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Renewable Energy

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Abstract The Energy Committee of the Royal Swedish Academy of Sciences has in a series of projects gathered information and knowledge on renewable energy from various sources, both within and outside the academic world. In this article, we synthesize and summarize some of the main points on renewable energy from the various Energy Committee projects and the Committee's Energy 2050 symposium, regarding energy from water and wind, bioenergy, and solar energy. We further summarize the Energy Committee's scenario estimates of future renewable energy contributions to the global energy system, and other presentations given at the Energy 2050 symposium. In general, international coordination and investment in energy research and development is crucial to enable future reliance on renewable energy sources with minimal fossil fuel use.

Keywords Renewable energy · Hydropower · Wind power · Solar power · Bioenergy

INTRODUCTION

Reducing the fossil fuel contribution to the global energy system, and in particular doing so with renewable energy sources, is a great challenge for the world community. Many of the projects carried out by the Royal Swedish Academy of Sciences' Energy Committee since 2005 have therefore specifically addressed renewable energy. These projects considered energy from moving water (Energy Committee at the Royal Swedish Academy of Sciences 2008), wind power (Energy Committee at the Royal Swedish Academy of Sciences 2010), bioenergy (Energy Committee at the Royal Swedish Academy of Sciences 2008; Fredga et al. 2008), and solar energy (Energy Committee at the Royal Swedish Academy of Sciences 2008; Pihl 2009).

The Energy Committee projects have gathered knowledge from various sources, both within and outside the academic world, and from a number of seminars and hearings, in addition to the Committee's Energy 2050 symposium. In this article, we summarize the Energy Committee's scenario estimates of future renewable energy contributions, which were reported for the first time in their entirety at the symposium, together with the other presentations given at the renewable energy session of the symposium. In a concluding discussion, we synthesize some of the main points on renewable energy from the symposium and relevant Energy Committee projects.

A Quantitative Renewable Energy Scenario for 2050

Figures 1 and 2 illustrate the Energy Committee's global energy projection for the year 2050, compared to conditions in 2007. Figure 1 shows the shares of different renewable sources in the global primary energy supply, and Fig. 2 shows their share in the global production of electricity. In 2007, the total renewable energy contribution was 12% of the global primary energy supply of 140,000 TWh and 18% of the global electricity production of 20,000 TWh. By the year 2050, renewable energy is expected to reach 35% of an estimated global primary energy supply of 170,000 TWh and 50% of an estimated global electricity production of 45,000 TWh.

Among the renewable energy sources, hydropower is presently the most important source for electrical power generation. It also provides grid stability and reliability, as well as balancing support to intermittent renewable energy, such as wind and solar power. The global contribution of hydropower, in a 40-year perspective, is estimated to be

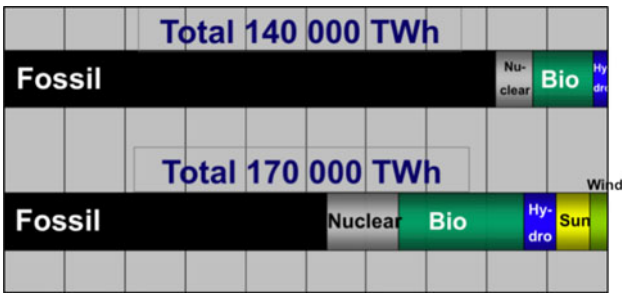

Fig. 1 The shares of different renewable and other sources in the global primary energy supply for 2007 according to IEA statistics (2007) (*upper*) and in a scenario estimate for 2050 by the Energy Committee (*lower*)

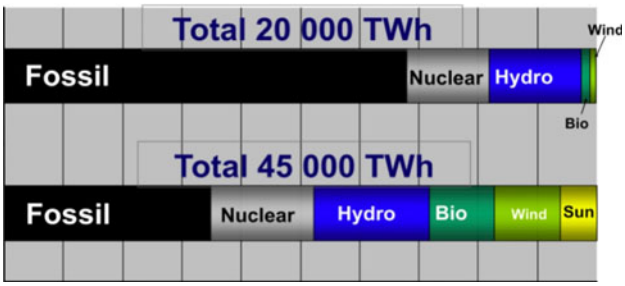

Fig. 2 The shares of different renewable and other sources in the global production of electricity for 2007 according to IEA statistics (2007) (*upper*) and in a scenario estimate for 2050 by the Energy Committee (*lower*)

around double that of today. The future hydropower shares of global electricity production and the total energy supply in 2050 are expected to be around 20 and 6%, respectively.

Bioenergy is an all-round energy source, which can be used for production of electricity, heat, and fuels. The major future biomass energy option is expected to be residues from forestry and agriculture, along with organic wastes. By 2050, the bioenergy contribution is expected to be about 20% of the global energy supply and 10% of global electricity production.

In 2008, wind power provided 0.2% of the global energy supply. It is a rapidly increasing source of renewable electricity generation, with the main constraint for its development being related to its intermittency. A balancing power source is therefore needed. Today, balancing power comes mainly from fossil fuels. In order to reduce fossil fuel use, a combination of hydropower and wind power constitutes an excellent combination. With the estimated hydropower development and the main aim to minimize the use of fossil fuels, the 2050 share of wind power is expected to be around 3–4% of the global energy supply and 12–15% of global electricity production. A future development of large-scale energy storage facilities may allow for greater long-term expansion of wind power.

Solar energy using direct sunlight is potentially the most powerful renewable energy source for electricity and heat. The technologies are developing rapidly, and in 2050, solar energy is expected to contribute up to 6% of the total global energy supply and 6% of the global electricity production. The main solar power constraints are high costs and its intermittency. However, while global energy prices are rising, the costs for solar energy are decreasing. Concentrating solar power (CSP) has the potential to provide significant amounts of base-load power, but is not expected to be viable in areas without much direct sunlight.

Based on our current knowledge, renewable energy sources can be expected to provide up to 35% of the global energy supply and nearly half of the electricity production by 2050. Fossil-energy use is thus expected to remain high, mainly due to increasing energy demands in the developing countries. However, the share of fossil energy in the global energy supply is still expected to drop from the current 80 to 53% by 2050. With most renewable and non-fossil energy sources providing electrical energy, electricity is set to become a major energy carrier in the future. Electricity is expected to increase by as much as 125% by the year 2050, while global primary energy increases by 21%.

Additional Views on Renewable Energy Development

Carlo Rubbia, CERN, Geneva, talked about innovation as the key to a more successful development of renewable energy than expected, based on today's knowledge. He stressed the fact that the world has been increasingly powered by fossil fuels over the last 150 years and must now reverse this trend over a much shorter time period.

The current trend is unsustainable with respect to both global warming and energy security. Rubbia's assessment is that this trend can only be changed by vigorous innovative efforts in research and development by universities and other research institutions, and a prompt industrial deployment by the business sector toward new energy sources. Only in this way can today's carbon-intensive economy be transformed into a new sustainable and equitable system.

Rubbia discussed different concrete ways to achieve these goals, viewing environmentally friendly uses of fossil fuels (e.g., by CO_2 sequestration and storage) as temporary solutions. For longer-term solutions, he discussed mainly two renewable energy sources: solar power, and second and third generation bioenergy, involving non-food crops, organic wastes, and algae. In general, Rubbia emphasized investment in energy research, development, and innovation as crucial for the emergence of a sustainable energy system beyond the fossil-energy era.

Robert Pitz-Paal from the German Aerospace Center, Köln, talked more about solar power, in particular about CSP, and its possible road from research to market. He described how CSP plants with thermal energy storage can be built to allow for efficient and CO_2-free power supply. Such CSP plants can be managed to scale up and down, following the load, with the storage being dispatchable to quickly meet peak demand, independent of weather conditions.

A main CSP option involves export of electricity through high voltage direct current (HVDC)-transmission lines, from countries in the Sun Belt to densely populated areas with lower incident solar radiation in developed countries, as envisioned in the DESERTEC concept illustrated in Fig. 3. Projections with this option for the countries of the EU and the Middle East and North Africa (MENA) are foreseen to include a mix of different power sources (see Fig. 3) and to reduce the EU dependency on fuel imports from 80% (year 2050, business as usual) to 32%.

Pitz-Paal described the CSP development from the first to present commercial plants. The first plants had a total capacity of several hundred MW and were built in the late 1980s in the Californian Mojave desert. They have accumulated more than 15 TWh of solar electricity and 20 years of commercial operation experience. During 2008, commercial systems were into operation in Spain and the US, with further deployment of several GW being underway in other countries.

Hermann-Josef Wagner from Ruhr Universität, Bochum, talked about the status and prospects of wind energy in the world. Wind energy will be an important component of the future electricity system. In some countries, such as Germany, where the potential of wind energy onshore has been nearly exhausted, future projects will have to go offshore.

Wagner emphasized that wind is a stochastically fluctuating energy source. In order to meet consumer demands, it must be embedded in a complex electricity system that can react quickly and can use alternative power stations as the wind fluctuates. Today, these alternatives are mostly fossil-fueled power stations. The EU expansion of wind energy requires extension of the electrical grid in every country that introduces renewable energy sources. In Germany, for example, 800 km of new high voltage lines are needed to meet the political goal of 20% electricity from wind in 2020. Wind energy systems are material intensive, but the technical problems involved are solvable.

Wagner also stressed that the use of wind energy requires further research. This research must address wind power life cycle and sustainability analyses, material and design requirements, and forecasting of the wind resource and the needs and use of energy storage.

CONCLUDING DISCUSSION

Among the renewable energy sources, hydropower plays a key role, with a unique capacity to quickly respond to

Fig. 3 The DESERTEC concept of exporting electricity through high voltage direct current (HVDC)-transmission lines, from countries in the Sun Belt to densely populated areas with lower incident solar radiation in developed countries (DESERTEC Foundation 2010)

fluctuating electricity demands. It has large development possibilities in different parts of the world, but there are a number of essential social and environmental obstacles and constraints to its development. Most of the hydropower development potential is to be found in developing countries, whereas, for example, the EU already has exploited most of the readily accessible resources.

Less developed technologies for energy production from moving water than traditional hydropower, such as wave and tidal power, have large theoretical potential for renewable energy production. However, significant energy production cannot be expected from these sources within the next few decades. Research and development efforts are needed to clarify their feasibility and enable sustainable use of their renewable energy potential.

Wind power will play a role in future electricity supply. However, it currently depends mainly on gas and coal power to balance its intermittency. In the long term, 2050 and beyond, this balancing must be provided by non-fossil or CO_2-emission-free energy sources. Hydropower is the most interesting renewable alternative for this purpose. Demand, management, and geographic location optimization of new wind power plants are important issues for improving wind power efficiency.

Bioenergy will increase in importance, and the major future biomass energy option is expected to be residues from forestry and agriculture, along with organic wastes. Added agricultural production of biofuels may not yield a net positive climate effect (Crutzen et al. 2008; Destouni and Darracq 2009) and will need to compete with the production of food for land and water (Académie des Sciences 2006). The global population of 9–10 billion people expected in year 2050 will need food with an energy content of about 10,000 TWh per year (2,500 kcal/person/day), which is several times more energy than that provided today by fossil fuels.

Solar energy technologies are developing rapidly and, in the next 40 years, can become important global energy providers. The solar resource base exceeds that of all other renewable alternatives, but a breakthrough has so far been limited by the high costs involved and the intermittent nature of solar radiation. CSP with integrated heat storage has the potential to provide significant amounts of base-load power, but will be feasible only in regions with high input of direct sunlight, i.e., in or close to desert areas. Electricity export from these areas requires long-range, high-capacity continental power grids. Small-scale solar energy systems, such as photovoltaics and heating panels, are expected to become increasingly important at the local level. Large-scale research efforts and development needs still remain for the development of viable large-scale solar power solutions.

In general, for the global energy system, international coordination and investment in energy research and development are crucial to enable future reliance on renewable energy sources with minimal fossil fuel use.

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