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Effects of renewable energy resources on the landscape

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Abstract

One of the most important prerequisites of the sustenance of modern societies is the safe energy supply. An energy supply system, which is currently based mainly on fossil energy resources cannot be maintained even in the medium-term, at least not longer than for a few decades. Therefore, the application of renewable energy resources will play a significant role in forming our energy future. Most of them except geothermal and tide energies, use directly or indirectly solar energy. In this paper, the direct use of solar energy, wind energy, biomass and hydropower will be discussed. It will be shown that the widespread application and the broad expansion of any of the renewable energy resources and the large-scale production of renewable energies are always connected with serious environmental impacts, whichever of the resources is used. They all require a relatively large area for use in the case of producing a significant amount of energy. Renewable energy production methods will be an important factor of landscape change, and will have a strong influence on landscape management. In this study, particularly, hydropower will be investigated. In the typical case of the Gabčikovo (Bős) Hydropower Station on the Danube the influences on the landscape structure and functions will be demonstrated. It will be shown that intensive human use and alteration (river engineering, the constructions of dams and hydroelectric power plants) of riverine landscapes have led to enormous degradation.

Keywords: energy utilization, solar energy, wind energy, biomass, hydropower, landscape impacts

Introduction – the significance of the safe energy supply

The continuous and reliable energy supply is perhaps the most significant prerequisite for the organization of modern societies. Everything which is necessary for a larger community, e.g. the food, water industry, appropriate homes, heating and lighting, traffic, waste deposition etc. needs energy (e.g. Boeker,

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E. and van Grondelle, R. 1999). The needed energy sums up to a high amount in our complicated and interconnected world. Even a short disruption, caused by technical failures or natural catastrophes can create dangerous situations and sometimes great social tensions. By now, it is clear that the sustainability of human societies requires a safe and smooth-running energy supply.

Since the first energy crisis in the early 1970's, every decision maker knew that energy supply is a vulnerable and sensitive issue and energy consumption should not grow. However, in spite of all the considerations, energy consumption has steadily increased from approximately by 300 EJ/year in 1980 to about 550 EJ/year today (*Figure 1*).

The analysis showed that there was a strong correlation between population and energy consumption. In *Figure 2*, per capita consumptions for the period of 1980–2010 are shown. Consumption per capita is about 73 GJ/year and it reveals only a slight (~10%) increase in the last three decades. Of course, there are big differences among the regions of the world.

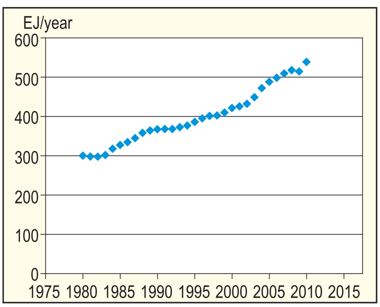

Fig. 1. Yearly energy consumption of the world in the period of 1980–2010. *Source*: Compiled by the authors based on EIA data, 2013

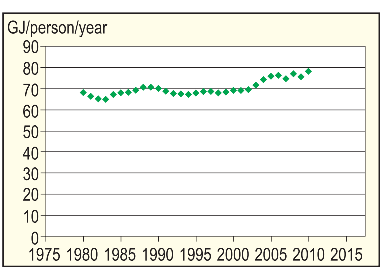

Fig. 2. Per capita yearly energy consumption of the world in the period of 1980–2010. *Source*: Compiled by the authors based on EIA data, 2013

The almost stationary nature of per capita energy consumption suggests that the energy consumption will grow at least proportionally with population growth. We should be prepared for an increasing need of energy in the medium term, as the world population is estimated to grow from 7.1 billion (2012) to at least 9 billion by 2050.

The present energy consumption is assured by up to more than 80% by fossil fuels, and besides the small contribution of nuclear energy (2.7%), the share of renewable energy resources is only 16–17% (EIA, 2013). In the future, the extensive use of fossil fuels will be limited partly by the restricted resources, by unacceptable effects on the environment and by their contribution to climate change. The effectiveness of energy saving projects seems to be limited (Vajda, Gy. 2009) and the extension of nuclear energy is debated, so the introduction of renewable energy resources is inevitable in the near future.

The present work assumes the necessity of the widespread expansion of the most important renewable energy resources. We shall outline the environmental effects of these alternative energy production methods, with special emphasis on the landscapes. After some general remarks, a case study of landscape degradation caused by the Gabčikovo (Bős) Hydropower Station will be presented, and the consequences of renewable energy production will be shown, as well.

Survey of environmental aspects of renewable energy production

The most important renewable energy production methods are the following: solar energy, wind energy, biomass energy and hydropower[3] (hereafter the expression "renewable energy resources" will be used). It is proved that all of them are able to generate a considerable amount of energy for human use.

Many illusions are connected with the widespread usage of renewable energy resources. The main reason of making them desirable is the low emission of harmful byproducts. It is true even for the application of biomass which is neutral to carbon dioxide emission in regard to the whole production cycle.

The major problem of renewable energy resources is that all of them occupy huge areas when the objective is to generate a great amount of energy. The facilities for solar energy, such as photovoltaic elements or mirrors cover large areas, wind turbines need many wind power stations, the production of biomass needs huge arable fields and the hydropower stations have big reservoirs. The areas with any of the above mentioned facilities for energy production can hardly be used for anything else. The use of renewable resources changes the whole surrounding environment. In the case of solar energy and wind power, there are serious difficulties caused by the considerable fluctuations in production rates. There are no technologies to store surplus energy. Even the power coming from a hydropower station and the production of biomass depend on the meteorological circumstances, but they can be planned for a longer period. Biomass is the only renewable energy resource which has a storage capacity.

The comparison of the energy sources, from the point of view of the environmental effects, is a hard task. In the cases of the renewable energy resources, the capacity of a facility is always much bigger than the actual amount of the produced energy. The basic starting point is that the comparison must be made for the same amount of produced energy.

Characteristics of renewable energy resources

Renewable energy resources represent very different energy production methods. The scientific, physical and biological backgrounds are completely differ-

[3] Wave, tidal and geothermal energy are also renewable energy sources, however, their importance is less and therefore we did not analyze them.

ent and even the principles are not the same. Therefore, the survey of the most important characteristics of renewable energy sources should be performed individually.

There are two ways to use *solar energy*. It is possible to produce electric energy by the irradiation of photovoltaic (PV) elements and it is feasible to use the heat which is generated by solar irradiations.

PV technology is one of the most rapidly developing branches of the materials science (Wagemann, H-G. and Eschrich, H. 2007). The most informative parameter is radiation efficiency. The efficiency of the PV elements nowadays is about 7–10% in mass production (in laboratory it is up to 40%). There is a big development potential in commercial PV elements. There is about 12 GW installed capacity (2012) in the world and it is growing very fast, by 40–50% a year. However, today the contribution of the PV energy supply to the produced electric energy is very low; it is below 0.1% (EIA, 2013).

The other possibility to use solar energy is to apply it as a heat source. It is feasible to build solar farms for electric energy generation. Using mirrors in order to concentrate radiation, and electric generators can be driven by the generated heat.

Large areas covered by PV elements and mirrors are needed for the utilization of the solar energy. An estimate for the power density of the achieved average power is about 7–10 W/m^2 (Szarka, L. and Ádám, J. 2009). It means that areas up to 100 km^2 should be covered by a facility with a potential of 1 GW_{el} on the average. Such a facility is a dominant element of the landscape.

Wind energy (Kaldellism, J.K. and Zafirakis, D. 2011) has a significant potential close to the sea. However, its ability to produce energy decreases with the distance from the seashore. In the central parts of the continents, the average wind-velocity is significantly lower. Therefore, the availability of wind power stations is close to 50% at the seashore and it is difficult to find places for about 25% availability in a continental country like Hungary. The total installed wind power capacity was well over 250 GW in 2012 and it is growing very fast, first of all, in Europe, North America and China.

The major difficulty of applying wind energy is the big fluctuations of its distribution in time. This problem can be solved by coupled hydropower systems or by spinning on gas turbines.

The height of a modern wind power station is close to 100 meters and its nominal capacity is about 1.5 to 2 MW. Its average power is about 100 kW in a country without a seashore. To have an energy system which produces 1 GW_{el} power on the average about 1,000–2,000 wind power stations are needed. According to Szarka, L. and Ádám, J. 2009, the average power density of wind energy is 1.2 W/m^2. In the case of major wind power use landscape would be dominated by wind turbines.

There are many controversies about *biomass energy*. On the one hand, it is an important agricultural activity creating jobs for people. On the other hand, it can take away large areas from food production. The basic problem with biomass is energy low efficiency photosynthesis.

The areal density of biomass energy use is about 0.4 W/m^2 for electric power production (Szarka, L. and Ádám, J. 2009). It means that about 4,000 km^2 should be covered by appropriate energy plants for 1 GW_{el} average electric power. The produced energy grasses or woods decrease biodiversity, creating monocultures of sublimated plants of the same age (like locus-tree, hybrid poplars, willow species etc.) leading to landscape degradation.

Hydropower has been used by human society for several thousands of years. Today we have well-known, reliable and proved technologies. Hydropower has a significant share in the electric energy production of the world (~17%).

Hydropower has many advantages. There is no fuel cost and the working costs are low. It emits no harmful materials. Dams are a good tool against flood and support shipping on the rivers. On the other hand, the construction of a hydropower station is time-consuming and costly. In the case of big hydropower stations, big areas are generally flooded. The power stations are non-native landscape elements, sometimes huge constructions.

Hydropower stations have an estimated average areal power density of about 14 W/m^2 (Szarka, L. and Ádám, J. 2009). A reservoir of about 70 km^2 area created for a hydropower station produces 1 GW_{el} power on the average. Such an artificial lake is a determining element of the landscape changing almost all characteristics of it.

There are several serious analyses which dealing with the environmental effects of the renewable energy sources (e.g. Community Research, 2003). The studies do not deal with the landscapes and landscape details. A thorough analysis is only possible if each individual case is discussed separately (Owen, A.D. 2004, and Hemiak, J., 2011).

In the following part of the paper, as an example, a case study will be presented to show the effects of the Gabčikovo (Bős) Hydropower Station (GHPS). The GHPS was built on the Danube, at the border between Slovakia and Hungary *(Photos 1–2)*. The power station is a dam-on-the-river type facility. The installed electric power capacity is 749 MW_{el}. According to official data of the Slovak Republic, the average of produced electricity of GHPS in 15 years is ~259 MW_{el} (see e.g. Bödők, Zs. 2008).

80% of the Danube water was diverted through the dammed lake at Čunovo (Dunacsún) into the artificial service channel for energy production. The diversion of the Danube was a fundamental turning point in the ecological functioning of the riverine wetland system.

Photo 1–2. The Gabčikovo (Bős) Hydropower Station (Photos: Kiss, Á.)

Landscape effects: the Gabčikovo (Bős) Hydropower Station case study

The complex ecosystem of large floodplain rivers with their enormous variety of diverse habitats in a relatively small area contributes to the natural biodiversity of an ecoregion considerably. However, with river regulation and the increasing use of floodplains, a significant proportion of the natural functions of the ecoregions was lost.

Covering almost 36,500 hectares, Szigetköz in Hungary is the largest semi-natural floodplain area in the Danube Valley of Eastern Central Europe (*Figure 3*). Its wetland habitats are of outstanding importance. Due to the geological, geomorphological, climatic, hydrological and soil properties of the region, a great habitat diversity developed. The sites of highest natural value are protected by law as parts of the Szigetköz Landscape Protection Area (1987).

The highly varied topography of the region, plains, sand dunes, bars, islands of various sizes and a peculiar hydrographical system with oxbow lakes and various types of aquatic habitats, sustains a wide range of biotopes from dry terrestrial to aquatic biotopes (*Photo 3*). Vegetation, flora and fauna are remarkably diverse, including aquatic, marsh, swamp and meadow communities, willow-poplar (softwood) and oak-ash-elm (hardwood) forests, oakwoods and the forest-steppe vegetation of the sand ridges were all preserved in an almost natural state until diversion of the Danube (Simon, T. *et al.* 1993; Gergely, A. *et al.* 2001).

River-floodplain systems have a special mosaic-like landscape structure. Intensive human use and the alteration of riverine landscapes have led to enormous degradation, especially in highly industrialized countries (Dynesius, M. and Nilsson, C. 1994; Schiemer, F. 1999; Hohensinner, S. *et al.* 2005). The

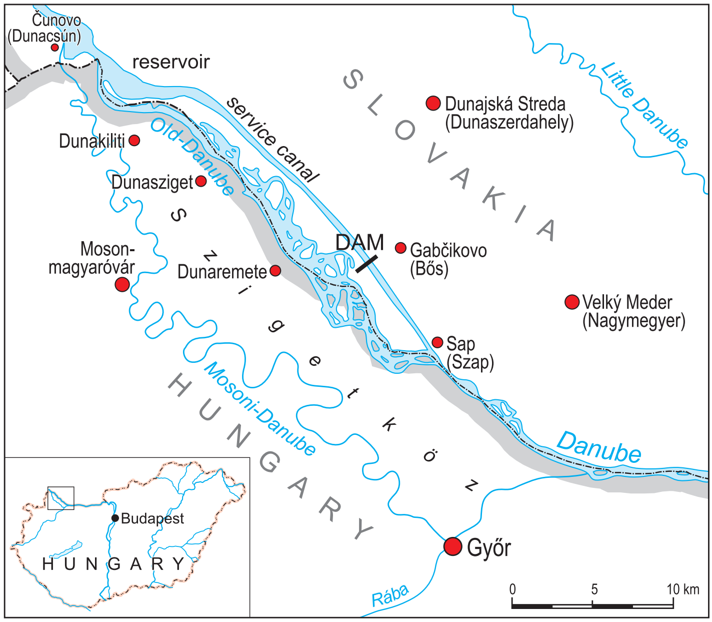

Fig. 3. Szigetköz at the border between Hungary and Slovakia

Photo 3. Dunasziget side-branch system (Photo: Szabó, M.)

related problems are recognized by the society and by the governments. Their interest to restore ecosystem functions of regulated and dammed rivers is very significant. That recognition is also emphasized in the EU Water Framework Directive (WFD, 2000).

The determining ecological factor of floodplains is the cycle of flooding and drying. The hydro-, morpho-, pedo- and biodynamic processes of natural floodplain areas determine the variety of landscape structures and their functions.

Landscape changes caused by the Gabčikovo (Bős) Hydropower Station

The hydrological regime and the hydro-morphological processes are the most important landscape-forming factors playing an essential role in landscape evolution in Szigetköz. The most important driving forces of river geomorphology are the volume and the temporal distribution of water supplied from upstream, the sediment volume and character. Local climate (particularly the occurrence of a freezing in winter and an extended dry season) as well as the nature of the riparian ecosystems are also important.

The first significant water management interventions directly forming the Szigetköz water system were water regulations in the 19th century. As a consequence of this river engineering, the area of floodplain habitats considerably decreased (Szabó, M. 2011). The second large effect was the construction of Gabčikovo/Bős–Nagymaros Dam in the frame of the Czechoslovakian–Hungarian joint project at the beginning of 1980's. In 1989, due to the increasing awareness of the environmental and ecological aspects and the protest against the dam system, the Hungarian Government suspended the project.

In October 1992, the Czechoslovak government dammed the Danube at river-km 1,851.75 and diverted it into a 29 km-long canal. Thereafter, Hungary had no influence on discharge into the main Danube channel. As a consequence, the water level of the river reaching Szigetköz between Čunovo (Dunacsún) and Sap (Szap) dropped by 2–3 m within a few days and several side channels of Danube dried out. In the following two years, the flow of water practically stopped on the active floodplain branches cut off from the main riverbed. At the same time, the surface of point bars emerged in the river bed (*Figure 4).*

Groundwater level and the capillary moisture conditions are essential factors of wetland ecology, and also for agriculture. Groundwater levels markedly decreased after the diversion and remained so even after the construction of the underwater weir in 1995. They stayed under the mean level even after the subsidence of the water level of the Danube and the groundwater level by 2.5–3.0 meters in less than a week (*Figure 5*). The wells in the figure are between Dunakiliti and Dunaremete, close to the main Danube channel.

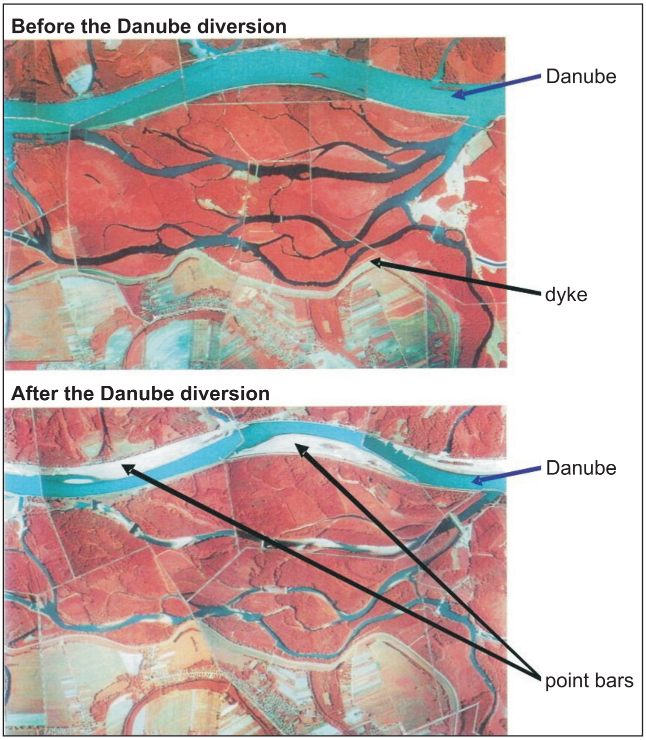

Fig. 4. Infrared image of the Danube branch system. 12 June 1990, before the Danube diversion (upper image); 8 September 1993, after the diversion (lower image). Aerial colour infrared photos taken at altitude 2,500 m a.s.l. Processed by ARGOS Studio, Budapest

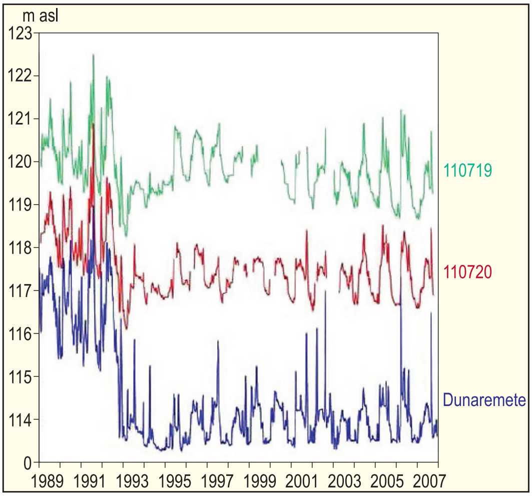

Fig 5. Two weekly means of surface (Dunaremete) and groundwater levels, wells No. 110719 and No. 110720. Blue line: gauge at Dunaremete; red and green lines: groundwater levels in wells No. 110719 and 110720, respectively. *Source*: Hungarian Hydrological Database

This abrupt change had a severe impact on the ecosystems in Szigetköz, especially on fish and other aquatic biota, as well as on alluvial forests in the active floodplain and on several habitats of the former floodplain. The area of wetlands and the diversity of ecosystems decreased. In line with that, the area of the degraded, characterless dry grasslands and woodlands increased (Fitzmaurice, J. 1996; Gergely, A. *et al.* 2001; Jansky, L. *et al.* 2004; Szabó, M. 2007).

Aquatic habitat quality deteriorated considerably at the same time. *Figure 6* shows the decline of sand and gravel bars of different succession stages. During the implementation of the Gabčikovo (Bős) Hydropower Station, the remaining point bars in the main channel were turned into permanent softwood stands.

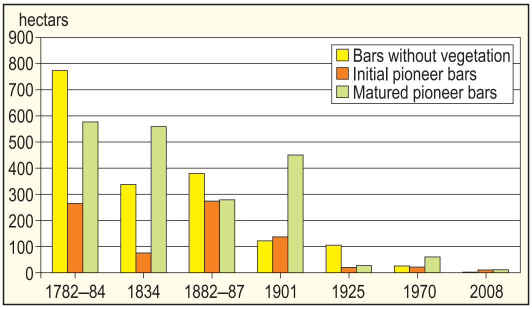

Fig. 6. Change of the total area of unvegetated and vegetated sand and gravel bars in hectares. *Source*: Ijjas, I. *et al.* 2010

Summarising the above statements, construction of Gabčikovo (Bős) Hydropower Station had the following consequences:

– Reduced or disconnected riverine – floodplain interactions.

– Alteration of hydromorphological dynamics of the Danube: reduction of bed load transport by upstream dams.

– Changes of landscape structure and function.

– Changes of biodiversity because of the extinction of aquatic and wetland species and because of the habitat's drying.

– A number of native wetland species became threatened.

– Spreading of several non-native invasive species in dry habitats.

– These are all irreversible landscape changes.

Conclusions

The investigation on the effects of the Gabčikovo (Bős) Hydropower Station was only an example for the complex influence of a large energy generating facility on the environment and landscape. In similar cases, the environmental effects of power stations should be accompanied by have similar discussions.

However, the present energy supply system using fossil fuels up to 80% cannot be maintained not even for the coming decades. Renewable energy sources should have a major role in the future. The methods of renewable energy resources for the production of large amount of energy have grave effects on the environment.

The effects of these types of power stations on the landscape and on the environment are significant. There will be landscape structure and function changes by using renewable energies causing the degradation of habitats and ecosystems. These prospects must have a strong influence on general energy policy and on regional development plans.

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