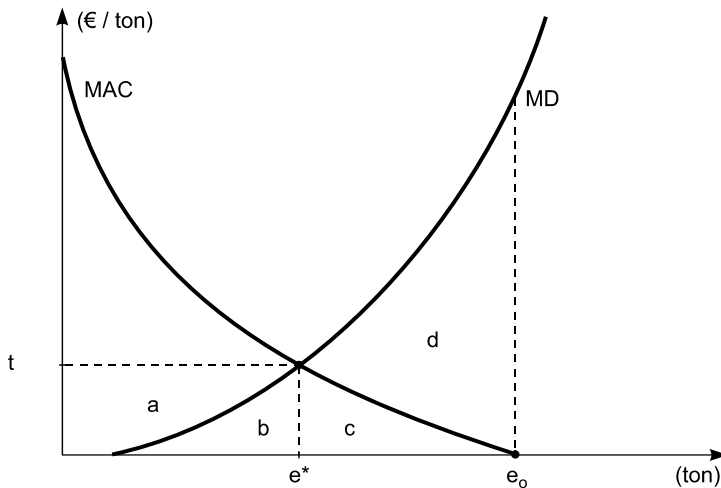


Figure 4. Determination of the efficient level of an environmental tax or levy.

Figure 4 shows that the tax should be set equal to that value where the marginal damage cost equals the marginal abatement cost (compare with Figure 1, hence  $s = t$ ).

For a certain tax equal to  $t$  (€/ton), as shown on the ordinate axis of Figure 4, the polluting actor will now reduce his emissions to the efficient level  $e^*$ . By reducing from  $e_0$  to  $e^*$ , a total environmental cost equal to  $(c+d)$  is avoided. The actor spends a total amount equal to the area (c). For a tax

higher than the one depicted in Figure 4, an emission level  $e < e^*$  will be reached, but as explained above, that would lead to a waste of resources for the society at large (including the actor). Note also that the actor, even if he has reached the efficient emission level  $e^*$ , still will have to pay an amount equal to the area (a+b) of Figure 4. Hence, the amount to be paid is larger than the environmental damage cost, which only amounts to the area (b). This means that such a fixed environmental tax is not a compensation for the damage caused by the remaining emission level  $e^*$ , but that it should be considered as an amount to be paid for the right to use these “environmental resources”. Because that sort of tax can lead to a situation for which the total amount in taxes to be paid is much larger than the damage caused — hence  $(a+b) \gg (b)$  — some people make a plea to introduce a variable levy that is identical to the MD function. In such case, an actor would still strive to reach the level  $e^*$ , but the remaining tax would then “merely” be a compensation for the environmental damage remaining. If the levy would coincide with the MD function, then this levy, which would be incorporated in the sales prices, would correspond to an internalization of the external costs.

#### 4.3. Practical translation of sustainable development: security of supply, affordable and clean energy provision

Hence, although our generation is not able to guarantee sustainability in the narrow sense, it can perfectly well develop new technologies to pass on to the next generations and to share them with the other countries and peoples, so as to guarantee a ***reliable, affordable and clean energy provision***. Indeed, the population has no need for classical energy sources as such, but it wishes to enjoy energy *services* (such as comfortably heated dwellings, the possibility to cool food and beverages, the possibility to travel sufficiently fast to different places, etc). With which energy sources or energy-conversion technologies that happens, is not really of interest to the consumer. The most important thing is that those services are available whenever the customer wishes to call upon them (hence, *reliability*), that this has no side effects for health and environment (e.g., sufficiently *clean*), and that all this is available at an acceptable price level (thus *affordability*).

Establishing an energy provision system that satisfies the broad interpretation of sustainable development is not an easy task and is characterized by a variety of challenges. Generally speaking, the following concrete elements must be pursued:

- avoiding unnecessary waste of energy, and strive for an energy conversion that is as efficient as possible (and reasonable). This aspect stresses energy saving where possible and meaningful;
- ensuring reliable and secure energy supply routes for the future;
- guaranteeing that energy services are provided with a minimum use of scarce resources; i.e., at minimal total cost (internal and external);
- ensuring that the quantity of economically accessible end energy (of whatever form) handed over to the next generation is no less than we inherited;
- limiting the excessive use of slowly renewable energy resources such as biofuels to rates which do not exceed their regeneration rate (including deforestation);
- limiting energy-related pollution and waste flows into the environment to a level for which the absorption capacity of the natural environment is not exceeded; and
- limiting hazards and risks to human health from energy use so that they are below natural hazards and risks and those avoided by the use of energy.

Fortunately, there are many technical options for the necessary energy technologies, and some of them with an interesting potential. Regrettably, though, none is without shortcomings and disadvantages, which has so far prevented their widespread use. These shortcomings will have to be faced and will have to be overcome in the future. To reach sustainability in the broad sense, we will have to:

- demonstrate the practicality and acceptable cost of the *new* energy technologies;
- ameliorate the performance (efficiency, flexibility in use, availability and life time) and reduce the cost of *existing* technologies; and
- ensure that the existing and new energy technologies achieve a high degree of safety and are characterized by a low impact for health and environment.

Because of the future uncertainties for a *clean, reliable and affordable* energy provision, it looks like there is no “silver bullet” and that we will have to keep all options open; it is expected that many energy-conversion technologies can contribute only to a limited extent. We will have to rely on a reasonable mix of fuels and conversion technologies if we wish to reach a sustainable energy-provision system. It is clear that Research & Development will have to play an important role here.

We remark that the notion of **reliable energy provision**, or thus a guaranteed *security of supply*, actually has **two facets**.

First, there is what could be called the **strategic security of supply**. Here, the issue at stake is the availability of sufficient primary *energy* (mostly fossil or nuclear fuels). In this regard, especially those regions that have no or insufficient domestic primary energy sources need to remain alert at all time concerning their strategic energy supply. Especially because of the concentration of most primary sources in the Middle East and the former Soviet Union, geopolitical circumstances could hamper a guaranteed and timely delivery. Although this is no guarantee in the long run, the wisdom of a good housewife can already be of great help: diversify sufficiently and do not put all the eggs in the same basket.

The second aspect is related to the **continued delivery of power**<sup>13</sup>, and this both for supply of electricity (i.e., avoiding black outs) and the guaranteed supply of sufficient gas flow (e.g., if there is a conflict between domestic heating in very cold circumstances and generation of electricity). In this context, sufficient investment in generation and transport capacity (especially peak capacity) is a necessity. In strictly environmentally regulated and liberalized markets, this could give rise to “late” investment actions.

Some reflections on the long-term availability of energy resources and the exhaustion of the fossil energy sources will be addressed below in Section 4.4.

Even if we could dispose of a sufficiently stable guarantee of delivery, even then, the energy provision should be **affordable**. Here, both the prices of the primary sources themselves and the costs for energy-conversion technologies are important. Demand and supply will play a role; it is evident that we will never empty the oil and gas fields until the last drop, but at some point in time, oil and gas will become so expensive that it becomes “unreasonable”<sup>14</sup>; i.e., that they will no longer be used and be replaced by then cheaper alternatives.

At what level the future energy costs will stabilize, is an open question.

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<sup>13</sup> “Power” is considered here as the “flow” of energy; i.e., actually as the time derivative of *energy*. It is not solely related to electric power.

<sup>14</sup> In this sense, but also in the short run because of geopolitical instability and other influences, one should note that security of supply is also coupled with price evolution; one could say that reliable energy provision only holds when “reasonable” prices apply. See further below.

Some reflections on the price levels of primary fuel will be made in Section 4.6.

At last, we come to the issue of a **clean** energy provision. Here, especially aspects such as health, safety and environmentally friendliness request attention. In practice, this means that a sufficient air quality should be guaranteed (which encompasses constraints for the emissions of NO<sub>x</sub>, SO<sub>x</sub>, volatile aromatic substances and very fine dust PM10<sup>15</sup>, and the avoidance of ozone) and that the CO<sub>2</sub> emissions should be decreased. About the radiological aspects of nuclear energy, there exists less of a consensus; while a large part of the population considers everything related to radioactivity rather skeptical and disapproves of it, the majority of knowledgeable experts claiming to rely on rational arguments, put these dangers into perspective and consider them as acceptable.

In fact, the three qualifications mentioned above (**reliable**, **clean** and **affordable**) are not independent of each other and are actually intertwined with each other. In fact, if everything is accounted for “correctly”, these three elements focalize into an *affordable* energy provision. Indeed, the burden for the **environment** also amounts to a cost for society and this should be incorporated into the market price. Dirty or careless energy conversion that leads to a higher burden for the environment will lead to the already mentioned external costs that should be incorporated (i.e., internalized) into the market cost. Likewise, **reliability**, or security of supply, is related to the availability of primary sources and useful end energy. Depending on the amount of primary energy that is physically available and the difficulty of exploitation, of the conversion to useful end energy and of the delivery to the final customer, the price will be accordingly, which then again converges into an *affordable* supply. Moreover, it is a fact that by paying more, one could, on the one hand, utilize cleaner energy-conversion technologies, and/or, on the other hand, one could “buy” a higher security of supply or reliable delivery.

We thus realize that the whole issue of energy provision can be “reduced” to the question of *how much one is willing to pay for it*. Of better still, from a societal viewpoint, *how much should it cost to a society to have a reliable and clean energy provision*.

The overall rationale behind this reasoning is as follows. In the end, we wish

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<sup>15</sup> PM10 is particulate matter with a size smaller than 10 micrometer.

to see a maximization of prosperity for society. Globally seen, everybody benefits from that. Or put differently, if the economy of a particular country underperforms, it will always be the lower part of the societal ladder that “foots the bill”, by compromising on hygiene, on health, on equilibrated nutrition, etc, often with negative consequences for their life expectancy. Therefore, it is of uttermost importance that the economic resources are used appropriately: subsidizing non-cost-effective energy options or prohibiting potentially cost-effective energy technologies, etc does not lead to a judicious spending of the scarce resources and is therefore a wasting. Or still said differently, for a certain spending of financial means, the economically most optimal approach will lead to the best result. In terms of e.g., possible harmful consequences for the environment, this means that we will have the lowest amount of damage (or the largest avoidance of discharge or emission) for a given spending.

To focalize our thoughts and to illustrate the concepts discussed above, we now consider some relevant subjects such as the issue of finiteness of fossil resources, the enhanced greenhouse effect and the current high oil prices.

#### **4.4. Exhausting the finite fossil resources**

How about the ethical aspect of “merely consuming” the fossil stocks that the earth has accumulated over such a long time? Those who claim that it is irresponsible to use these energy stocks by the current generations, err, at least according to our insights.

The fossil stocks are finite; that is irrevocable. At some point, there comes an end to the new discoveries. If we reduce our consumption, then the depletion will be delayed, but sooner or later, the stocks will be depleted eventually. The only way to avoid such depletion is to reduce the consumption to zero. That way, the stocks will be saved for future generations. However, those future generations will have to face the same ethical question, and they could also decide to keep those “geological treasures” for later generations. But, what is then the value of those stocks? Are they then really “treasures”? If one is not allowed to utilize those stocks, then, for the non-users, they are simply worthless!

For our forebears, the generations that lived before the discovery of fossil resources - at least before their exploitation on an industrial scale, those so-called “treasures of the earth” were worthless. They did not even know of their existence! Clearly, we cannot blame them for having used those

stocks; on the other hand, they did not do anything positive with them either! Since they had no energy sources to speak of - and by lack of technology for power conversion, the life expectancy and the standard of living has remained very low for many ages: an average life expectancy of thirty to forty years, slavery, etc.

Now that one has discovered the fossil stocks, and that one has invented and developed the technological means to utilize them in a meaningful way (like producing work and electricity, generating heat “efficiently”, provide cooling,...), it would rather be irresponsible not to utilize them, do nothing with them and “save” them for our descendants. In other words, we find it justifiable that present-day generations use the available energy sources, even if that will lead to their depletion and thus disappearing, eventually.

However, to this (perhaps somewhat provocatively sounding) thesis, some quite stringent conditions must be added:

- the use of the energy stocks must lead to a higher standard of living (prosperity and general well-being);
- during our consumption of fossil sources, it is the duty of our present-day generations to develop other/alternative energy sources, so that the future generations no longer need the fossil sources (that will have been depleted by that time, anyway). This means that on the one hand, the consumption of fossil sources must be slowed down until there are valuable alternatives; on the other hand, it will be required that our generation invests sufficiently into the means for research and development of long-term solutions. Since we cannot afford to rely merely on “chance”, we must invest *in parallel* into the research and development of *all* potentially successful long-term options. Here, we think of a well focused and determined effort for improving energy efficiency, the use of renewable energy sources and the options of breeder reactors and nuclear fusion;
- a sufficiently large fraction of fossil resources should be reserved for petro-chemical purposes;
- it is to be recommended that the industrialized countries reduce their consumption of those “easy” energy sources (which can simply be lit by a match), and make use of more sophisticated techniques. This could allow the developing countries to support their economic growth with those so-called easy combustion techniques.

According to this reasoning, thus, we need not worry too much about the present-day energy issue. The only thing we should guarantee is that we

have replacement energy sources available in a timely manner (which means, before the fossil stocks have been depleted).

#### 4.5. The enhanced greenhouse effect

The environmental constraint that will put a definite mark for the next few years, but also in the long run (in part because for the other “concerns” such as air pollution and radiological aspects, there exist technically acceptable solutions), is undoubtedly the enhanced *greenhouse effect*.

It concerns here a global issue, because there exist (at least not presently) no “simple” solutions.<sup>16</sup>

At first sight, it seems simple. The presence of gasses such as water vapor and carbon-dioxide (CO<sub>2</sub>) in the atmosphere, guarantees that we know mild temperatures on earth. Without these gasses, the temperatures on earth would be about 30°C lower. These gasses are transparent for visible light and UV-solar light, but they absorb the long-wave length heat radiation re-emitted by the earth. An increase of those gasses would therefore lead to a global temperature increase on earth. This effect is called the *greenhouse effect* (Houghton, 1996 [18]; Houghton, 2001 [19]).

The natural greenhouse effect is not disputed. The question, however, is whether a human-caused increase of the so-called greenhouse gasses would lead to an *enhanced* greenhouse effect.

Although it seems that the effect is quite plausible, it turns out that matters are quite a bit more complicated because of the numerous feedbacks between the atmosphere, the hydrosphere, the cryosphere, the biosphere and the lithosphere. Especially the influence of the oceans and the creation and presence of clouds leads to considerable uncertainties in the numerical modeling that tries to predict this temperature increase. The *oceans* are an enormous reservoir of CO<sub>2</sub> and can absorb and release substantial amounts of that gas; in addition they are responsible for convective heat transport from the equator towards the poles. *Clouds* reflect solar radiation back into space, which leads to a cooling effect; on the other hand, a cloud cover acts as an insulating blanket around the earth preventing that heat is radiated back to space. The creation of clouds, in turn, is dependent upon the presence of the amount of water vapor in the atmosphere and the presence

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<sup>16</sup> Indeed, it is still an open question whether capture of CO<sub>2</sub> and storage are feasible and practicable.

of condensation nuclei (such as dust particles). Many other feedback mechanisms (both positive and negative; one more important than the other) can and must be taken into account.

Even at this moment, it must be recognized that there is no 100% scientific certainty concerning the enhanced greenhouse effect. Although still many questions remain unanswered, the numerical simulations, on the one hand, and the experimental (historical) evidence of the increase in temperature are such that the Intergovernmental Panel on Climate Change (IPCC), being a UN recognized international team of climate experts, believes that there are sufficient reasons to sound the alarm: “*The balance of evidence suggests a discernible human influence on global climate*” (Houghton, 1997 [18]). This statement was amplified in the Third Assessment Report of the IPCC (Houghton, 2001 [19]): “*In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely (with a 67 to 90 % chance) to have been due to the increase in greenhouse gas concentrations*”.

It is interesting to mention that an annoying discrepancy has been clarified recently. Until 2004, there seemed to be a non-negligible difference between the surface temperatures and the temperatures measured by satellites. According to Qiang Fu (Kerr, 2004 [25]), however, it is possible to reconcile both measurements, which leads him to state that “*it is getting warmer no matter how you measure it*”.

The climate experts of the IPCC are mostly concerned with the rate of increase of CO<sub>2</sub> as a consequence of human activities: during the last two hundred years, the CO<sub>2</sub> concentration in the atmosphere has increased by the same amount (from 280 to 360<sup>17</sup> ppmv) as during the last twenty thousand years (from 200 to 280 ppmv). Because of the “very fast” human influence and the uncertainties concerning (positive) feedback mechanisms, one is afraid that our climate could at some point “run away”, and hence, a cautious attitude is called for.

The IPCC is pleading for the *precautionary principle*: the risks are too high to ignore the enhanced greenhouse effect. Therefore, it will be necessary to decarbonize our energy provision. According to this philosophy, the Kyoto protocol is nothing more than just a small first step; the following reductions will have to be of a totally different order of magnitude and will

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<sup>17</sup> At this moment, the CO<sub>2</sub> concentration has already increased to 370 ppmv.

have a more dramatic impact. (See Bruce, 1996 [4] and Metz, 2001 [28].) Actually, the situation is even more alarming. Still according to the IPCC, we will probably not be able to prevent the rise in temperature on a medium-term time scale and we will have to prepare for adaptation and try to mitigate the consequences of the resulting situation. Apparently, further reductions of the use of carbon-intensive fossil fuels will be necessary to avoid a further sliding down the hill. Since our current economies rely heavily on fossil sources, this means that there is considerable pressure to look for alternatives, whatever their nature. (Alternatively, one could still allow that we use the massive coal reserves but only if one succeeds to realize the already mentioned CO<sub>2</sub> capture and storage options. The same applies to the potential resources or methane hydrates in the oceans; see e.g., Suess, 1999 [33]). A different way of saying the same thing is that the external costs of fossil sources will become too high for them to remain so dominantly present in the future energy-provision chain. Alternative energy-provision routes will become relatively cheaper or will in the end remain as the only affordable alternatives, unless one manages to neutralize the disadvantageous environmental effects of fossil fuels.

According to the current predictions, the long-term consequences of the enhanced greenhouse effect are not negligible. Depending on the behavior of human society over the next 100 years, it is possible to draw up some scenarios. This has been done in a special report of the IPCC (Nakicenovic & Swart, 2000 [24]; see also Houghton, 2001 [19] and Metz, 2001 [28]). Over the period from 1990 till 2100, we would be confronted with an average temperature increase of 1.4 to 5.8 °C. This projected increase is much larger than the observed increases during the 20-th century. As far as the sea level is concerned, matters are not any better. Still according to the same report, the sea level would rise between 10 cm to 0.9 m between the years 1990 and 2100. This rise would be a consequence of the thermal expansion of the water and the melting of the ice caps and the glaciers, both because of the higher temperatures.

In the mean time, the international community has decided not to wait for the scientific confirmation, with the argument “better safe than sorry”. For the remainder of this contribution, we assume that the Kyoto protocol will be executed, at least in Europe. The CO<sub>2</sub> factor will be considered as a given; the objective then is to adapt our energy household so as to satisfy the GHG-reduction of 8 % for the EU (in the period 2008-2012 compared to 1990). Furthermore, it is expected that after 2012, deeper cuts in CO<sub>2</sub> emissions will be demanded.

The concern for the enhanced greenhouse effect has unseen consequences. The requirement to emit as little as possible CO<sub>2</sub> puts quite some pressure on our energy household: because of the global nature of this effect, for which no simple corrective “plumbing” measures are available, the use of fossil fuels is to be discouraged. This actually means that one has much less time than we have led to believe in earlier sections! We do not have the time to “quietly” look for alternative energy sources; unless science and technology find satisfactory “solutions” for the CO<sub>2</sub>-issue (e.g., decarbonization of exhaust gases and storage of the CO<sub>2</sub>, or other presently unknown techniques), one will be obliged to search at an accelerated pace for alternative energy provision measures.

#### **4.6. Affordability of energy; Price of energy resources: A perspective**

The prices of primary energy (whereby we concentrate especially on the price evolution of oil) have fluctuated considerably over the last few years. This is evident from the figures below.

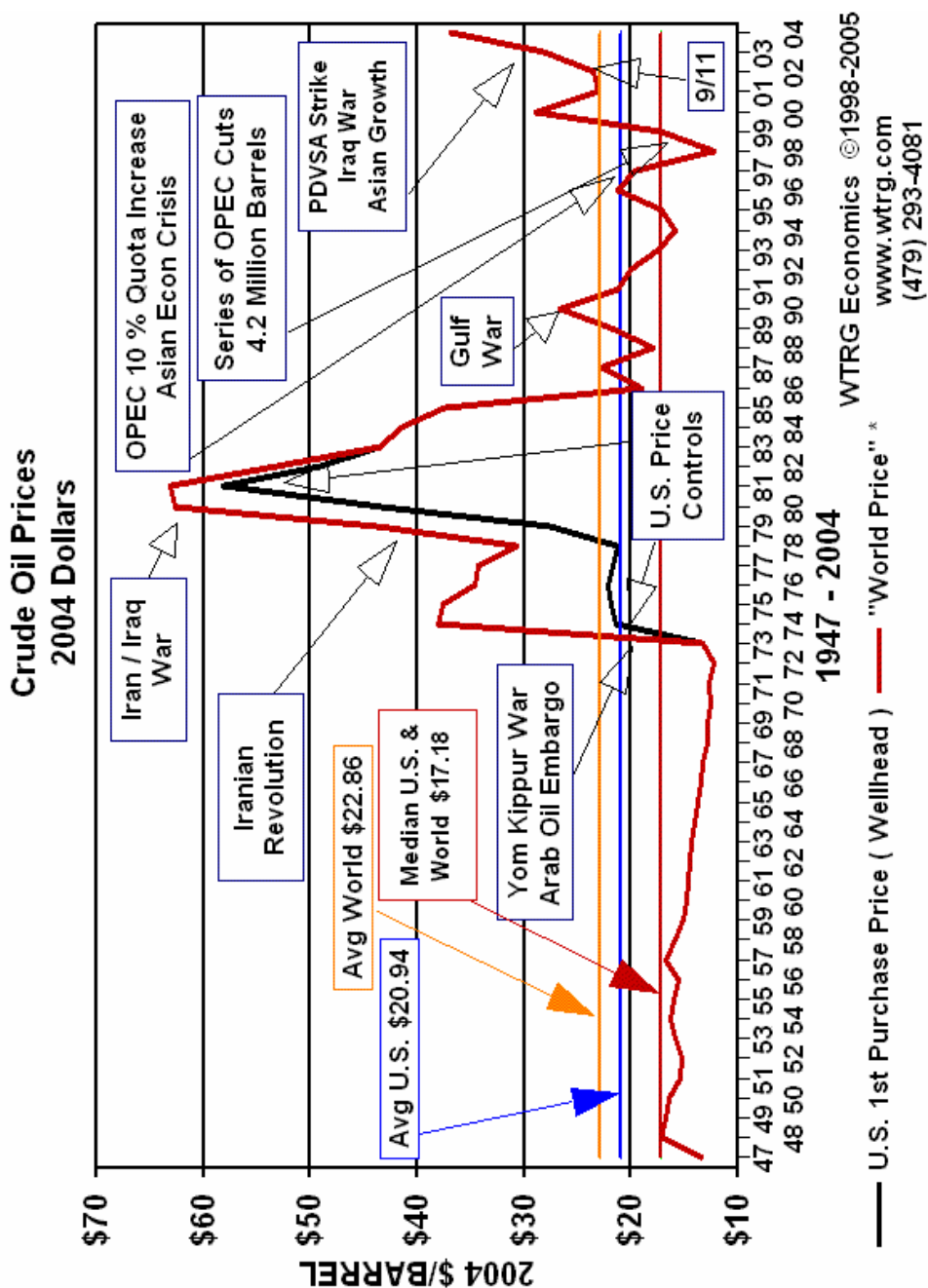


Figure 5. Historic evolution of the oil prices. From website [www.wtrg.com](http://www.wtrg.com)

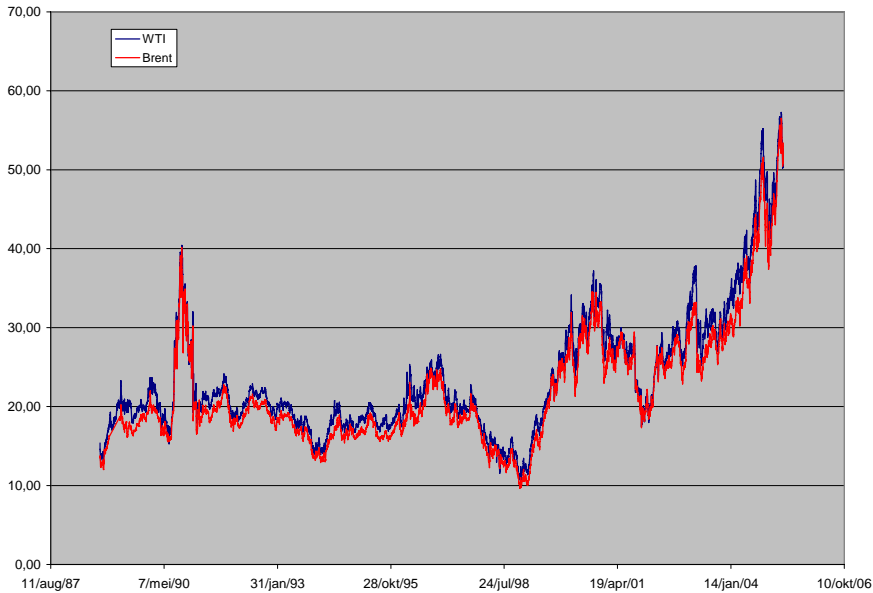


Figure 6. Evolution of the oil prices (Brent in red; West Texas Intermediate in blue) from 1988 till April 2005 (source Fortis).

The daily evolution of the energy prices can be followed on the web sites given in the reference list (see Energy Price Information web sites [12]).

According to the IEA (IEA, World Energy Outlook 2004 [21]), it is expected that that prices will decrease in the “near future”. It says literally: “We assume that...the prices reached in mid 2004 are unsustainable and that market fundamentals will drive them down in the next two years”. In the reference scenario of the World Energy Outlook, it is assumed that the oil prices will drop down to about 22 \$ per barrel in 2006 (measured in \$ of the year 2000). The price would then remain flat until about 2010 after which it would increase linearly till about 29 \$ in 2030 (again in \$ of 2000). This is only an assumption, but it shows that the energy analysts - ignoring temporary price fluctuations - expect that oil will remain quite affordable over the next 25 years.

It remains to be seen whether the assumptions of the IEA, as far as prices are concerned, will be correct. However, when looking at the oil prices, it is important to take into account the inflation, on the one hand, and the rate of exchange euro/dollar, on the other hand. It is a fact that (disregarding the year 1991, when the first gulf war took place) oil prices have been very

low during the years 1990. At the end of 1998, the price was even less than 10 \$/barrel. If one corrects for the inflation and the rate of exchange of the dollar, the price in Europe was lower than before the oil crisis in 1973.

In the years 1980-2000, and also still now, the situation was/is different and actually more comfortable than in the years 1970-1980. Because of the oil crises of 1973 and 1979 (and the accompanying higher prices), one has started to diversify in energy resources: both between the different sorts (coal, oil, gas, nuclear) and regionally. Moreover, one has realized that annual growth rates of about 7 % of the dominating energy source are no longer bearable, that it became time to stop unnecessary wasting of energy and that there was a need for a more rational use of energy. Since 1973 the worldwide growth rate of primary energy is (albeit with quite some fluctuations) of the order of about 2 %/a; for some fast growing economic countries, however, growth rates of 6 % and more are being observed. Especially the enormous growth in China, India and Brazil are causes for concern.

In addition, since the oil crises, the exploration for fossil sources has been increased considerably and at present, we have respectable reserves of primary energy sources. That there are enormous coal reserves was no secret; since a few years, one is making major efforts to better estimate the gas reserves, with increasing reserves as a consequence (Watson, 1996 [35]).

In the medium to long term, though, somewhat towards the year 2030, we will again run the risk of becoming unilaterally dependent upon the Middle East and other less politically stable countries, which will by then have become again our most important oil and gas providers. See a.o. (IEA, World Energy Outlook 2004 [21]).

## **5. The possibilities of energy savings**

In the discussion above, the point of departure has been that the world energy consumption will rise and the supply side of energy resources with regard to depletion and price formation, has been touched upon. Even though it seems reasonable that the worldwide demand for energy will rise “considerably” over the next hundred years, it is clear that it will make quite a difference whether it will be with a factor of two or with a factor of four. Indeed, no matter how “reasonable” one may find the increase in energy consumption, it should nevertheless be evident that one should avoid any unnecessary wasting of energy. By making an effort concerning energy

saving, it could be possible to flatten out the increase as much as possible. The question really is, how much can realistically be reached?

To address the issue of energy saving properly, one must distinguish between two aspects: *energy intensity* and the *demand for energy services*.

First, there is the amount of energy utilized per unit of activity or product. This is usually called the ***energy intensity***. The energy intensity can be improved (i.e., reduced) by applying more efficient energy technologies (appliances, equipment, facilities, systems, etc), the simultaneous generation of different useful energy streams (as is the case in combined heat and power —or CHP— installations) and avoiding “visible” or evident energy losses (whereby heat insulation is a prime example).

Second, there, is the ***amount of energy services*** that one wants to enjoy. This aspect has to do with comfort, discipline, substituting to different processes and activities, in short, with a different behavioral attitude. Here, we think of lowering the thermostat in a building, dimming the lights when leaving a room, the available living or working area in dwellings and offices, the number of km's driven, the transformation of an industrial society to a service-oriented society, etc.

Over the years, one has learned that a change of mentality is not easy, and furthermore not permanent. The only real way to “enforce” less energy services is to make energy more expensive. But before raising the price of energy, e.g., by means of taxes, one should pay careful attention concerning the possible loss of economic prosperity of the customer (if that were the case) and the competitive position of our industries and businesses. This is the (non-trivial) issue of energy taxes and more especially, where they should be applied and their influence on the economic activity.

For that reason, one concentrates more and more on technology-driven efficiency improvements of energy-conversion technologies and a more efficient approach at the implantation and the construction of buildings.

Undoubtedly, there still exists a large technological savings potential before the limits of the second law of thermodynamics will have been reached. It is, however, important to distinguish between the *technically realizable* potential, the *economic* potential and the *market* potential (whereby this last one takes into account the consumer's purchasing behavior). As a matter of fact, it is usually the case that the investment cost of the most energy-

efficient equipment or building-technical measures is more expensive than that of standard equipment or measures. It then is the aim that by consuming less energy, the extra investment cost will be recovered after some time. For some technologies and measures, no matter how efficient, the payback time will be too long. For others, it will be acceptable, but the customer may nevertheless decide not to purchase them. In addition, sometimes, there is a natural inertia in the system. Hence, a quick penetration of these more efficient technologies or construction philosophies is not guaranteed. Two typical examples are the introduction of frequency-controlled electric motors and the building-construction sector. Because of fear for the unknown, the introduction into the market of frequency-controlled electric motors is much more slowly than desired, and although there are ample energy savings to be “captured” in the building-construction sector, the number of new buildings per year in our regions is limited, since we have the habit to build dwellings for the duration of 50-100 years. One should also mention that the non-careful application of many of these (often power electronics-controlled) technologies or of CHP can lead to non-desirable side effects for the electric grid, such as harmonics, or loss of voltage stability. These problems are certainly not unsolvable, but it is necessary to do sufficient research to recognize the problems and to come up with a satisfactory solution, albeit usually with a higher cost.

In fact, increased energy efficiency has been a characteristic of our technological development. Historically, over the last 200 years, the energy intensity (defined here as the energy consumption per unit GDP) of the industrialized world has been characterized by an average decline of about 1% per year. This means that our primary energy demand has grown more slowly than the GDP. The IIASA/WEC projects that future decreases in overall global energy intensity are “expected” to be of the order of 0.8% – 1.4% per year. (Nakicenovic, 1998 [29]) Given the fact that the growth in GDP (or better GWP, for Gross World Product) is of the order of 2 – 2.5% per year, it is clear that increased energy efficiency is very important, but that it does not solve the energy issue.

Especially in the industrialized world, alternative groups advocate a strong focus on improved energy efficiency for *electrical* applications because the energy savings in primary energy are amplified by the inverse of the conversion efficiency. Although increased electric efficiency is certainly to be applauded, one should be careful about the expectations. One should not focus on the electricity side as such, but on the primary energy necessary for that electricity consumption (and also on the environmental consequences

and the cost of those primary sources). It happens not infrequently that electric applications are preferable compared to combustion-related technologies (industrial electro heat, heat pumps and later perhaps electrically powered vehicles).

A last element concerning the aspect of energy conservation makes the link with the ***liberalization of the energy markets*** (a subject that will be addressed shortly). Because of the liberalization, one expects lower energy prices. Because of the (granted quite limited) price elasticity, one should expect that the customer will react by requesting more energy services. In addition, the payback time of the investment cost of more efficient equipment will be longer, such that the customer will be less inclined to make that purchase. Also concerning the liberalization, it should be mentioned that the intervention possibilities of the authorities have been seriously reduced because of the new legislation. In a regulated market, the authorities could simply impose certain actions on the utilities to stimulate the customers to save energy. In a liberalized market, with a great number of players such as generators, transmission-system operators, distribution-system operators, traders, brokers and suppliers, that will be less evident and one should always ask the question whether governmental intervention is not against the free-market principles of the liberalization (perhaps leading to counter-productive feed-back effects).

In conclusion, improved energy efficiency is to be encouraged strongly, but its real contribution is uncertain and in all likelihood insufficient in the long run. It is one of the important elements, but on its own, it does not provide the full answer.

## **6. The supply side**

### **6.1. Physical availability of energy**

For the next 20-40 years, there is ample *physical* availability of primary energy sources. The current estimates for oil and gas reserves are about 40 and 60 years, respectively. For coal, the estimates are 200 to 300 years, whereas for uranium it depends whether one opts for reprocessing and breeding or not: these reserves vary between 50 and 3000 years depending on the option chosen. If one takes into account the non-conventional fossil sources such as tar sand and oil shale, if one counts on the availability of the massive resources of methane hydrates in the deep ocean, on the uranium concentration in the seas or on the thorium cycle, or even on nuclear fusion

from deuterium and tritium, it is obvious that the physical presence of primary energy is not really a concern. In any case, we could still continue to use it for quite a while, at least from the standpoint of availability.

## **6.2. A decarbonized energy economy**

As has been argued above, the threat of the enhanced greenhouse effect implies a considerable downward pressure on the (for the time being still sufficiently physically available) fossil sources. Therefore, the energy provision needs to become “decarbonized”. In a first instance, this will lead to a shift towards more gas (at least where this is easily feasible) and eventually to a global reduction of all fossil sources. Unless one manages to remove the carbon dioxide from the flue gases and to store them safely and both at an affordable cost, because of environmental reasons, we will not be able to utilize the considerable amounts of fossil resources, especially coal. To bring these separation and storage technologies to full commercial maturity, there is still a need for substantial technological research.

In the long run, however, it is clear that we will have to come up with “other”, i.e., carbon free, energy provision routes.

In first instance, it seems logical to check whether it is possible to capture part of the natural energy flows that are present on earth. For many of these so-called “*renewable*” sources, there exists a large potential that can be tapped at least as far as *energy*<sup>18</sup> is concerned. In some important cases (like hydro electricity) it is indeed possible to capture these enormous potentials at acceptable cost. Others, like especially wind energy, are gradually entering the commercial market, while still others still need to go a long way before reaching market maturity. In any case, there is still much work to be done to integrate the renewable technologies into the global energy provision system before they will be cost effective. (Actually, as has been discussed above, the appropriate way to estimate the real cost effectiveness of energy-conversion technologies is to take into account the external costs and to incorporate these consistently in all routes - taking into account the full life cycle from cradle to grave.)

Because the instantaneous power delivered by especially wind and solar (PV) energy can vary substantially, large-scale storage of electricity or the use of hydrogen as an indirect storage medium (whereby in this last case

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<sup>18</sup> It is important to recall the difference between “energy” and instantaneous “power”.

fuel cells would really get a chance for breakthrough) could support the penetration of these fluctuating renewable sources considerably. However, both large-scale electricity storage and the so-called hydrogen economy are for the time being nothing more than a far dream. It should be said that presently the renewable contribution is still quite small and that its degree of future penetration remains uncertain. Some further elements of renewable energy conversion are discussed in Section 6.4.

A different carbon free route is of **nuclear** origin. Here we talk about nuclear fission and nuclear fusion. As far as the first one is concerned, for quite some time, there has been a pause (in the Western world), but at this moment there seems to be a moderate revival in Europe. The issue here is rather one of public acceptance. The nuclear community is working hard on new concepts in the hope to take away the reservations of the public at large. Concerning nuclear fusion, it is justified to be optimistic from a technical-scientific viewpoint. The question remains, however, whether this route will turn out to be competitive. These nuclear aspects will be elaborated on further in Section 6.5.

Both for renewable sources and for nuclear routes, the cost picture becomes more “rosy” if the fossil fuels become more expensive. On the other hand, however, it should not be forgotten that high fuel prices weigh heavily on the global economy, such that there are fewer financial means available for subsidies and other support schemes.

### **6.3. Continued use of fossil fuels**

From all of the above, it is also quite clear that we still have to rely on fossil fuels for quite some time.

We believe that **gas** has still a very large growth potential because of its relatively low CO<sub>2</sub>-emission and the possibility to use quite efficient technologies such as combined cycles (CC) and combined heat and power (CHP). As mentioned above, the gas reserves are quite promising, meaning that gas can make a valuable contribution for our energy provision and the CO<sub>2</sub> issue. However, one should make sure not to repeat the mistakes from before 1973 and put all the eggs in one basket and allow very large growth rates. In addition, one should not forget to keep the necessary fraction for petrochemical means.

*Cogeneration* or *CHP*, deserves some attention in this regard, especially because sometimes rather “sloganesk” (and not quite correct) “sales

arguments” are utilized to promote it. CHP is a very valuable technology, but if it is used in the wrong place, it can do more harm than good. Indeed, the risk exists that a blind “sloganesk” and dishonest advertisement approach will in the end turn against CHP, with the risk that the baby is thrown away with the bathwater, preventing the realization of worthwhile CHP projects.

From a correct energetic viewpoint, it is misleading to state that CHP is a handy way to recuperate the heat of electricity generation. Rather, CHP is a clever way to produce heat, whereby – in order to limit the exergy<sup>19</sup> degradation – a thermodynamic cycle or turbine is inserted between the combustion and the end use of the heat. In the same context, the total first-law efficiency, whereby the electricity and the heat are simply added, is totally misleading. Indeed these two forms have a completely different “quality” (or exergy), even though they are both expressed in Joule. A more correct characteristic is the total exergetic efficiency, which takes into account the relative quality of those two forms.

The only thing that really matters for CHP is the *fuel or primary energy saving* compared to separate generation of electricity and heat. This characteristic is clearly dependent upon the separate production technologies of electricity and heat with which one compares. In addition, it is necessary to have the CHP operating at rated power, since the efficiencies at partial load are sometimes rapidly deteriorating. Another point for the correct operation of a CHP installation is that all energy “produced” is effectively utilized. For electricity that poses no problem, but for heat it is not at all guaranteed that part of it will not be thrown away. Hence, the golden rule that CHP-generated heat should not be cooled away. This means that CHP should be heat driven: when there is no demand for heat, then the CHP should be shut down, or one should make use of heat buffers.

To have a correct estimate of the primary energy saving of a CHP, one must take the correct reference for separate production. The only justified comparison is the following: at the moment of the decision for the investment of a CHP installation, one has to compare the CHP option with the best available technology at that moment, based on the same energy carrier (e.g., gas). Comparisons with the average electric plant-system efficiency are intellectually dishonest.

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<sup>19</sup> “Exergy” is a technical name for “quality” of the energy. Electricity or work has a relative quality of 1. The quality of heat depends on its temperature T; its relative quality equals  $(1-T_0/T)$ .

Finally, we mention a few words about oil and coal.

Since the oil crises, **oil** has been suppressed for electricity generation in many countries. It is not easy to predict the future market for oil, but it is our belief that oil, and its derivatives diesel and gas oil/petrol will continue to play a dominant role for many years to come, especially in the transport sector. The performance characteristics of internal-combustion engines are so high (and the environmental burden and the cost are so low) that it will be very difficult to push these oil products (which are characterized by a high energy density) out of the market. For the heating sector, it is less clear since there exists a possibility for substitution with gas (and the available high efficiency boilers, including condensing boilers). Also, for petrochemical purposes, a sufficient amount should be set aside.

Because of the enormous reserves in countries such as the USA, China, India, Australia and Russia, **coal** will be important for energetic purposes in the future. The biggest problem with coal, however, is that it is quite polluting with heavy metals, with particulates and that it is characterized by a substantial CO<sub>2</sub> emission. But also here, it should be said that technology progresses. Gasification of coal (Integrated Gasification Combined Cycles, IGCC) seems to be a promising route, especially if one would manage to “decarbonize” the synthesis gas. The CO<sub>2</sub> could then subsequently be stored in e.g. depleted gas fields. (Although one might be skeptical with respect to this storage, it should be recognized that the gas fields have been filled by the Earth itself with methane, which has a Global Warming Potential of 20. This means that an unexpected release of CH<sub>4</sub>, e.g., by means of an earthquake, would be much worse than a possible accidental release of the stored CO<sub>2</sub>.) At this moment, however, the available technologies for ‘decarbonization’ and storage are still “far-future options”. But also here, technological progress can bring part of the solution. For whatever they are worth, the orders of magnitude for CO<sub>2</sub>-capture costs are estimated to lead to an extra cost of 30% to 120% (depending on the technology used) of the price per kWh from a coal fired plant. For storage, about an additional amount of about 10% to 50% of the decarbonization cost would be needed. Hence, if it all works out well technologically, the kWh price would likely increase by a factor of 1.5 to 2. These extra costs must then be compared to the external costs of coal-fired power plants.

#### **6.4. Capture of natural flows: renewable energy**

As hinted above, there exist a considerable theoretical potential of

renewable energy sources on the world scale. At least, a considerable *energy* potential; which is different from saying that there is sufficient instantaneous *power* available at affordable cost.

Several issues are to be considered for an honest appraisal of renewable energy sources. To some extent, their environmentally friendliness is overshadowed or neutralized by some serious disadvantages or shortcomings. The low energy-density nature of most renewable sources and the intermittent character of some of them give rise to large footprints, and high investment cost. Since electrical storage is not really doable in large quantities, the need for back-up power makes the overall generation cost even more costly. Large hydro, for which the above is less of a problem, is no longer considered as an environmentally friendly option. For biomass, it is not clear whether massive application would not lead to regional land-use conflicts (e.g. in Asia, in Europe but also in Africa). Also deforestation should be avoided in this context.

To deal with the electricity-storage problem, a potential and presently quite popular “solution” may be to produce hydrogen by means of electrolysis, and then later generate electricity using fuel cells. Although there is ample enthusiasm for a future hydrogen economy, the global chain efficiency and the accompanying cost will probably be a problem. The cost seems to be a major bottleneck: especially when photo-voltaic electricity generation is used, this route is likely to remain very expensive for many years to come. Whether this route will become an affordable reality, remains to be seen.

Although there seems to be an unmistakable “drive” towards decentralized generation of electricity, one can bet on it that (certainly for the next 50 years) the massive use of renewable energy sources will be expedited by, and will even have to rely on, a considerable fraction of continuously operating robust electricity generation plants, based on a varied basket of “fuels”.

Other, at this moment still somewhat speculative, routes are solar energy from space (via satellites in orbit or on the moon — see Chriswell 2002 [10]) or a worldwide strongly interconnected electricity grid to neutralize the intermittent character of some renewable sources (see GENI [17]).

Whether renewable applications are advocated as decentralized generation means, or as large centralized generation facilities (e.g., as large offshore wind farms), possibly interconnected by a worldwide electric grid, or even as space-based solar energy generation (on the moon or in orbit), it is clear that

still many issues remain to be resolved for this type of fluctuating generation, the grid stability and the grid architecture, and that further power-electronics development is to be focused on.

In conclusion, by the second half of this century (2050 – 2100), renewable sources may perhaps contribute some 10 – 30% of the primary energy “production”; however, the degree of massive penetration is highly uncertain.

### **6.5. Nuclear energy provision**

There are two nuclear-based technologies that are both “emission free”, nuclear fission and nuclear fusion.

The former finds itself in a strange situation. Although, according to all objective criteria, the present generation of commercial *fission* reactors for electricity generation and the future designs now on the drafting board, are characterized by a reasonable cost effectiveness (inclusive the external costs related to radioactive waste management, decommissioning and accidents), this energy-conversion technology does not seem to be appreciated by the public at large (and their representatives in some countries). Witness thereof, is the phase-out decisions in certain European countries like Sweden, Germany and Belgium. Whether a nuclear phase out in these countries is really feasible in the long run, remains to be seen. In contrast to those countries mentioned, there are the recent developments in Finland and France, where it has been decided to construct a reactor of the third generation (European Pressurized Reactor; EPR). Not too long ago, the Swiss have decided by referendum not to close their nuclear power plants prematurely, and they have rejected a moratorium for new reactors.

In any case, the nuclear research community seems to be motivated to design even better power plants (with still higher safety, with better fuel usage and production of less radioactive waste). One type of these reactors is the high-temperature gas cooled reactors of the type GT-MHR<sup>20</sup> or the Pebble-bed reactor. Also the research agenda for the fourth generation (known as Gen-iv) should be mentioned. See Generation iv websites [16].

For some people, a nuclear phase out is the means to launch the breakthrough of “alternative” routes; for others, such phase out is an

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<sup>20</sup> Gas Turbine Modular Helium Reactor

incredible mistake that will be paid for several times later on, by loss of expertise & know-how, by higher electricity prices, and with higher CO<sub>2</sub>-emission levels. Whatever the outcome, at some point in time, this discussion will have to come to a conclusion. Society will have to decide whether nuclear energy is acceptable and/or desirable.

**Nuclear fusion** is again a different story. It should be clear that electricity generation by means of nuclear fusion is not for tomorrow. When it will become a reality is less evident, albeit perhaps not because of technical-scientific reasons. Controlled fusion is still in the development phase and one hopes to be able to offer commercial electricity generation by fusion means in about 30-60 years. During the last 30 years, the scientific-technical progress of the research has been remarkable and indeed very successful. In fact, there is sufficient scientific-technical information available in order to be able to “comfortably” extrapolate to commercial reactor conditions. The chances are very real that fusion becomes a reality. The problem, however, is situated in the concrete realization of the experimental devices to demonstrate these theoretical predictions. The “annoying” thing in fusion research is that one needs large and expensive, i.e., capital intensive, devices to prove what needs to be proven. To construct such big devices, international cooperation is required, with the expected international tensions with regard to prestige, etc. The recent stalemate concerning the location of the reactor experiment ITER (International Thermonuclear Experimental Reactor), which has lasted for about three years, does not need further clarification! In fact, the technical design of ITER was already ready about six years ago. If the scientific community always has to wait for more than five years (after the finalization of a design phase) before one decides where the experiment will be built, then it will clearly still take quite some time before fusion becomes a reality. Along the same line, one should “interpret” the intentions for a so-called “fast-track” approach with some healthy skepticism. In principle, it should be possible to have commercial fusion reactors ready in about 30-40 years, but only if decisions are taken timely and one is prepared to invest in parallel. The author regrets that the great world powers still do not seem to realize that global energy provision is indeed a serious challenge and that apparently it is not considered as a strategic issue. The hesitation to take a potentially successful long-term energy source seriously and to invest in its development with the hoped for determination, is a clear witness of this lack of long-term vision. Without being pessimistic, but with the necessary degree of realism, the author fears that commercial fusion (as a routine product) will not be a reality before the year 2070. Information concerning fusion development can be found on the

fusion-related web sites in the reference list. (See Fusion [15].)

## **7. Liberalization of the energy markets**

During the last years, the energy scene has been (and is still being) influenced by the liberalization of the grid-based energy carriers, electricity and gas. Sometimes, and somewhat misleading, one talks about “deregulation” of the energy markets. Indeed, in the early days, when vertically integrated players covered the full chain of production, over transport and distribution, up to delivery, the regulation was much simpler. In order to come to a correctly functioning free market, there will be a need for more, albeit carefully designed, regulation.

Without hesitation, it may be said that, as far as this is concerned, the energy world is going through a revolution, and this both on the supply side and on the side of the consumers. Because of nervousness, many headquarters of players on the supply side presently opt for a survival strategy (usually based on pragmatic short-term thinking) while long-term strategies (such as long-term investments) are being put on the back burner. In this respect, one should pose the question whether this short-term thinking is compatible with the need for a long-term strategy for coping with the enhanced greenhouse effect. Moreover, nobody seems to feel the need to invest in base-load generation capacity since the prices for base load are too low. Even for peak-load investments, there does not seem to be much interest because the number of hours of operation is limited (and hence the possibilities for earning back the investment, unless one introduces real-time pricing). In turn, this can have negative consequences for the security of supply in certain regions, as has been demonstrated in California in 2001. Although the blackouts in North-America and Italy in the summer and fall of 2003 are not directly related to the liberalization, it should be clear that liberalization-related aspects have had an unmistakable influence.

The liberalization of the markets for electricity and gas (and the accompanying competition) acts as a “perturbation” in the community of energy actors, leading to inconveniences for some and to opportunities for others. In any case, this liberalization exercise makes the outcome of the long-term energy issue less transparent. In contrast to earlier times, electricity generators can no longer take it for granted that all their generation capacity will be used as before. Since in the liberalized philosophy, the prices will be set by the market (and no longer according to

a “cost plus” approach) and the profits for the “utilities”<sup>21</sup> will be determined by the expenses made to provide the electricity, the first priority of the “utilities” these days is cost cutting. Even stronger, in the liberalization philosophy, the market is supposed to solve everything and therefore “utilities” are no longer required (and even supposed) to have a long-term responsibility for sufficient electricity supply! The market is supposed to “take care of everything”. As a consequence, capital-intensive investments are being delayed or even cancelled, while giving priority to cheap investments with short construction time — such as Combined Cycles for electricity generation, although the current explosion of fuel prices has mitigated that tendency. Also long-term research and development is given low priority. If there is some money available, it will preferentially be spent on marketing!

The liberalization may have unexpected consequences with regard to ***energy saving and improved energy efficiency***. First, and as already mentioned before, lower electricity prices will likely lead to more consumption and reduce the tendency to buy more efficient appliances and equipment. Second, the intervention capability of the governments in the energy household is strongly limited. The often hailed “Integrated-Resource-Planning” methodology that obliged “utilities” to equally focus on the reduction of consumption as on the increase of generation capacity, is no longer allowed in a liberalized market. Anybody who wishes to build a generation plant (and who satisfies general conditions) should be able to do so. Along the same lines, it is clear that “Demand-Side-Management” programs are less evident than they used to be in regulated markets. (See Didden and D'haeseleer, 2003 [11].)

The above does not mean that liberalization of the grid-based energy markets is doomed to failure. But it will require perhaps 10 - 15 years before we will see again long-term stability. However, it will be some sort of “dynamic equilibrium”, in which matters will keep changing but in a more “predictable way”. Put differently, the new actors will have learned the new rules of the game and long-term perspectives will return.

Whether the liberalization, with its multitude of players, will see a decrease in market prices is being questioned by many observers. It is interesting to note that now one rather speaks about a “correct” price, whatever that

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<sup>11</sup> We still use the term “utility” as a generic term. In principle, we should distinguish between generators, suppliers, transmission, grid operators, distribution operators (and perhaps even traders and brokers).

means. Do not forget that all the intermediate players need to earn their money as well, and in the corridor it is sometimes suggested that the big winners of the liberalization are the consultants and the lawyers. At the moment, it seems like we have in Europe 25 (more or less) locally liberalized markets, but a single integrated market, with sufficient flexibility for import and export, on the one hand, and a uniform regulatory framework, on the other hand, is still a long way off. If matters do not settle sufficiently quickly and if a real level-playing field only remains wishful thinking, then it is not excluded that an opposite movement sees the daylight which may lead some to give in to the seduction to plea for a re-nationalizing of the sector.

## **8. Conclusion**

In conclusion, it must be said that the energy-provision issue has many facets and that it is not easily solvable with simple recipes or slogans. The energy issue is not a matter of exclusivities like “either-or”. It will be necessary to move in parallel on different fronts, and no potentially successful options should be excluded a-priori.

The energy issue is clearly driven by the requirement for a reliable, affordable and clean energy economy. The most important aspects here are a guaranteed security of supply at affordable prices, the threat for a global climate-change effect, and the influence of the liberalization of the electricity and gas markets.

Energy conservation is of primary importance, and it is imperative to consider the most cost-effective energy mix, whereby one should properly take into account the “hidden” costs due to environmental externalities. An energy provision that is too expensive will lead to a reduction of the overall prosperity and for the lower classes of the population also to a reduction of well being. A healthy engineering approach, with correct analysis of all aspects, is the only reasonable way to go. If one evaluates all elements objectively, and one disposes of the necessary numbers and data, one can make well-founded choices to come to a well-suited energy-provision economy.

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