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About climate change and future energy systems

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Abstract

The history of mankind, the process of civilisation dynamics, is inseparably linked with the utilisation of material, energy and information. Productivity, population and resource consumption are grown permanently during history, since the last century with increasing acceleration. Some decades ago a turning point in environmental awareness can be observed in early industrialised countries. The blessings of technology have been overshadowed from its risks and dangers. Articles about climate change and about finite resources increase in the media. This has led to the formulation of the ideal model sustainability and various approaches to manage it, from an engineering point of view by technology assessment. After natural and engineering science these topics are adopted by social science, which has led to a partial convergence of the two cultures. In addition considerations have been started to rethink teaching and research in order to deal with the world problems (in the sense of the Club of Rome). Recently energy scenarios have been published the message: The future belongs to renewable energies.

Zusammenfassung

Die Menschheitsgeschichte, die Zivilisationsdynamik, ist untrennbar mit der Nutzung von Materie, Energie und Information verbunden. Im Laufe der Geschichte sind Produktivität, Bevölkerung und Ressourcenverbrauch ständig angestiegen, seit dem vergangenen Jahrhundert mit zunehmender Beschleunigung. In den früh industrialisierten Ländern entwickelte sich vor wenigen Jahrzehnten eine Bewusstseinswende, die Segnungen der Technik wurden zunehmend kritisch beurteilt. Das führte zur Formulierung des Leitbildes Nachhaltigkeit und unterschiedlichen Ansätzen, dieses zu operationalisieren, aus Sicht der Ingenieure mit dem Konzept Technikbewertung. Nach den Natur- und den Ingenieurwissenschaften haben die Gesellschaftswissenschaften diese Themen aufgegriffen, was zu einer teilweisen Annäherung der Zwei Kulturen geführt hat. Weiter sind Überlegungen entstanden, Lehr- und Forschungsinhalte zu überdenken, um auf die Weltprobleme (in der Sprache des Club of Rome) angemessen reagieren zu können. In jüngerer Zeit wurden Energieszenarien vorgestellt, deren Kernaussage unmissverständlich lautet: Die Zukunft gehört den erneuerbaren Energien.

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1 Introduction

Technology always has been the main driver for social changes. If we ask what engineers are doing, the simplest answer will be: They deal with the media material, energy and information, using the *processes* change, transfer and storage. In school we have learned the history of mankind using different materials, from the stone age to the iron age. I like to start with the story of information technologies for two reasons. At first information technologies have changed societies more radically than other technologies. The second reason is the fact, that the digital revolution is the central requirement to realize the way towards sustainable energy systems.

Civilization dynamics have been driven by four radical innovations concerning communication processes, the four «Gutenberg-Revolutions». Learning how to speak, the «first Gutenberg-Revolution», has been the central innovation at the beginning of development of human species. We are the only species that has developed the medium language. This has given us an enormous evolutionary advantage compared with other species. Because the transfer of experiences is much more efficient using languages compared with the extremely slow genetic transfer.

In the history of mankind three revolutionary transitions took place. The Neolithic Revolution describes the process from hunting societies, organized in tribes, to agrarian societies, organized in feudal systems. The Industrial Revolution, based on the Scientific Revolution, was a European process. It describes the way from agrarian to industrial societies, accompanied by nation-building. The Digital Revolution, where we just live in, describes the way from industrial to service societies, characterized by global structures. The designation global does not mean that the service or information society will lead to a global state instead of national states. It suggests that the information society forces global structures. Fig. 1 shows the stages of civilization dynamics qualitatively. On the horizontal axis the central source of the respective types of societies is shown. It can be interpreted as a time axis, because the transitions took place in temporal succession. The vertical axis shows the productivity or the creation of values respectively, in today's terminology as national income per capita and year.

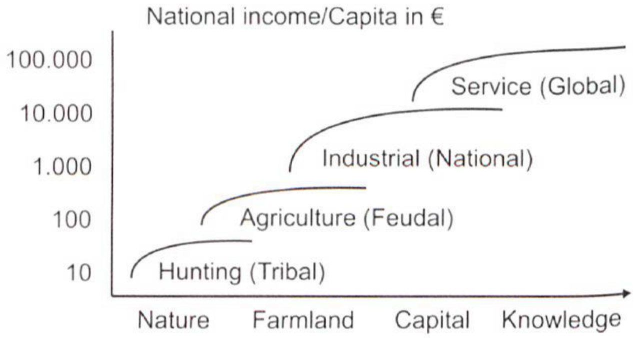

Fig. 1: Technological innovations drive social changes (Jischa 2005).

The Neolithic Revolution started about 10,000 years ago in different places of the world with appropriate climate conditions. Two processes, farming and the domestication of animals, were followed by settlements. This was the first great social and technical performance of mankind. Handling irrigation and draining became necessary, therefore these societies sometimes are called «hydraulic societies». Oral instructions were no longer sufficient. It became necessary to quantify the stock of food and animals. So from the practical point of view numbers, measures and weights as well as documents were needed, this was the beginning of writing and counting. This is called the «second Gutenberg-Revolution».

In the following food stuff and population increased rapidly. The social structure of tribes had been really democratic. Now the transition into feudal structures started in some parts of the world. Different social classes came up, rulers, a caste of priests, writers and soldiers, and a caste of farmers and workmen. Therefore, the first feudal systems had to solve a new problem, how to distribute the additional revenue. The result was an unequal distribution, the economic basis of different classes. Since that time we have a permanent discussion about different solutions, from capitalistic to communistic societies and something between.

The next radical communication innovation followed in the middle of the 15th century by Gutenberg, the printing with moving letters, the «third Gutenberg-Revolution». This new technology has led to massive social changes. In former times writing and reading was a privilege of the upper classes. Exclusive knowledge now became popular knowledge, it was democratized. Each kind of knowledge, in religion, science and technology became available for everybody. Books were published with breathtaking acceleration. So the basis for the Scientific Revolution and the following Industrial Revolution was prepared. *«The European Miracle»* (Jones 1981) started, the technology driven transformation and domination of the world by European nations.

Feudal states changed into national states. Capital, accumulated in the agrarian society, was the essential resource to make investments in starting industrial complexes. The age of coal and steel began. Again productivity and population increased rapidly. Interposed question: Could the Reformation have been successful without printing media, 70 years after Gutenberg? The theses of Martin Luther had been the first mass prints in history. Never before in history ideas could diffuse so easily into societies. Catholics like this assumption, but Protestants don't.

Only some decades ago the last radical communication innovation started, the Digital Revolution, the «fourth Gutenberg-Revolution». This has led to a time-space-compression of all processes, mainly economic processes. We don't have the fantasy to imagine the consequences about future developments in the network society. Nearly every day we are surprised by new messages. *«World Wide War»*, which is the German title of the book *«Cyber War»* (Clarke & Knake 2010) instead of *World Wide Web* is such a phrase.

Mankind has lived for some 100,000 years in a world of hunters and gatherers. From an anthropological and psychological point of view we are still hunters and gatherers. In the following mankind has lived some 1000 years in an agrarian society, 200 years in an industrial society and in the digital information society only since a few decades. So the timescales of societies decrease rapidly. This leads to a conclusion, described by the philosopher Lübbe as *«shrinking of the present»*, in german *«Gegenwartsschrumpfung»* (Lübbe 1994). If we define the present as the length of time of constant life and working conditions, then our lifetime in the present constantly decreases. The unknown future moves closer and closer to the present. At the same time, the desire for steady circumstances in societies is growing. The increasing trade with antiques and classic cars describes the situation, because these products cannot become older, for they are already old. At the same time, experts and managers in industry and politics realize the disillusioning fact, which I describe briefly as *«Popper-Theorem»* (Popper 1957): We can know ever more and we shall know ever more, but we shall never know what we shall know tomorrow, since otherwise we should know already today. In our time we know more and more, although we become blinder regarding the near future. On the other hand the number of innovations increases steadily, which change our life irreversibly.

2 Energy systems yesterday and today

Fig. 2 shows the different energies mankind has used up to now. Until the Industrial Revolution mankind has lived in a first solar civilisation. The first energy sources used had been the energy of human beings and fire, than the energy of domesticated animals and wind and water power in later periods. From an energetic point of view Napoleonic troops had been in the same situation like the troops of Alexander the Great, Hannibal and Caesar. Their troops have had the speed of animal and men.

Coal was used since the beginning of the Industrial Revolution, that means since more than 200 years. With the second largest fossil primary energy, the oil, the ascent of two industrial branches, which are considerably involved in our current prosperity, started about 100 years ago: the automobile industry and the chemical industry. Natural gas contributes to the energy offer as the third fossil primary energy since about 50 years, at the same time with the use of the nuclear energy. The three fossil primary energies mentioned at present cover scarcely 80%.

Since the beginning of the Industrial Revolution we do not behave like a respectable merchant, who lives on the interest of his capital. In geological time scales the earth has accumulated solar energy as coal, oil and natural gas. Mankind will need only few centuries or even decades for burning out the entire resources of fossil energy. Without discussing the exact definitions of resources as well as static and dynamic ranges, it can be said briefly: Coal, oil and natural gas are only available for periods, which correspond to the time we have used it. So it is justified to call the short 200 years lasting fossil energy age a «flash of an eyelash» in the history of mankind. The question comes up whether mankind will enter after the long first solar civilisation, interrupted by the ending fossil energy phase, into a second intelligent solar civilisation, or whether it will carry on a substantial development of nuclear energy. In the central diagnosis all experts agree: The world is in the transition of the today's energy system, based on the fossil primary energy resources coal, oil and natural gas, to a new world energy system. How the new energy system in the future will look like, is still discussed controversially. Especially about the future role of nuclear energy the opinions go apart (see chapter 4).

The resource problem is limited here to the discussion of the world energy consumption, which is shown since the Industrial Revolution in Fig. 3 together with the development of the world population. While the world population from 1900 to 2000 has increased from 1.65 up to 6 billion, that means by a factor of about 3.5, primary energy consumption of the world in the same period grew by a factor of about 12. Since the Industrial Revolution the energy con-

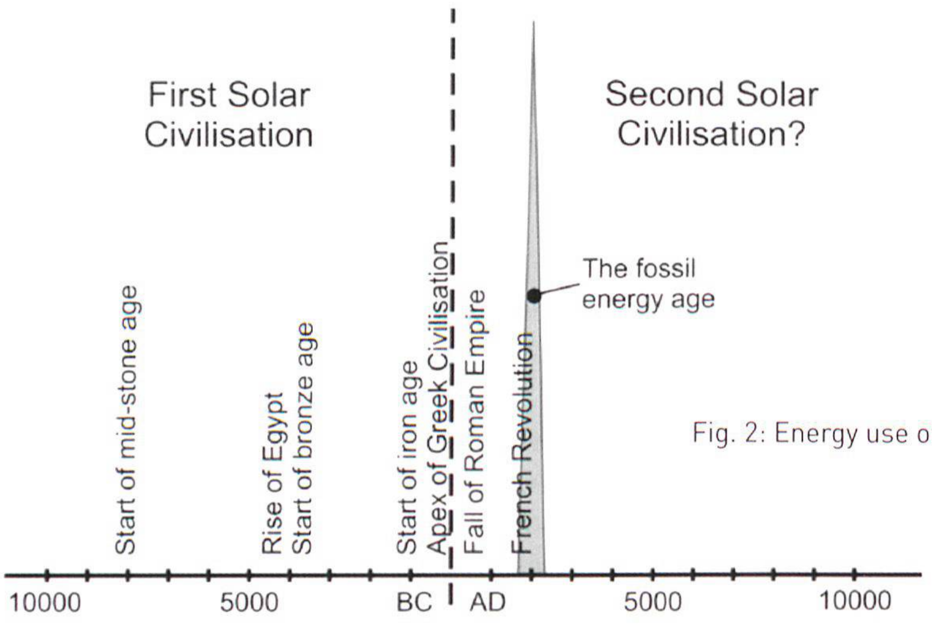

Fig. 2: Energy use of mankind (Jischa 2004, 2005).

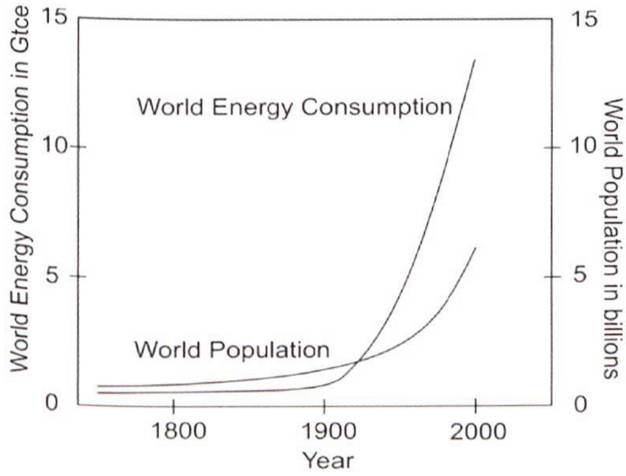

Fig. 3: World population and world energy consumption since the Industrial Revolution (Jischa 2004, 2005).

sumption per capita has grown significantly, this increase is still going on.

This is one reason because our today's energy system has no future (Fig. 4). It is an open system which has a source as well as a sink problem. The sources are finite, and the sinks as well. The carrying capacity of the system earth is limited, this is the sink problem. In the following I shall talk about the anthropogenic greenhouse effect.

3 Climate Change and Global Warming

It was Svante Arrhenius, the Swedish chemist and Nobel price winner, who has published 1896 an extensive estimation about the influence of CO_2 on atmospheric temperature. His result that doubling the CO_2 emissions would lead to an increase of atmospheric temperature by about 5 degrees is very near to later published computer simulations. In 1988 the Intergovernmental Panel on Climate Change (IPCC) was founded by the World Meteorological Organization (WMO) and United Nations Environmental Program (UNEP). Since that time the IPCC started reporting about global warming, at first 1990. The fourth report has been published in 2007, the fifth report appears 2013/2014. The message is clear. Since the Industrial Revolution the concentration of CO_2 has increased from 280 ppm up to about 400 ppm now. It was Charles Keeling who first made direct measurements of CO_2 in the atmosphere, in Hawaii and in the Antarctica (Fig. 5).

There are seasonal variations. In spring plants are growing and therefore they are a CO_2 sink, in autumn they are rotting and therefore a CO_2 source. This process is more remarkable on the northern, where the land is concentrated, then on the southern hemisphere. The problem is that the trend is going up. Fig. 6 and 7 show the enormous increase of CO_2 emissions for different countries.

In a time period of only three years these emissions have increased by about 50% (total and per capita), especially in the big emerging states China and India. On the other hand the reduction in highly developed industrial states is relatively small compared with their political program. All experts agree that this development cannot be extrapolated into the future. We should follow a path «*Towards Sustainable Energy Systems*» (WBGU 2003).

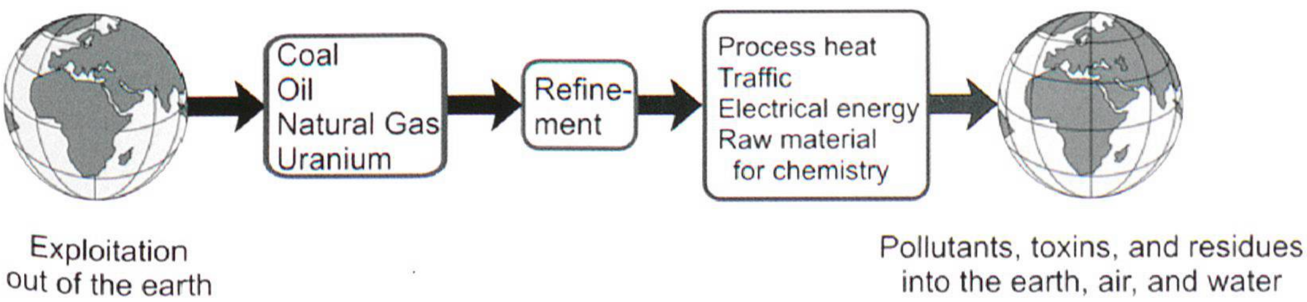

Fig. 4: Today's energy system (Jischa 2004, 2005).

4 Towards sustainable energy systems

This chapter is mainly based on relevant reports published by the German Advisory Council on Global Change (WBGU = Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen). All Flagship-Reports have the main title «*World in Transition*». I like to start with essential statements from the report «*Strategies for Managing Global Environmental Risks*» (WBGU 1988): «Global risk potentials and their interplay with economic, social and ecological processes of change have emerged as a novel challenge to the international community. Never before has human intervention in nature assumed global dimensions. [...] The approach taken by the council is to identify a taxonomy of globally relevant risks (Damocles, Cyclops, Pythia, Pandora, Cassandra, Medusa) and highlight the particularly relevant classes of risks and link both established and innovative risk assessment strategies and corresponding risk management tools to these classes, in order to define management priorities.»

The report «*Towards Sustainable Energy Systems*» (WBGU 2003) is particularly important for this text. The main message is: «Turning energy systems towards sustainability is feasible. [...] The exemplary path charted by the Council embraces four key components:

1. Major reduction in the use of fossil energy sources;
2. Phase-out of the use of nuclear energy;
3. Substantial development and expansion of new renewable energy sources, notably solar;
4. Improvement of energy productivity far beyond historical rates.»

In the literature there is a controversial discussion only about the future role of nuclear energy. Fig. 8 shows the proposed exemplary path until 2050/2100 (WBGU 2003).
In addition I mention the report «*Climate Change as a Security Risk*» (WBGU 2007). The report identifies «six threats to international stability and security:

1. Possible increase in the number of weak and fragile states as a result of climate change;
2. Risks for global economic development;
3. Risks of growing international distributional conflicts between the main drivers of climate change and those most affected;

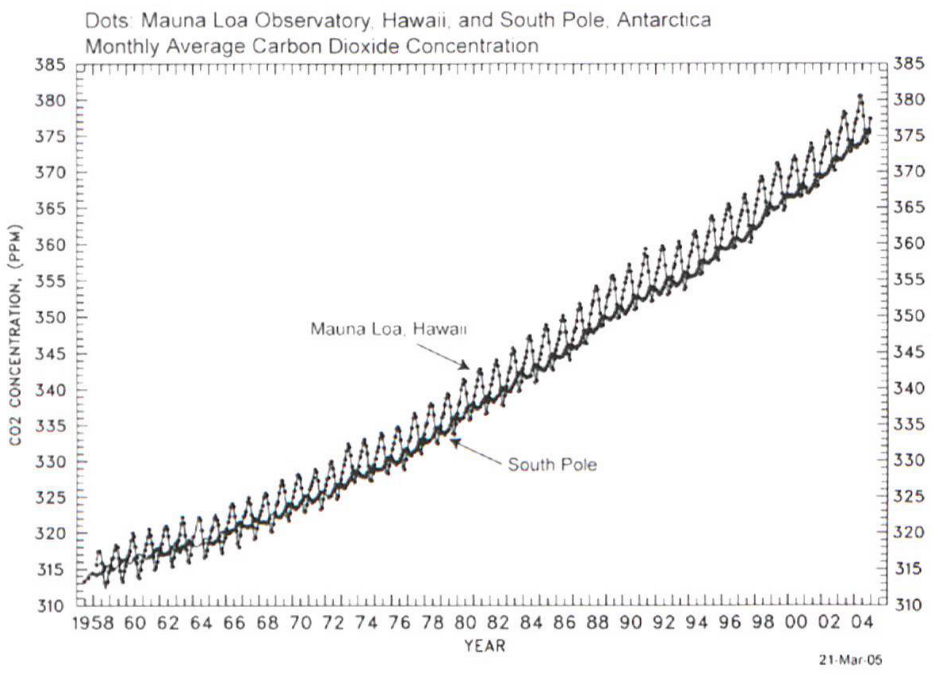

Fig. 5: The Keeling curve (source: Wikipedia).

4. The risk to human rights and the industrialized countries legitimacy as global governance actors;
5. Triggering and intensification of migration;
6. Overstretching of classic security policy.»

In Germany we have an increasing discussion about the costs of the energy *Wende*. For this debate the «*Stern Review on the Economics of Climate Change*» (Stern 2006) gives answers. The main message of the Stern report is the statement, that the benefits of strong, early action on climate change outweigh the costs. The climate change threatens the basic elements of life for people around the world – access to water, food production, health, and use of land and the environment. The impacts of climate change are not evenly distributed – the poorest countries and people will suffer earliest and most. And if and when the damages appear it will be too late to reverse the process. Thus we are forced to look a long way ahead. The transition to a low-carbon economy will bring challenges for competitiveness but also opportunities for growth. Policies to support the development of a range of low-

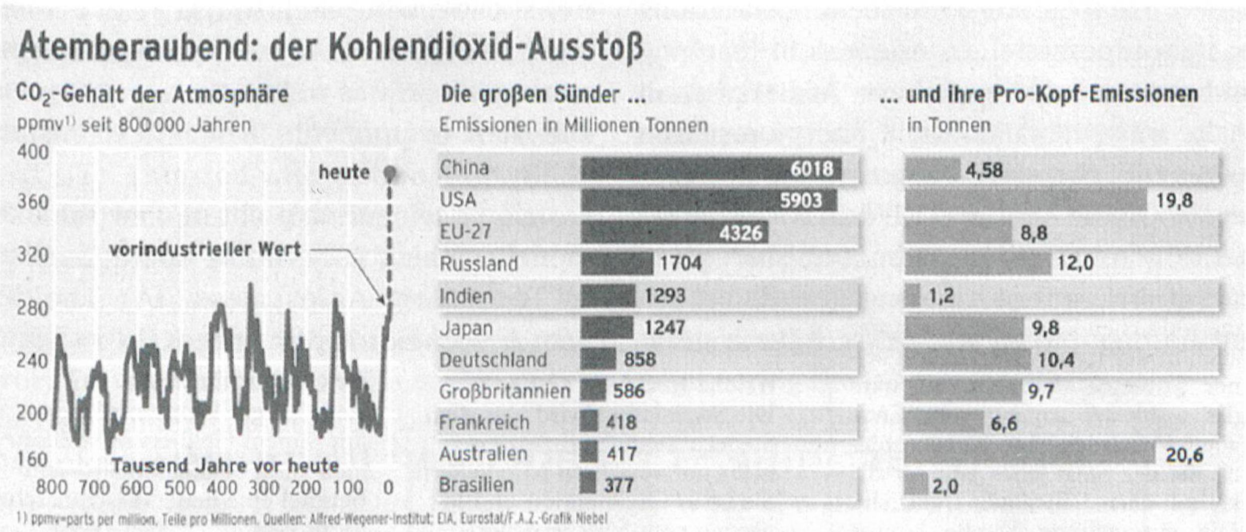

Fig. 6: CO_2 emissions 2009 (Frankfurter Allgemeine Zeitung, 27. Sept. 2009).

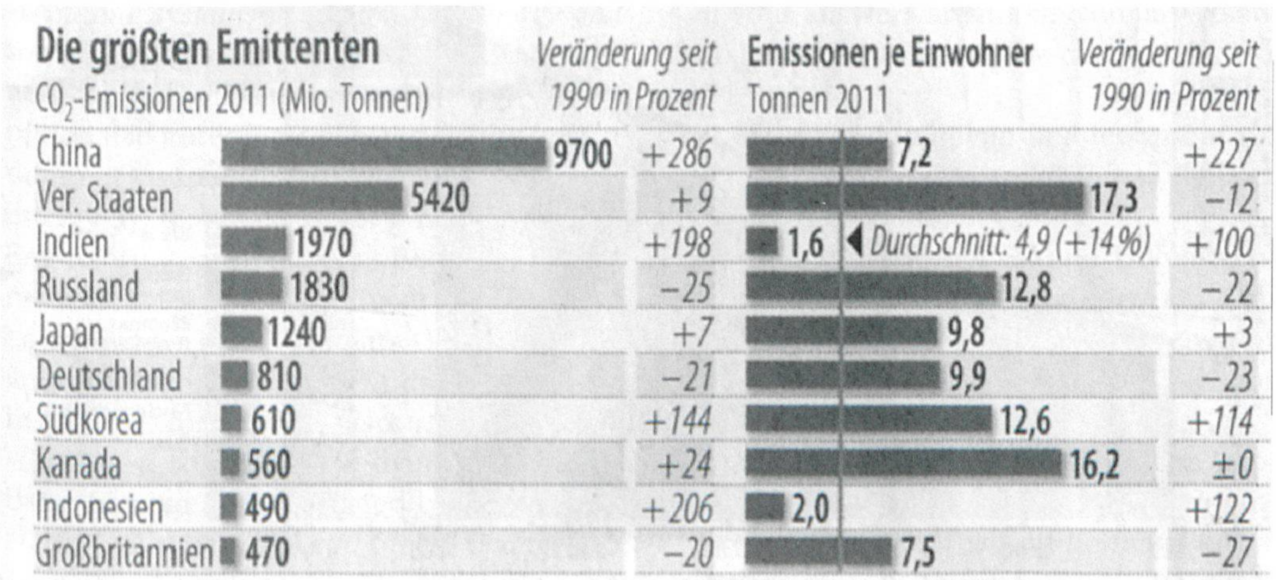

Fig. 7: CO_2 emissions 2012 (Frankfurter Allgemeine Zeitung, 27. Nov. 2012).

carbon and high-efficiency technologies are required urgently. An effective response to climate change will depend on creating the conditions for international collective action. There is still time to avoid the worst impacts of climate change if strong collective action starts now. In addition to the Stern report his book «*A blueprint for a safer planet – How to manage climate change and create a new era of progress*» (Stern 2009) is recommended.

5 Challenges for teaching and research

Here I like to make some recommendations based on personal experiences in teaching and research for engineers. At first I shall make some remarks about energy research in general, therefore I identify four different levels. On the first level we deal with components of change, transfer and storage of energy. These topics belong to classical scientific disciplines where we have a great treasure of knowledge. But the central question is how these different components can fit into existing or desirable energy systems. The energy system decides which components are more or less useless. But the problem of finding an optimal energy system depends on legal and institutional frame conditions, on regulations, on management rules. But where do these frame conditions come from? Who values the guidelines and management rules and how? If sustainability is the guideline, the frame conditions have to follow this concept. This means that energy research must follow a reverse strategy. Starting with the concept sustainability, we have to look for appropriate frame conditions. If we will reach in the year x a new energy scenario, than an appropriate framework will follow as well as the energy system and their components, which fit to sustainability.

From an engineering point of view the ideal model sustainability can be operationalised by Technology Assessment (TA). The German Association for Engineers (VDI = Verein

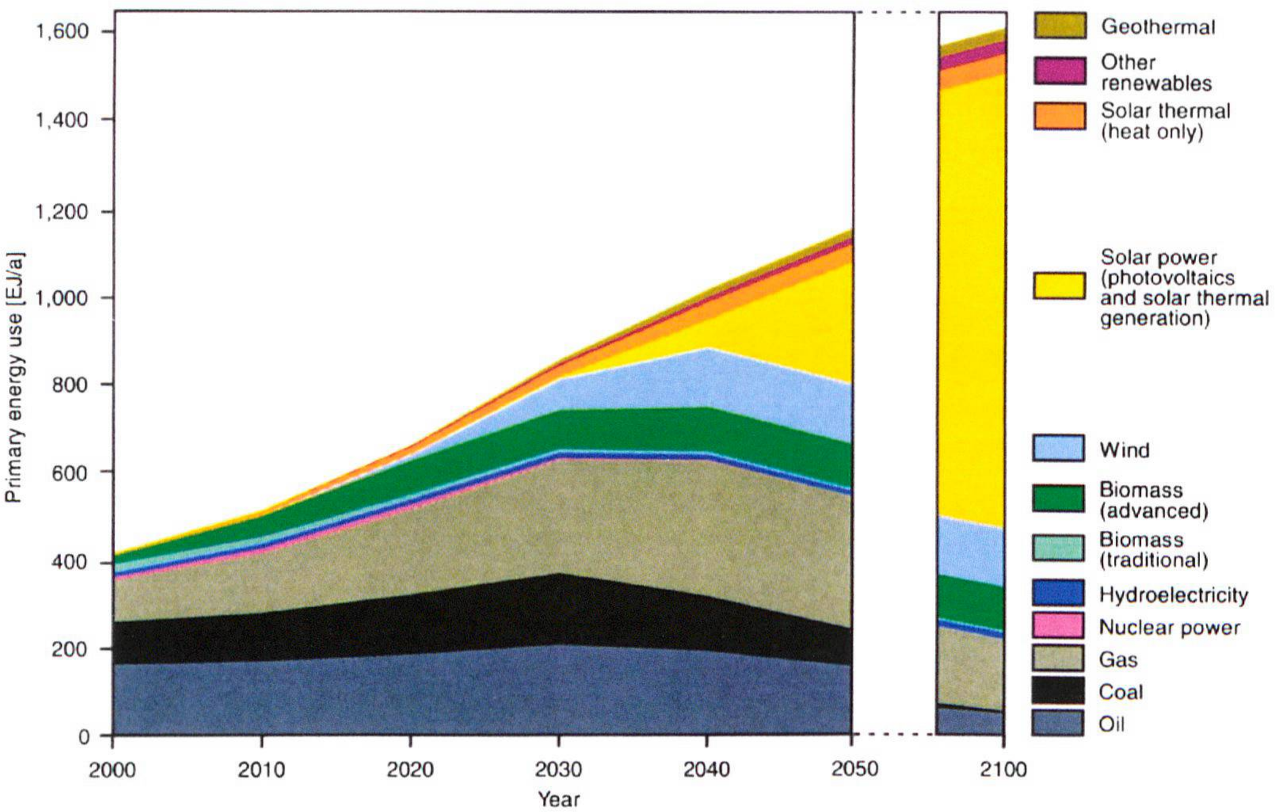

Fig. 8: Transforming the global energy mix: The exemplary path until 2050/2100 (WBGU 2003).

Deutscher Ingenieure) 1991 had published their guidelines *«Technology Assessment – Concepts and Foundations»* (VDI 1991). In 1989 the Office of Technology Assessment at the German Bundestag was introduced, in Switzerland TA Swiss was founded 1992. Similar institutions exist in other European countries and since that time we have a scientific TA community in Europe. In 1990 the EPTA network (European Parliamentary Technology Assessment) was formally established. The EPTA partners advise parliaments on the possible social, economic and environmental impact of new sciences and technologies.

Finally I like to talk about personal activities concerning Technology Assessment and sustainability management in teaching and research at Clausthal University of Technology (CUT). I started with optional (studium generale) lectures. In 1991/92, just before the Rio Conference, I presented the first lecture *«Challenge Future»* (*«Herausforderung Zukunft»*), to make the students sensible for the «worldproblematiques» in the words of the Club of Rome. This lecture has been the basis of a book (Jischa 1993, 2005). The lecture *«Technology Assessment»* followed in 1994/95 to discuss how the ideal model sustainability can be operationalised from an engineering point of view. In 1995 the lecture *«Dynamic systems in nature, technology and society»* followed to link up with control engineering, a typical engineering tool. These optional lectures later became obligatory for different courses like Chemical Engineering, Energy Systems Technology, Environmental Engineering and others. Because of my retirement these lectures have been overtaken by former Ph.D. students Christian Berg, Ildiko Tulbure and Björn Ludwig, later they became external Professors. The lecture *«Challenge Future»*, taken over by Christian Berg, has been transformed by Berg into a lecture *«Sustainability and Global Change»*.
From the beginning these lectures have been accompanied by research activities, some of them in cooperation with the industry. Therefore I was asked by Gerhard Kreysa, at that time managing director of the DECHEMA, who has initiated the «World Chemical Engineering Council» (WCEC), to make a proposal for a «sustainability project» for the WCEC. So I became member of a WCEC working group to formulate this project. The short version is a good summary of my concept:
«The pursuit of Sustainable Development (SD) is a major challenge for engineers. Chemical engineering is the profession most concerned with managing material and energy flows and, as such, is well equipped to address the sustainable use of resources. This can be achieved by identifying better ways of deploying technologies as well as economic and regulatory measures and by anticipating ways in which investment in process technology can help achieve sustainability. The WCEC wishes to promote a better understanding of sustainability for chemical engineers. Therefore the WCEC will ask all institutions teaching chemical engineering the following questions:

1. How is SD embedded into your Chemical Engineering Degree Program?
2. What are the curricula contents of the material referred to in question 1?
3. How are the curricula related to SD supported by research?
4. If your answers are no, do you have plans to implement SD into the curricula?»

A shorter version, given in a lecture at the ChemEng in Birmingham 2008, has focused to two major points:

1. Teaching concerning SD and TA has to be *embedded into engineering curricula*. Otherwise we would have the «cappucino effect», that means lectures like «X and ethics» at the end of the courses.
2. Teaching concerning SD and TA has to be *supported by accompanying research projects*. Otherwise it would be feature that means «nice to have».
   In several papers it was reported about

this process (Jischa 1993, 1997, 1998, 2004, 2005, 2010a, 2010b, 2012).

I too like to recommend another lecture at CUT, offered by Turek called *«Energy Flows, Material Cycles and Global Development – A Process Engineering Approach to the Earth System»* (see Schaub & Turek 2011). The book goes back to a course initiated 1990 by their academic teacher Lothar Riekert (TH Karlsruhe, now KIT). The authors write in their preface: «Engineers involved in the handling, processing, and utilising of materials and energy are constantly faced with the environmental and economic effects of their activities. These include environmental changes in local, regional and global scales, as well as the depletion of resources and the search for new raw materials and energy sources. This has been the experience of the authors during their professional activities as chemical engineers in industrial research and development, and in academic research and teaching in various areas of fuel chemistry and reaction engineering.»
The authors were motivated by the following questions: «What are the factors determining macroscopic material and energy flows in the Earth´s biogeosphere? What is the appropriate approach to understand potential perturbations of natural cycles, caused by human activities and to assess significant anthropogenic terms? When using materials and energy, our human societies today and for the foreseeable future limited by the depletion of resources or more so by global environmental changes? Given the considerable technology innovation and research activities ongoing worldwide: How to deal with the obvious lack of synthesis and integration approach? As for the industrialized countries, to what extent can they serve as examples for the less-developed countries? What are appropriate technology options for sustainable development?»
A strategy paper of the Deutsche Forschungsgemeinschaft (DFG) came to similar conclusions (Wefer 2010). The basic message reads (my translation): In order to get a better understanding about the components and the whole «system earth» the Geosciences (GS) should expand their research program. The specific GS topics still remain relevant. But to manage the today and future problems they have to cooperate with the humanities, especially the social sciences. Only connecting all disciplines of the *«Two cultures»* (Snow 1963) dealing with the system earth can lead to a better understanding of global change.

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