Preface: renewable energy and the way ahead

Milorad Bojić

Faculty of Mechanical Engineering at Kragujevac
University of Kragujevac
Sestre Janjić 6, 34000 Kragujevac, Serbia
E-mail: bojic@kg.ac.yu
E-mail: bojic@knez.uis.kg.ac.yu

Abstract: Our civilisation faces growing prospects of climate problems that are blamed on current fossil fuel energy consumption because of massive CO_2 release into the atmosphere and associated global pollution. If the use of fossil fuels continues, our civilisation will face environmental catastrophe in the near future. This special issue is an attempt to answer a fundamental question: how to handle the problem so our civilisation will survive in the future without experiencing lack of energy. In a future energy scenario, our civilisation may use nuclear energy, non-nuclear renewable energy, fossil energy with CO_2 sequestration, more efficient energy technologies, energy saving, *etc*. To design the scenario for the use of renewable energy, it is important to discuss the following issues: energy quality, energy payback time, real CO_2 emissions, energy concentration, CO_2 emission payback time, renewable energy increase in energy mix, and thermodynamic equilibrium of the earth.

Biographical notes: Milorad Bojić graduated with a BSc in Mechanical Engineering from Belgrade University, Yugoslavia, an MSc from Syracuse University, New York, USA and SciDr from Kragujevac University, Yugoslavia. He is a Full Professor of Mechanical Engineering and Director of the Centre for Heating, Air-Conditioning and Solar Energy at Kragujevac University. He was a Visiting Professor at Nagoya University, Japan, and also a Visiting Professor and Honorary Professor in 2002–2003 at the Hong Kong Polytechnic University. He is also a member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers. He has authored more than 200 papers in energy recovery, thermoeconomy, global warming and architectural engineering.

1 Introduction

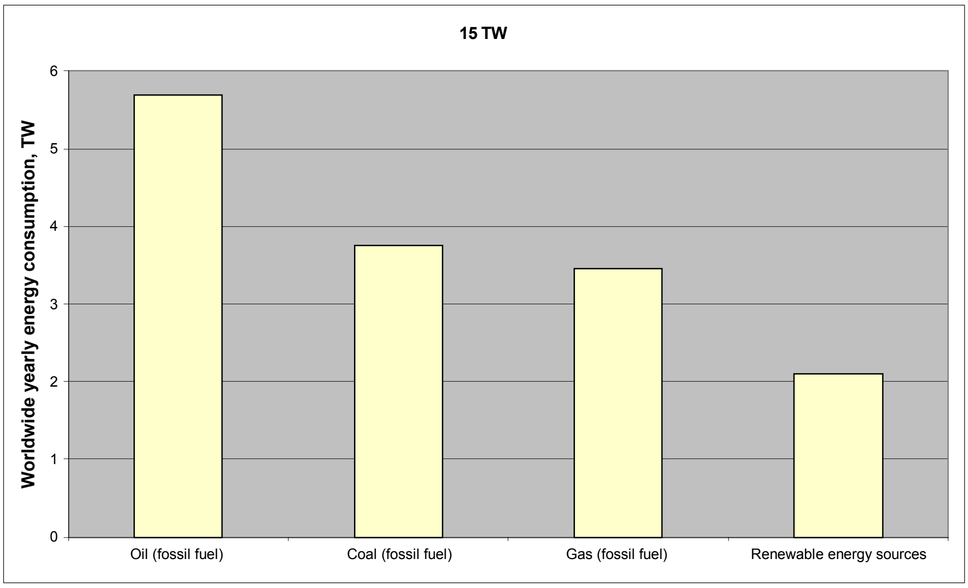
Nowadays, issues of renewable energy consumption and associated pollution prove very important in designing our way ahead in the future. Our civilisation faces growing prospects of global climate destabilisation that are blamed on current fossil fuel energy consumption with massive release of CO_2 and other Greenhouse Gases (GHG) into the atmosphere (IPCC, 2001). Although the phenomenon of the greenhouse effect is recognised, concrete actions are still not sufficient to handle the problem. In addition, these actions are not coordinated throughout the entire planet at the necessary pace and level. This special issue represents an attempt by the concerned scientific community to suggest how to control this problem and our future.

2 Energy

Energy is one of the most essential human needs. Energy in different forms has enabled the accomplishments of human civilisation, and created human good living. Its use has been affordable, efficient and extensive. However, like other human activities, energy consumption created (global and local) pollution. Through the release of CO_2 into the atmosphere, consumption (through combustion) of fossil fuels developed the most dangerous form of pollution – global pollution.

Right now, the leading source of energy in the world is fossil fuels, such as coal, oil and natural gas, as these are the most affordable. Yearly energy consumption in 2004 was 15 TW, with around 85% from burning fossil fuels, and 15% from using renewable energies (Figure 1) (British Petroleum, 2007; Renewable Energy Network, 2006). However, prolonged use of fossil fuels may not be sustainable even in the near future owing to the depletion of fossil fuel reserves and global warming. Because of this, a fossil fuel price rise is recorded that may make economically attractive the use of other types of energy that have lower influence on global warming. However, one should use other possibilities to decrease GHG emissions, such as increases in energy savings, decreases in energy consumption and cogeneration of electricity and heat.

Figure 1 Worldwide yearly energy consumption for different fossil energy resources

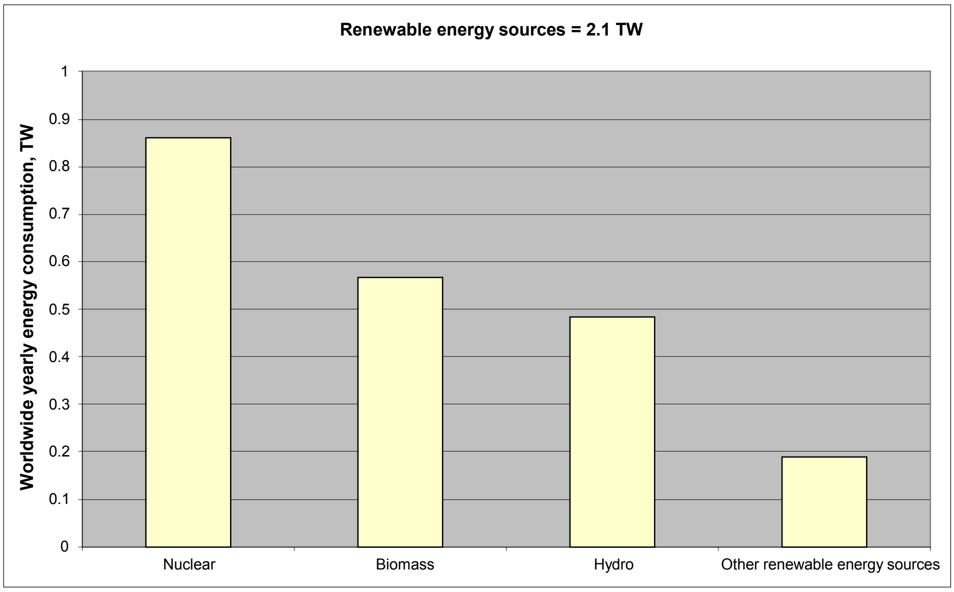


Note: Total yearly energy consumption in 2004 was about 15 TW.

3 Renewable energy

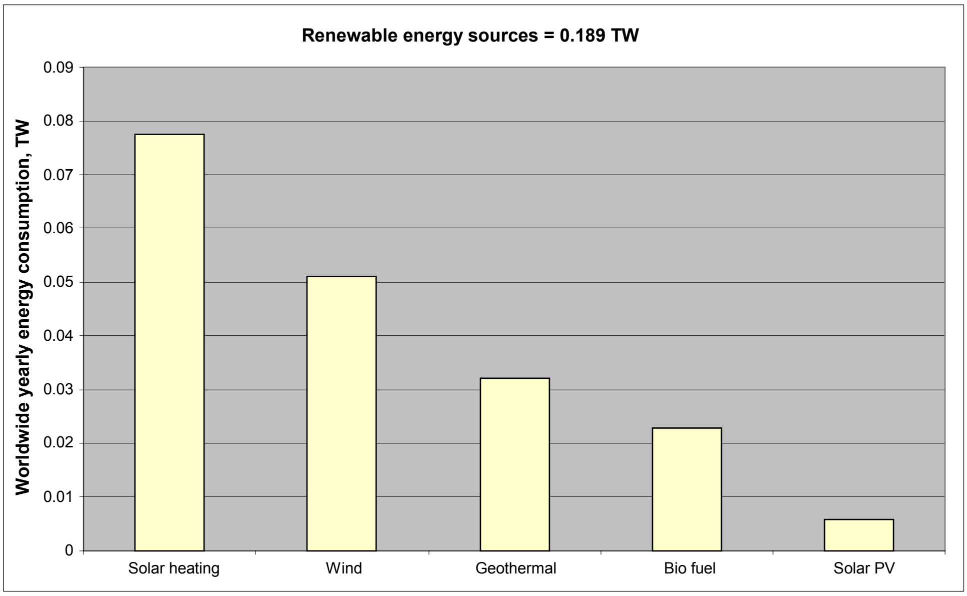
There are different definitions for renewable energy in literature. The concept of a Renewable Energy Source (RES) was introduced in the 1970s as part of an effort to move beyond nuclear and fossil fuels. There is much debate about how to define and distinguish renewable energy from non-renewable, and the terms and definitions chosen can have huge impacts on policy and regulatory efforts aiming to promote clean energy resources. Depending on these definitions, certain forms of energy receive subsidies or facilitations and others do not. In these definitions, the most common statement is that RESs are energy sources renewed (regenerated) rapidly (over a short time scale) by natural (ongoing) processes. RES is any source of energy that is continually replaced without depleting reserves. In general, it is less polluting than its counterpart, non-renewable energy. Finally, it could also be mentioned that RESs are limited in power (density) but not in energy, while non-RESs (fossil fuels in particular) are limited in (total) energy but, at least in principle, not in power. RESs are all non-fossil sources, and may be derived directly from the sun, indirectly from the sun, or from other natural movements and mechanisms of the environment. Now, it seems that the main pollution threat to humankind are CO_2 emissions during the use of fossil energy and the pollution threat owing to the use of nuclear energy becomes of lower degree of importance. Then, with advances in fast-neutron reactors that use mostly nuclear fuel for energy, there should be sufficient supply on earth of uranium ore without significantly depleting its reserves for many million years in the future. Because nuclear energy is inexhaustible and renewable, it should be a part of any energy mix in the future to replace fossil fuel energy. Nonnuclear renewable energy types are hydro, biomass, solar thermal, biofuel, geothermal, wind, photovoltaic, *etc*. When some RES types do not dispose CO_2 into the environment during their use, this does not mean that they do not dispose CO_2 in the environment during their entire life cycle. During construction and decommissioning of renewable energy plants and devices, CO_2 is disposed into the environment and nonrenewable energy is spent. Regarding renewable energy, the highest contribution to the yearly energy consumption is that of nuclear energy and then biomass with hydro energy at third place (see Figure 2). Furthermore, the highest yearly energy consumption is that of solar thermal and then that of wind energy (see Figure 3).

Figure 2 Worldwide yearly energy consumption for different non-fossil energy resources



Note: Total yearly energy consumption of renewable energy in 2004 was about 2.1 TW.

Figure 3 Worldwide yearly energy consumption for different non-fossil energy resources of small scale



Note: The total yearly energy consumption for these types of renewable energy in 2004 was about 0.189 TW.

4 Environmental problem: greenhouse gases consequences

Global warming is already occurring, and if combustion of fossil fuels continues, temperatures are projected to rise by up to 4°C and the sea-level by around 1 m in the next 100 years. In the long term, the planet may exceed the capacity of natural and managed way to adapt. Sustainable development in the entire planet also faces environmental problems that need to be addressed. The biggest impacts of the fact that the earth cannot radiate enough heat into outer space are foreseen in:

- coastal areas, because of the rise of the sea level
- rural areas and areas for productive activities, because of their soil would erode, acidify, and lose organic substance
- biodiversity and natural biotic landscape, because for instance in the northern hemisphere the ecosystems would displace towards north and the deserts may move instead
- higher dependency of the manufacturing activities on the climatic conditions, because of the increase both of intensity and frequency of extreme meteorological events, as well as of the unbalanced water availability. These impacts could strongly affect first of all the agricultural and industrial production, the tourist and insurance sector and, last but not least, human health.

5 Environmental problem: international action

As it was recognised by the EU Council of Ministers in 1996 and reasserted by the EU Commission in 2005 (Commission of the European Communities, 2005), in order to limit these greenhouse impacts, the "global average temperatures should not exceed 2°C above pre-industrial level". This target can be accomplished only with actions undertaken at a planetary scale.

The Kyoto Protocol represents the first step to win the battle against global climate change caused by man-made activities on the world level. The protocol expressed the commitment to lower the GHG emission through the improvement of energy efficiency, promoting of renewable energy sources, development of an efficient emission trade at a world scale, transfer of clean technologies also in the developing countries and investment in the research. The Kyoto Protocol, in force from 2005, binds the contracting countries to reduce the GHG emissions by 5.2% on the whole in the period 2008–2012. The level of emissions reduction imposed on each country varies according to the technology efficiency and historical emission levels.

6 Solutions to energy and environmental problems

Energy problems in the future may be related to the expected increase in energy consumption, and losing some of the electricity production capacity because of ageing nuclear and coal power plants. Environmental problems caused by energy consumption are related to the GHG emission increase and consequently to global climate change. Handling the last problem to achieve at least post-Kyoto GHG reduction targets can be achieved by the adequate energy mix, technologies used, and policies applied in some countries.

Each country has its own characteristic energy mix, where usually fossil energy use is predominant. It is expected that this situation would change fast in the future, as fossil fuel becomes more expensive because of its greater exploitation costs and higher environmental burden. Then, it may be replaced with different types of renewable energies, nuclear energy, or old fossil technologies with sequestration of CO_2. All these would depend on energy policies that would be adopted sometimes under public pressure, energy efficiency in different sectors of energy consumption, and on adequate energy management.

In their paper, 'The role of nuclear energy in the post-Kyoto carbon mitigation strategies', in this special issue, Rafaj and Kypreos modelled the role that nuclear power can play in achieving post-Kyoto GHG reduction targets. They found out that utilisation of nuclear energy is and will be an important component of the portfolio of carbon mitigation strategies, together with the use of other types of renewable energy. However for nuclear energy phase-out, they predict the use of advanced coal plants with CO_2 capture, integrated coal gasification combined cycle (IGCC) with CO_2 capture, and with natural gas as the main sources of electricity in carbon-constrained scenarios.

In their paper, 'A decision support system to compare different strategies for achieving the Italian Kyoto Protocol commitment', Beccali *et al.* describe the application of a multicriteria analysis model for the integrated evaluation of the Italian National Action Plan for the reduction of the GHG emissions. Nine different alternatives were compared, by using 14 different independent economic and environmental criteria belonging to seven sectors of intervention (energy industries, industrial processes, transportation systems, civil sector, agriculture sector, waste management, other sectors). The alternatives, which are always proffered, may allow the best compromise between reduction of GHGs and economic investment, with positive effects not only on the environment but also on the economy of the country. In order to decrease the GHG emissions, every productive sector has to improve its technological efficiency, with a consequent impact on the competitiveness of the country. On the other hand, the rise of the energy rate produced by renewable sources is supposed to change the national entrepreneurial framework with the opening of new markets. Nuclear energy could play a very important role in the abatement of GHG emissions and the diversification of the electricity mix; however, the nuclear option is not included in the Italian National Action Plan.

In their paper, 'Integration of wind generating units into the Corsican electrical grid: determination of the maximal integration rate from a reliability analysis based on a stochastic process', Poggi *et al.* report that the role of a wind farm in electricity generation in the island environment of Corsica, France, is to save the accumulated hydro energy (avoid hydraulic production of electricity) and to save coal and oil energy (avoid thermal production of electricity and generation of GHG). The effects of wind electricity use are complementary to the effects of nuclear energy use in the case of France.

In their paper, 'Reengineering of energy management', Carabulea and Gheorghiu describe the role of reengineering of energy management in GHG abatement.

7 Fundamental issues to the application of RES

It is important to be aware of the following fundamental issues of renewable energy as a climate change mitigation technology: (1) energy quality–exergy, (2) energy payback time, (3) GHG emission over RES life cycle, (4) energy concentration, (5) GHG emission payback time, (6) RES increase in energy mix, (7) thermodynamic equilibrium of the earth.

7.1 Energy quality: exergy

Every type of energy has different qualities that can by quantified by the notion of exergy. When studying energy future, this fact also has to be taken into account. To explain energy quality, we would detail the difference in energy quality of electrical energy E and heat Q. Electrical energy is considered to be of the highest quality as it can be almost entirely transformed into either work or heat. It is considered that entire electrical energy consists of exergy, *i.e.*, $E_x = E$. Heat is considered as energy of lower quality because only part of it can be transformed into either electricity or work. It is considered that only part of heat consists of exergy given as $E_x = Q(1 - T/T_0)$. Here, T is the temperature (in K) of medium that release or adsorb heat and T_0 is the temperature (in K) of environment. To conclude, by definition, exergy is the highest amount of energy that can be transformed into electrical energy.

When dealing with energy and energy consumption, energy planners would like to generate energy of the highest quality or to know what quality of energy is available for energy consumption. To obtain energy from coal, oil, gas, nuclear energy, biomass, geothermal flow and solar energy, we would first transform it into energy of lower quality (heat). Solar energy can also be partially transformed into electricity simultaneously giving heat. Hydro energy and wind energy can be used to generate electricity only, *i.e.*, to give energy of higher quality. In their paper, 'Radiation exergy: the case of thermal and nuclear energy', Isvoranu and Badescu analyse exergy for solar radiation and nuclear energy.

7.2 Energy payback time

Like every product in the market, the life cycle of an RES consists of its production, consumption and decommissioning stages. Usually in the popular press, people perceive only energy they obtain in the consumption stage. Then, they may conclude that some renewable energy forms (for hydro power, nuclear energy, solar thermal, geothermal, solar photovoltaic, wind, *etc*.) are an 'energy-free' source of energy and their payback time is 0. In other words, no other energy is spent in order to get, for instance, solar energy, which is not true, because its payback time is greater than 0. Moreover, if the energy used during construction and decommissioning of RES devices in order to obtain renewable energy during its capture is not counted, all analyses would be somewhat naive.

In his paper titled 'Thermodynamic limitations to nuclear energy deployment as a greenhouse gas mitigation technology', Pearce states that for nuclear power, the energy payback time depends on the grade of the uranium ore and on the energy mix of the area where the nuclear power plant is located.

7.3 GHG emissions during the RES life cycle

Like every product in the market, a life cycle for RES use has its RES device (plant) construction, operation and decommissioning stages. Usually, people perceive only emission of CO_2 in the operation stage. Then, they may conclude that some renewable energy forms (hydro, nuclear, solar thermal, geothermal, solar photovoltaic, wind, *etc*.) are emission-free sources of energy. Some renewable energy sources (such as biomass) are treated as emission-free sources of energy, although during their combustion they emit CO_2 into the atmosphere. However, for these types of RESs, their GHG emissions are not counted towards global pollution, as new biomass would absorb emitted CO_2 for its growth. Moreover, if the pollutant emission during device (for instance, solar collector) construction and its decommission is not counted, all analyses would again be somewhat naive.

In his paper, 'Thermodynamic limitations to nuclear energy deployment as a greenhouse gas mitigation technology', Pearce showed that nuclear power is not free of GHG emissions. He noted that in the USA, the GHG emissions during life cycle for nuclear energy are from 16 to 55 g CO_2-eq./kW-h and for the US electric mix is about 695 g CO_2-eq./kW-hr. The average life cycle GHG emission factor of the US electric mix (which includes coal, natural gas, hydroelectric, nuclear and some non-hydro renewable energy sources such as wind and solar) is about 695 g CO_2-eq./kW-hr. Then, the best case nuclear energy scenario provides around 43 times fewer emissions than the status quo and the worst case nuclear energy scenario 12 times fewer emissions than the status quo.

7.4 Energy concentration

One of the most important factors that determine the GHG emissions for a given kWh of different RESs is the concentration of renewable energy. The eventual extraction energy and energy used to construct devices are proportional to the concentration of renewable energy. As the energy concentration decreases, the energy needed to extract renewable energy increases as do the GHG emissions. The second law of thermodynamics thus has it that, at some point, usability of renewable energy resources as an energy supply does not exist because the energy needed to extract renewable energy is equal to the obtained useable renewable energy.

In his paper, Pearce showed that as the uranium concentration in the ore decreases, the energy needed to extract and concentrate the uranium increases as do the GHG emissions. Thus at some point, the usability of nuclear-fuel resources as an energy supply is limited, because the energy needed to extract and concentrate the uranium is equal to the useable energy provided by the fission reaction of the uranium.

7.5 Cannibalisation effect

For renewable energy to have a net negative impact on GHG emissions of the energy supply, first it must produce enough zero emission electricity to offset the emissions that it is responsible for, and finally it must continue to produce electricity to offset emissions from existing or potential fossil fuel plants. This can become challenging in view of rapid electricity consumption growth because the construction of additional renewable energy devices to enable the rapid growth rate create emissions that cannibalise the GHG mitigation potential of all previously installed renewable energy devices.

In his paper, Pearce showed that owing to the cannibalisation effect, the necessary growth rate to obtain 18 849 GW of nuclear plants by 2050 is calculated to be 10.5% in order to break even with GHG emissions. However, the goal of GHG mitigation is to actively reduce global emissions – not to simply break even.

7.6 Renewable energy increase in the energy mix

With each of the renewable energy devices (plants) operated, the embodied GHG emissions of the next device (plant) will be reduced because the fraction of renewable energy in the energy mix has increased. In his paper, Pearce commented that this effect may also play a significant role when nuclear power plants are employed in some energy mix for some state.

7.7 Thermodynamic equilibrium of the Earth

The primary cause of current observed global warming is the presence of GHG in the atmosphere that allow the thermal equilibrium of the Earth on higher temperatures and heat release to outer space. However, we should be aware of the fact that the use of any energy source of terrestrial origin can also contribute to an increase of the Earth temperature. In his paper, Pearce commented that the Earth temperature may be increased by heat released from nuclear power. Right now this temperature increase is not significant, but it might be in the future (if the energy use becomes higher).

8 Conclusion

This special issue is an attempt to answer the fundamental question: how to survive our energy future. Nowadays, our civilisation faces climate problems (global warming) blamed on fossil fuel energy consumption and associated GHG environmental pollution. Although this phenomenon is recognised, the concrete actions are still not sufficient to handle the problem. In addition, the actions are not coordinated throughout the entire planet. If use of fossil fuels continues, air temperatures may rise by up to 4°C and the sea level up to 1 m in the next 100 years. In the long term, this burden would eventually exceed the capacity of humans to adapt.

Some authors in this special issue have tried to answer what energy mix in the future would stop GHG pollution. This may be a different mix: nuclear energy, non-nuclear renewable energy, or fossil energy with CO_2 sequestration. In addition, more energy-efficient technologies, energy saving, and decreases in energy consumption will be required.

When trying to propose an energy mix for a country and its energy future, some authors discuss renewable energy issues such as energy quality, energy payback time, real CO_2 emission for some RESs, concentration of renewable energy, cannibalisation effect, renewable energy increase in the energy mix, and the thermodynamic equilibrium of the earth.

Acknowledgement

As guest editor, I would like to thank the authors P. Rafaj and S. Kypreos from Austria; P. Poggi, M. Muselli, and C. Cristofari from France; G. Beccali, M.C.V.L. Brano, and A. Marvuglia from Italy; A. Carabulea, I.D. Gheorghiu, D. Isvoranu, and V. Badescu from Romania; and J. Pearce from the USA for their appreciable involvement in this special issue. I also thank the Editor-in-Chief of IJNGEE, Professor A. Maisseu, for his kind invitation to publish this special issue.

References

British Petroleum (2007) *BP Statistical Review of World Energy June 2007*, http://www.bp.com/productlanding.do?categoryId=6848&contentId=7033471 (retrieved 16 July 2007).

Commission of the European Communities (2005) 'Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions', *Winning the Battle Against Global Climate Change*, {SEC(2005) 180} Brussels, 9.2.2005, COM(2005) 35 final, ec.europa.eu/environment/climat/pdf/comm_en_050209.pdf (retrieved 16 July 2007).

Intergovernmental Panel on Climate Change (IPCC) (2001) *Third Assessment Report – Climate Change 2001*, IPCC/WMO/UNEP.

Renewable Energy Network (2006) 'Renewables global status report update', *Renewable Energy Policy Network for the 21st Century*, http://www.ren21.net/publications/default.asp (retrieved 4 March 2007).