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A comparative analysis of environmental impacts of non-fossil energy production methods

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Abstract. The widespread proliferation of other then fossil based energy production methods is a development, which inevitable comes in the next future. It is proven that the photovoltaic conversion or the use of heat of Sun radiation, the water energy, the utilization of the wind, the biomass production, the use of geothermal energy can all produce big amounts of energy for human use. In addition, the nuclear energy from fission is a technology, which has already long history and is widely used. However, these all, like the fossil energy sources, have great impacts on the environment. Nevertheless, the comparison of the environmental effects of these alternative energy sources is not easy. The effects are of considerable different natures and their spatial and the time distributions vary on large scales. The present work overviews the principles and the methodological prerequisites of performing a comparative analysis of the environmental effects for the non-fossil energy production methods. After establishing the basic principles for comparison, we shall go through all the non-fossil energy sources and analyze the most important environmental impacts of each energy production method. In conclusion, the comparison of the environmental effects will be discussed.

1. Notes on the energy supply of contemporary societies

The reliable energy supply of the human societies is an important major element of the sustainability of modern life. However, the sustenance of the continuous energy supply needs thorough planning and complex organization from the side of the available energy sources, of their transformations and from the side of the methods of distribution. Latest since the first energy crisis in 1973 every decision makers have known that the energy consumption of the World must not grow. In spite of this general revelation, the energy consumption has grown continuously. It was about 300 EJ in 1980 and around 540 EJ in 2012 for the societies of the World.

Figure 1 shows the yearly per capita consumption of the inhabitants of the World since 1980. It reveals a surprising constancy around 70 GJ/person/year/ over the three decades from 1980 to 2010 (though the values show a slight (< 10 %) increase with the time). The main conclusion from these data is that the total energy consumption grows mainly because the number of the people in the World grows.

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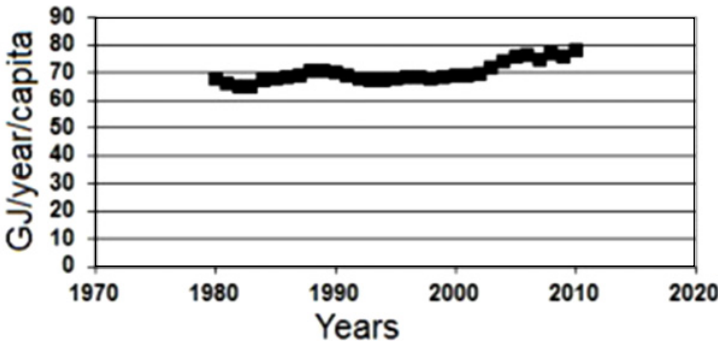

Figure 1. Per capita yearly energy consumption from 1980 to 2010. (The figure was made by using the data of Ref. [1].)

Such a strong correlation does not change in a short time. The population of the World will grow to $\sim$ 8–9 billion around the year 2050. In addition, there is a fast economic development in Asia, especially in China and India, and big areas should join to continuous energy-supply systems, like parts south of the Sahara in Africa, areas in South-America and in the Far-East. All these need huge amounts of energy. Therefore, one may be sure that the total energy consumption will inevitable significantly grow in the next decades.

On the other hand, the system of the present energy supply cannot be maintained for long, not even for the next three-four decades. Now the fossil fuels produce 80,6% of the total consumption, the non-fossils $\sim$ 19,4% [1]. The nuclear share is 2,7% and the renewables give 16,7% of the energy budget [1]. It is absolutely necessary that the ratio of the fossils should go down because of the limited resources and because of the environmental harms they cause. From these facts it is without doubt that the share of renewables will be enhanced appreciable.

2. Environmental aspects of the energy production from non-fossil sources

There are a lot of experiences with the energy production from non-fossil energy sources [2]. These energy sources are the hydropower, the wind energy, energy from the direct radiation of the Sun, energy from the biomass, the geothermal energy and the fissile nuclear energy [1]. It is proven that all of the previous energy production methods are able to produce big amounts of energy for human use

The main observations of the energy production from the non-fossil sources show that the generation of significant amount of energy always and unavoidable lead to considerable environmental effects. In addition, the different methods of energy production have basically different technological backgrounds; there are generally no similarities among them. The environmental effects are not of the same origin and they differ considerable from each other.

Under the circumstances that the scientific, the physical and in the case of the biomass the biological background of the non-fossil energy sources are completely dissimilar, the comparisons of the different energy sources need well-defined basic principles, while the advantages and disadvantages should clearly be pointed out. Now a non-detailed, short survey will summarize the advantages and the disadvantages of each of the non-fossil energy sources from the points of view of the environmental effects.

[1] The fissile nuclear power is, of course, a non-fossil energy source. However, its character and the problems connected with it are very much different from those of the renewables. Therefore, this work will not discuss it in details.

The main advantages of the *hydropower* are the well-known and proved technology; no cost for the fuel and low working costs; no emission of harmful materials; renewed water economy; improved protection against floods and improved possibilities of shipping on the river. In addition the hydropower stations are useful elements to regulate big electric systems.

The disadvantages of the dam-on-river type hydropower stations are that the construction is long and costly; it may affect many people, there may be many displacements; generally big lands are flooded; huge and perhaps frightening constructions are built; it modifies water quality and there are mostly considerable changes of the ground water table. The danger from the dams is not nil, the laws of nature do not exclude the collapse of a major dam. Therefore, the construction and maintenance should be appropriate and political stability is needed.

The potential of the *wind energy* [3] is significant close to the seashores, but its ability to produce energy decreases further away from the seas, inside the continents. Now nearly 300 GW_{el} power capacities are installed worldwide. The application of the wind energy grows very rapidly. The regional distribution of the capacities is highly uneven, 53% of the capacities are in Europe, 20% is in North-America, 17% is in Asia and 10% is in the rest of the World.

The main environmental advantages of using the wind for energy production are: there is no harmful emission of any kind (real CO_2 free), it diminishes energy import dependence, it creates jobs (in the EU there are 400 000 jobs for wind energy).

The disadvantages of the application of the wind energy are that there are fluctuations in the electricity supply, which creates problems in the electrical net connection; the storage of the superfluous energy is not solved; there is dangerous degradation of ecological sensitive areas (e.g. karst regions), which would be otherwise excellent locations for wind power stations all over Europe; generation of noise and high investment costs, slow return.

The *solar radiation* has 178 PW power on the Earth, which is equivalent with 1,4 kW/m^2 outside of the atmosphere. Even if one takes into account that the air absorbs energy while the radiation comes down to the surface of the Earth, the equivalent of the energy used by the human societies in one year arrives on the surface in about 8 hours.

There are two ways to use the direct radiation of the Sun for energy production. First, it is possible to generate directly electricity by the irradiation of photovoltaic (PV) diodes [4]. Otherwise, it is feasible to use the heat, which is produced by solar irradiation. This second method may be used for heating bulk material for steam generation, for achieving very high temperatures (like $\sim$ 3800 K in Odeillo (France) solar furnace [5]), or for trapping heat for other than electricity generation. The energy use of direct radiation of the Sun develops rapidly; the increase of the PV application in a year is close to 50%. However, the share of the radiation of the Sun in the total energy budget was small in year 2012, i.e. 0.23% [1].

The environmental advantages of the direct use of the energy from the Sun are that the gas emission is nil, the external pollutions are negligible. - The disadvantages are the big areal use of the power stations, which occupies land from agriculture; the use of dangerous materials while building the power stations, which will be problems at decommissioning the facilities; the proper maintenance is tedious and costly; it is now expensive and needs subsidies.

There are many controversies about the energy use of *biomass*. Though it can be an important part of the agriculture, which creates many working places, it takes away large territories from food production in a World, which needs much food for the rapidly increasing human population.

The advantages of using biomass for energy production are that it uses agricultural waste, the resources are everywhere and it is carbon dioxide neutral. It assures continuous supply with storage capacity, diminishes the energy import dependence. Its application helps to restructure the agriculture, which is a problematic political issue in many countries.

However, the energy use of biomass has several major disadvantages. It needs much labour and organization. The application of biomass leads to the decrease of biodiversity and creates monocultures

of the same aged tree plantations (like white acacia, poplar and willow species, energy grass etc.). Planting invasive genera, genetic pollution, pests, new sicknesses are possible. It raises ethical questions for the aims of the land-use, and legal problems arise.

The application of *geothermal energy* is limited by the lack of many favourable occurrences and by the non-negligible environmental consequences. It has the advantage of generally small-scale areal need and of low gas emission in comparisons with fossil energy sources. - However, the application of the geothermal energy has some unfavourable consequences for the environment. Land and water pollutions can occur, as the solved content is high for the higher temperatures of the thermal water from the usually deep hot rocks. There are emissions of solid materials up to the surface. In addition, there could be distortions of the hydrothermal systems and the heat pollution is mostly higher than at power stations of other types with similar power capacity.

Prominent major non-fossil energy source is the fissile *nuclear energy*. It is very much different from the former renewable energy sources. Of course, here the areal need is significantly smaller than at the other non-fossil energy production methods. There are hardly any serious environmental problems with the nuclear energy, when the system is running on the proper way. However, the laws of the nature do not exclude major accidences, when high amounts of radioactive waste could escape into the biosphere (like at Chernobyl (1986) and at Fukushima (2011)). But even, when everything is going well, one must be prepared for the problems with the low, intermediate and high level nuclear wastes and decommissioning of the nuclear reactors.

The production of significant amount of energy from any of the former sources may be connected to some of the following harms.

- Change of the natural resources by the application.
- Landscape changes and landscape degradation.
- Landscape scars.
- Change and decrease of biodiversity.
- Decrease of habitats for native species.
- Disturbance of mother rocks, layers and soils.
- Decrease of the fertility of the soil.
- Spread of monocultures, destruction of ecosystems.
- Injections of poisonous chemicals into the upper layers.
- Continuous physical disturbance (like noise).

3. Principles for complex and consistent comparisons of the environmental effects of different non-fossil energy sources

The main difficulties in the comparisons of the environmental effects of the different renewable energy sources are the fundamentally different origins and the basically various methods of the realization of the energy production processes.

Therefore the basic principles of the comparisons of the environmental effects should include some standards. The important principle is that the comparisons should refer to the *same amount* of the produced energy and they should refer to the *whole cycle* of the production methods. Of course, the *space limits* and the *time span* for the comparisons should be the same. Furthermore, the effects on the *landscape* must be evaluated and the *economic*, *social* and *legal* effects should be analysed, as well. Up to now there are no accepted general procedures for the comparisons of the different non-fossil energy production methods, not even for the same environmental effects.

There are excellent group works on the externalities of the different non-fossil energy sources (e.g. [6, 7]). In these approaches the analyses have been done with different models.

One prominent example for such an analysis is the *Community Research of European Commission* [7]. This research work contains thorough analyses of Emission to Air, Water and Soil; Pollutant

dispersion and Sound propagation; Exposure-response functions, monetary valuation; Global warming; Assessment of Major Accidents; Ecosystems and Biodiversity. The measures of the harms of the externalities are mostly evaluated in terms of money.

4. A focus on some important, but less investigated environmental effects

Most analyses have hardly anything to say about a lot of environmental effects, which are connected with the energy production of the renewable energy sources.

Such effects are the influences on landscape, landscape degradation and landscape changes; the effect of changes in natural resources; environmental consequences of covering big territories; changes of the major elements of the scenery; consequences of the decrease of soil fertility; change of the habitat of the species around the energy producing facility; distribution of advantages and disadvantages for the different sections of the society; social effects of energy production, job market and legal effects. Some of these problems are difficult to be quantified. However, it is clear that special efforts should be devoted to these and similar issues.

The main problem with the non-fossil energy sources is– perhaps with the exceptions of geothermal and fissile energies – that they occupy big territories while producing substantial energies. The right approach is – as explained earlier – that the land use should be compared for the same, *in reality produced* energies. It is expressed in $\text{power}_{\text{produced}}$/area units, where the $\text{power}_{\text{produced}}$ stands for the in reality generated average electric power. Such an estimate can be done from the analysis of the production data of existing power station facilities.

The areal need for 1 GW_{el} in reality generated $\text{power}_{\text{produced}}$ was estimated by L. Szarka and J. Ádám [8].

Hydropower	$\sim 14\,\text{W/m}^2$,	area needed for 1 GW_{el} power station:	$\sim 72\,\text{km}^2$
Wind	$\sim 1,2\,\text{W/m}^2$,	area needed for 1 GW_{el} power station:	$\sim 770\,\text{km}^2$
Sun radiation	~ 7–$10\,\text{W/m}^2$,	area needed for 1 GW_{el} power station:	~ 100–$150\,\text{km}^2$
Biomass	$\sim 0,4\,\text{W/m}^2$,	area needed for 1 GW_{el} power station:	$\sim 2500\,\text{km}^2$
Geothermal	$\sim 125\,\text{W/m}^2$,	area needed for 1 GW_{el} power station:	$\sim 8\,\text{km}^2$

Of course, there could be arguments and perhaps some evidences according to which the former estimates are disputably. But they are surely realistic and they are not off by more than, say, a factor of two.

The implication from the former analysis tells that by the widespread changeover from fossil energy sources for renewables with the same energy output will drastically change our environment. Wide lands will be dominated by territories needed for the energy production and by facilities connected with energy generation methods. Hydropower, the direct use of the Sun's radiation, the application of the biomass option all cover big lands, which hardly can be used for other purposes at the same time. The application of the wind and the geothermal energy need large facilities over wide regions, which dominate the landscape.

It is clear that the widespread application of any of the renewable energy sources will be in conflicting interest with the landscape protection, with the design of the landscape, with the effective agriculture for food production. The use of them will hinder the maintenance of biodiversity and the protection of natural resources. The change of flora and fauna in and around the covered territory is unavoidable. The circumstances for life will change a lot, new species will extrude the native species and new compositions of ecosystems will come into existence. The harmful effects of each non-fossil energy sources are summarized in Table 1.

Table 1. Harmful effects of the applications of non-fossil energy sources.

Type of harm	**Hydro**	**Biomass**	**Wind**	**Sun radiation**	**Geo-thermal**	**Nuclear**
***Density (W/m^2)* [8]**	***14***	***0,4***	***1,2***	***7–10***	***125***	***200(-400)***
The need of big territories	+	+	+	+	-	-
Landscape degradation	+	+	+	+	+	-
Emission of by-products	-	+	-	-	+	-
Destruction of biodiversity	+	+	-	+	-	-
Distraction of living species	+	+	-	+	-	-
Pollution of layers of rocks	+	-	-	-	+	+
Decrease of soil fertility	+	+	-	+	-	-
Creation of monocultures	-	-	+	-	-	-
Destruction of ecosystem	+	+	-	+	-	-
Distraction of ground water	+	-	-	-	+	-
Poisonous chemicals	-	+	-	-	+	-
Physical distortions	-	-	+	-	+	-
Bring about social effects	+	+	+	+	-	+

In addition, the application of the non-fossil energy sources will have serious social consequences. The job market will be influenced a lot and there will be conflicts while distributing the benefits and disadvantages among the affected communities.

5. Conclusions

The energy supply is a major question of the sustainability of human societies. The present, mainly fossil based supply system cannot be maintained. The wide scale use of the non-fossil energy sources is an unavoidable and foreseen development in order to maintain the reliable and safe energy supply of the society in the medium range future, in the next three-four decades. However, any kind of the application of the renewables has substantial effects on the environment.

Large scale production of energy for human use from non-fossil sources generates many conflicts in environment and society. Most environmental issues are important and complex. They may be quantified and analysed by using well-established models.

Nevertheless, some important environmental effects are difficult to be quantified and analysed on a straightforward way. All non-fossil energy sources have effects on the biosphere, landscape, and biodiversity, change the living conditions on considerable territories and generate conflicts and some legal problems in social life. All these need thorough analysis while planning the future.

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