Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Long-Term Energy Scenarios

Information on Aspects of Sustainable Energy Supply as a Prelude to Participatory Sessions

Marco Semadeni

Input paper for the project "Public opinions of fusion via focus groups on energy scenarios including fusion and ITER sitting in Cadarache" (POFFICAD), supported as part of SERF3 "Fusion and the Public Opinion" by the European Fusion Development Agreement EFDA.

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Foreword

The paper summarizes in a condensed fashion the elements and facts important in long-term energy scenarios with the intent to impart basic knowledge for participants of group sessions, forums, interest groups, and other forms of group discussion events.

Since the length of the text provided is a main constraint of the session prelude, only topical flashlights can be given in this paper. The topics briefly touched are presented with the objective to provide some basics to be taken into participatory sessions that engage in questions about the future sustainability of energy systems. The prelude does not contain possible solutions for sustainable energy supply in the future; it lies out options including aspects of climate change mitigation.

The input paper has been produced for the project "Public opinions of fusion via focus groups on energy scenarios including fusion and ITER sitting in Cadarache (POFFICAD)" and does not necessarily agree with the views of the project sponsors.

1. The Population Growth Challenge

The human population entered the 20th century with 1.6 billion people and left the century with 6.1 billion, showing an explosive growth.

10 billion people may be expected by the end of the 21st century.

1.1 World population growth, 1750–2150

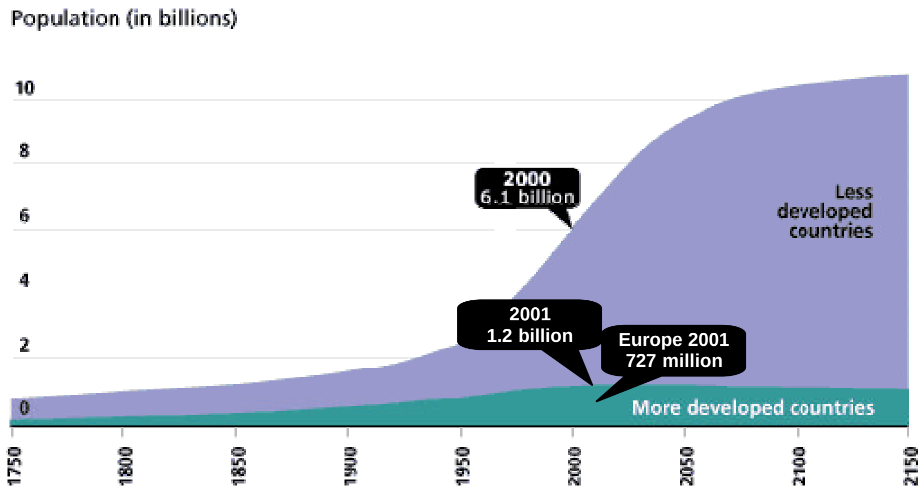

Figure 1: United Nations, World Population Prospects, The 1998 Revision; and estimates by the Population Reference Bureau[1].

Between 2000 and 2030, nearly 100 percent of the annual growth will occur in the less developed countries in Africa, Asia, and Latin America, while the more developed countries in Europe and North America, as well as Japan, Australia, and New Zealand, are growing by less than 1 percent annually.

Equally important: A 3- to 5-fold increase in world economic output by 2050 and a 10- to 15-fold increase by 2100 is expected, and per capita income in most of the currently developing countries will have reached today's developed countries by 2100 (increase of purchasing power). And even with greenhouse gas mitigation constraints, top-down energy economy models predict that GDP will grow by almost the same magnitude in the next century (*1*).

Increased purchasing power will translate into higher energy demand.

Presently, each European consumes on the average about 6 kW of energy each year. The world's average lies at 2.1 kW, and if it rises to 3 kW by 2100, the per capita world energy consumption will rise about 3 times above the present value.

[1] http://www.prb.org/Content/NavigationMenu/PRB/Educators/Human_Population/Population_Growth/Population_Growth.htm

2. World Energy Outlook

Energy services, i.e. mobility, lighting, room heating or cooling, automation, industrial products, communication and household appliances, etc., are fundamental to all three pillars of sustainable development: the economic, social, and environmental pillar.

Today, the main energy sources world wide are from fossil fuels; and one third of the world population does not have access to commercial energy.

2.1 World's energy needs up to 2020

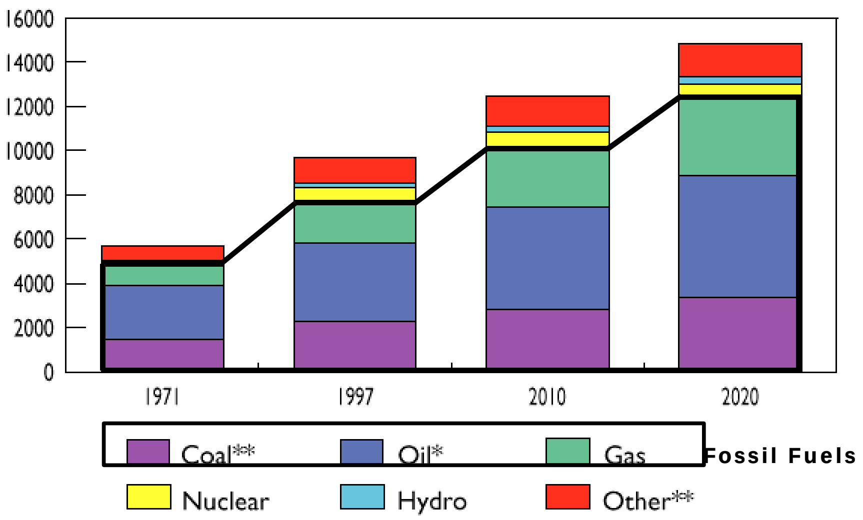

Figure 2: Global **total primary energy supply** in Mtoe by fuels (*2*).

* Includes bunkers
** Includes geothermal, solar, wind, tide, and combustible renewables & waste for OECD countries
Mtoe: million tons of oil equivalent

The different energy sources are the basis for the energy services and constitute a given energy mix (Figure 2). To secure these fundamental services, future potentials to satisfy energy demand are derived form past total primary energy supplies, estimated demands and reserves and resource capacities:

- For **crude oil**, there is no shortage expected before 2020[2].
- **Coal**, the most abundant fossil fuel, is estimated to last for at least another 220 years[3].
- The potential for **natural gas** is large – including a growth rate of 2.6% per year, it is expected to serve global requirements well into the second half of the 21th century[4].
- Considering the relative growth stagnation of **nuclear fission**, nuclear fuel (uranium) is not the limiting factor for this energy source for many decades to come. Alternative to fission, there is **nuclear fusion** being researched and not yet on an industrial scale; it is a completely different nuclear energy supply technology with practically unlimited fuel resources.

[2] This resource perspective includes economic considerations, e.g. economic feasibility of additional extractions which strongly depends on the energy prices and technological innovations for exploitation assumed - energy economics perspective. The uncertainty in reserves is relatively high.
[3] This resource perspective is a relative conservative estimate based on available reserves – resource or geologic perspective.
[4] similar to footnote 2, but even higher uncertainty in reserves.

- **Hydropower**, having still a growth potential of a factor of 5 worldwide, for many regions environmental and economic reasons limit this resource being exploited much further.
- **Other renewables**, like wind, biomass, solar and geothermal have a promising potential, however growth towards significant contributions to the overall energy mix depends on incentives given for further development, future energy prices and energy policies regarding environmental impacts of energy systems.
- **Energy efficiency technologies** especially of the demand side and **rational energy use,** though not energy sources by themselves, are very important factors to take into account. The energy saved can be considered as an indirect resource.

The world's primary and final energy use will grow less than the demand for energy services due to a smaller energy use per economic output, i.e. decreasing energy intensities.

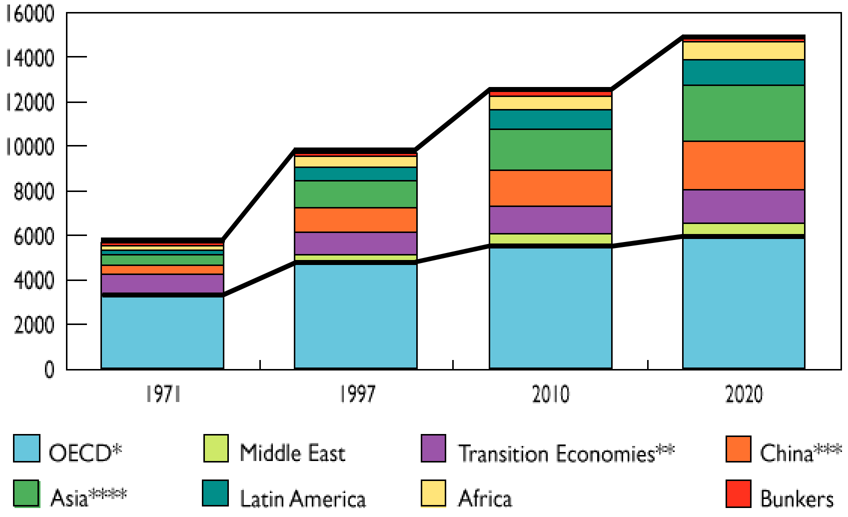

Figure 2: Global **total primary energy supply** in Mtoe by world regions (*2*).

*Does not include Mexico, Poland or Korea.
**Includes Former USSR and Non-OECD Europe.
***China includes Hong Kong.
****Asia excludes China.

Electricity consumption is anticipated to increase at rates faster than overall energy supply. The International Energy Outlook 2000 forecasts that global electricity consumption will be 76 per cent higher in 2020 than in 1997, increasing from 12,000 TWh (1997) to 22,000 TWh (2020). When the electricity share of total energy consumption is considered, the increase becomes even more dramatic.

Electricity demand will also increase due to increased purchasing power and rapid worldwide spread of communication and information technology. However, depending on lifestyle, domestic energy use and households purchasing of non-energy goods and services may change energy requirements differently throughout different demographic sections and cultures.

The growing demand increases pressure on the environment and natural resources. This makes the investigation into and implementation of efficiency strategies even more valuable.

How will the growing demand be satisfied after 2020?

3. Scenario Aspects[5]

3.1 Scenario 1

A first scenario may be envisaged to be strongly oriented towards free markets and high-tech solutions imposing high rates of investments in technological innovations including education and institutions. A high degree of international mobility of people, ideas, and technology; enhances productivity and technology diffusion.

Progress is fossil-fuel-intensive with fast advances in transport and communication technology and uncertainties in development of energy sources and conversion technologies. The energy intensity decreases by 1.3% per year, and energy and mineral resources become more abundant due to a fast technological progress.

The carbon-intensive path with its focus on abundant coal reserves, non conventional oil and natural gas path, i.e. partial decarbonization, may ultimately include more renewables (e.g. centralized solar) and a nuclear paths (fusion), i.e. strong decarbonization, approaching a more balanced mix by 2100.

3.2 Scenario 2

A second scenario envisages a fast technological development. High growth allows investments into alternative directions of technological change with natural gas as the transitional fuel, and strong efforts towards cleaner, carbon neutral and carbon free technologies. The shift towards renewables is guided by tightening of standards and environmental control measures, and leads to high rates of decarbonisation. The secondary benefits of a cleaner energy production sustain the rich economy[6].

3.3 Scenario 3

A third scenario envisages an affluent economy with high rates of investments in technological innovations including education and institutions with special focus on end-use energy efficiency and energy conservation (rational energy use). The progress is policy-intensive[7] and supports non-fossil and decentralized technologies with high technological diffusion rates.

The path enforces decoupling of energy and economic growth with a strong emphasis on energy conservation and efficiency, and ultimately aims at a transition to post-fossil (emission-free) economy by 2100. The secondary benefits of a cleaner energy production sustain a rich economy[8].

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[5] Based on scenario family descriptions from a global perspective and dynamics seen in major world regions today (3). All scenario families describe future worlds that are more affluent than today. The scenarios represent progression in different directions and with different rates of change, varying environmental standards or regulations (excluding explicit policies about climate change) in order to reduce air pollution and address many other socio-economic concerns.

[6] When market prices do not fully reflect environmental and social costs, consumers' choices are distorted. Imposing an appropriate market signal (price) to encourage rational energy use including both reducing consumption (energy savings) and changing its composition of the energy mix in favour of more environmentally friendly goods and services (support for the development and introduction of clean technologies) generates secondary benefits for the economy. This may be accomplished through a variety of economic instruments, from direct taxes to tradable permits.

[7] Regarding regulation related to tradable permits, carbon or environmental taxes or regulatory constraints

[8] As in 1; note the scenario 2 and 3 are synergistic

4. Energy and Sustainability

The availability of commercial energy boosted economic development in many regions of the world, though with the draw back of having to live with new risks, pollution and waste problems. With regard to the whole energy chain from resource extraction, conversion and energy service activities, there is no energy technology without risk implications or waste generation.

The combustion of fuels is presently the major source of impact on human health and the environment through air pollution, regional acidification and the risk of climate change. For instance, activities like present day biomass burning predominant in developing countries, put enormous pressure on indoor and outdoor air quality and on natural resources like forests contributing to desertification and loss of biodiversity. Other energy technologies like present nuclear fission power plants contribute to global radioactive waste and nuclear weapon proliferation problems. But also new energy technologies, like photovoltaics, may produce toxic wastes during manufacturing processes, or, like hydropower and wind, impact on ecosystems.

The future of sustainable human development is confronted with an exponential world population growth and a continuous and fast rise of per capita energy demand possibly leading to unreasonable dependencies, societal and ecological risks.

Today, the major issues of a general energy policy for a sustainable energy supply are:

- the challenge to mitigate climate change due to greenhouse gas emissions like CO_2,
- the present and future energy import dependency affecting supply security and quality,
- the support of technological developments to boost competitiveness and diversity of new renewable and alternative energy sources,
- the harmonization of regulations and standards to approach the internalization of external costs and encourage clean technologies for the market

4.1 CO_2 emissions and climate change mitigation

The Intergovernmental Panel for Climate Change (IPCC) forecasts electricity demand growth rates 6-20 times higher between 2020 and 2100. Presently, about 60% of the electricity is produced by fossil fuels contributing 1/3 of the CO_2 emission of the energy sector worldwide (*3*).

Emissions of CO_2, as a major greenhouse gas, will be responsible for future climate changes if the global energy systems cannot be replaced by less fossil fuel dependent systems within the next decades.

Many countries propose renewable energy technologies, energy conservation, carbon taxes or carbon emission certificate trading as solutions to reduce the environmental impacts of energy systems, for instance regarding climate change, within the next 10 to 20 years.

Renewable energy sources like hydropower, biomass, wind, solar, etc. are either CO_2 neutral or practically non-CO_2 emitters, except for some special cases of hydropower reservoirs located in warmer regions of world.

The new renewable energy technologies are those technologies, which have only been developed on a large scale in recent times. Predominantly, wind power parks have now been installed with over 8000 MW worldwide (*4*). For Europe alone, a potential of 100,000 MW of installed capacity is estimated by the year 2030, producing 167 TWh_e or 4% of the total electricity consumption forecast (*5*).

Similar shares are expected for the conversion of biomass and waste to electricity. New biomass conversion technologies are capable of using agricultural and forest residues and an array of energy crops to produce heat and power.

Together with large scale developments of solar thermal power conversion systems, major off shore wind farms, geothermal and ocean energy systems, the new renewable energy technologies combined with the old renewables, hydropower and biomass burning, are expected to reach a share between 20-50% of the world's energy supply in the second half of the century (*6, 7*).

The share of the renewables will depend strongly on the kind of energy policy followed internationally, for instance regarding climate change, and the developments on the fossil fuel markets, supply security and improved fossil fuel conversion technologies with sequestered CO_2.

Boosting the share of renewables must go hand in hand with strong efforts in energy efficiency and conservation. Major energy conservations are realized already today by energy efficient architecture of new buildings, for instance integrated building designs exploiting energy-saving opportunities. Together with demand side management, the smart use of electric appliances and lighting systems leads to additional reductions of building power consumption, and allows for the installation of smaller power generating units like photovoltaic and micro-turbines as distributed generation systems with reduced CO_2 emissions.

The compatibility of the future energy demand of a 10 billion-world population and a sustainable energy supply system that adequately addresses social and environmental risks may not be resolved based on renewable energy sources alone.

Looking beyond 2020, long-term strategies need to be developed to combat environmental risks like climate change, resolve the pressure on natural resources and foster supply security for sustainable energy systems, even if energy demand growth is stabilizing in the developed countries. Possibly inherent secure nuclear fission technology will be reality by 2050, or cost reduced solar energy technologies together with fusion energy could finally allow for the vision of a solar energy age becoming reality by the end of the 21st century.

Efficient use of resources, which includes energy conservation throughout the energy chain, clean energy conversion technologies and the development of inexhaustible supply options like renewable resources and possibly new nuclear energy from inherently safe reactors and from nuclear fusion may be strategies to achieve sustainable energy systems for the future.

5. Uncertainties

5.1 IPCC CO_2 emission outlook[9]

Greenhouse gas mitigation scenarios are developed to explore the required efforts and effects of climate policies. Worldwide CO_2 emissions vary from 6.3 GtC to 13.9 GtC per year by 2020 and, depending on the scenario used for the estimation, vary much more by 2100. Less variation is expected in developed regions.

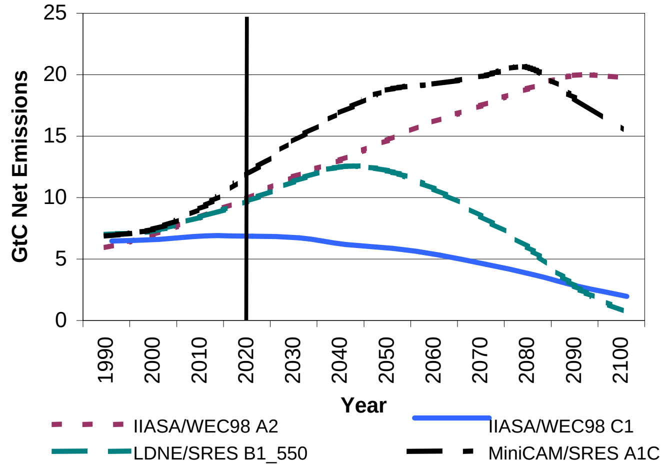

Figure 5: Four global CO_2 emission scenarios from 1990 to 2100 (*3*). The CO_2 emission curves represent different simulation runs from models using various economy, policy, and technology routines and/or variables.

IIASA/WEC 98	A2	Base case; high growth driven
LDNE/SRES	B_550	Intervention; stabilize at 550 ppmv, economic growth
IIASA/WEC 98	C1	Base case; ecologically driven
MiniCAM/SRES	A1C	Base case; climate assessment model, "clean coal" without CO_2 scavenging

The differences in the curves of figure 5 clearly show that large variations along the CO_2 emission mitigation paths exist between different intervention models.

5.2 Anecdotes of uncertainty

1). The 1992 United Nations Convention on Climate Change (UNFCCC) aims at stabilizing greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system.

The ability to unambiguously determine 'safe' greenhouse gas concentration levels is still confronted with too many uncertainties (*8*).

However, most available studies to date seem to agree that baseline emission scenarios without additional climate change policies will result in **significant climate change with associated adverse impacts**. The extent of change still underlies uncertainties but the direction of change is mostly unfavorable.

2). Essentially all energy economy models take **productivity growth for granted**. The growth is assumed to be driven by technological change. Overall productivity growth is often assumed to be 2%–3%/y, resulting in a projected rise in global world product of an order of magnitude by the end of the next century. The productivity growth is the same regardless of the kind of constraints put on the energy system (*1*)

9 see (3).

3). Forecasting total primary energy consumption would seem to be a much easier task than glimpsing the fortunes of various energy conversion techniques. After all, the use of **commercial energy is clearly tied to population growth** and to the overall economic performance (income).

Near-term population forecasts (up to 10 years) are fairly accurate, and GDPs, particularly those of mature economies, are advancing in a rather orderly fashion (*9*).

4). In 1983, predictions of global primary commercial energy consumption submitted by the participants in the International Energy Workshop for the year 2000 ranged from 5330 million tons of oil equivalent (Mtoe) to 15240 Mtoe. Using the actual consumption statistics brings the global consumption to about 9200 Mtoe by the year 2000 (*9*).

Even if the overall demand had been estimated fairly correctly, the **forecasting on the energy mix** of the world's primary energy consumption would have been still **much less successful**. Using such a forecast on the energy mix for calculating the future emissions of CO_2, or emissions of SO_2 and NO_x, the errors would have been considerable (*9*).

5). International trade of energy resources and services is essential for energy supply security. Over the past decade, world energy has entered a period of profound change - privatization and liberalization have opened energy markets around the world - changes may increase risks like increased **volatilities of energy prices**.

6. Innovations for the future

Future energy options hold promises in terms of supply security and environmental improvements, e.g. in reducing CO_2 emissions, but may also be risky in terms of fulfilling their economical or technical promises. It takes several decades until a given energy supply technology is replaced by a working alternative. For technological change, a discovery of a promising alternative is not enough; it must be researched and developed in order to ultimately demonstrate its innovative power. And if successful, it must gain significant market shares, which is mostly driven by cost reduction mechanisms through applied research and learning to deal with the new technology under real market conditions.

In addition to uncertainties regarding the supply technologies, there exist large uncertainties on the demand side, which have both a technology component and a lifestyle component. It is unclear how different lifestyles in a society or changes in lifestyles can impact on energy demand and society's choices of future energy technology options, be it energy conservation, renewable energy or high tech / high density energy supply strategies.

6.1 Energy supply technologies

Presently, the long-term alternatives to burning fossil fuels are the efficient use of renewable sources, nuclear fission and fusion energy. Although **renewable energy resources** in the world are large and inexhaustible, this potential is not necessarily unlimited.

Future innovations will possibly overcome some of today's constraints for renewable energy technologies. There is a lot of room for its development. With the long-term prospect of CO_2-free energy generation in order to cope with the risk of climate change, **new renewables** and nuclear fusion technology are thought to be likely to emerge within the next several decades.

In terms of CO_2 emission mitigation, different options are possible in the future to address the climate change problem.

The potential strategies are the following:

In the short term (next 10 years)

- the replacement of carbon intensive fuels with low carbon intensity fuels, called decarbonization through **substitution with natural gas or carbon neutral fuels from biomass**.

In the medium term (up to 50 years)

- the capturing or **scavenging of CO_2** produced from fossil fuel (and possibly biomass) combustion and transferring it into deep sea or geological reservoirs, called **CO_2 sequestration**,
- the replacement of high-emission energy technologies with **near zero-emission technologies** like gasification and combined cycle gas turbines including CO_2 scavenging, and
- further diversification of regional energy markets by
  - using **CO_2–neutral biomass** with diverse technologies like pyrolysis, gasifiction, hydrolosis, fermentation and digestion to produce different hydrocarbons like bio-alcohols (methanol, ethanol), biogas (methane), bio-oils and other bio-fuels like biodiesel or hydrogen,
  - using **CO_2-free offshore wind power** having new turbines of installed capacities of up to 4-5 MW
  - using **CO_2-free solar power** passively and actively for buildings (photovoltaics, integrated building designs, etc.),
  - using the sun to generate hydrogen or hydrogen rich fuels through **CO_2-free solar collector driven furnaces and artificial photosynthesis**,
  - using the **ocean's CO_2-free tide, waves and currents** (i.e. heat and salinity differences), and
  - harvesting the **ocean's CO_2–neutral biomass** for the production of more bio-fuels.

In the long term (more than 50 years):

- the replacement of low-emission energy technologies with **zero-emission technologies** using fuel cells to produce hydrogen, syngas or electricity,
- the introduction of **inherently safe nuclear fission** reactors as low-emission but virtually CO_2-free energy source, and
- the introduction of **nuclear fusion** as a clean and CO_2-free energy supply technology.

And in the very long term **(futuristic options)**:

- Space based solar power station consisting of a huge thin-layer photovoltaic array orbiting at a geostationary height of about 36’000 km above the earth. The station would convert solar radiation to electricity 24h a day and transfer the power by micro waves to a receiver placed on the earth’s surface.
- The MegaPower tower is a 5 to 7 km high tube-like tower, which uses the temperature difference of the atmosphere to evaporate and condensate different liquids while capturing the gravitational backflow of the condensate by turbines.
- The solar energy tower uses the sun to evaporate sea water in the desert at heights of around 1000m (spraying water tower) and recaptures the cooled down draft by wind turbines.

6.2 Lifestyles

It is often argued that new energy technologies are necessary to fill a future gap between energy supply and demand. But to be able to support a sustainable development for the future well being of society, clearly more than solely technological endeavors are necessary.

The influence of **different lifestyles in a society**, i.e. practices, meanings, beliefs and artifacts in social groups, is given more and more importance, for instance, in forecasting future energy needs of households.

⇨ There is evidence that **lifestyles are status-graded and depend on social class**, i.e. wealth, where the poorest consume energy only modestly and the wealthy use large amounts of energy.

This view may change dramatically in the future, since the social practices, like clothing, shelter, food, travel, sport and leisure have many possibilities to be improved through **energy conservation** and **environmental behavior** which ultimately pays back to individual well-being. For poor economies however, only a few choices with regard to different lifestyles exist, while a well developed economy may be able to offer many choices for alternative, energy conscious life styles.

The need to respect the different choices of individuals, groups of people or cultures about their preferences and way of life within given ethical and moral boarders, is key to an emerging diversity of lifestyles in more open societies.

⇨ Therein the development of energy technologies as a **negotiated choice of a society**, i.e. allowing for public participation, depends on many choices involving risks and novelty, and may be suitable to certain economic cultures or lifestyles and less suitable to others.

The quantity of energy used in a society however, may be large or small, high-tech or low-tech, but be either risky, novel or both. **Technological *and* lifestyle diversity** within an open society with its various choices may be the basis to change energy consumption patterns using high-tech and low-tech options under different regional, urban or rural circumstances.

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