Energy 43 (2012) 174–191

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Sustainable energy development: The present (2011) situation and possible paths to the future[☆]

Noam Lior[*]

University of Pennsylvania, Department of Mechanical Engineering and Applied Mechanics, Philadelphia, PA 19104-6315, USA

ARTICLE INFO

Article history:
Received 12 October 2011
Received in revised form
13 November 2011
Accepted 18 November 2011
Available online 2 February 2012

Keywords:
Energy and power assessment
Sustainability
Shale gas and oil
Nuclear power
Electric cars
Africa energy

ABSTRACT

This invited keynote paper is the most recent among similar reviews published by the author, update to year 2011. In a format similar to that in past reviews, recent estimates and forecasts of the conventional fossil fuel resources and their reserve/production ratio, nuclear power, and renewable energy potential, and energy uses are surveyed. A brief discussion of the status, sustainability (economic, environmental and social impact), and prospects of fossil, nuclear and renewable energy use, and of power generation is presented. Beyond the general review, the paper focuses this year on some of the many important areas that deserve more attention: (1) the recently emerging game-changing developments of postponement of "peak oil", nuclear power future following the disaster in Japan, and effects of the recent global economy downturn of global sustainability, (2) the potential and impacts of electric cars (3) the often neglected energy status and promising potential of Africa. Some ways to resolve the problem of the availability, cost, and sustainability of energy resources alongside the rapidly rising demand are discussed. The author's view of the promising energy R&D areas, their potential, foreseen improvements and their time scale, and last year's trends in government funding are presented.

1. Introduction

This paper summarizes key highlights of the global status at the writing of this paper (August 2011) of energy resources and use, related environmental effects, an unofficial review of the progress and plans in these areas by the U.S. administration, partly as reflected by its U.S. Department of Energy proposed fiscal year 2012 budget, and description of some possibly sustainable paths to the future. Beyond the general review, the paper focuses this year on some of the key areas that deserve more attention: (1) the recently emerging game-changing developments of postponement of "peak oil", the nuclear power future following the disaster in Japan, and effects of the recent global economy downturn of global sustainability, (2) the rising potential and impacts of electric cars, (3) the often neglected energy status and promising potential of Africa. Some of the basic references include the latest energy statistics annual report of BP (British Petroleum) for 2010 [1,2],[1] the excellent web sites of the USDOE (U.S. Department of Energy) [3] and of its Energy Information Administration [4], the International Energy Agency [5], and the International Atomic Energy Agency [6]. The analysis, interpretation, and comments are entirely the author's and do not represent any institutional or government views. Reviews of similar nature were published by the author in 2002 [7], 2006 [8], 2008 [9], 2010 [10], and 2011 [11,12] to update the information about this very dynamic field.

2. An executive summary

(Some of the summary in this Section 2, with some differences, was also included in the recent invited keynote paper presented at the World Energy Panel of the ECOS2011 conference [12]).

[☆] Invited keynote paper from the 6th Conference on Sustainable Development of Energy Water and Environment Systems, September 25 – 29, 2011, Dubrovnik, Croatia.

[*] Tel.: +1 215 8984803; fax: +1 215 5736334.
E-mail address: lior@seas.upenn.edu.

[1] While British Petroleum (BP) has published the Annual Statistical Review of World Energy for 60 years without significant challenges, and serves most frequently as the source of the proved fuel reserves data, the accuracy is unknown and is subject to large errors. Comparison with other information sources shows some differences.

0360-5442/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2011.11.038

Table 1
Some key data during the period 2006–2010.

Item		Global amount
Total primary energy use (2010)		502 EJ [1]
Industry		30% [13]
Transportation		29% [13]
Residential		22% [13]
Commercial		19% [13]
Electricity		40% [13]
Electric power installed (2008)		4.4 TWe [14,15]
Electricity generated per year (2010)		21.3 PWh = 77.2 EJ [1]
People without electricity (2009)		1.44 billion [14]
Global temperature change, °C	industrial period	+0.76, exponential rise[a] [16,17]
	2006–2010 average	−0.04 [16]
Water shortages [18,19]		884 million people lack safe drinking water, 2.5 billion people have inadequate access to water for sanitation and waste disposal, Ground water depletion harms agriculture
Food shortages		925 million undernourished people (1 in 7)[b] [20]

[a] The temperature increase per decade is more than twice as fast as that observed over the preceding hundred years.

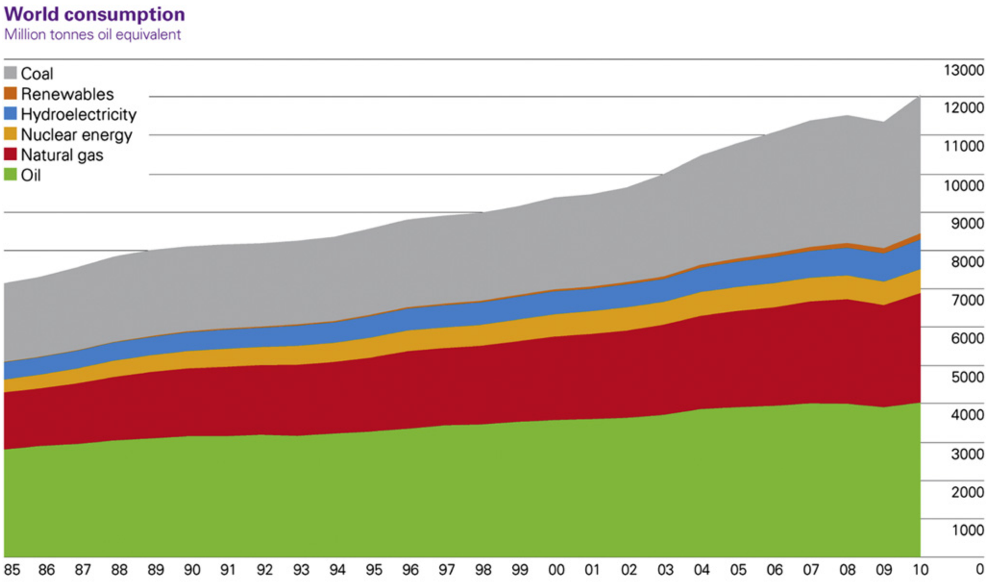
[b] An encouraging drop of 9.4% relative to 2009; It is noteworthy that at the same time 1.9 billion people, twice as many as the undernourished and rapidly rising, are overweight [21].

2.1. Critical global information

Energy resources and consumption are intimately related to environmental quality and other vital resources such as water and food. The energy situation must be viewed in that context, and some of the related key global data are therefore shown in Table 1.

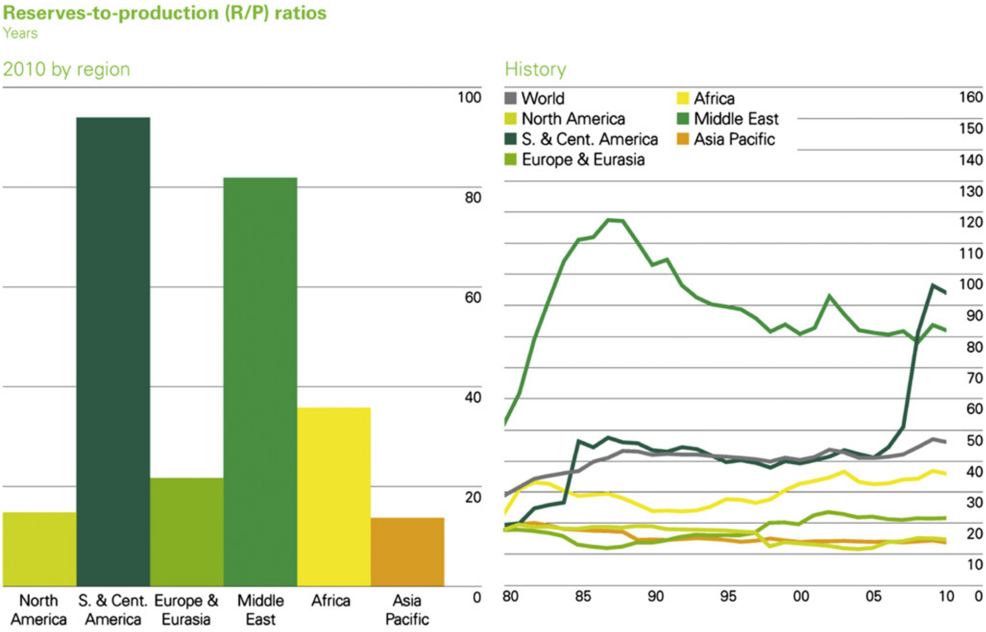
2.2. Energy resources and consumption: significant changes relative to last year

- ➢ After a world primary energy use drop by 1.1% in 2009, which followed years of consistent rise, 2010 has seen an increase of 5.6% (Fig. 1), the highest since 1973, at least partially due to at least partial recovery (especially in China and India) from the economic downturn in 2008–2009. and as the large developing countries in Asia keep improving their standard of living, In 2010:
  - ◦ China's rose by 7% (lowest since 2002), the U.S. rose by 4.8% (notably after a 5% drop in 2009) and India's by 4.2% (lowest in recent years).
  - ◦ It rose even in all other countries that have in 2008 exhibited a drop, such as the EU, Japan, and Australia [1,13,22].
  - ◦ Consumption in OECD countries grew by 3.5%, the strongest growth rate since 1984, U.S. rose by 4.8% (notably after a 5% drop in 2009), non-OECD grew by 7.5%, China's grew by 11.2%, and India's by 9.2% (highest historically).
  - ◦ A few smaller OECD countries had slight drops in energy consumption: Norway −3.7% (it is one the highest per-person consumers though), Switzerland −2.4% and Greece −2.4% [1,12,21].
- ➢ The reserves-to-production ratio (R/P) remains rather constant: ∼40 for oil (actually rose to 47 in 2010), ∼60 for gas, and 120 + for coal, and mostly rising! (Figs. 2–4). There probably exists sufficient oil and gas for this century and coal for 2 or more.



World primary energy consumption grew by 5.6% in 2010, the strongest growth since 1973. Growth was above average for oil, natural gas, coal, nuclear, hydroelectricity, as well as for renewables in power generation. Oil remains the dominant fuel (33.6% of the global total) but has lost share for 11 consecutive years. The share of coal in total energy consumption continues to rise, and the share of natural gas was the highest on record.

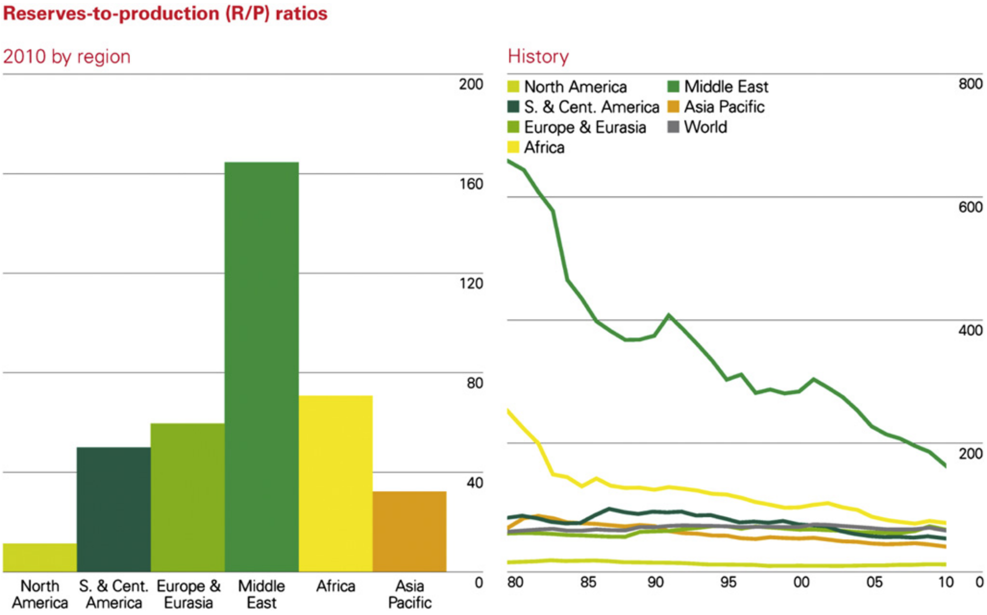
Fig. 1. World primary energy consumption 1985–2010 [1].



World proved oil reserves in 2010 were sufficient to meet 46.2 years of global production, down slightly from the 2009 R/P ratio because of a large increase in world production; global proved reserves rose slightly last year. An increase in Venezuelan official reserve estimates drove Latin America's R/P ratio to 93.9 years – the world's largest, surpassing the Middle East.

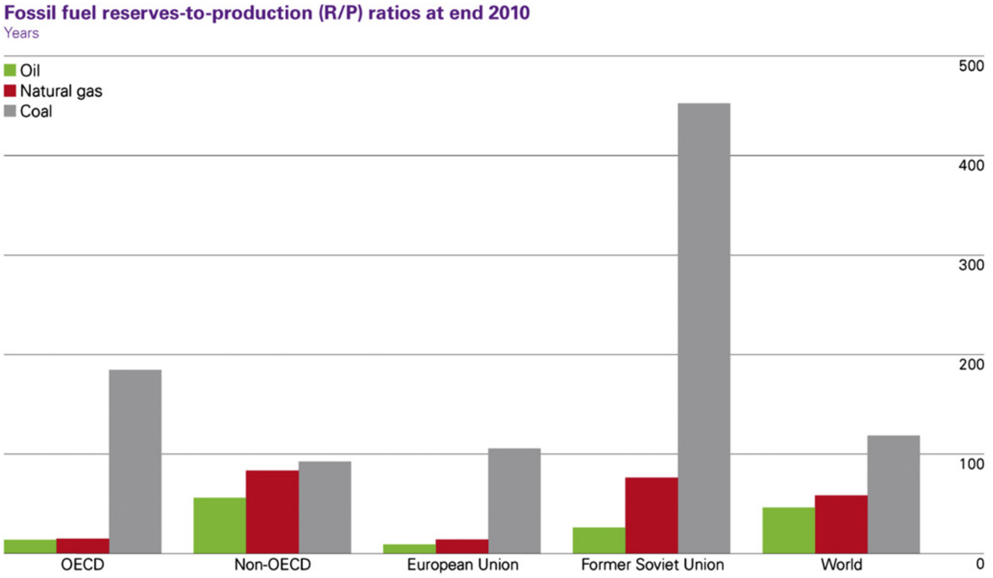
Fig. 2. The oil (Proved Reserves)-to-production ratio (R/P), 1980–2010 [1].

- Tar sands and oil shales are becoming more attractive and available in quantities probably exceeding those of conventional oil and gas; most notably large amounts of shale gas have been discovered and are increasingly being exploited (Section 3.2 below).
- Nuclear power produces ~14% of world electricity; the number of reactors is increasing very slightly [6] but the recent nuclear disaster in Japan has placed nuclear power development in at least temporary limbo, more about it in Section 3.4 below. The 2009 stoppage in the U.S. of the development of the U.S. Yucca Mountain long-term nuclear waste storage facility [23–25] is another serious setback to nuclear power development at least till a satisfactory storage alternative is found.
- Renewable energy can satisfy at least two orders of magnitude more than the world energy demand (cf. 10–12.), but negative impacts aren't inconsequential (cf [26,27]).
  - Wind, geothermal, solar, biomass and waste energies satisfy only 1.8% of global energy consumption



World natural gas proved reserves in 2010 were sufficient to meet 58.6 years of global production. R/P ratios declined for each region, driven by rising production. The Middle East once again had the highest regional R/P ratio, while Middle East and Former Soviet Union regions jointly hold 72% of the world's gas reserves.

Fig. 3. The gas (Proved Reserves)-to-production ratio (R/P), 1980–2010 [1].



Coal remains the most abundant fossil fuel by global R/P ratios, though oil and natural gas proved reserves have generally risen over time. Non-OECD countries account for 93.4% of the world's proved oil reserves; 90.9% of natural gas reserves, and 56% of coal reserves. The Middle East holds the largest share of proved oil and natural gas reserves; Europe and Eurasia hold a significant share of the world's natural gas and the largest coal reserves. Asia and North America also hold substantial coal reserves.

Fig. 4. Fossil fuels (Proved Reserves)-to-production ratio (R/P), 2010 [1].

  - Wind and solar PV (photovoltaics) are continuing their exponential growth as costs decrease and with the strong support from government incentives.
  - The renewed interest in solar-thermal power is continuing with additional installations.
  - Biomass energy has an important role but questions about its sustainable use continue increasing (cf [10,11]), placing now more focus on use of inedible biomass and algae.
  - Geothermal energy continues deserving more attention (cf [10,11,28]).
  - The occasionally deceitful and unscientific promotion of renewable energy, which usually emphasizes growth rates rather than realistic unsubsidized costs and aggregate sustainability, plays on public sentimentality, and sometimes unjustifiably dismisses and even demonizes the practical significance of the competing conventional energy sources, does much damage to the credibility of this vitally important energy source.
- While hydrogen and fuel cells continue to be valuable in the energy portfolio and deserve further development, global interest and funding are currently waning.
- The plug-in electric or hybrid car seems to be the preferred route to private transportation. Improvement of traffic management, roads, and public transit are at least as important but don't receive adequate attention. The newly discovered gas resources point to increased interest in its use as vehicular fuel, mostly in nearly-conventional internal combustion engines.

2.3. *Future electric power generation*

- A most imminent challenge is that expected demand for electricity would require during the coming two decades the installation of as much power generation capacity as was installed in the entire 20th century.
  - One 1000 MW plant every 3½ days
  - e.g., China is adding already one coal-fired 1000 MW plant each week [1].
  - The global electric energy generated growth in 2010 was a record of 5.9%.
  - After past drops, it rose again in the US by 4.3% and in EU by 3.7% and continued rising in India by 6.0%, and in China by the record 13.2%; the highest regional growth was in the Asia-Pacific region, 9.1%.
- While the plug-in hybrid electric car and electric-driven public transportation seem to be the most promising ways towards energy-efficient transportation, and may thus raise electricity demand by as much as 25% [11], smart use and grid can minimize this increase significantly with overall positive results (see Section 3.5 below).
- Because of coal abundance in the most energy consuming countries such as China, the USA, parts of Europe, India, and Australia, and the currently relatively low cost of power generation when using it, it is likely to be increasingly the main basic fuel for power generation, partially after conversion to gaseous or even liquid fuels, with the reduced emissions IGCC (Integrated gasification combined cycle) plant receiving major attention buy still making slow progress to large scale commercialization. "Clean coal" is a very worthy challenge.
- The combined cycle power generation plants (CC) are the most desirable; having efficiencies of up to about 60% even at present, less emission than other plants when using natural gas, and reasonable cost that would keep decreasing as the technology advances further. The rapidly increasing availability of gas is bound to also rapidly increase CC power generation.
- The technology and capacity for CO_2 capture in fossil fuel power generation is within reach, but for sequestration of the CO_2 is neither yet (cf [29,30]).
- Despite the unresolved problems of waste storage, proliferation risk, possible shortage of fuel for conventional reactors, and safety (that was perceived to be dormant since some time after the Chernobyl disaster in 1986 but woke us up with a vengeance in the recent nuclear disaster in Japan), nuclear power plants are likely to be constructed, at least for special needs.

  - Interest is growing in small modular LWR nuclear reactors (SMR) of 40–300 MWe capacity built offsite and shipped to site [31], but their advantages have not yet been demonstrated.
  - Following the recent nuclear disaster in Japan, future development directions and magnitudes of nuclear power are being re-examined, Japan shelved the plans for construction of 14 nuclear power plants and is focusing on strong reduction in demand combined with strong increase in renewable energy and is likely to use more gas-fired CC power generation plants, and in some countries (Germany, Switzerland) moratoria have been imposed.
  - The competition to nuclear power is also advancing, mostly from the large amounts of gas being found that can be used for the highly efficient combined cycles for power generation, and from the push for more massive use of renewable energy.
- Wind power generation will be deployed rapidly and massively, but will be limited to regions where wind is economically available, and will be limited by the extent and quality of the electricity distribution grid.
- Photovoltaic power generation will continue increasing in efficiency and decreasing in price, and being employed in many niche applications, but typically being three to five times more expensive now (unsubsidized) than other power generation methods, and also limited by the extent and quality of the electricity distribution grid, and even by availability of materials, it may not reach parity in the coming decade.
- Geothermal power generation requires significant R&D investment to reach the next level of deployment but deserves much more attention as a viable and potentially abundant renewable energy source.
- Effective storage of energy, and of power-plant-magnitude electricity in particular, are off essential importance for improving electric power generation efficiency and for incorporating intermittent electricity sources such as wind and solar; Improvements and technological advances in the distribution [32] and storage of electric power will continue and should be advanced much faster.

2.4. *Environmental and food impacts of energy*

- Global temperatures are generally rising over the past 50 years on average at an unprecedented and exponential rate, alongside with similar rises in greenhouse gas emissions; there is clear evidence of major melting of polar ice caps, glaciers, and snow caps; on a shorter time scale, however the 5-year land and ocean average temperature during the 2006–2010 temperature dropped by 0.04 °C relative to the 2001–2005 period [17], perhaps due to La Niña in the recent period (or melting of polar caps?).
- Emissions continue to grow and CO_2 concentrations had increased to over 390 ppm, or 39% above preindustrial levels, by the end of 2010 [15,16,33].
- The water and food supply are in crisis, with about 1 in 8 people lacking safe drinking water, 1 in 2 lacking access to it for sanitation and waste, and 1 in 7 being undernourished (Table 1).
- Energy and water use are strongly interdependent.
- Conversion of food to fuel endangers the food and water supply and is likely to raise their price (see some details in [10]), especially if very large quantities are used.
- The "Living Planet Index" is estimated to have declined since 1970 by about 30%, and the "Ecological Footprint", increased 2.4-fold in the same period (cf [34].): we seem to be running out of environment much faster than out of resources.

2.5. *Economic/financial implications*

- A major concern (or opportunity?) is that the price of oil (Fig. 5; Brent)[2] was generally growing very rapidly, from \$28/barrel in 2003, to \$38 in 2005 and occasionally to above \$80 in 2006 and peaking at \$147 in 2008, precipitously dropping to \$36 by the end of 2008, and then rising to \$127 by May 2011 with drops to as low as \$68, on 15 August it was \$109 (but \$87 WTI) [1,13]; Natural gas prices grew strongly in the UK and in markets indexed to oil prices (including much of the world's LNG) [35]; but prices remained weak in North America – where shale gas production continued to increase – and in continental Europe (partly due to a growing share of spot-priced deliveries) [13,14,35].
- The large fluctuations are very large, up to 4 times the stable minima
  - The peak price remains one to two orders of magnitude higher than the cost of extraction, possibly meaning that financial speculation is overwhelming supply and demand, and all technical improvements.
  - Gas and coal prices track to some extent the oil prices often even when they aren't competing fuels.
  - The combination of these effects is a severe and perhaps insurmountable barrier to the development of non-fossil-fuel energy sources such as renewable and nuclear.
- The global economic downturn in 2008 caused the stock market to drop by up to 45% (MSCI World Index [36] but the world GDP PPP per capita between 2007 and 2009 dropped by only 1.5%, the world primary energy consumption per capita dropped by 3.5%, and the CO_2 emissions dropped by 1.5% [4,13–15,37,38].
- Many countries show evidence that national GDP can be increased without increasing energy consumption.
- Globally, costing of energy resources remains inequitable, as it doesn't include subsidies, environmental impact, and other consequences [15].
- The investments in energy R&D remain much too low, less than half a percent of the monetary value of the energy use, to meet the future needs.

2.6. *Social aspects*

- Compared with the year 2010, the World population is predicted to rise 35% by 2050 [39]; This estimate is based on the current trend of slowly declining population increase rate, but some populous countries are at this time encouraging their population growth or implicitly allowing it, so the population increase may in fact be much larger. New generations consume on average more energy per capita, than their parents did.
- Many governments of the world are subsidizing energy conservation, development of renewable energy, and reduction of greenhouse gas emissions to some extent. While the intent is very positive, the outcome is not always so because political creation of artificial economies is unstable and

---

[2] Fig. 5 1. is based from 1984 on Brent crude oil prices, and until September 2010 they were within+/−±\$3/bbl of the WTI and OPEC Basket, however they became significantly higher, up to about \$20/bbl, since then.

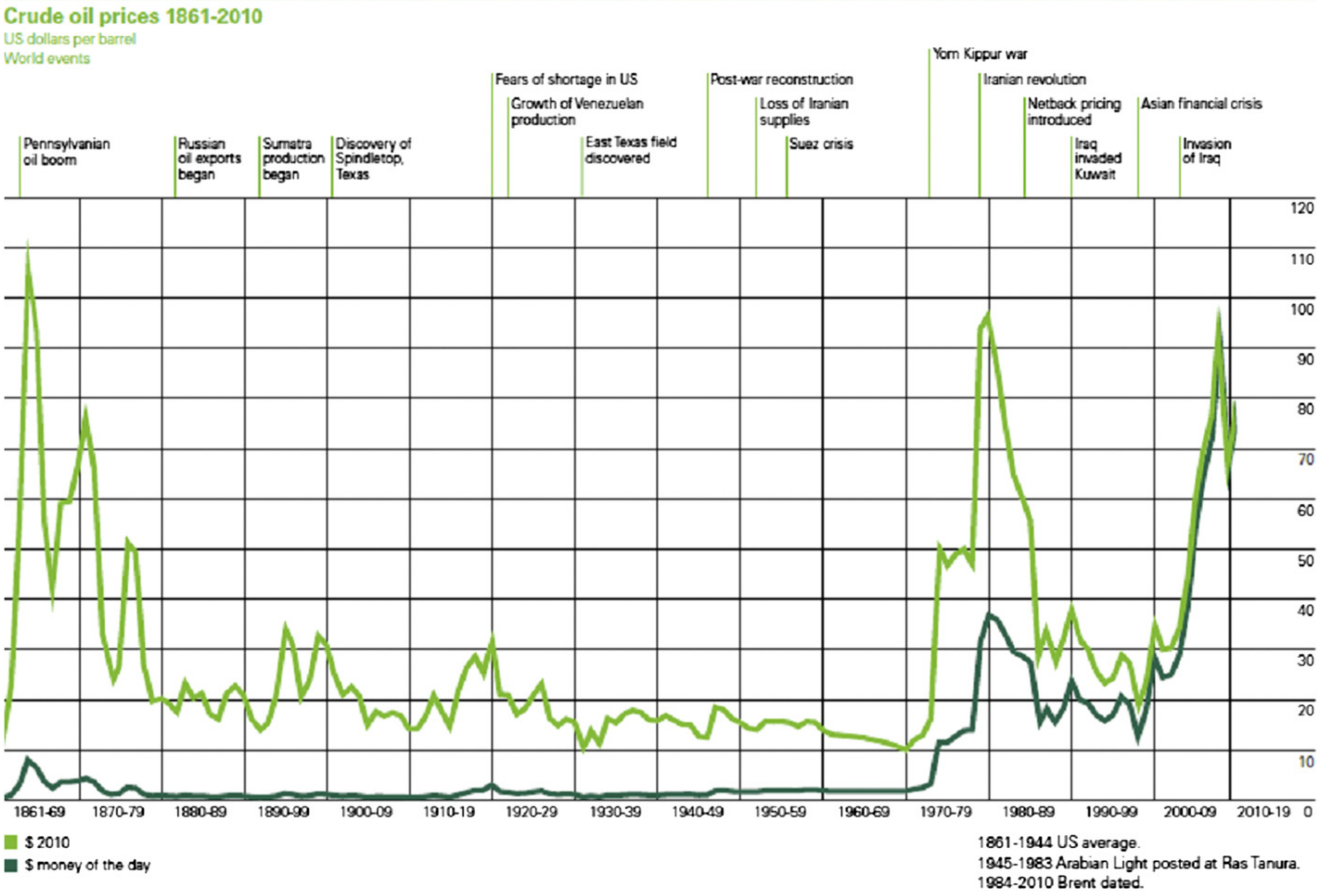


Fig. 5. Crude oil prices from 1861 till 2010 [1].

misleading, and often not well planned, especially in regard to longer term broader effects.

- There is a huge and socially ominous national disparity [1,40] in energy use demonstrated by the range of 5.7 (Eritrea) to 788.3 (Qatar) GJ/capita/year, especially significant since it has the highest populated nations at the top of energy poverty, a disparity that stymies human development of the energy-poor nations and is a trigger for conflict.
- Energy's increasingly important role in economics, accompanied by government interventions that are at times not well thought out, and by international strife and competition that ignore global sustainability threats, give rise to massive fraud by entire countries, companies, and individuals, and to breakdown of free markets, as demonstrated for example by the Enron scandal, by the financial systems' bankruptcies that led to the current economic turndown, and by the wildly fluctuating oil prices that are unrelated to supply and demand.

3. Extraordinary energy situation drivers and recent game-changers

3.1. Preface

The steady need for energy and its use are obvious, but were at different periods decelerated or accelerated due to certain circumstances. The interest in energy has received important boosts in the 1970's due to concerns about excessive and dangerous dependency on foreign oil as well as to fear of imminent depletion of fossil fuels ("Peak Oil"). These concerns were strongly compounded in the mid to late 1990-s by increasing concerns about global warming from energy-related combustion, and in the last few years by the exponentially rising energy consumption by the highly populated countries of China and India.

The last few years have also introduced some important game-changing events: (i) the apparent postponement of the threat of depletion of fossil fuels (Peak Oil"), (ii) new realization of the strong impact of economics on energy use and related emissions that arose from the recent global economy downturn, (iii) the realization of the vulnerability of nuclear power as exhibited by the recent tragic nuclear disaster in Japan, and (iv) the likely advent of an increasing replacement of gasoline or diesel fueled cars by electric ones. These events are discussed below in a little more detail.

3.2. End of fossil fuels postponed?

It is now increasingly acknowledged that the last few years have experienced the discoveries of large amounts of fossil fuels and of their associated developments in exploitation technology, that include to some extent additional already exploitable conventional oil, gas, and coal, but to large extent "unconventional" fuels led by tar (oil) sands, "extra heavy" crude oil, coal bed natural gas (CBNG),[3]

---

[3] Wells produce from relatively shallow coal seams which act as source and reservoir of the natural gas, frequently producing water alongside. The gas was formed by thermogenic alterations of coal or by biogenic action of indigenous microbes on the coal. There are some horizontally drilled CBNG wells and some that require hydraulic fracturing. At this time the use of CNG in the US is large, roughly the same as that of shale gas or non-associated gas [13].

“Tight Gas”,[4] recently shale gas and potentially shale oil, as well as large (but also very difficult) resources of methane hydrates [41]. The quantities of these unconventional fluid hydrocarbons are estimated to be significantly larger than those of the conventional ones. The vast “unconventional” hydrocarbon resources pose significantly higher negative environmental impacts than the conventional ones, and typically not only do not reduce global greenhouse gas emissions via fuel substitution, but even increase them. These problems can be alleviated with proper technology and at increased product cost, and governmental environmental protection regulation must be properly formulated and enforced prior to commercial exploitation and use. A brief description and status of the already commercially exploited tar (oil) sands and shale gas, and the largely unexploited shale oil, follows.

Tar sands (Canada prefers to call them *oil sands*) contain bitumen and are found in at least 70 countries, but so far it is thought that the largest deposits are in Canada (Alberta), which exploits them aggressively and is already producing about 1.5 million barrels of crude oil per day from them, mostly exported to the US, and planned to be increased to 3 million bbl/day by 2018 [42]. The Albertan technically recoverable reserves are estimated by the Alberta government at 171 Gbbl [42] (and by others at 280-300 Gbbl), second only to (or larger than) the optimistically estimated Saudi Arabian oil reserves (240 Gbbl) and can be 13% (or up to 23%) of total current global crude oil production. The total reserves for Alberta, including oil not recoverable using current technology, are estimated at 1700–2500 Gbbl, much higher than the total proven global oil reserves. The U.S. tar sands resource in place is estimated to be 60 to 80 billion barrels of tar sands. About 11 billion barrels of U.S. tar sands resources may ultimately be recoverable [43].

Using the current procedures, which appear to devastate at least the local environment, the operating cost of tar sand crude oil is below $30/bbl with the total cost being about $60/bbl, and at most $75/bbl [44]. Addition of costs associated with complete removal of lasting environmental impacts, removal of explicit and implicit government subsidies and fair adjudication of social challenges by indigenous populace would raise the total cost significantly [45].

Shale gas [46,47] is a natural gas, primarily methane, that is contained within low porosity, low permeability shale rock, most often found at depths of 2–4000 m below the earth surface. It is available in many countries.

Recently shale gas production in the United States rose, and keeps rising, exponentially: from 11 Gm^3 in 2000 to 138 Gm^3 in 2010, i.e. a 12.3-fold rise in 10 years, and to 23% of U.S. dry gas production. The shale gas resource is estimated to be immense [48]: for the US, the total technically recoverable natural gas resource base is 72 Tm^3 (or up to 98 Tm^3 according to some estimates) of which the shale gas resource is 24.4–49.4 Tm^3. This can imply that at the U.S. current production rates of about 0.6 Tm^3/year, the current recoverable shale gas resource estimate provides enough natural gas to supply the U.S. for the next 41–82 years (some estimates claim more than a 100 years), The total world proven reserves of natural gas are about 187 Tm^3, and technically recoverable are roughly 453 Tm^3, both largely excluding shale gas, while in a recent study of shale gas resources in 32 countries [48], theirs were estimated at 187.5 Tm^3. Since the studied countries did not yet include many high-potential ones, this estimate is much lower than the potential total. Thus, adding the identified shale gas resources in just these 32 countries to other gas resources increases total world technically recoverable gas resources by over 40% to at least 640 Tm^3. If indeed recovered, these gas resources would be sufficient for 203 years at the 2010 annual world gas consumption rate of 3.15 Tm^3.

Shale oil [43,49–53] is typically a matrix of marlstone (dolomite, calcite, quartz) that contains kerogen and bitumen. The U.S. Department of Energy estimates [43,49,53] that recoverable oil shale in the Western United States amounts to ~2000 billion barrels of oil (vs. 260 billion barrels of oil that Saudi Arabia claims to have) and is assessed at present as the richest and most geographically concentrated oil shale and tar sands resource in the world. The global reserves are estimated at 3300 billion bbl [50], sufficient to last the world for 104 years at the current oil consumption rate of 31.9 billion bbl/year.

Depletion of fuel resources depends of course not only on the magnitude of the resource but also on the demand rate. Demand is very difficult to forecast because it is affected by important objective parameters such as price and its regulation level, efficiency, technology, and government intervention to support national fuel independence or new export and employment potential. Good examples of potentially profound technology impact on “peak oil” is the ongoing transition to electric cars, that would reduce dependence on oil, in the intermediate term breakthroughs that would make renewable energy, such as solar, more competitive, or in the longer term commercialization of fusion and space power [10,54–57].

Demand is also obviously affected by price, and a powerful example of the unpredictability and presently uncontrollability of fuel price are the extreme price fluctuations that are largely unrelated to either supply and demand forces or to the actual cost of the fuel (Fig. 5 and [10–12]). These fluctuations are increasingly understood to be largely controlled by speculation inherent in the world “free” market system, which, in addition, also often gives undue significance to oil as a fuel because it indexes prices of other fuels to that of oil even when they do not compete for the same customers [35]. An example of that is linking gas price to that of oil in the Asian-Pacific markets even though oil is principally used for transportation fuels while gas serves completely different customers such as those engaged in power generation, chemicals, and heating.

The prices not only determine the direct economic impact on customer expenses preferences and habits but also severely stymie the establishment of competition from other energy sources such as renewable and nuclear.

3.3. The 2008–9 economic downturn and its influence on energy use, emissions, and quality of life

The severe economic downturn during 2008 and 2009, which has eased afterwards but is still ominously present, has had also strong effects on energy consumption and related emissions as succinctly shown in Table 2. One way to describe the downturn is by noting that within 9 months from about June 2008 till March 2009 the MSCI World Index [36] dropped by 45% (Fig. 6). Such an abrupt and major downturn shook the world economy, and alongside it obviously the energy field including consumption, emission equipment sales, environmental legislation, and planning.

Table 2 shows the values for the downturn period 2008–2010 (some also for 2011) of a number of important sustainability parameters for the world, the USA as one of the leading energy per-capita-users and CO$_2$ emitters, for the UK arbitrarily chosen as a developed country that has a very high standard of living using a much smaller amount of energy per capita than the US, the population leaders China and India that are experiencing exponential energy use growth, and in contrast the small developing countries of Croatia and Serbia. The parameters are primary energy, electricity, CO$_2$ emissions, gross domestic product purchasing

---

[4] Wells produce from regional low-porosity sandstones and carbonate reservoirs.

Table 2
Some sustainability effects of the global 2008–2009 (2010) economic downturn on the world, USA, UK, China, India, Croatia, and Serbia.

Region	USA [1,13]				UK [1,14,15,58]				China				India ([1] except where noted).			
Year/Parameter	2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011
Total PE consumption, EJ	97.14	92.28	95.70		9.00	8.52	8.75		85.42 [59] (87.08) [1]	89.87 [59] (91.59) [1]	95.25 [60] (101.83) [1]		44.46	48.00	52.42	
Energy consumption, GJ/person	319.14	300.57	308.48		146.70	136.85	139.75		64.32 [59,61]	67.33 [59,61]	71.10 [60,61]		38.98	41.49	44.68	
Electricity generated[a], TWh	4325.40	4146.60	4325.90		388.70	375.70	381.20		3433.4 [62] (3466.9) [1]	3681.2 [63] (3714.7) [1]	4228.0 [64] (4206.5) [1]		824.5	869.8	922.2	
Electricity generated, kWh/person	14,211	13,506	13,944		6336	6034	6088		2585.35 [61,62]	2758.00 [61,63]	3155.88 [61,64]		722.89	751.84	786.12	
Electricity generation capacity, GW	1010.10	1025.4 (1121.7 annual)			83.4	85.30			792.53 [62]	873.84 [63]	962.19 [64]		168.0 [68]	175.0 [68]	187.9 [68]	
Electricity generation capacity, kW/person	3.30	3.30			1.36	1.37			0.597 [61,62]	0.655 [61,63]	0.718 [61,64]		0.147	0.151	0.160	
Total CO_2 emissions, million tons	5837.97	5424.85	5632.50		525.10	473.70	491.70		6907.9 [1]	7518.5 [1]			1463.3	1591.1		
CO_2 emissions, ton/person	19.18	17.67	18.16		8.56	7.61	7.85		4.91 [1,61]	5.59 [1,61]			1.28	1.38		
GDP PPP, $/person [65]	43,250	41,735	42,551		33,860	31,985	32,173		5712	6206	6810		2781	2993	3241	
Unemployment, % [66]	4.80	8.50	9.70	8.70	5.30	5.60	7.90		4.2 [61] (9.2) [66]	4.3 [61] (9.3) [66]	4.1 [61] (4.1) [66]	(6.1) [66]	4.3	6.8	10.7	10.8
HDI [67]	0.90	0.90	0.90		0.85	0.85	0.85		0.648	0.655	0.663		0.506	0.512	0.519	
Population, millions [38]	304.38	307.01	310.23	311.32	61.35	62.26	62.61	62.32	1328.02 [61]	1334.74 [61]	1339.72 [61]		1140.57	1156.90	1,173,11	1,189,17

Region	World Average [1,14,15,40]				Croatia [1,14,15,69]				Serbia [1,14,15,70,71]			
Year/Parameter	2008	2009	2010	2011 (Jan–May)	2008	2009	2010	2011	2008	2009	2010	2011
Total PE consumption, EJ	482.96	475.73	502.49		0.414 [69]	0.407 [69]			0.66	0.60	0.63	
Energy consumption/person, GJ/person	77.44	74.74			92.20	90.65			90.04	81.97	86.18	
Electricity generated[a], TWh	20,342.00	20,135.50	21,325.10		18.90	18.46			37.38	38.32	38.34	
Electricity generated/person, kWh/person	3042	2971.19	3095		4209	4111			5.10	5.23	5.24	
Electricity generation capacity, GW	4711.58				4.00 [69]	4.12 [69]			7.1[b]	7.1[b]	7.1[b]	
Electricity generation capacity, kW/person	0.70				0.89	0.92			0.97	0.97	0.97	
Total CO_2 emissions, million ton	30,400.00	30,313.00			22.33	21.27			51.8 [71]	50.1 [71]		
CO_2 emissions, ton/person	4.54	4.47			4.97	4.74			7.07 [71]	6.84 [71]		
GDP-PPP/person (2005 US$)	9680	9508	9869		17,300	16271	16085		10,234	9956	10,174	
Unemployment, % [66]	8.20	8.70	8.80		11.1	13.7	19.2	17.5	14.4	16.90	20.00	22.9
HDI [64]	0.598 (2005)	0.62			0.766	0.765	0.767		0.73	0.73	0.74	
Population, millions [38]	6688.00	6776.92	6890.65	6917.41	4.49	4.49	4.49	4.48	7.33	7.32	7.31	7.31

---

[a] Note that world electricity consumption was 18,603.00, implying an 8.5% loss.

[b] data from [70]., EIA shows 8.721.

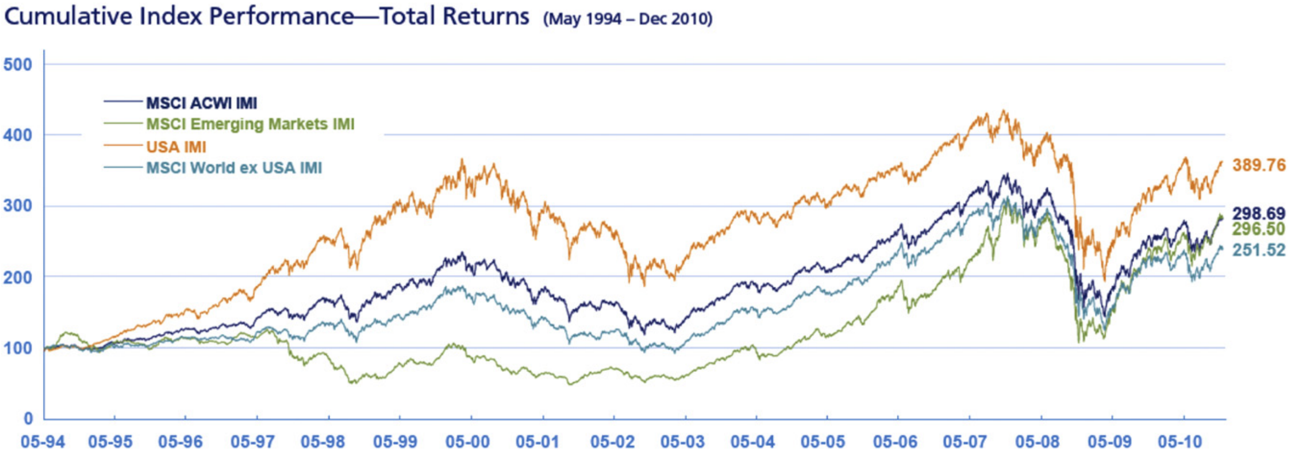


Fig. 6. Stock market comprehensive indeces changes with time, the discussion in the paper relates to the MSCI ACWMI IMI (the MSCI all country world investable market index, contains 45 countries) [36].

power party (GDP-PPP), the Human Development Index (HDI, [65]) that combines indicators of income, education and health into a single index, unemployment, and population. Per-capita values are included to shift the focus of development from national income accounting to people-centered policies and to emphasize the importance of individual human responsibility.

Table 3 shows the changes in these sustainability metrics during that downturn period. While plain examination of raw data trends is not likely to fully capture the nature of the relationship between the global economics and the sustainability and other data shown in Table 2, we nevertheless can draw a few useful conclusions:

- For the per-person metrics of primary energy consumption, electricity generation, CO_2 emissions, and GDP-PPP, the downturn effects are entirely different for the regional group composed of the USA, the European countries, ad entire world on the one side, and the regional group composed of China and India. In the first group these metrics have exhibited a decline from 2008 to 2009 (and have then returned close to the 2008 levels in 2010); On the contrary, for the second group, China and India, all these metrics exhibited a continuing rise.
- Notably, the 2008–2009 drop in per-person CO_2 emissions was in most cases much higher than that in energy consumption, partially explained by probable switching to more efficient methods of transportation and energy conversion.
- From 2008 to 2009 unemployment increased everywhere and with the exception of China[5] keeps increasing thereafter despite some economic recovery; this can be explained by the fact that employers remain wary of the economic situation, probably for good reason, and because some employment lines were eliminated during the economic downturn and have not been replaced.
- The Human Development Index (HDI) remain unaffected in the USA and all the considered European countries regardless of development level, but is rising in China, India and the World; these observations are explainable by the fact that people in developed countries have more of a personal and governmental welfare cushion that at least temporarily maintains the HDI despite such economic trends, and by the fact that people in developing countries started with a much lower HDI, and especially in the highly populated China and India the economic downturn was of a somewhat shorter and lesser effect.
- It is also interesting to confirm the weak dependence of HDI on per-capita GDP/PPP and on unemployment rate;
- Huge rises in unemployment rate seemed to have no effect on HDI, despite the fact that HDI includes income (as Gross National Income, GNI as one of its main metrics; perhaps existing welfare systems supplied adequate income to the unemployed during the economic downturn, or, flippantly, maybe the metrics for health and education improved with unemployment…
- When considering these facts it is important to keep in mind, however, that while HDI is widely used, especially by the UN, it is certainly not a perfect metric of quality of life [72–74].

The main conclusions from this major economic downturn event used here as a global experiment, are that its biggest impact was on:

I. decreasing per-person energy consumption and CO_2 emissions in the USA, the considered European countries, and the world, in all of which the GDP dropped too, but in the large rapidly-developing India and China where the GDP continued rising despite the global economic downturn they continued rising at a nearly undiminished rate,
II. increasing unemployment that continues despite some economic recovery.

3.4. The nuclear disaster in Japan and nuclear power future

Past reviews by the author [10–12] have described nuclear power generation statistics, the advantages based on low GHG emissions and fossil fuel independence, but also the remaining unresolved concerns with radioactive waste (especially the long life, dangerous up to a million years) disposition, with mounting proliferation risks, and to some extent with safety, considerations leading in balance to very slow growth of nuclear power. Since no major nuclear accidents occurred for about 25 years since the massive 1986 disaster in Chernobyl, and since the 104 US reactors operated at a remarkable capacity factor of 91.2% (much higher than those of fossil fuel power plants), safety was increasingly

---

[5] The accuracy of unemployment numbers given by China is unclear.

Table 3
Some sustainability indicator changes (%) due to the 2008-2009 economic downturn.

	World	USA	UK	Serbia	Croatia	China	India
TPES/person	−3.5	−5.6	−7.7	−9.0	−1.7	+4.7	+6.4
Electricity/person	−2.3	−5.0	−5.1	+2.5	−2.3	+6.7	+4.0
CO_2/person	−1.5	−7.9	−11.1	−2.8	−4.9	+6.3	+7.8
GDP-PPP/person	−1.8	−3.5	−5.5	−2.7	−5.9	+8.6	+6.7
Unemployment	+6.1	+77.1	+5.7	+17.4	+23.4	+2.4	+58.1
(2008–2010)	(+7.3)	(+102.1)	(+49.1)	(+38.9)	(+73.0)	(−2.4)	(+148.8)
HDI	∼+3.0	0.0	0.0	0.0	−0.0	+1.1	+1.2

considered to b**e** a relatively low risk problem. In fact, Japan itself has devoted vast resources to persuade the Japanese public of the safety and necessity of nuclear power, including the use of government-mandated school textbooks with friendly views of nuclear power, all resulting in a widespread adoption of what is now termed the “safety myth” that Japan’s nuclear power plants were absolutely safe.

The recent and continuing Fukushima disaster, in which 4 reactors were destroyed, in three of which the fuel cores melted, and the 2 remaining undamaged ones in this cluster probably inoperable because of the radiation from the damaged 4 units, causing very dangerous radioactive emissions to soil, air and water to very large distances, and that had severe impacts on the Japanese and world economies, caused, justifiably, a major reconsideration of the future of nuclear power. The cleanup is expected to take decades [75]. Some immediate consequences ranged so far from a re-examination of all US and EU nuclear reactors, shelving by Japan of a 2010 goal to build 14 nuclear reactors over the next 20 years [76], and to complete moratoria on nuclear power in Germany and Switzerland.

Even when considering the extremely severe and low probability simultaneous coincidence of a scale 9 earthquake (nuclear plants are designed for much lower earthquake levels) with a 10–15 m high Tsunami, both at the large reactor concentration (6 units in close vicinity) Fukushima Daiichi site, as well as on the weaknesses of these 40-year old BWR type reactors, it is clear that the overall damage and long-term consequences and fear would have been incomparably smaller if these 6 power plants were fossil-fuel fired, or using some types of renewable energy such as solar or wind.

Considering the persistent energy demand growth, practically each energy source is likely to be exploited, including nuclear energy with which about half a century of satisfactory power production was achieved, but to avert the unacceptable risks demonstrated by the Chernobyl and the recent Fukushima accidents it would be wise to wait till a new generation of proven nuclear reactors is available that can withstand extreme natural upheavals, that: produce only safe-level short-term manageable radioactive waste, that are proliferation proof, and, practically incredibly, at the same time also produce electricity at a competitive price when considering all externalities. Designing all nuclear power plants to withstand catastrophic freak accidents like Fukushima’s (or worse) would probably make the power produced uncompetitive, and yet designing them based on some below-certainty risk probability forecast maintains the risk of another major disaster. Designs combining all these desirable features would go beyond the currently planned Generation IV reactors [77,78], and may take more than 50 years to materialize. It is also good to keep in mind that during that long time the competition for power generation would not remain still, and breakthroughs are likely to take place that may further postpone nuclear power acceptability.

In addition to technologically reduce risk probability, it is critically important to establish and unfailingly maintain an effective, comprehensive and fast-reacting crisis management system, which also includes forecasting, monitoring and adequate evacuation methods. None of the major nuclear accidents had this in place and it clearly appears that the communications and coordination between those responsible were, at least at the critical beginning of an accident, woefully bad.

Lastly, a consistent iniquitous trait of all major nuclear accidents, Three Mile Island in the US, Chernobyl in the USSR, and Monju and Fukushima in Japan, is the coverup and outright lies to the public by the plant owners and the authorities. While the justification given by them for such behavior is protection of the public from panic that may significantly increase the accident consequences, it breeds distrust both in those responsible and in the technology. Apparently, a combination of ethics and regulation must be applied to information dissemination in such disasters.

3.5. Market entry of electric cars [79–81]

Plug-in electric vehicles (PEVs) are a very attractive option relative to conventional ones for many reasons, including usually high overall energy efficiency, no local emissions and typically reduced ones overall,[6] reduced dependence on oil imports, quietness, and low operating cost and maintenance. The electricity for charging the batteries can be generated by fossil, nuclear or renewable energy power plants. Apart from the input energy, the power plant efficiency should always also consider the embodied energy, and for fossil and nuclear power plants must also include the fuel extraction and preparation and any environmental restoration energy, and for all these reasons obviously varies widely. The overall energy efficiency is a product of that electricity generation efficiency, electricity transmission efficiency, battery charging and discharging efficiency, the battery-to-wheels efficiency that is typically about 75% [83] (or possibly somewhat higher), and the extent to which braking and even suspension mechanical energies are converted back to electricity. The latter regenerative processes are of advantage to PEV efficiency, and the actual improvement depends on the type of driving and vehicles but is estimated to be about 10–25%

PEVs were invented already in the 19th century, but a major deficiency that is holding back their massive use is the short driving range, limited by the batteries, as well as the currently high cost of batteries if the range is made comparable to that of conventional vehicles. A combination of battery technology and cost improvements, with prospects for further improvements in the relatively near future, alongside with government subsidies of one type or another, made PEVs a major target for vehicle development in the world.

---

[6] It of course depends on the power generation and its emissions mitigation method; Dirty use of coal may actually increase CO2 emissions when using PEVs [82], but it still may reduce overall emissions, such as organic compounds and ozone generation that are created by IC engines.

The operating range of commercial PEVs is still much shorter than cars driven by internal combustion engines (a battery electric vehicle that approaches affordability, with generous subsidies, has a driving range of about 100–160 km on a full charge), the infrastructure for charging the batteries is still weak, and PEVs cost more than conventional cars of similar size, but they are nevertheless appearing in the market and being sold in increasing numbers. Major commercial models are the General Motors Corporation 2011 Chevrolet Volt and the Nissan Corporation 2011 LEAF, these in addition to hybrid vehicles made by many manufacturers but that still rely partly on conventional fuels. The U.S. declared a goal of putting one million plug-in electric vehicles on the road by 2015, and some policies to encourage this have been established by federal, state, and local governments. For example, the U.S. government currently grants a $7500 federal income tax credit for purchasing a qualified PEV. Virtually all major vehicle manufacturers and several start-up companies are offering or planning to offer a PEV for sale soon. In addition to the issues of cost and range, the extent of market capture will also depend on the extent to which any PEV advantages, primarily emissions but also low noise, will be monetized.

In view of the imminent global need for huge and rapid increase in electric power generation (mentioned in Section 2.3 above), we address here briefly the perceived impact of the additional power demand for satisfying a large transition to PEVs.

Following the extremely simplistic and rough estimation briefly mentioned in [11], there are about 650 million cars in the world, and if each is made electric and uses 20 kWh electricity/day (average world value), we would need an additional electricity amount of 4.745 PWh/year. Assuming about 10% transmission losses and 20% battery charging losses, this needs generation of about 6.3 PWh/year. This would increase the current total global electricity production demand of 21.3 PWh/year by about 30%. This of course is an extremely high upper bound, since it is impossible to convert the entire car fleet to plug-in drive, and since it does not consider electricity savings that can be obtained by proper timing of battery charging that would coincide with periods of low electricity demand, and of the electricity storage capacity that all these cars would provide and thereby raise electric generation efficiency.

Electric grids in most countries, including the U.S., are extremely deficient even without this larger and different load, being a part of a decaying infrastructure on the one hand, and of severe insufficiency in developing countries on the other. To make the mentioned improvements in PEV-related electricity supply practically possible, the grid will have to be made much more robust, extensive and smarter in most countries.

Many PEV owners would be expected and encouraged to charge their vehicles over night when many power utilities operate at below 50% capacity, when electricity is the least expensive to generate. PEV battery charging during such periods may thus not require the construction of additional power generation capacity, and would increase the efficiency and cost effectiveness of the existing one. A recent study for the U.S. concluded that sufficient excess capacity exists to charge between the hours of 6 p.m. and 6 a.m. approximately 84% of the nation's cars, pickup trucks, and SUVs (198 million) or 73% of the light duty fleet (about 217 million vehicles) for a daily drive of 33 miles on average [80].

PEVs are also seen as large electricity storage potential for utilities when used in a "vehicle-to-grid" (V2G) mode in which PEVs charged during off-peak hours can then dispatch some electricity back to the grid during peak load, thus reducing the need for operating the utilities' expensive peaking systems and reducing the need for capital investment to meet an increasing electric load growth, and consequently potentially reducing electric rates to customers participating in V2G.

The important needed grid smartness is, for example, to automatically time battery charging to off-peak lower price periods and V2G operations to the utility need.

Instead of home recharging, appealing alternative business models for public recharging include the battery-switching approach and quick-charging kiosks that leave batteries in place.

Investment into an extensive, robust, low-loss and smart grid is a well-recognized worldwide necessity for many reasons beside the use of electric vehicles. Examination of the above-presented information indicates that minor modifications to such a grid can allow a very large increase in the number of PEV's without much of an increase in power generation capacity.

Summing briefly, in view of the current advances, both still in dependence on battery development and monetization of the energy and environmental benefits, massive introduction of electric vehicles is likely to start soon, with very positive effects on reducing energy consumption and emissions, noise, and vehicle maintenance. The use of extensive, efficient and smart grids can provide the electricity required for PEV's with minimal increase in overall electric power generation.

4. A reminder of Africa, a forthcoming global energy development frontier

Most global energy reviews focus on the largest energy users or environmental transgressors, usually ignoring commensurate mention and analysis of Africa. A recent international forum at the University of Pennsylvania Wharton Business School [84] had asked me to chair a panel of experts to discuss the African energy situation and prospects and it is telling that we have titled this panel "The energy paradox: Addressing power needs in Africa's resource-rich countries". While the United Nations states that "the African continent remains by and large marginalized in the world economy, with over half of its population living under US$1 a day per person. If the major Millennium Development Goal of reducing poverty by half by the year 2015 is to be achieved in Africa, major policy shifts are required, at national and international levels, to boost growth and development in the region", Africa is rich in energy resources relative to most of the world. These resources are currently topped by biomass and include also fossil fuels, nuclear fuels (Uranium, Thorium, etc.), hydropower, solar and wind energy, geothermal energy, as well as potential for various types of marine energy. While the energy resources aren't distributed uniformly, their abundance is somewhat maintained by compensating a regional deficiency in some type of resource with abundance of some other. For example, whereas Saharan Africa has minimal biomass resources relative to Sub-Saharan, it then has much higher solar and wind resources, with the former deemed capable of satisfying the electricity needs not only of the Middle-East/North-African (MENA) region but even of all of Europe's [85].

The above-cited paradox arises from the fact that despite these resources and a good base of educated people, and even taking into consideration the extreme disparity between the bottom-to-top African countries, Africa on average shows up very low at the global scale with respect to some of the most critical energy-related metrics. A brief discussion of this situation, with emphasis on the large latent potential of Africa in energy-related matter, follows.

Some key energy data about Africa are shown in Tables 4–6. Table 4 summarizes some important energy-related sustainability indicators, including energy use, economics, and CO_2 emissions, while Table 5 compares some of these indicators with world averages as well as with those of the OECD, Asia, and Latin America. Further comparisons, with the 6 countries characterized in Table 2, can be made: they demonstrate, importantly, that Africa has an extremely low consumption of electricity per person, which is

Table 4
Some important energy-related sustainability indicators for Africa, 2008 [14].

Basic indicators		Compound indicators	
Population (million)	984.25	**TPES/Population** (toe/person)	0.67
GDP (billion year 2000 US$)	876.24	**TPES/GDP** (toe/year 2000 US k$)	0.75
GDP (PPP) (billion year 2000 US$)	2499.13	**TPES/GDP (PPP)** (toe/year 2000 US k$)	0.26
Energy Production (Mtoe)	1160.87	**Electricity Consumption/Population** (kWh/person)	571
Net Imports (Mtoe)	−486.93	**CO_2/TPES** (t CO_2/toe)	1.36
TPES (Mtoe)	655.44	**CO2/Population** (t CO_2/person)	0.90
Electricity Consumption[a] (TWh)	562.11	**CO_2/GDP** (kg CO_2/year 2000 US$)	1.02
CO_2 Emissions[b] (Mt of CO_2)	889.93	**CO_2/GDP (PPP)** (kg CO_2/year 2000 US$)	0.36

[a] Gross production + imports − exports − losses.
[b] From fuel combustion only.

a barrier for both human and industrial/commercial development (also see [87]), and has very high energy consumption relative to GDP, indicating poorest economic efficiency of energy use.

Table 6 shows the energy use by source, with coal + peat at 16.6%, crude oil 21%, natural gas 12.4%, nuclear 0.5%, and among renewables, combustion of biomass and waste at an impressive 47% share of the total, hydropower with a minuscule share of 1.2%, and other renewable energies at a disappointing negligible share of 0.17%.

Table 7 shows the R/P ratio for major resources of energy in Africa (except solar, discussed further below), and for comparison, in the world. Based on these data, Africa has an R/P for fossil fuels that is similar to that of the world, but is likely to become much larger even at the current state of technology if practical conditions for exploration and use are made more amenable. What stands out in this table is the huge unexploited potential for use of hydropower and biomass.

The “technically exploitable” capability of hydropower in Africa is currently estimated to be about 19-fold of the present use [88]. The economically exploitable ratio is obviously lower, and depends also on prevailing energy prices, local regulations and costs, and proper accounting for all relevant externalities.

Even much more impressive is the huge unexploited biomass energy resource (also see 89,90). Although 47% of Africa’s energy already comes from biomass, Table 7 shows that the estimated overall potential is vastly (531-fold at least) higher, even when considering use of only inedible biomass and a combination of abandoned agricultural land, degraded land and other marginal land that does not have competing uses. After easily satisfying its entire energy needs, the realization of this potential could serve for large export of either fuel or electricity and for significantly improving Africa’s economic and social condition. Biomass use has significant environmental and social impacts that must be carefully taken into account. Such two orders of magnitude increases in biomass cultivation and use requires thorough conscientious planning and execution, with sustainability imperatives [93], accompanied by major investments.

The solar power generation potential of Africa is stunningly large [94,95]. Assuming the use of concentrating solar power, Trieb et al’s careful analysis ([85], that considers only suitable and unused land areas with insolations above 2000 kWh/m^2/year, and current CSP parabolic trough technology), shows the potential for generating 1,458,379 TWh/year, about half of the world’s total potential of 2,945,926 TWh/year. The potential of even just the 5 North African countries (Morocco, Algeria, Tunisia, Libya and Egypt) considered in that study for the DESERTEC project to supply electricity to Europe, is 407,991 TWh/year. Keeping in mind that Africa’s current electricity consumption is 562 TWh/year and the world’s 21,300 TWh/year (Table 4), Africa’s solar power could provide 2595-fold of its own electricity demand, and notably, 68-fold the world’s electricity demand.

For the past decade or so, increasing consideration has been given to the DESERTEC project where the electricity transmission distances from North Africa to southern Europe are less than 500 km. Similarly, CSP can be transmitted inside Africa, from suitable less sunny regions to those with higher demand. While Saharan Africa is prominently suitable because of low land use and high insolation, it is estimated to have a CSP potential of only about 1/3 of Africa’s total, because of the many sub-Saharan African countries that are very suitable for CSP including Sudan, Chad, Niger, Mali, Mauritania, and Senegal in the northern part, and Angola, Namibia, and South Africa in the southern part. Consequently, power transmission distances for intra-African CSP could be relatively short too, perhaps typically 500-3000 km.

Summing, Africa has the potential of supplying its own energy demand, significantly increasing electricity use for domestic, commercial, industrial and transport uses, as well as exporting global-capacity energy to the world.

It is a common consensus feeling (repeated frequently during the Africa Business Forum [84]) that the main reason for the stated paradox and the main obstacle for holding back the human and energy resource-rich African energy development is a combination of difficulties of doing business due to the many unsatisfactory government systems, poor planning, management and infrastructure, and risk due to these reasons and to high levels of lawlessness. This creates a very difficult and unpredictable business environment, and therefore restricts investment in just about anything, including the potentially highly lucrative energy field. Even the R/*P* values for fossil fuels can most probably be much higher than shown under current circumstance and can be attained only in a proper business environment that is also based on sustainability.

Table 5
Comparison of energy intensities per person of Africa with some other world regions [14].

	TPES, (toe/person)	TPES/GDP, (toe/year 2000 US k$)	TPES/(GDP-PPP) (toe/year 2000 US k$)	Electricity consumption, (kWh/person)
OECD	4.56	0.18	0.16	8486
Latin America	1.24	0.28	0.15	1956
Asia	0.65	0.58	0.16	719
Africa	**0.67**	**0.75**	**0.26**	**571**
World	1.83	0.3	0.19	2782

Table 6
2008 Energy Balance for Africa, (ktoe, LHV) [86].

Supply and consumption	Coal and peat	Crude oil	Oil products	Gas	Nuclear	Hydro	Geo-thermal, solar, etc.	Combustible renewables and waste	Heat	Total
Production	145,588	511,579	0	176,407	3389	8165	1191	314,544	10	**1,160,872**
Imports	7037	40,356	50,491	4949	0	0	0	1	0	**106,061**
Exports (58%)	−40,941	−410,650	−40,981	−97,624	0	0	0	−288	0	**−592,987**
Net Internal use	111,684	141,285	9510	83,732	3389	8165	1191	314,256	10	**673,222**

Table 7
R/P (proven reserves to production) ratio, Africa in comparison to the Wold [1].

	Oil	Gas	Coal	Hydro	Biomass
Africa	37	72	118	Up to 12 [88] or 19 [89]	531[a] [88] or much more [91]
World	46.2	58.6	118	388 [90]	2–6 [89,92]

[a] Technical potential, just for lignocellulosic biomass.

5. Some recent Energy R&D budgets and trends

5.1. An unofficial review of the U.S. administration's energy R&D budgets and trends [96]

While 2009 was an important year for energy in the U.S. because it was the first after the Democrat Party took over from the Republicans (see USDOE budget comments in the author's paper [11]), the USDOE budget request for 2012, the presidential election year, allows some examination of the administration's ongoing goals as adjusted by government experience and pressing competition with other budgetary needs. The latter are dictated to large extent by the highest-ever monumental national debt of $ 14,592,242,215,641.90 (∼$1.46 × 10^{13}, 17 August, 2011 [97]), that rose by 38,0% since the 2008 elections, or 32.4% in 2008 dollars when considering a. 4% total inflation CPI.

In this section I briefly summarize the U.S. Department of Energy (DOE) fiscal year 2012 budget request to the US Congress that pertains to the energy and environment area and discuss changes relative to past years. Such a request is an indicator of the administration's wishes and directions but is subject to Congress approval. Under the current Republican Party majority and national debt circumstances, significantly exacerbated by the very recent disagreement between the administration and Congress about the national debt limit, which resulted in the downgrading by Standard & Poor's of the US credit rating that is currently creating significant downturn and instability the world financial markets, the 2012 budget request is likely to be significantly reduced.

Some of the budget request statements here are taken verbatim from the DOE budget documents, but the commentary is entirely the author's and does not represent, nor is sanctioned by, government. The requested budget is stated to support the President's commitment to the challenges of innovation leadership, and to generate 80% of U.S. electricity from clean sources by 2035, reduce dependence on oil, accelerate the transition to a clean energy economy and promote economic competitiveness, and clean up the wastes of the nuclear legacy (continue cleaning up, with no clear end, I add).

The R&D budgets, their changes and some of my clarifications are briefly summarized in Table 3 of [12], and because of the strong likelihood that the proposed budget will have to be significantly revised after Congress and Senate review by the end of 2011, it is not repeated here. Instead, a general discussion characterizing the budget request highlights and changes relative to past years are presented.

$550 million are requested for the Advanced Research Projects Agency-Energy (ARPA-E [98],) to continue support for the promising early-stage research projects that could deliver what the DOE calls "game-changing" clean energy technologies, and $146 million to support the three existing Energy Innovation Hubs and to establish three new Hubs in the areas of batteries and energy storage; smart grid technologies and systems; and critical materials, and $100 million to continue supporting 46 Energy Frontier Research Centers started in 2009 (also see [11]).

Originally the new administration proposed to use a cap-and-trade process, planning to reduce the U.S. greenhouse gas emissions by 14% under the 2005 baseline by the year 2020, and by 83% below the 2005 baseline by 2050 (similar to the IPCC proposal). This proposal met strong opposition in Congress and is currently at best in limbo.

The remaining information presented here about the budgets must be prefaced with a statement that examination of governmental and institutional aims and budgets is very difficult, in part because of duplication and overlap of programs, and frequent changes across them, and all the numbers given here are thus not always precise.

Out of the USDOE energy R&D part, the programs of energy efficiency and renewable energy continues to increase their dominance to 67% (from 58% in 2010, 53% in 2009 and 48% in 2008) relative to those of fossil energy (dropped to 9%), and civilian nuclear energy (dropped to 18%). The only drops in the energy efficiency and renewable energy category are in hydrogen and fuel cell technology, −69%, and water power, −21%.

A few more interesting details are that biomass and biorefinery systems R&D appears to move strongly away from food-to-fuel conversion to cellulosic ethanol, and continuing recognition of the importance of geothermal energy (+135%) and of electricity delivery and energy reliability (transmission, smart grid, etc., +41%).

The severe drop of 44% in fossil fuel energy, including the clean coal program with carbon capture and sequestration should be of great national and global concern because of the abundance of coal and its leading role in power generation in China, India and the US, and its leading contribution to global warming. What can be interpreted as an important public message is that USDOE Secretary Chu's speech and presentation introducing the 2012 budget request [99] does not mention the word coal while it does mention renewable energy and efficiency frequently and mentions nuclear power advancement by an additional $36 billion in loan guarantee authority, and small modular reactors development. It is a big question whether industry can take these fossil-fuel tasks over, relying on the commercial potential of associated processes and technologies. Furthermore, the USDOE is also catching up very slowly to the significant R&D needs for the huge shale gas resources recently discovered in the US and available in other countries too.

About nuclear energy, the USDOE states that "the aim of the nuclear program is to enable nuclear energy to be used as a safe, advanced, cost-effective source of reliable energy that will help address climate change by reducing greenhouse gas emissions", with a safety focus on proliferation resistance and on development of advanced reactor designs and technologies, including small scale standard design modular reactors (<300 MWe, based on LWR principles), but the budget was slightly reduced. All funding for development of the Yucca Mountain facility for permanent geologic storage site for spent nuclear fuel and high-level radioactive waste nuclear waste has been eliminated already in 2009 (after the US spent about $13.5 billion (2007 value) over the 26 years of the project). The absence of prospects for availability of such a facility is a significant blow to global nuclear power development since the world has no alternate methods for storing the growing amount of long-lived radioactive waste, especially that generated by nuclear power generation. A Blue-Ribbon Commission was established and charged with providing recommendations about long-term nuclear waste storage, and their first report to President Obama was due in July 2011.

The FY 2012 budget request includes $300 million in credit subsidies to support approximately $3-4 billion in various energy projects, and $36 billion in loan guarantee authority to help jumpstart the domestic nuclear industry, as well as additional investments in the research and development of advanced nuclear technologies, including small modular reactors. The loan guarantee authority is to support 6 to 8 nuclear power projects resulting in the construction of anywhere from 9 to 13 new reactors. The nuclear jumpstart budget request was prepared prior to the Fukushima nuclear disaster and is likely to be reduced or redirected to safety assurance of the existing nuclear reactor stock.

The DOE's Science programs (nuclear physics including major facilities, materials, nanoscience, hydrogen, advanced computing) was significantly increased by 9.1%, with the only decrease being in the nuclear fusion program (−4.1%).

Based in large part on the USDOE budget trends, Table 8 very qualitatively summarizes the author's view of the promise and potential of the major energy R&D areas, foreseen improvements and their time scale, and trends in the U.S. government funding.

A very important observation that needs re-emphasis is that while the overall USDOE energy budget is raised by only a few percent each year, it is remarkable that it even holds its own in view of the staggering US national deficit, which also explains why the significant increases in allocations to renewables and energy conservation are associated with commensurate significant reductions in fossil energy development.

While the USDOE oversees most of the moneys related to energy, there are some additional but smaller amounts within other government domains such as the EPA (Environmental Protection Agency), Department of Transportation, Department of Housing and Urban Development, the National Science Foundation, and the National Aeronautics and Space Administration (NASA, it overall budget request for 2012 is 18.7 billion dollars, significantly higher than that of the energy-related USDOE one).

An educational endnote to the US energy budget discussion is that environmentally unsustainable 60 years of nuclear weapons

Table 8
The author's qualitative assessment of promising research directions and their U.S. Government funding trend (based on the proposed 2012 annual budget).

Direction	Potential	Foreseen improvement	Time scale, years	2012 Government funding trend
Conservation	★★★+	50% of use	Ongoing	☺☺
Buildings energy	★	20% reduction by 2020	8?	☺☺
Transportation	★★★+	50% of use; 120 g CO_2/km by 2012; 1 million electric cars by 2015[a]	3–20	☺☺
Hydro power	★	Small hydro, pumped storage, reduction of environmental harm	ongoing	☹☹☹
Biomass	★★+	30% U.S. energy; cellulosic ethanol at S2.76/GGE** in 2012	4–40	☹
Wind	★★★	2.5c/kWh, 15% of electricity	1–6	☺☺
Solar PV	★★★+	Competitive price: S1/WDC, 4-5c/kWh	8+	☺☺
Solar thermal	★★★	Competitive price: 4-5c/kWh	8+	☺
Geothermal (deep)	★★	Expand resource: exploration and deep drilling	20	☺
Hydrogen	★★	Affordable transport fuel	15	☹☹
Fossil fuel power	★★	67–75% efficiency, ~0 emission	6–15	☹☹
Oil and Gas	★+	Exploration, recovery, transportation	3–15	☹☹☹
Coal	★+	Exploration, recovery, transportation, conversion	8	☹☹
Energy Storage	★★★+	Cost, weight and volume reduction	5–12	☺
Electricity transmission	★★★	Grid expansion, smart grid, loss reduction	10	☺☺
Global warming	★★	0 CO_2	10–15	☺
Fuel cells	★+	60% + efficiency; order of magnitude price reduction, 6 kW/gr Pt-type catalyst in 2012	7	☹☹
Micropower	★★★	Cost, market penetration	7+	☺
Superconductivity	★★★	Order of magnitude	30+	☹☹
Nuclear fission	★	Manageable wastes, no proliferation, safety: Gen IV, thorough review	10	☹
Nuclear fusion	★★★	Feasibility	35+	☺
Space power	★★★+?	Competitiveness	50+	☹☹☹

**GGE: Gallon Gasoline Equivalent.

☺: Increased; ☹: decreased.

[a] The US has about 260 million highway vehicles.

production and government-sponsored nuclear energy research resulted in a long-term annual management and remediation ("cleanup of the environmental legacy") expenditure that is now at 6.3 billion dollars a year (with no sign of ending any time soon), larger than the entire annual "Energy and Environment" R&D budget of 4.8 billion dollars, and separately of the energy science R&D program netting specifically for energy about 5 billion dollars. It consummately demonstrates how past unsustainable activities penalize progress to the future.

5.2. The EU (European Union)

The EU (that is the largest importer and second largest consumer of energy in the world) 7th Framework Programme (2007–2013) had a 50% increase in the energy area (energy, environment, transportation) over the 6th program, and is annually about $1.68 billion plus $0.77 billion for the nuclear research in Euratom [100] for a total of $2.45 billion/year (at 1 Euro = 1.40 US$). Some of the goals for the year 2020 include a 20% reduction of energy use, a 20% share to renewables, and all new coal power plants being of the CCS type. To accomplish this, he EU Commission presented in 2007 a strategic plan to accelerate the development and deployment of cost-effective low carbon technologies for "fight against climate change, security of energy supply and competitiveness of European companies" with a funding of €3 billion per year [101]. In 2009 they requested €50 billion over the next 10 years, thus tripling the annual allocation. It is noteworthy that individual European countries also have their own energy R&D budgets that in total exceed that of the EU.

6. A serious problem with energy data and units

Having examined many international, national, institutional and private energy-related data sources over many decades, and since this data serves as the basis for important decisions at all these levels, and for attempting to influence public opinion, I have the following observations that would hopefully receive a proper remedy by all those who publish such data, and a sense of healthy wariness by those who read, hear or use it:

- The amount of data is vast, as needs to be, but an increased effort should be invested in adding appropriate condensations and brief summaries for major common applications, to relieve each user from having to do their own analyses.
- Better guidance is needed for discovering available data, without having do too many searches, sort of a database for ways to discover and access data would be most welcome.
- Some databases are more "generous" than others, in open, free and facilitated access, for example the USDOE Energy Information Administration (EIA) is probably leading in that respect, especially about information on the USA.
- Most databases, especially the international ones, contain data that is 2–5 years old, much too old in this dynamic field that exhibits strong and fast reactions to various circumstances, for examples such as those resulting from the recent economic downturn. To add insult to injury, some have a title that presents the publication date of the compendium rather than the date of the data in it, e.g., the latest data in the "OECD Factbook 2010" are from 2007.
- One of the sorest problems is the quality and accuracy of the data. It starts from the methods by which it is gathered (often not made clear, and in most cases done by voluntary uncertified reporting by private entities, such as fuel and power companies) and ends in the way by which it is recorded and interpreted. Significant differences of the values of the same data are found not only among different data publishing centers, international, governmental and private, but also within the publications of the same center. For example, a 2009 report that presents data for prior years may have different numbers for year 2005 then the annual reports from 2005 to 2008 for the same year, but even different forms of presentation of the same data often show different values. The situation is much worse for many developing countries and for the energy giants China and India: numerous authors bemoan the quality of data from there. That is obviously particularly important when assessing global energy and its environmental impacts because these countries not only represent an important fraction of these parameters but also their development is the most rapid. It is also noteworthy that such data are very sensitive politically, carrying with them some degree of international "competition" as to leadership and growth in use of resources and in emissions, or as to compliance by say the EU, UN, etc.
- Finally, there is severe problem of lack of uniformity of units that include a dumbfounding mix of SI, MKS and CGS, and British systems, unnecessary use of Latin words such as "*capita*", "*annum*", "*diem*", and such that only adds confusion, different notations of the decimal point. and the thousands dividers, and frequent use of "industrial/commercial" units such as tons oil equivalent (toe), tons coal equivalent (tce), quads, and the ubiquitous but strange kWh. Adding to that calories (sometimes meaning kilocalories), bar and the such tops this tower of Babel. A uniform system of units and their notation, using Joule for energy, Watt for power, Celsius or Kelvin for temperature, Pascal for pressure, etc., would substantially simplify the situation and, very importantly, reduce the effort and associate errors in attempting to convert them from one system to another, A side observation is that the broad use of "tons oil equivalent" (toe), psychologically overemphasizes, for better or worse, the importance of oil as an energy source. Furthermore, uniform units are of essential importance for international trade, globalization, and sustainable development.
- It is high time for professional societies, standards institutions, the United Nations, and national governments to remedy these problems.

7. Possibly sustainable paths to the future

- The last few years have introduced four game-changers in the very dynamic energy field: the apparent postponement of the threat of depletion of fossil fuels, new realization of the strong impact of economics on energy use and related emissions that arose from the recent global economy downturn, the realization of the vulnerability of nuclear power as exhibited by the recent tragic nuclear disaster in Japan, and the potential for massive introduction of electric vehicles. These have, or should have, major consequences for sustainable development as discussed in somewhat more detail below and in some other parts of this paper.
- The first step in any path to the future is wiser use of the energy resources, also referred-to as conservation (nicely reminded by Smil [102] and discussed by Lund [103]). This would include elimination of obvious waste, higher energy conversion efficiency, substitution for lower energy intensity products and processes, recycling, and more energy-modest lifestyles. Conservation must be implemented in a way that does not deprive people from the basic necessities and comforts of life, nor has a very negative impact on

productivity. Considering that the per capita energy consumption in some leading energy consumers is much higher than the world average, e.g. ~3.4-fold higher for the USA, and importantly, for the USA more than two-fold higher than that in developed countries of similar quality of life, it is clear that ways can be found to reduce the demand significantly without undue stress on life quality. There is even the clear prospect that reduction of such extravagant energy consumption may improve the quality of life. Such demand reductions have significant potential for numerous countries, including many of the developing ones that actually have an excellent chance to learn from the unsustainable paths taken in the past by the developed ones and to incorporate sustainability during their development, all this leading to a more sustainable world.

- Important steps must also be taken to prevent energy efficiency "rebound", the frequent outcome in which higher efficiency and lower costs lead to increased consumption (cf [104,105].).
- It is impossible to find and implement effective ways for curbing energy demand and related emissions, and for supplying the needed energy, if the wide fluctuations in oil and gas prices, like those experienced in the course of the recent years, are not curbed (also see [106]). Apart from inadequately regulated speculation, parts of that problem are the market practices of linking/indexing the prices of non-competing fuels, such as oil and gas, in several major areas of the world. These fluctuations could be diminished by a combination of technical measures and fiscal regulation, and should be implemented rapidly.
- Much more effective involvement of, and cooperation among, the countries of the world in reducing GHG emissions and other negative environmental consequence of energy use must be more rapidly put into action. Respecting the need of developing countries for more complete and rapid electrification and better transportation, the needed methodology and technology must be aided by developing countries to the benefit of both and of the world in general. Since large scale carbon sequestration is still impractical, proper credit should be given to maintenance and increase of carbon consuming forest and other green areas, and major research, development and testing must be performed on carbon sequestration as well as on increased use of appropriate renewable energy.
- The pursuit of more efficient and less polluting transportation must include not only vehicular improvements (with preference for the plug-in electric or hybrid car) but also traffic management, significant development of efficient public transit, and redesign of cities [10]; significant improvement in the extent and smartness of the electric grid will mitigate the increase in electricity demand that would follow massive introduction of electric cars.
- Buildings are the biggest single contributor to world greenhouse-gas emissions, and it is generally felt that one of the most effective ways to reduce this problem is through market drivers, by legislation that assigns real costs to building energy use and emissions, accompanied by financing practices that monetize long-term energy costs in near-term investment decisions (for more about buildings energy see [10]). Governments make huge investments in subsidizing energy-efficient buildings and their use, but this is a very ineffective method without generating the above mentioned market drivers.
- At least for this century, more efficient and less polluting use of fossil fuels, as well as better and cleaner exploration and extraction of such fuels, is to continue to be pursued. Since coal is and will remain in the foreseeable future to be the major fuel for electricity generation, development of clean use of coal should be accelerated. Environmentally acceptable ways of making use of the vast oil sands, shale gas, and perhaps even shale oil, must be developed before they are massively used.
- It appears that massive use of nuclear fission power would be stymied until the reactors are deemed or developed to be safe enough, with permanent and economical solutions to the nuclear waste problem. Nuclear fusion power could produce a very satisfactory long term solution, but the R&D is underfunded and unstable, and commercial use is still rather far from achievement.
- R&D and implementation of renewable energy must continue vigorously, with the most promising technologies currently being wind, solar photovoltaics and solar-thermal power, and to some extent biomass that does not compete with food. Economical very deep drilling technologies for reaching the enormous renewable geothermal heat resources should be pursued.
- Africa's energy deserves a close look and development by its governments and the international community, to synergistically advance the quality of life of its populace and sell global-capacity energy to the rest of the world.
- The inequitable costing of energy resources and their conversion must stop, by governments and industry assigning a true value based on all short and long-term externalities. In-depth scenario studies are necessary for quantitative forecasting of the best ways to spend government research moneys for attaining the sustainable development objectives.
- It is not conceivable that sustainable development can take place without applying reasonable measures for population control.
- As I wrote in several past papers, sustainability is only emerging as a science, and must be developed and applied urgently to provide analysis and evaluation tools. It is of immediate importance because energy conversion and use are associated with major environmental, economical and social impacts, and all large energy projects should therefore be designed and implemented sustainably.
- The critical problems that energy development poses and the possible paths to the future create at the same time great opportunities for respected solutions that promote new and expanded creativity, higher employment (also see [107]), and higher job satisfaction. It also offers special prospects for small enterprises and nations that are not hampered by the inertia inherent in larger organizations.
- A frequent major obstacle is the political system needed to support rapid and effective movement along the new paths, and to plan beyond its tenure, and that often prefers solutions that are primarily supportive of its own survival: popular support for sensible paths should be sought/educated to diminish this obstacle [107] (some constructive suggestions can also be found in [108,109]).
- Many of the innovative solutions require very long periods of time. It is of vital importance to start intensively now, so we wouldn't be too late.

Acknowledgments

The help of Professors Ying Fan, Kirit Parikh, Daniel Schneider, Petar Škundrić and Ms. Maja Krunić-Lazić in pointing me to sources of some of the data shown in Table 2, for China, India, Croatia, and Serbia, respectively, is gratefully acknowledged.

References

[1] British Petroleum. Statistical review of world energy. and Electricity, http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf; June 2011, http://www.bp.com/sectiongenericarticle800.do?categoryId=9037156&contentId=7068663; June 2011. Accessed 17.8.2011.

[2] British petroleum energy outlook 2030, http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/2030_energy_outlook_booklet.pdf; 2011. accessed 17.8.2011.

[3] U.S.D.O.E. HTTP://www.energy.gov/ (accessed 17.8.2011).

[4] U.S.D.O.E. Energy Information Administration http://www.eia.doe.gov/ accessed 17.8.2011.

[5] International Energy Agency http://www.iea.org/ accessed 17.8.2011.

[6] International Atomic Energy Agency, http://www.iaea.org/ and http://www.iaea.org/programmes/a2/index.html (accessed 17.8.2011).

[7] Lior N. The state and perspectives of research in the energy field. invited keynote paper. In: Ulgiati S, editor. The Third international Biennial Workshop "Advances in energy studies: Reconsidering the importance of energy". Italy: Porto Venere; 24-28 September 2002. p. 351–64.

[8] Lior, N. Energy resources and use: the present situation and possible paths to the future, Invited Keynote Lecture, PRES 06 (9th Conference "Process Integration, Modeling and Optimisation for Energy Saving and Pollution Reduction"), joint with CHISA 2006 (17th International Congress of Chemical and Process Engineering), Praha, Czech Republic, August 2006; in revised form in Energy 33 (2008) 842–857.

[9] Lior, N. Energy resources and use: the present situation and possible sustainable paths to the future, invited keynote presentation at SET 2008, the 7th Conference on Sustainable Energy Technologies, Seoul, Korea, 24-27 August 2008. Proc. ISBN-978-89-961095-1-894540 Vol. 1 pp. 55-67, published by Korea Institute of Ecological Architecture and Environment, Seoul, Korea. In revised form: Lior, N. Energy resources and use: The present (2008) situation and possible sustainable paths to the future, Energy 35 (2010) 2631–2638.

[10] Lior N. Sustainable energy development: the present (2009) situation and possible paths to the future. Energy 2010;35:3976–94.

[11] Lior N. The ECOS 2009 World Energy Panel: an introduction to the Panel and to the present (2009) situation in sustainable energy development. Energy 2011;36:3620–8.

[12] Lior, N. Sustainable energy development: A brief introduction to the present (May 2011) situation" ECOS 2011: the 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, Novi Sad, Serbia, 4-7 July, 2011. ISBN 978-86-6055-016-5.

[13] U.S.D.O.E. Energy information administration - Annual energy Outlook, http://www.eia.gov/forecasts/aeo/; 2011. accessed 17.8.2011.

[14] IEA. Key world energy statistics, http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf; 2010. accessed 17.8.2011.

[15] IEA. World energy Outlook 2010; 2010. Parisaccessed 15.6.2011.

[16] W.H.O. and U.N.E.P. Intergovernmental Panel on Climate Change, Geneva, Switzerland. http://www.ipcc.ch/ accessed 17.8.2011).

[17] National Oceanic and Atmospheric Administration. National Climatic data Center. State of the climate. Global Analysis, http://www.ncdc.noaa.gov/sotc/global/; May 2011. accessed 17.8.2011.

[18] UNICEF and World Health Organization. Progress in water and sanitation, http://www.unicef.org/wash/; 2008. accessed 17.8.2011.

[19] Lior N, Bakish R. Water, supply and desalination, Chapter in the Kirk-Othmer Encyclopedia of Chemical technology. 4th ed., vol. 25. John Wiley and Sons, Inc.; 1998. 438–487.

[20] U.N. World Food Programme, Hunger, Rome. Italy http://www.wfp.org/hunger (accessed 17.8.2011).

[21] Weil RH. Levels of overweight on the rise. Worldwatch Institute, http://vitalsigns.worldwatch.org/vs-trend/levels-overweight-rise; Jun 14, 2011. accessed 17.8.2011.

[22] ENERDATA. World energy use in 2010, ober 5 % growth, http://www.enerdata.net/; May 5, 2011. accessed 17.8.2011.

[23] Ewing RC, von Hippel FN. Nuclear waste management in the United States—Starting over. Science 10 July 2009;325:151–2.

[24] USDOE Blue Ribbon Commission on America's nuclear future. What we have heard, www.brc.gov; March 2011. accessed 17.8.2011.

[25] Toleffson J. Battle of Yucca Mountain rages on. Nature 19 May 2011;473:266.

[26] Trainer T. Renewable energy Cannot Sustain a consumer Society. AA Dordrecht: Springer; 2007.

[27] Turney D, Fthenakis V. Environmental impacts from the installation and operation of large-scale solar power plants. Renewable and Sustainable Energy Reviews 2011;15:3261–70.

[28] MIT Panel. The Future of Geothermal Energy, 206, Massachusetts Institute of Technology. Cambridge, MA. http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf accessed 17.8.2011.

[29] Sundset T, de Koeijer G. Future power generation in oil and gas industry, in: Lior, N. Brief summary of the ECOS '05 Panel on Future Power Generation. Energy 2007;32:255–6.

[30] Ehlig-Economides C, Economides MJ. Sequestering carbon dioxide in a closed underground volume. Journal of Petroleum Science and Engineering 2010; 70:123–30.

[31] USDOE Nuclear Energy. Small modular reactors, www.nuclear.energy.gov/pdfFiles/factSheets/2012_SMR_Factsheet_final.pdf; 2/11/2011. accessed 17.8.2011.

[32] Amin SM, Gellings CW. The North American power delivery system: balancing market restructuring and environmental economics with infrastructure security. Energy 2006;31:967–99.

[33] IPCC SRREN. Summary for policy Makers, http://srren.ipcc-wg3.de/report; May 31st 2011. accessed 17.8.2011.

[34] WWF. World Wildlife Federation; world wide Fund for nature. Living Planet Report, http://www.panda.org/about_our_earth/all_publications/living_planet_report/2010_lpr/; 2010.

[35] Stern J, editor. Natural gas in Asia: the challenges of growth in China, India, Japan, and Korea. Oxford, UK: Oxford Institute For Energy Studies; 2008.

[36] MSCI Index ACWMI IMI http://www.msci.com/ accessed 17.8.2011.

[37] Index Mundi http://www.indexmundi.com/g/g.aspx?c=xx&v=67 accessed 17.8.2011.

[38] IEA. World energy Outlook 2009; 2009. Paris.

[39] U.S. Census Bureau. International data base (IDB). World population: 1950-2050. Update, http://www.census.gov/ipc/www/idb/worldpopgraph.php; December 2010. accessed 17.8.2011.

[40] The World Bank, Energy use per capita. http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE accessed 17.8.2011.

[41] Energy resource potential of methane hydrate US DOE methane hydrate primer, http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2011Reports/MH_Primer2011.pdf; 2011. accessed 17.8.2011.

[42] Government of Alberta – Energy http://www.energy.gov.ab.ca/OilSands/oilsands.asp accessed 17.8.2011.

[43] USDOE Office of Naval Petroleum and Oil Shale Reserves, National strategic unconventional resources model Instruction Manual, April 2006. http://fossil.energy.gov/programs/reserves/npr/NSURM_Documentation.pdf accessed 17.8.2011.

[44] Shell, report on Royal Dutch Shell plc & oil sands, http://www-static.shell.com/static/investor/downloads/news_and_library/report_royaldutchshell_oil_sands_march2010.pdf; March 2010. accessed 17.8.2011.

[45] Sawyer D, Stiebert S. (EnviroEconomics Inc.), fossil fuels – At what cost? Government support for upstream oil activities in three Canadian provinces: alberta, Saskatchewan, and Newfoundland and Labrador. Geneva, Switzerland: The Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD), http://www.globalsubsidies.org/files/assets/ffs_awc_3canprovinces.pdf; November 2010. accessed 17.8.2011.

[46] Harper JA. The Marcellus Shale—An old "New" gas reservoir in Pennsylvania. Pennsylvania Geology 2008;38(1). Spring.

[47] U.S. Department of Energy. Office of fossil energy and national energy technology Laboratory, Modern shale gas development in the United states: a Primer. Prepared by Ground water protection Council, Oklahoma City, OK 73142 and ALL Consulting, Tulsa, OK 74119, http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf; April 2009. accessed 17.8.2011.

[48] EIA World Shale Gas Resources. An Initial assessment of 14 regions outside the United States. Release date, http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf; April 5, 2011. accessed 17.8.2011.

[49] USDOE Oil shale and other unconventional fuels activities http://fossil.energy.gov/programs/reserves/npr/npr_oil_shale_program.html accessed 17.8.2011.

[50] Bunger JJ, Crawford PM, Johnson HR. Is oil shale America's Answer to peak-oil challenge? Oil&Gas Journal; August 9, 2004.

[51] Johnson HR, Crawford PM, Bunger JW. Strategic significance of America's oil shale resource, volume I assessment of strategic issues, prepared for U.S. Department of energy, Office of the Naval Petroleum and oil shale reserves (DOE/NPOSR), http://fossil.energy.gov/programs/reserves/npr/publications/npr_strategic_significancev1.pdf; March 2004. accessed 17.8.2011.

[52] Johnson HR, Crawford PM, Bunger JW. Strategic significance of America's oil shale resource, volume II oil shale resources- technology and economics, prepared for U.S. Department of energy, Office of the Naval Petroleum and oil shale reserves (DOE/NPOSR), http://fossil.energy.gov/programs/reserves/npr/publications/npr_strategic_significancev2.pdf; March 2004. accessed 17.8.2011.

[53] Bartis JT, LaTourrette T, Dixon L, Peterson DJ, Cecchine G. Oil shale development in the United states: prospects and policy issues. RAND infrastructure, safety, and environment (ISE), a division of the RAND Corporation, prepared for the national energy technology Laboratory of the U.S. Department of Energy, www.rand.org/pubs/monographs/2005/RAND_MG414.sum.pdf; 2005. accessed 17.8.2011.

[54] Glaser PE, Davidson FP, Csigi KI, editors. Solar power satellites, the emerging energy option. New York: Ellis Horwood; 1993.

[55] Lior N. Power from space. Energy Conversion & Management Journal 2001; 42(15–17):1769–805.

[56] Mankins JC. Space solar power: a major new energy option? Journal of Aerospace Engineering 2001;14(2):38–45.

[57] Zidanšek A, Ambrožić M, Milfelner M, Blinc R, Lior N. Solar orbital power: sustainability analysis. Energy 2011;36:1986–95.

[58] Department of Energy and Climate Change Satistical Release - UK Climate Change Sustainable Development Indicator. Greenhouse gas emissions, Provisional Figures and 2009 greenhouse gas emissions, Final Figures by fuel type and end-user 31 March 2011, http://www.decc.gov.uk/media/viewfile.ashx?filetype=4&filepath=Statistics/climate_change/1515-statrelease-ghg-emissions-31032011.pdf&minwidth=true; 2010. accessed 17.8.2011.

[59] National Bureau of Statistics of China. China energy statistics Yearbook; 2010.

[60] National Bureau of Statistics of China. National economy and social development Statistical Bulletin; 2010.

[61] National Bureau of Statistics of China. China population & employment statistics Yearbook; 2010.

[62] China Electricity council. National electric power industry statistics Express, http://www.cec.org.cn/yaowenkuaidi/2010-11-26/2639.html; 2008. accessed 17.8.2011.

[63] China Electricity council. National electric power industry statistics Express, http://www.cec.org.cn/nengyuanyudianlitongji/hangyetongji/dianlixingyeshuju/2010-11-27/29958.html; 2009. accessed 17.8.2011.

[64] China Electricity council. National electric power industry statistics Express, http://www.cec.org.cn/tongjixinxibu/tongji/niandushuju/2011-02-23/44236.html; 2010. accessed 17.8.2011.

[65] World Bank, World Development Indicators, http://data.worldbank.org/data-catalog/world-development-indicators accessed 17.8.2011.

[66] Global Peace Index - Vision for humanity. http://www.visionofhumanity.org/gpi-data/#/2011/unem/ accessed 17.8.2011.

[67] UNDP. Human Development Indices: Statistical Update 2008. United Nations Development Program. http://hdr.undp.org/en/media/HDI_2008_EN_Complete.pdf accessed 17.8.2011.

[68] Government of India: Economic Survey 2010-11 Statistical Appendix, A27, http://Indiabudget.Nic.In accessed 17.8.2011.

[69] Government of Croatia. Energy in Croatia 2008. http://www.mingorp.hr/UserDocsImages/ENERGETIKA/EUH08_za%20web.pdf and Energy in Croatia 2009. http://www.mingorp.hr/default.aspx?id=117 accessed 17.8.2011.

[70] Statistical Office of the Republic of Serbia http://webrzs.stat.gov.rs/WebSite/; Ministry of Infrastructure and Energy, Republic of Serbia http://www.mi.gov.rs/; Ministry of finance, Republic of Serbia http://www.mfin.gov.rs/ accessed 31.8.2011.

[71] Serbian Ministry of Environment, Mining and Spatial Planning -Environmental Protection Agency (Maja Krunić-Lazić). Report on the state of environment in the Republic of Serbia for 2009 and Draft Report on the state of environment in the Republic of Serbia for 2010; Some data also available in accessed 17.8.2011.

[72] Sagar Ambuj D, Najam Adil. The human development index: a critical review. Ecological Economics 1998;25(3):249–64.

[73] Neumayer Eric. The human development index and sustainability – A constructive proposal. Ecological Economics 2001;39:101–14.

[74] Wilson J, Tyedmers P, Pelot R. Contrasting and comparing sustainable development indicator metrics. Ecological Indicators 2006;7:299–314.

[75] Cyranoski D. Japan rethinks its energy policy. Nature 19 May 2011;473(11):26.

[76] Smith J. A long shadow over Fukushima. Nature 7 April 2011;472(7):7.

[77] US DOE. Gen IV Nuclear Energy Systems. http://www.ne.doe.gov/genIV/neGenIV1_demo.html accessed 17.8.2011.

[78] Lake JA. The fourth generation of nuclear power. Progress in Nuclear Energy 2002;40(3):301–7.

[79] Denholm P, Short W. An evaluation of utility system impacts and benefits of Optimally Dispatched plug-in hybrid electric vehicles. Technical Report NREL/TP-620-40293, http://nrelpubs.nrel.gov/Webtop/ws/nich/www/public/Record?rpp=25&upp=0&m=22&w=NATIVE%28%27AUTHOR+ph+any+%27%27short%27%27%27%29&order=native%28%27pubyear%2FDescend%27%29; October 2006. accessed 17.8.2011.

[80] Kintner-Meyer M, Schneider K, Pratt R. Impacts assessment of plug-in hybrid vehicles on electric utilities and regional U.S. Power grids, Part 1: technical assessment. Pacific Northwest National Laboratory, http://www.ferc.gov/about/com-mem/wellinghoff/5-24-07-technical-analy-wellinghoff.pdf; 2007. accessed 17.8.2011.

[81] Electrification Coalition Electrification Roadmap - Revolutionizing transportation and achieving energy security, November 2009. Electrification Coalition 1111 19th street, NW suite 406 Washington, DC 20036 Tel 202-461-2360 Fax 202-461-2379. Electrification Coalition.org accessed 17.8.2011.

[82] Reed T, Doucette RT, McCulloch MD. Modeling the CO_2 emissions from battery electric vehicles given the power generation mixes of different countries. Energy Policy 2011;39:803–11.

[83] USDOE Fuel Economy www.fueleconomy.gov/feg/evtech.shtml accessed 17.8.2011.

[84] Wharton Africa Business Forum. Panel: "The Energy Paradox: Addressing power needs in Africa's resource rich countries" in "A Blueprint for Africa" 19–21 November 2010. http://whartonafrica.com/wabf/speakers/panelists/ accessed 17.8.2011.

[85] Trieb F, O'Sullivan M, Pregger T, Schillings C, Krewitt W. Characterisation of solar electricity import Corridors from MENA to Europe - Potential, infrastructure and cost. Stuttgart, Germany: German Aerospace Centre (DLR); 2009. 172 p.

[86] IEA. Energy balance for Africa, http://www.iea.org/stats/balancetable.asp?country_code=11; 2008. accessed 17.8.2011.

[87] Brew-Hammond A. Energy access in Africa: challenges ahead. Energy Policy 2010;38:2291–301.

[88] IPCC special report on renewable energy sources and climate change mitigation. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, http://srren.ipcc-wg3.de/report/IPCC_SRREN_; 2011.

[89] World Energy Council 2010 Survey of Energy Resources. World energy Council. Regency House 1–4 Warwick Street. London W1B 5LT United Kingdom, www.worldenergy.org/documents/ser_2010_report_1.pdf; 2010. accessed 17.8.2011.

[90] International Hydropower Association (IHA) www.hydropower.org, Overview, 2009, (private communication, June 2011).

[91] Smeets EMW, Faaij PC, Lewandowski IM, Turkenburg WC. A bottom-up assessment and review of global bio-energy potentials to 2050. Progress in Energy and Combustion Science 2007;33:56–106.

[92] Field CB, Campbell1 J, ElliottLobell DB. Biomass energy: the scale of the potential resource. Trends in Ecology and Evolution 2007;23(2):65–72.

[93] Amigun B, Kaviti Musango J, Stafford W. Biofuels and sustainability in Africa. Renewable and Sustainable Energy Rev. 2011;15:1360–72.

[94] Rogner H-H, Barthel F, Cabrera M, Faaij A, Giroux M, Hall D, et al. Ch. 5: energy resources. In: World energy assessment. Energy and the challenge of sustainability. United nNations Development Programme, United Nations Department of economic and social Affairs. New York, USA: World Energy Council; 2000. p. 508.

[95] IPCC special report on renewable energy sources and climate change mitigation. Cambridge, United Kingdom and New York, NY, USA: Solar Energy Cambridge University Press, http://srren.ipcc-wg3.de/report/srren; 2011. accessed 17.8.2011. especially Chapter 3.

[96] USDOE, FY. DOE budget request to Congress, http://www.cfo.doe.gov/budget/12budget/Content/FY2012Highlights.pdf; 2012. accessed 17.8.2011.

[97] U.S. Department of Treasury. Debt to the Penny and who holds it. http://www.treasurydirect.gov/NP/BPDLogin?application=np accessed 17.8.2011.

[98] USDOE ARPA-E http://arpa-e.energy.gov/Home.aspx accessed 17.8.2011.

[99] Simmons G. Secretary Chu Hosts FY 2012 budget Briefing, http://blog.energy.gov/blog/2011/02/14/watch-live-130-secretary-chu-hosts-fy-2012-budget-briefing; February 14, 2011. accessed 17.8.2011.

[100] European Commission CORDIS, Seventh framework programme (FP7) http://cordis.europa.eu/fp7/budget_en.html (accessed 8.22.2009).

[101] European Comission Strategic Energy Technology (SET) Plan http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm (accessed 1.02.2010).

[102] Smil V. Global energy: the latest infatuations. American Science 2011 May–June;99:212–9.

[103] Lund H. Renewable energy strategies for sustainable development. Energy June 2007;32(6):912–9.

[104] Herring H. Energy efficiency—a critical view. Energy 2006;31:10–20.

[105] Sorrell S, Dimitropoulos J. The rebound effect: Microeconomic definitions, limitations and Extensions. Ecological Economics 2008;65:636–49.

[106] Lund H, Hvelplund F. The Economic Crisis and Sustainable Development. The design of Job Creation Strategies by use of Concrete Institutional Economics. The 6th Conference on Sustainable Development of Energy, Water and Environment Systems, September 26-29 2011, Dubrovnik, Croatia. ISBN 978-953-7738-12-9; Submitted for publication in Energy, 2011.

[107] Lior, N. Reconciling long-term Sustainable Development and R&D planning with the short-term preferences that drive governments, businesses, institutions, and individuals. Paper FP-85 in the 6th UNESCO sponsored Conference on Sustainable Development of Energy, Water and Environment Systems, September 26-29 2011, Dubrovnik, Croatia. ISBN 978-953-7738-12-9.

[108] Lund H, Mathiesen BV. Energy system analysis of 100% renewable energy systems - The case of Denmark in years 2030 and 2050. Energy May 2009; 34(5):524–31.

[109] Lund H. The implementation of renewable energy systems. Lessons learned from the Danish case. Energy October 2010;35(10):4003–9.