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ENERGY SYSTEMS - A CRITICAL NATIONAL INFRASTRUCTURE

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1. Introduction

Electricity is regarded as one of the indispensable means to growth of any country's economy. This source of power is the heartbeat of everything from the huge metropolitans, industries, worldwide computer networks and our global communication systems down to our homes. Electrical energy is the lifeline for any economic and societal development of a region or country. It is central to develop countries for maintaining acquired life styles and essential to developing countries for industrialisation and escaping poverty.

Linkages between energy use and environmental quality have always been apparent, from the deforestation caused by fuel wood use even in early societies to the high levels of local air and water pollution that have commonly accompanied the early phases of industrialization. In recent decades, advances in scientific understanding and in monitoring and measurement capabilities have brought increased awareness of the more subtle environmental and human-health effects associated with energy production, conversion, and use. Fossil-fuel combustion is now known to be responsible for substantial emissions of air pollutants-including sulfur, nitrogen oxides, hydrocarbons, and soot-that play a major role in the formation of fine particulate matter, ground-level ozone, and acid rain; energy use is also a major contributor to the release of long-lived heavy metals, such as lead and mercury, and other hazardous materials into the environment. Energy-related air pollution (including poor indoor air quality from the use of solid fuels for cooking and heating) not only creates substantial public health risks, especially where emission controls are limited or nonexistent, it harms ecosystems, degrades materials and structures, and impairs agricultural productivity. In addition, the extraction, transport, and processing of primary energy sources such as coal, oil, and uranium are associated with a variety of damages or risks to land, water, and ecosystems while the wastes generated by some fuel cycles-notably nuclear electricity production-present additional disposal issues.

Although the most obvious environmental impacts from energy production and use have always been local, significant impacts-including the long-range transport of certain pollutants in the atmosphere-are now known to occur on

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regional, continental, and even transcontinental scales. And at a global level, climate change is emerging as the most consequential and most difficult energy-environment linkage of all. The production and use of energy contributes more than any other human activity to the change in *irradiative forcing* that is currently occurring in the atmosphere; in fact, fossil-fuel combustion alone currently accounts for well over half of total greenhouse gas emissions worldwide (after accounting for different gases' carbon dioxide equivalent warming potential). Since the dawn of the industrial era, carbon dioxide levels in the atmosphere have increased by about 40 percent; going forward, trends in energy production, conversion, and use-more than any other factor within human control-are likely to determine how quickly those levels continue to rise, and how far. The precise implications of the current trajectory remain unknown, but there is less and less doubt that the risks are large and more and more evidence that human-induced global warming is already underway. In its recent, Fourth Assessment report, for example, the Intergovernmental Panel on Climate Change (IPCC) [4] concluded that evidence for the warming of the Earth's climate system was now 'unequivocal' and identified a number of potential adverse impacts associated with continued warming, including increased risks to coasts, ecosystems, fresh-water resources, and human health. In this context, making the transition to lower-carbon energy options is widely acknowledged as a central imperative in the effort to reduce climate-change risks.
Another issue that will continue to dominate regional, national, and international energy policy debates over the next several decades is energy security. Defined as access to adequate supplies of energy when needed, in the form needed, and at affordable prices, energy security remains a central priority for all nations concerned with promoting healthy economic growth and maintaining internal as well as external stability. In the near to medium term, energy security concerns are almost certain to focus on oil and, to a lesser extent, on natural gas. As demand for these resources grows and as reserves of relatively cheap and readily accessible supplies decline in many parts of the world, the potential for supply disruptions, trade conflicts, and price shocks is likely to increase. Already, there is concern that the current environment of tight supplies and high and volatile prices is exacerbating trade imbalances, slowing global economic growth, and directly or indirectly complicating efforts to promote international peace and security. The problem is particularly acute for many developing countries that devote a large fraction of their foreign exchange earnings to oil imports, thus reducing the resources available to support investments needed for economic growth and social development.
Electrical energy is a high quality form of energy which is not found in nature. Instead it has to be obtained from the conversion in power plants of other types of energy supplies.

These energy supplies can broadly be divided into two classes:

- Renewable energy which is obtained from continuous or repetitive currents of energy occurring in the natural environment
- Non-renewable energy which is obtained from static stores of energy that remain boundless released by human interaction

2. The Electricity Power Systems - the new paradigm

The industrialised world has satisfied the demand for electrical energy by developing technologies for the generation of electricity which use mainly non-renewable energy supplies such as coal or nuclear. These environmentally hazardous generation technologies continue to be the backbone of the electricity generation system. The need for harnessing renewable energy supplies is apparent as world population increases and as each individual presses for a higher standard of living in terms of material goods especially in rural and developing regions.

Energy supply in Europe has been dominated by the large scale centralized combustion of fossil fuels (coal, oil and gas), nuclear and hydro power, with energy delivered over long distance to consumers. Concerning the Europe sustainable development, this traditional economy of scale presents some drawbacks.

Fig 1 and Fig 2 show the new and the old paradigm of the structure of the new power systems.

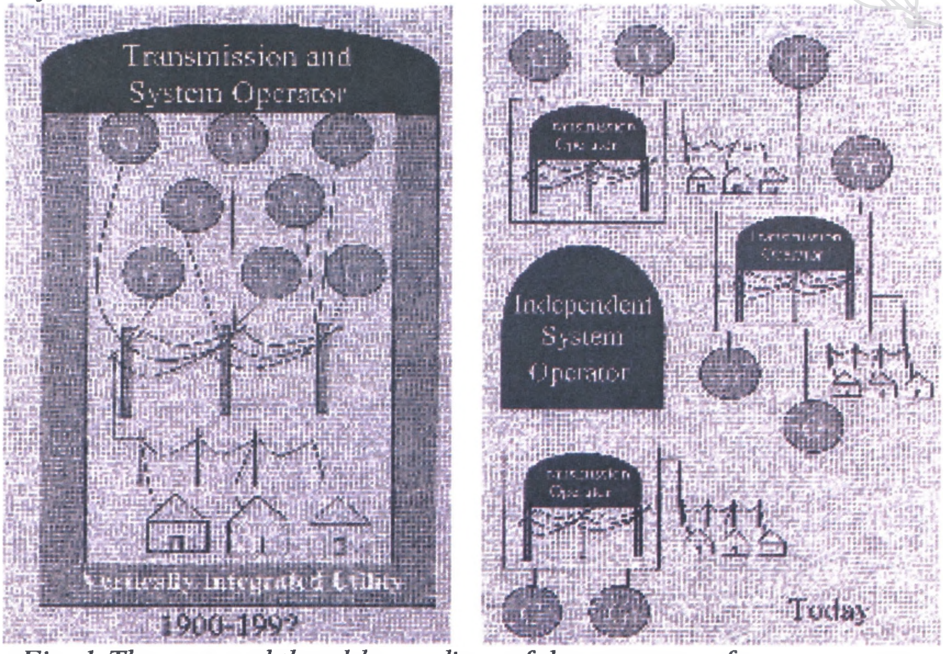


Fig. 1-The new and the old paradigm of the structure of power systems

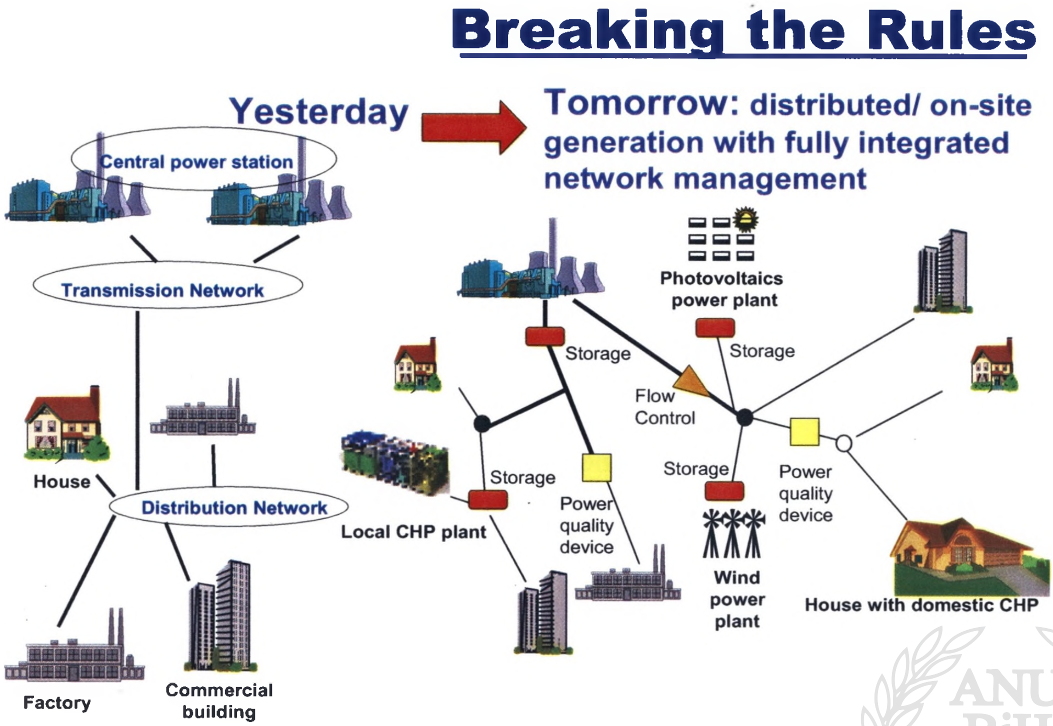


Fig.2 - Yesterday and tomorrow power systems

As societies began to modernize and shift from traditional forms of energy (such as wood, crop residues, and dung) to commercial forms of energy (liquid or gaseous fuels and electricity), their energy consumption per capita and per unit of economic output (gross domestic product) often grew rapidly. At a later stage of development, however, further growth in energy consumption typically slowed as the market for energy-using devices reached a point of saturation and as wealthier economies shifted away from more energy-intensive manufacturing and toward a greater role for the less energy-intensive service sector. The rate of growth in energy consumption also diminished in some industrialized countries as a result of concerted energy efficiency and conservation programs that were launched in the wake of sharp oil price increases in the early 1970s. Figure 3 shows declining energy intensity trends for OECD and non-OECD countries over the last 18 years.

In recent years, the energy intensity of the world's industrialized economies has been declining at an average annual rate of 1.1 percent per year, while the energy intensity of the non-OECD economies has been declining, on average, even faster (presumably because these economies start from a base of higher intensity and lower efficiency). Because the rate of decline in energy intensity has generally not been sufficient to offset GDP (gross domestic product) growth, total energy consumption has continued to grow in industrialized countries and is growing even faster in many developing countries.

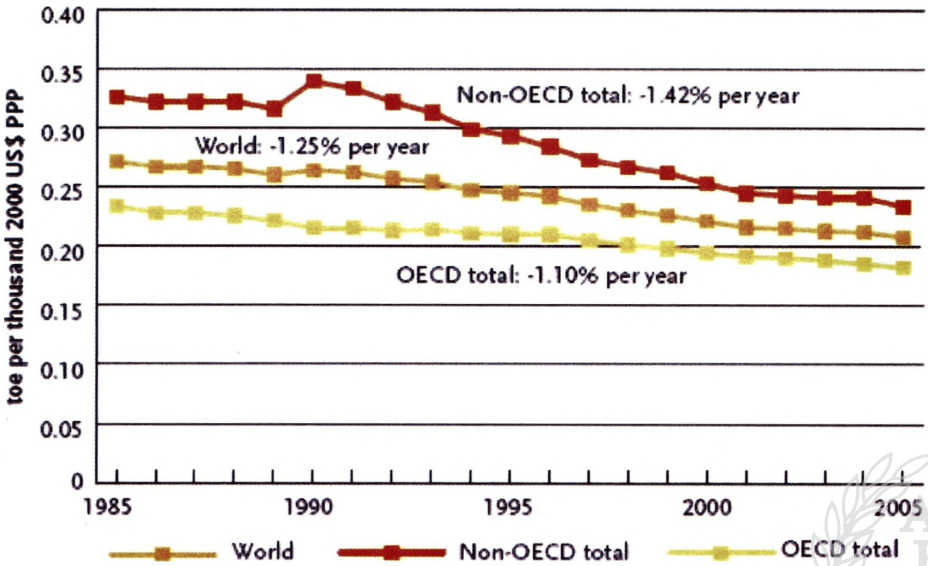


Fig. 3 - Energy intensity versus time, 1985-2005 [5]

Looking ahead, current projections suggest that the world's population will grow by another 50 percent over the first half of this century (to approximately 9 billion by 2050), world income will roughly quadruple, and energy consumption will either double or triple, depending on the pace of future reductions in energy intensity. But projections are notoriously unreliable: patterns of development, structural economic shifts, population growth, and lifestyle choices will all have a profound impact on future trends.

Even small changes in average year-to-year growth or in the rate of intensity reductions can produce very different energy and emissions outcomes over the course of several decades. Simply boosting the historical rate of decline in energy intensity from 1 percent per year to 2 percent per year on a global average basis, for example, would reduce energy demand in 2030 by 26 percent below the business-as-usual base case.

Numerous engineering analyses suggest that intensity reductions of this magnitude could be achieved by concerted investments in energy efficiency over the next half century, but even seemingly modest changes in annual average rates of improvement can be difficult to sustain in practice, especially over long periods of time, and may require significant policy commitments.

Confronted with the near certainty of continued growth in overall energy demand, even with concerted efforts to further improve efficiency, reduce energy intensity, and promote a more equitable distribution of resources, the scale of the sustainability challenge becomes more daunting still when one considers the current mix of resources used to meet human energy needs. Figure 4 shows total primary energy consumption for the OECD countries, developing countries, and transition economies (where the latter category chiefly includes Eastern European countries and the former Soviet Union), while Figures 5 and 6 show global primary energy consumption and global electricity production, broken down by fuel source.

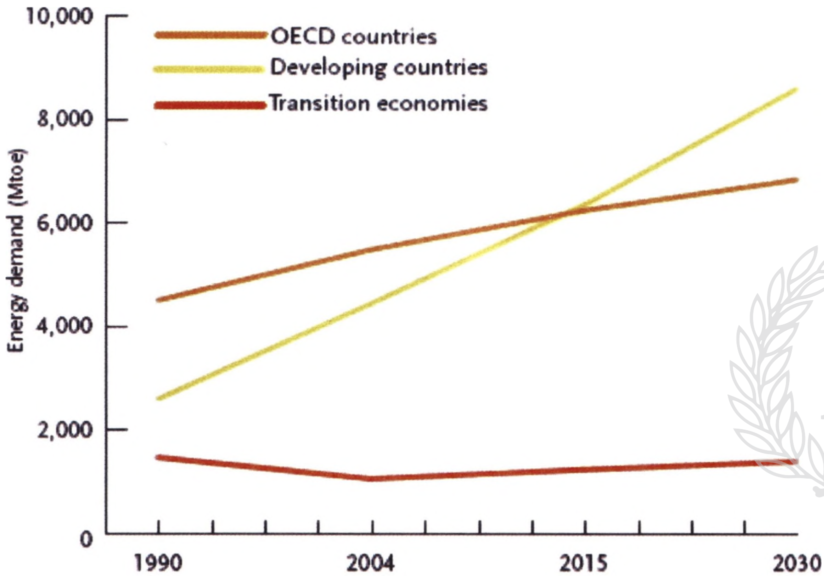


Fig. 4 - Regional shares in world energy demand [5]

Non-renewable, carbon-emitting fossil fuels (coal, oil, and natural gas) account for approximately 80 percent of world primary energy consumption (Figure 5). Traditional biomass comprises the next largest share (10 percent) while nuclear, hydropower, and other renewable resources (including modern biomass, wind, and solar power), respectively, account for 6, 2, and 1 percent of the total. Figure 6 shows the mix of fuels used to generate electricity worldwide. Again, fossil fuels-primarily coal and natural gas-dominate the resource mix, accounting for two-thirds of global electricity production. The nuclear and hydropower contributions are roughly equal at 16 percent of the total, while non-hydro renewables account for approximately 2 percent of global production.

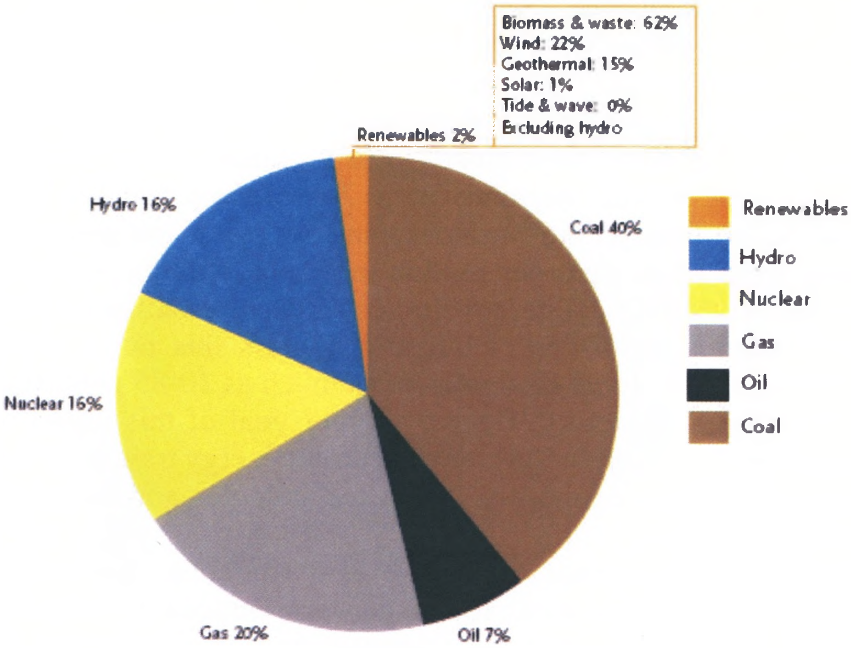


Fig.5 - World primary energy consumption by fuel, 2004 [3]

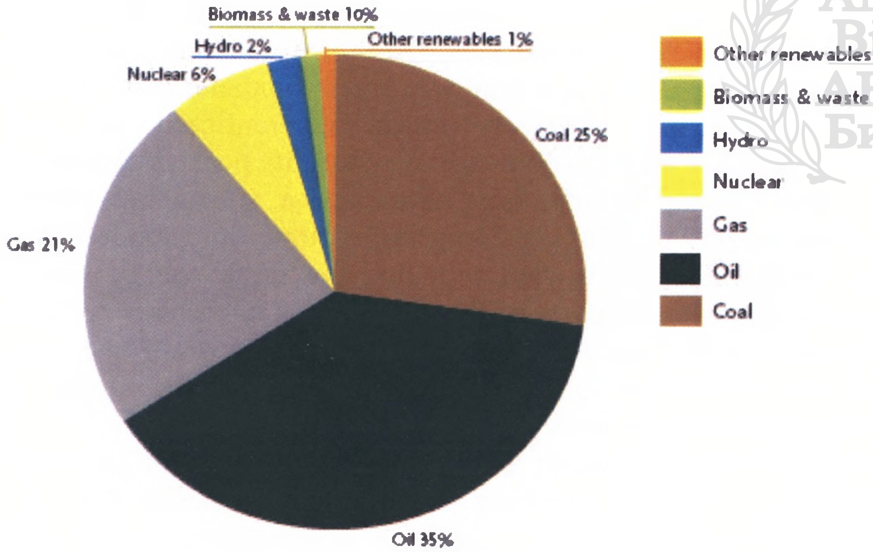


Fig 6 - World electricity production by energy source, 2004 [3]

Most projections indicate that fossil fuels will continue to dominate the world's energy mix for decades to come, with overall demand for these fuels and resulting carbon emissions rising accordingly.
IEA's [5] projections assume moderate growth in the use of renewable energy technologies. But since non-hydro renewable accounted for only 2 percent of

world electricity production in 2004, fossil-fuel consumption and global carbon emissions continue to grow strongly by 2030. Indeed current forecasts suggest that a continuation of business-as-usual trends will produce a roughly 55 percent increase in carbon dioxide emissions over the next two decades.

The implications of these projections, from a climate perspective alone, are sobering. Limiting global warming to a 2-3 degrees Celsius change will require stabilizing atmospheric concentrations of greenhouse gases somewhere in the range of 450-550 parts per million in carbon dioxide equivalent terms. Based on numerous IPCC (Intergovernmental Panel on Climate Change) [4] developed scenarios, achieving stabilization within this range could require absolute reductions in global emissions of as much as 30-85 percent compared to 2000 levels by mid-century. Hence, a major goal of this report is to offer recommendations for shifting the world's current energy trajectory through the accelerated deployment of more efficient technologies and sustainable, low-carbon energy sources.

The consequences of current trends are also troubling, however, from an energy security perspective given the longer-term outlook for conventional oil supplies and given the energy expenditures and environmental impacts it implies, for countries struggling to meet basic social and economic-development needs. Recent forecasts suggest that a continuation of business-as-usual trends will produce a nearly 40 percent increase in world oil consumption by 2030, at a time when many experts predict that production of readily accessible, relatively cheap conventional oil will be rapidly approaching (or may have already reached) its peak. Moreover, IEA reference case projections, though they anticipate a substantial increase in energy consumption by developing countries, assume only modest progress over the next several decades toward reducing the large energy inequities that now characterize different parts of the world. This is perhaps not surprising insofar as the IEA projections are based on extrapolating past trends into the future; as such they do not account for the possibility that developing countries might follow a different trajectory than industrialized countries.

On one hand, a significant amount of Europe's generation capacity, both coal and nuclear fuel, is reaching the end of its useful life and the network infrastructure is also old, requiring investments in a short-term on the transmission and distribution system.

Renewable energy replaces conventional fuels in four distinct sectors: power generation, hot water and space heating, transport fuels and rural (off-grid) energy. In power generation, renewable energy supplies about 3.4% percent of global electricity production (excluding large hydropower) (Fig.7).

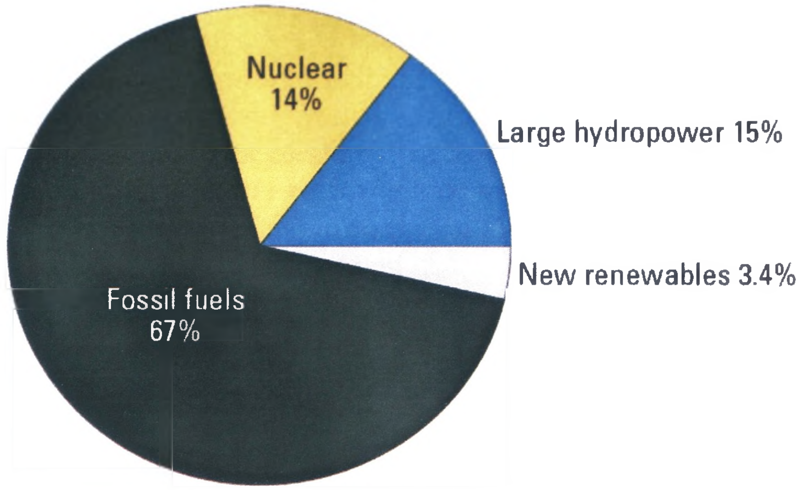


Fig. 7 - Share of global Electricity from renewable energy, 2006 [8]

On the other hand, the continuous increasing demand for energy, in particular for electricity, has stressed a number of shortcomings:

- High level of dependency of imported fuels leading to potential price rises and potential supply disruptions;
- Large environmental impact on greenhouse gases and other pollutants;
- Increased transmission losses;
- Continuous upgrading of transmission and distribution systems.

3. Renewable Energy Systems

Renewable Energy Systems (RES) and Distributed Generation (DG) for heating, cooling and electricity have the potential to become the foundation of a future more sustainable energy supply system. Their scale deployment will transform the energy landscape from a system dominated by the centralized combustion of fossil fuels to a new one in which new technologies, environmentally friendly, contribute to a substantial development. On the other hand, DG can offer additional value to the grid system operators by providing:

- Deferral of investment to transmission and distribution systems;
- Reduction of losses in the distribution system;
- Provision of network support services or ancillary services.

From an investment view point, it is generally easier to find sites for RES and DG than for large central power plants and, in addition, such units can be installed in a short time, near to the end consumer. The widespread integration of RES and DG together with energy efficiency, covering supply and demand, has provided support to achieve the major EU policy objectives:

- Sustainable energy development, combating climate changes and reducing air pollutants is the paradigm of the future power systems. The shift from the large scale combustion of fossil fuels to a more decentralized energy supply based on RES has contributed for meeting the Kyoto commitments, regarding the emission of greenhouse gases, particularly CO2: 8% reduction of emissions from 1990 levels by 2008-2010 and 20% by 2020 compared to 1990;
- Security and diversity of energy supply. Reducing the external energy dependence is crucial for the development of a dynamic and sustainable economy for Europe;
- Increasing the penetration of RES, doubling their share in energy supply quota from 6% to 12% of gross Energy consumption and raising their part in electricity production from 14% in 2001 to 22% is an objective to be attained by 2010.
- Energy marked liberalization, increasing opportunities for smaller scale generators.

The main objective of any generation and distribution utility is to satisfy the demand of customers with a high quality product. This product namely electricity must be supplied continuously round the clock.

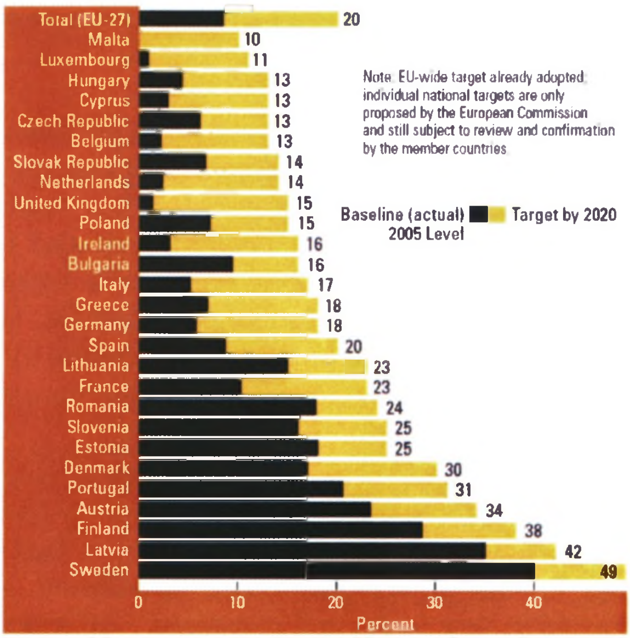


Fig. 8 - EU Renewable Energy Targets - Share of Final Energy by 2020 [8]

Wind generation, photovoltaic's panels, fuel cells and microturbines - just to mention a few- are new forms of electricity under development (Fig.14). They define the so called RES (**R**enewable **E**nergy **S**ystems) and involve the exploitation off distribution sources through the concept of DG (**D**istributed **G**eneration). Today, wind power and CHP (**C**ombined **H**eat and **P**ower) are entering into a competitive level with traditional forms of energy generation. Tomorrow it is expected that one speaks also about microgeneration (microturbines. Micro-CHP, photovoltaic systems and fuel cells).
Wind energy is the renewable energy source that had a higher growing in the last decades and can be considered a hope in future based on clean and sustainable energy (Figs. 9,10,11,12 and 13).

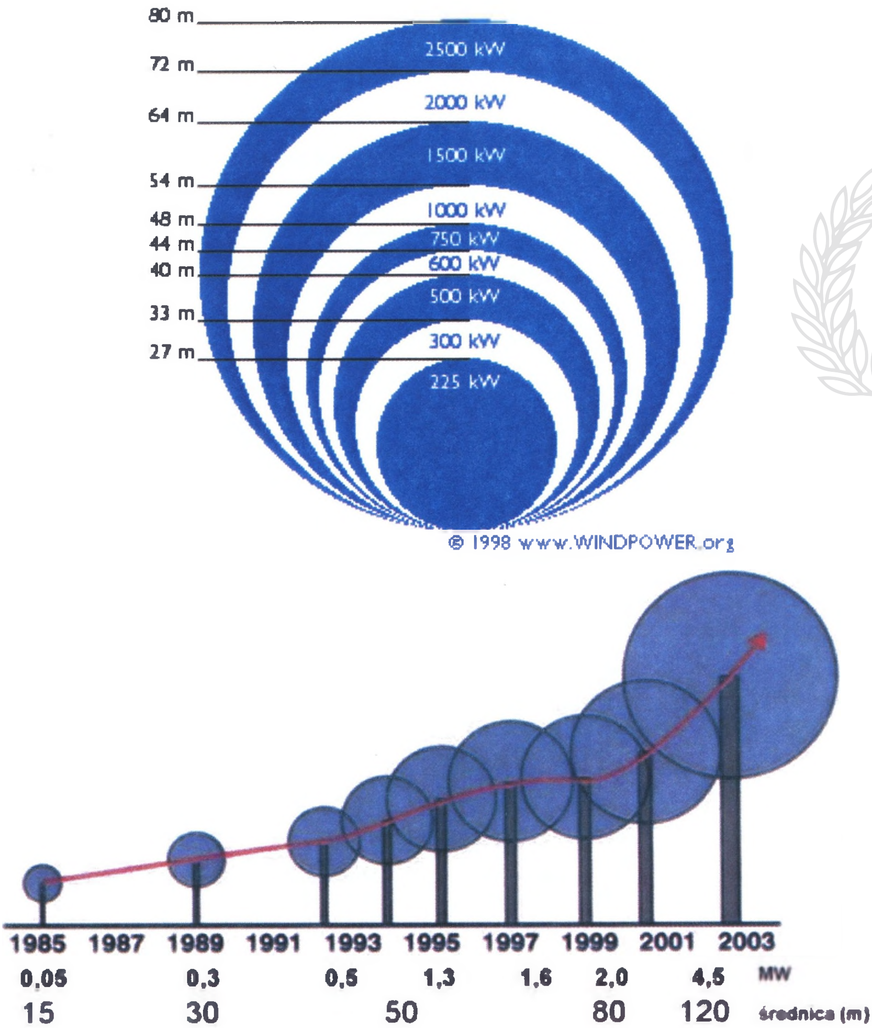
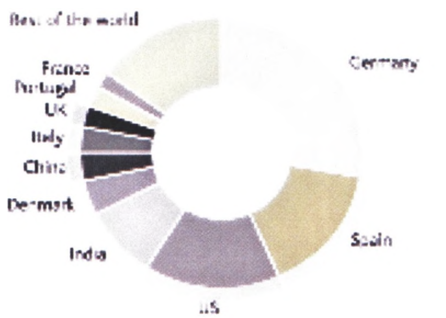


Fig.9 -Technology development -wind energy [6]

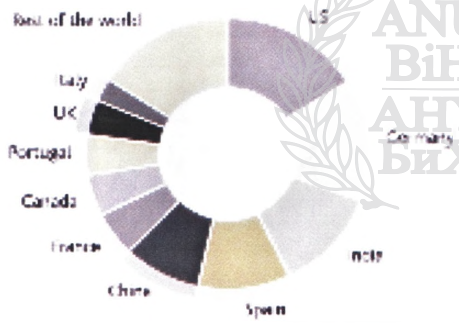
However, the integration of both RES and DG into the overall power systems operation requires that energy generation in both transmission and distribution systems can no longer be considered as passive appendage. Reliability, safety and quality of power are the main issues linked to the large-scale deployment of DER (**D**istributed **E**nergy **R**esources) so that their effect on the European transmission and distribution networks cannot be neglected. Rather, it must be addressed with a comprehensive system approach.
Following the increasing penetration of DG in MV networks, dissemination of small size dispersed microgeneration systems connected to LV distribution systems is expected to become one of the means to face the continuous demand growth. The need to reduce greenhouse gas emissions, recent technological developments related with the improvement of microgeneration efficiency and the possibility of exploiting RES are important factors that will contribute, in a short term, to an effective integration of microgeneration in LV grids.

TOP 10 TOTAL INSTALLED CAPACITY



	MW	%
Germany	20,622	27.8
Spain	11,615	15.6
US	[illegible]	[illegible]
India	6,270	8.4
Denmark	[illegible]	4.2
China	[illegible]	[illegible]
Italy	2,123	2.9
UK	[illegible]	[illegible]
Portugal	[illegible]	[illegible]
France	1,567	2.1
Rest of the world	[illegible]	[illegible]
Total top 10	**63,218**	**85.2**
Total	**74,223**	

TOP 10 NEW CAPACITY



	MW	%
US	2 454	[illegible]
Germany	2 233	14.7
India	[illegible]	[illegible]
Spain	1 587	10.4
China	[illegible]	[illegible]
France	810	[illegible]
Canada	776	5.1
Portugal	694	4.6
UK	634	4.2
Italy	417	2.7
Rest of the world	2 405	[illegible]
Total top 10	**12.792**	**84.2**
Total	**15.197**	

Fig.11- The top 10 wind power installed capacity and the top 10 new wind power capacity countries [7]

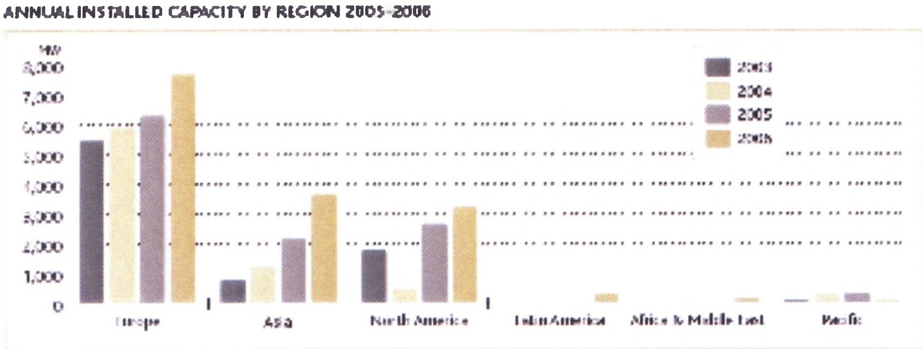


Fig 10 - Annual wind power installed capacity by region 2005-2006 [7]

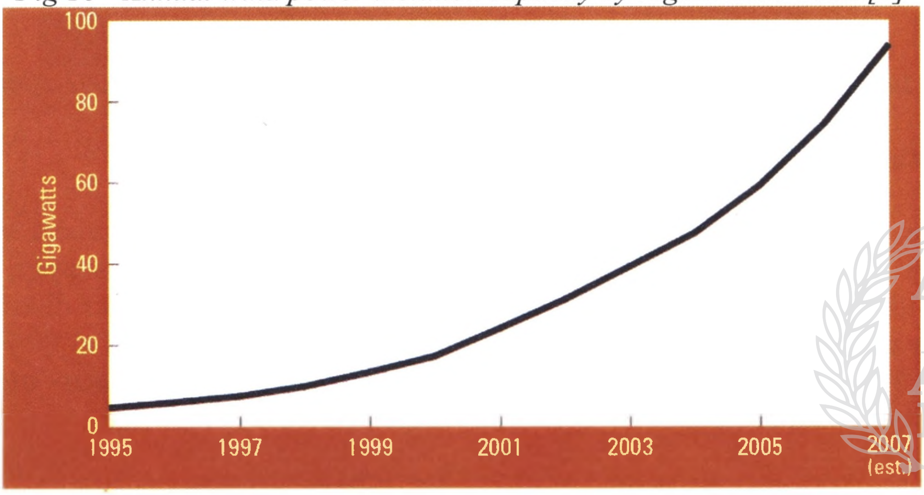


Fig. 12 - Wind Power, existing World Capacity, 1995-2007 [8]

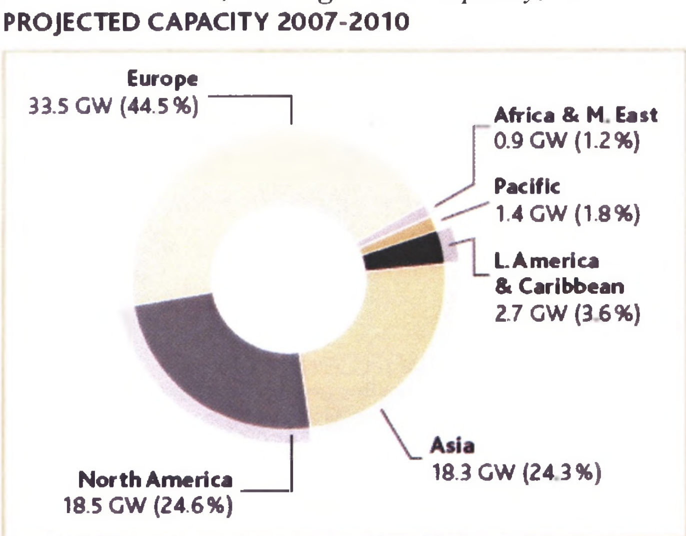


Fig. 13-Targets of wind capacity to be installed [7]

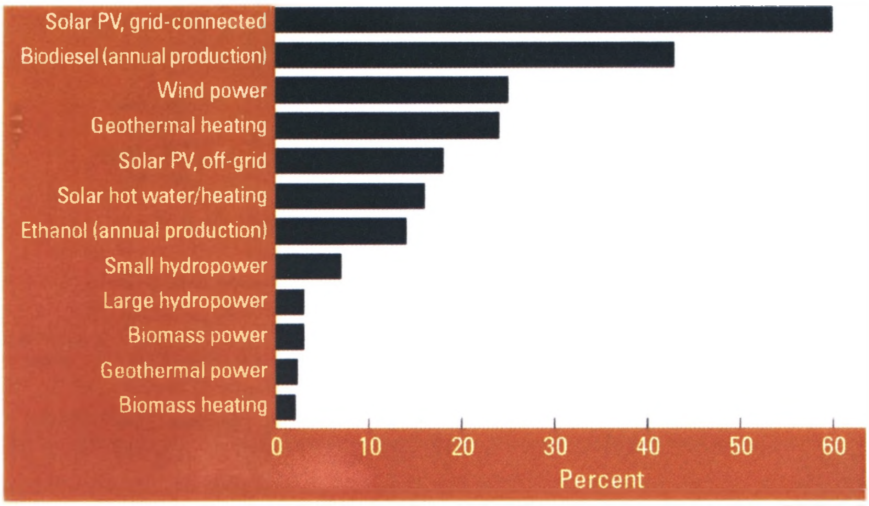


Fig. 14-Average annual growth rates of renewable energy capacity, 2002-2006 [8]

4. Future electricity markets and networks

Future electricity markets and networks must provide all consumers with a highly reliable, flexible, accessible and cost-effective power supply, fully exploiting the use of both large centralized generators and smaller distributed power sources across Europe.

Fig. 15 shows the three driving forces of the new power systems- marked, security and environment.

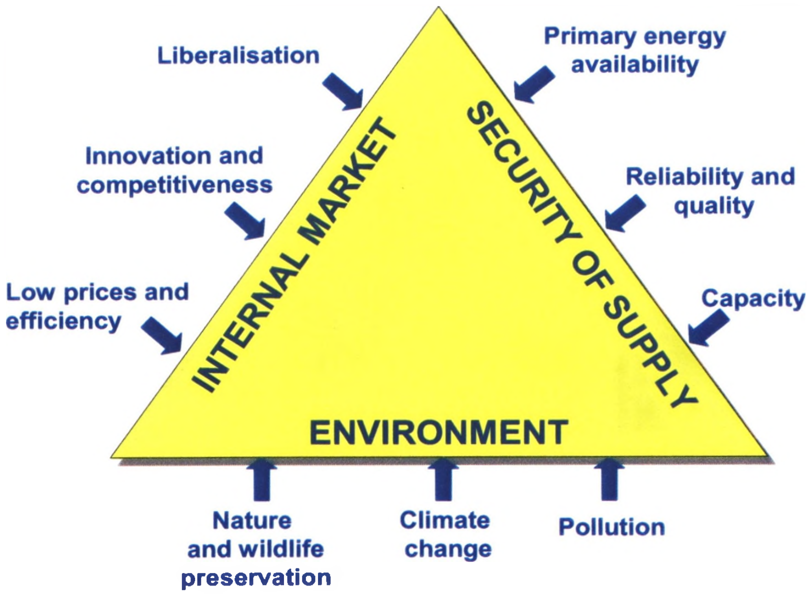


Fig. 15 - The three driving forces of the new power systems [2]

End users will become significantly more interactive with both markets and grids; electricity will be generated by centralised and dispersed sources; and grid systems will become more inter-operable at a European level to enhance security and cost-effectiveness. This new concept of electricity networks is described as the 'SmartGrids' [2] vision. It will enable a highly effective response to the rising challenges and opportunities, bringing benefits to all network users and wider stakeholders.

In recent years there has been a growing awareness, within the electricity supply industry, of the need to reinvent Europe's electricity networks in order to meet the demands of 21st century customers.

The Distribution Network is defined as the system covering all wires and equipment that play a role in supplying all medium to low voltage consumers and also giving network connection to DG technologies. Distributed Generation, becoming an integral part of European energy system, should provide consumers and energy providers with safe, affordable, clean, reliable, flexible and readily accessible energy services. DG has the fundamental benefit of producing electricity at or close to the point of consumption.

This reduces the losses resulting from delivery to customers and allows waste heat from generators to be used beneficially. Promoting and deploying distributed generation and, indeed, technologies that facilitate demand participation, therefore have the potential to benefit energy consumers, the European energy system and the environment through the optimization of the value chain from energy suppliers to active end customers utilising SmartGrid infrastructures.

Electricity market liberalization is increasing the interest of different stakeholders to the energy field. Over the coming years, energy supply will become more and more tailored to customer needs. Beside high focus on quality of service and cost reduction, total connectivity, energy "on demand", a service oriented portfolio and flexible contract management will play a leading role to fulfil customer expectations.

One of the enablers for this development is research for a set of "plug and play" interfacing modules for network connection of demand and DG using standardization and modularization, leading to lower costs throughout the power delivery chain and faster and simpler connections for generation and demand users. These plug and play interfacing modules will be environmentally friendly and can, to a high degree, be customized to individual needs. Through standardization, modularization and programmable functionality an economy of scale will be possible, leading to lower costs and more expandable systems.

Enhancing this work with multidirectional communication and control systems for horizontal and vertical integration, will facilitate participation of customers and DG in system operation resulting in effective distribution control for the benefit of power quality and reliability enhancement at the connection point. In this context, metering services and statistical metering tools represent the gateway for the access to the "active network", to the transaction platform, to the decentralized facilities and are requisite to support fully the electricity demand evolution. For that reason, electronic meters and Automated Meter Management systems represent the enabling advanced hardware and software technologies to facilitate and inform customer preferences and opportunities in the energy field and to optimize demand forecasting.

This can offer the customer choice and quality of supply at relatively low cost provided that minimal technical requirements are met and measurable, enabling network operators to maximize efficiency, flexibility and reliability through the use of smart advanced technologies.

One of the major problems limiting the wider penetration of Distributed Energy Resources (DER) in today's power systems is the lack of harmonization of grid connection requirements and the lack of compatibility of fault protection systems and metering. Differentiated definitions of grid connection requirements for the various types of generators are needed because of their different nature. Further obstacles arise from the operational engineering requirements of the networks where DER is connected. At distribution level, power flow constraints may lead to local reinforcement, in particular related to bi-directionality and possible conflicting requirements with natural gas and heat distribution networks (Combined Heat and Power). Where such obstacles are found in practice, appropriate research should be initiated to alleviate the constraints.

The objective assessment of DER effects on the network performance emphasizes the need for new system structures. Examples include: inadequacy of existing dynamic simulation tools to handle large numbers of power electronic converters in the power system and of analytical tools to study planning and development of networks taking into account the stochastic nature of DER, both in steady state and under dynamic conditions. Deterministic approaches based on maximum-minimum conditions are generally far too conservative, unnecessarily limiting a larger penetration of DER or underestimating its potential benefits. A stochastic approach is needed.

Much of the equipment of the present electricity networks was installed with a nominal design life of about 40 years. Increasingly this equipment is reaching the onset of significant unreliability in its life cycle. Meanwhile, the amount of load has grown beyond what has been predicted when the grid system was planned and designed.

Demand has doubled since the 1960s; peak demand and its timing have also changed and will continue to do so in ever less predictable ways. In recent years, environmental policies are encouraging lower carbon generation including renewable energy sources, generally using smaller unit sizes with a far less predictable output. These developments call for the re-engineering of Europe's electricity grids incorporating an innovative response to ensure cost-effective investment.

As very significant investments will be required to renew this infrastructure, it is likely that the most efficient way forward will be to incorporate new technologies and solutions when planning and executing asset renewal. This approach 'designs-in' greater network capability, flexibility and functionality will also enable Europe's networks to respond to the challenges and uncertainties as yet unforeseen.

Asset management is hindered by the traditional paradigms of reliability and long pay back periods (>30 years) associated with capital-intensive plant. The underlying uncertainty associated with recovery of such long-term investments calls for an improved knowledge of the condition and natural life cycles of networks and their components. Any consideration of future electricity networks should take into account also the life-expectancies of future new and refurbished assets - and the functional performance expectations (e.g. reliability, security, availability, accessibility, flexibility, adaptability, safety, environmental impact, aesthetic impact, operational impact, efficiency, and whole-life cost) of all stakeholders with respect to those assets from installation to disposal.

The goal is to realise robust and inter-operable European grid architecture to support the internal electricity markets and wider EU policy objectives. The European grid can be envisaged as a platform to facilitate the coexistence of intelligent local, self-controlling (smart) grids and active consumer participation, with high amounts of distributed generation on the one hand and large-scale centralised power plants and renewable bulk power injections on the other. The European grid will also have to fulfil control functions that are significant challenges to decentralise e.g. supply/demand balancing (frequency control).

The interconnection of the system could be increased e.g. by selective reinforcements or by co-ordinated action to create an ultra high voltage ac or dc transmission system architecture. Such development of the network has to take place in the context of a liberalised market with many independent players. It will require both engineering innovation and effective dialogue between the European transmission system operators in order to establish a highly inter-operable European network architecture that is coherent, viable as a business proposition, and consistent with national regulatory and commercial frameworks.

The future European grid will differ from the present in several aspects such as greater large scale cross-border energy trading, the presence of variable large-scale (e.g. off shore) wind power sources Fig 4, cross-border grid ancillary services (e.g. trading of reserve power) and the interaction of more dispersed generation and demand side management. There will almost certainly be new power flow patterns within member state grids. Better utilisation of grids and more fluctuating power in-feeds from renewable sources call for improved power flow controls at the transmission level (e.g. HVDC, FACTS), to enable renewable bulk power generation facilities to provide ancillary services and for methods to safeguard the stability of these more complex and inter-dependent transmission and distribution systems. Regional interconnection and local distribution (e.g. including mini and micro grids) will have to be developed and integrated into the architecture.

5. Blackouts

Power system blackouts have been a historical problem in interconnected grids. However in recent years, frequency and severity of this phenomenon has considerably increased. This may be in part the consequence of new regulations and restrictions imposed by power system deregulation. In fact, it is not possible to completely prevent these catastrophic failures. However by improving monitoring control and protection techniques, frequency and severity of the blackouts may be reduced

Whilst energy remains a major component of economic growth, such deficiencies have a direct impact on the world economical development, stability concerning the security of energy supply, environmental protection and well-being of world's citizens. These issues provided the main drivers for energy research in a sustainable development.

6. Conclusions

The demand for energy is proportional to the world's wealth. Current efforts in controlling the resulting rise in energy demand mainly focus on efficiency improvement and sustainable conversion technology.

Security of supply has been always a key factor in the development of electric power systems. Adequacy, quality of supply, stability and reliability and costs has to be carefully considered when planning the future of the electric power systems.

Energy systems need to be fundamentally restructured and rethought to take in account namely:

- Improvements of security standards in the context of critical infrastructures;
- Integration of both central and distributed generation;

- Integration of innovative technologies into existing grids;
- Harmonisation of equipment standards to allow "plug-and-play";
- The impact of neighbouring electricity systems.

An efficient approach to energy supply has to ensure that all relevant factors are considered in the system development for the future.

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