ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 40-41, 2007, 147-154.

ANTHROPOGEOMORPHOLOGIC IMPACTS OF ONSHORE AND OFFSHORE WINDFARMS

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Összefoglalás – A szélerőművek építése során kisebb-nagyobb mértékben átalakítjuk a berendezés közvetlen környezetét. A mesterségesen létrehozott formák és az esetlegesen kiváltott folyamatok azonban a telepítés helyszínétől függően különbözőek lesznek. Az onshore szélparkok létesítése több évtizedes múltra tekint vissza. Nagy körültekintéssel, a lehető legkisebb környezeti beavatkozással végzett telepítések antropogeomorfológiai hatásai elhanyagolhatók. A szélenergia hasznosítás másik, egyre jelentősebb szerepet betöltő helyszínei a selfterületek lesznek. Az offshore telepítési körülmények természetesen különböznek a szárazföldön tapasztaltaktól. A tengeri szélparkok környezetre gyakorolt hatásairól még kevés információáll rendelkezésre, hiszen ezek telepítése a közelmúltban indult meg. A tanulmányban felvetett kérdések időszerűek, mert a következő évtizedekben az offshore parkok jelentős növekedése várható.

Summary – During the **e**stablishment of wind farms their close environment can become more or less altered. Artificial forms and processes triggered by the construction and operation of wind turbines can be different depending on the site. There is a several decades-long history of the operation of onshore wind farms, so many studies have dealt with their effects on landscape evolution. Anthropogeomorphologic issues of well-planned and appropriately carried out projects are insignificant. Continental shelf areas are sites with increasing importance for the establishment of wind farms today. The conditions for offshore projects are different from those of continental ones. There is not much information on the environmental effects of offshore wind farms, since their establishment has begun just recently. Questions raised in this paper have a growing importance together with the growing investments in this field.

Key words: wind turbines, establishment of wind farms, anthropogeomorphology, onshore and offshore wind farms, reef development

1. INTRODUCTION

The importance of renewable energy sources, thus wind energy is increasing in the energy strategy of the World today. In the EU the number of wind farms has been multiplied in the past ten years. Wind energy utilization is popular, since it is clear, abundant and easy to use.

Opponents of wind energy utilization criticize the effects of wind turbines on birds, on the landscape and the noise of the turbines. However, contrary to those opinions, many studies have proved that the noise loads of wind turbines are under the threshold limits, there is no mass loss of birds, and the effects on landscape are subjective issues. On the other hand there's much less research carried out on the anthropogenic forms created by the installation of wind turbines and their impacts on the surface.

To declare that wind energy utilization is really one of the most environment-friendly technologies, every factors should be taken into consideration which can be important from the aspect of the effects of wind farms on their living and inanimate environment.

This paper focuses on the theoretical examination of geomorphologic forms and processes connected to the construction and operation of onshore (built on the land) and offshore (built on the continental shelves) wind turbines and experimental hybrid systems.

2. DISCUSSION

2.1. Forms and landscape evolution processes connected to the construction and operation of onshore wind turbines

In the planning phase of the wind farms, the impacts of the turbines on the soil must be taken into account first, since during the construction there are significant mass movements. The most time-consuming part of the construction is the groundwork, the preparation of the area and the laying of foundations for the turbines. A solid base is required in order to resist the most severe storms. The first step is the excavation of the pit of the foundation, when special care is taken to save the upper, fertile layer of the soil. The excavated surplus of soil is carried away, or it is used for road building or levelling the ground. Significant amount of artificial materials are put into the foundation during the steel-concrete fitting, formworks and concrete works (*Fig. 1*). The actual amount depends on the size of the turbine (capacity of the turbine and height of the tower). In the case of a 0.6 MW turbine the volume of the fundamentals can reach 500 m^3.

Fig. 1 Phases of laying the foundations for the wind turbine at Kulcs
(source: *www.winfo.hu*)

Although fundamentals do not reach the groundwater and streamlets, it is incontestable that they have certain impacts on the flows of ground waters. It still does not pose a threat in the case of the individual turbines or the whole farm, since due to the diffuse spacing of the turbines groundwater is not banked up, but flows around the concrete bodies of the fundamentals.

The soil suffers slight disturbances during the laying of the ground cables. Electricity generated by the turbines is fed into the public electric network via converters and ground cables. Cables are laid into a depth between 1.5 and 5 meters according to the licence, this way they will not be visible in the landscape (*Horváth*, 2005). When turbines are connected to the public electricity network soil horizons are disturbed in the zone of the cable laying and in the vicinity of those zones. Soil becomes more compacted due to treading.

Before the establishment of a wind farm, the infrastructure of the area must be surveyed. Important factors are the availability of the aforementioned public electric network, the accessibility of the area and the quality of its roads. For the excavators and bulldozers any kind of roads are suitable, but the heavy trailers, which transport the elements of the turbine towers, nacelles and blades and the heavy duty cranes require good-quality, paved roads and hardened unpaved roads. The site is often not accessible on paved roads, because in Hungary those areas are banned, where there are public roads and electric cables within the range of falling (the total height of the tower and the vertical blade) of the turbine (*Fegyverneky*, 2004). As a consequence of this, for the transportation and construction of the turbine the hardening of an existing unpaved road or building of a paved road is necessary in almost every case. Although impacts and landscape forms created by road building are not connected directly to the operation of the turbines, they must be considered as “by-products” of the establishment of wind farms. In the sides of unpaved roads hardened by crushed gravel, asphalt paving, or rarely clinkers, gullies can form due to runoff, while on the lower surfaces along the roads accumulation forms can be established. In the case of paved roads the strong runoff can lead to more marked forms. The size of the forms and the activity of the landscape evolution processes are determined by the type of the pavement, the geological and pedological conditions, the height above sea level and the relief.

The time demand of the preparation of the area for the construction depends on the infrastructure. It usually does not mean a long time, since the accessibility and availability of the public electricity network are important factors in the selection of the site. The installation of the turbine takes only a few days; during the operation, practically, there are no significant changes in the environment of the turbine tower till its removal. During the removal of the turbine cranes, trailers and other vehicles use the roads built for the construction; therefore, there is no further landscape forming.

Built-in blast holes in the fundamentals make the demolition of the base of the tower much easier. Parts of the turbine like the tower trunk and the blades are made of recyclable materials. These, together with the debris of the tower base can be used again. After the removal of artificial materials only the pit of the tower base is left behind, which will be filled and the fertile upper soil layer will be replaced. In this phase the area can be reclaimed for agricultural (or actually any other) use. After the recultivation the paved roads, which became part of the road network of the area, are the only reminders of the former wind farm.

In the case of wind turbines in Hungary the hill of the fundamental is under the ground level and completely covered with grass or crushed gravel; therefore, there are no positive forms except the tower. Only a narrow concrete ring is visible from the fundamentals along the tower base. The extent of artificial surface cover is insignificant even if compared to the area of the fundamentals; therefore runoff will not increase to a degree that would lead to the formation of erosion forms.

The wind turbine of Kulcs, which operates since 2001, is a slightly different case. There the fitting ring of the tower and the fundamental are both visible, but the result is not a level surface rather a small negative form, characteristic of this turbine only in Hungary.

The soil was replaced onto the fundamental there as well, but the road, built for the construction lies higher than the base of the tower. As it was one of the first operating wind turbines in Hungary a conference and exhibition room was built near the tower and the hardened unpaved road, and the yard was paved later in order to make the site easily accessible. The higher, well-ordered surface emphasizes the almost entirely closed small basin with the trunk of the tower, which can be accessed via a few steps. Water from precipitation is drained westward (*Fig. 2b*).

The fundamental became covered with grass quite early, so it protected the soil already in the phase of the construction (*Fig. 2a*). In the second year of the operation there were no visible signs of material movement processes during our field observations, therefore there were no measurements carried out. During the six years operation time of the wind turbine of Kulcs (which means the quarter of the planned operating time), there were no signs of material movements; therefore it is probable that there won't be any mass movement processes in the future either.

a b c

Fig. 2 The wind turbine of Kulcs and Újrónafő
(source: *www.winfo.hu*, *www.szelenergia.lap.hu*)

In connection with the onshore establishment of wind turbines it can be stated that the primary form created during the appropriate construction of the turbine does not trigger the formation of any secondary forms, new landscape evolution processes, nor does it modify the working processes significantly. The base hills of the wind turbines are small positive or negative forms; for this reason, classic geomorphic features like fluvial forms, gullies, etc. can occur on them rarely. It can be explained partly by the small size of these forms (*Fig. 2*c). In addition the soil is covered with grass or crushed gravel, which protects them from wind and water erosion. The possibility of mass movement processes caused by the weight of the turbines can be excluded, because the construction can only be licensed in statically stable sites.

2.2. Forms and landscape evolution processes connected to the construction and operation of offshore wind turbines

Recently in the establishment of wind farms in coastal countries there has been a tendency of moving from the land out onto the continental shelves. In Europe in 2005 the capacity of offshore wind turbines reached only 680 MW (less than 2%) within the 40 500 MW total installed wind power capacity, but, according to the EWEA (European Wind Energy Association), their ratio can reach 30% by 2020 and even 50% by 2030 (*ec.europa.eu*).

The main reason for the investments in the field is the higher effectiveness and profit rate of offshore wind turbines. The better wind profile originating from the low roughness over the sea surface provides 40 percent more energy. There are other advantages of offshore wind farms over onshore ones: the area of individual wind farms is not limited; and the environmental protection licence procedure is simpler than in the case of onshore wind farms.

Although the establishment of offshore wind farms is advantageous from the aspect of energy production, they can cost more by up to 60 percent. Higher costs are not originated from laying the foundations or the construction itself, but from the more complicated process of laying the submarine cables. Higher losses of electric power during long range transportation must also be taken into account.

Besides economic possibilities it must be taken into consideration as well that the sea bed does not remain undisturbed under offshore wind farms. Offshore wind turbines need much stronger fundamentals, since, due to its higher density, moving sea water exerts much higher pressure on the trunks of the towers of wind turbines than the flowing air. Different conditions require different building technologies; stronger concrete structures have to be used (*Fig. 3a-b*).

In order to decrease costs, out of the way sites with water depths between 5-10 meters are preferred, although it is possible to lay the fundamentals and cables for the turbines even into 40 meter deep waters. In the case of most of the planned German wind farms in the North Sea, water depths are between 20-40 meters, which causes high additional costs. In waters shallower than 10 meters, the base for the wind turbines is made of concrete, while in deeper waters, due to its weight, the base is made of steel. It is advantageous, since it can be put together on the land and it is adjustable to any types of sea beds. Nevertheless, it is still necessary to prepare the site: divers have to clear deposits from the seabed and a gravel bed has to be laid before the construction (*www.windpower.org*).

The huge steel-concrete base hill is much more a positive form on the sea bed, than in the case of onshore wind turbines. For the crane that lifts the elements of the turbine a stable platform is required on the seabed. For this reason, the sea bed is disturbed not just under the fundamentals of the turbines, but under the platforms of the cranes either (*Fig. 3c*). However, the strongest disturbances of the sea bed are caused by laying the submarine cables for the turbines.

a b c

Fig. 3 Main phases of the establishment of offshore windparks
(source: *www.windpower.org*, *www.windpowerphotos.com*)

The process of the construction of offshore wind turbines does not create significant new geomorphic forms or processes. On the other hand – in the authors' opinion – installing the fundamental structures of the wind turbines into the sea bed can affect the surface evolution processes in the shallow water environment and can lead to the creation of new forms.

The towers and, depending on the depth of the water, even the base hills of the turbines can alter the dynamics of waves. On the sides of the towers of turbines facing the waves, processes characteristic of abrasion shorelines occur: waves break on the vertical concrete and steel bodies of the towers. The breaking of the waves results in much smaller "microforms" than in the case of abrasion shorelines forming at the base of the towers on the sea bed. Their small size is a consequence of the relatively small surface of the tower trunk under sea level and the diffuse spacing of the towers.

The basement embedded into the sea bed can have a significant impact on the mass movements on the sea floor. These artificial bodies do not alter the flows of the water directly but they behave as obstacles for the currents.

Coarse material rolled on the sea floor can be trapped at the base of the tower directly; or indirectly, it can lose most of its kinetic energy in the collision with the tower body so it will be deposited in the front and along the sides of the tower. Due to water movements from the opposite direction (the soog) from the shores deposition of coarse grains can occur behind the tower as well (*Fig. 4*). Microforms of the abrasion terrace will not affect the developing form strongly, since material transport towards the shores evens the roughness of the sea bed. The size of the new form and the time of its development are determined mainly by the amount of deposits.

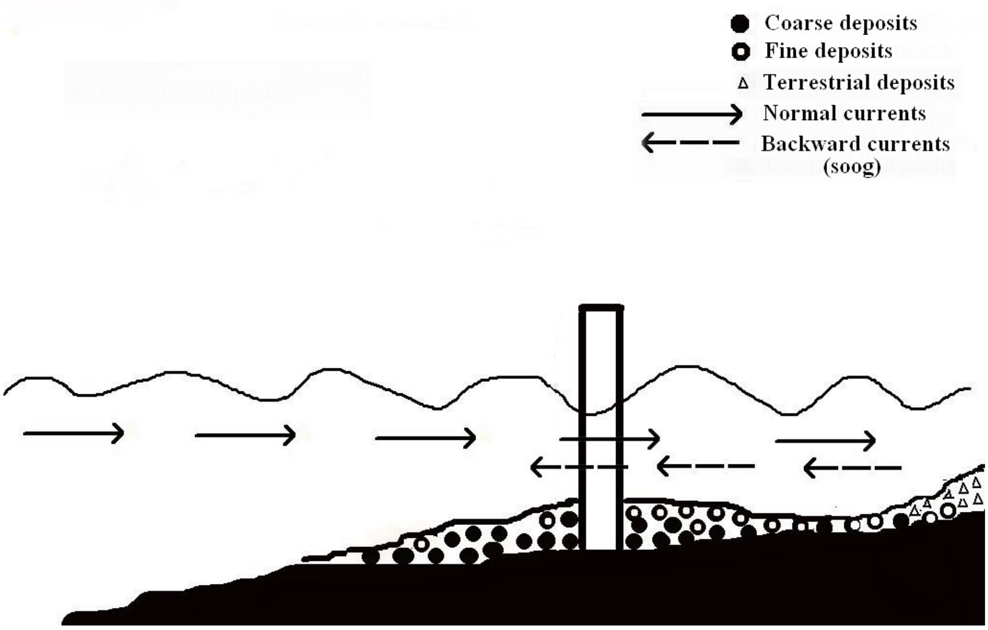

Fig. 4 Developement of accumulation forms in the environment of a wind turbine.

Along the coastline of North Germany the depth of water exceeds 10 meters at a distance of several hundred meters from the coast only. Some 10 meters wide, moving underwater bars run parallel with the coast on the abrasion terrace there. Under permanent and even winds and waves, they move towards the coast, but in a strong storm they withdraw towards the deeper waters due to the violent soog. The process of their development is not clear in every detail, but it can be assumed that they form due to the collusion of the coastward and seaward currents (*Borsy*, 1992).

It is a hard task to determine the shape of the reef formed on the sea bed on a purely theoretical base. If the strength of the two currents equals, the shape will be symmetric. However it is clear from the aforementioned facts that the strength of the currents is different, so the shape of the accumulation form will be deformed in one direction.

The role of underwater moving bars should be taken into consideration, since the towers of wind turbines mounted on abrasion terraces can alter those unique interactions between the currents there. If there is a visible and measurable effect of the base hills and tower trunks within a short period of time, it is necessary to take into consideration that the planned life span of those objects in the seabed is 50 years.

Without field measurements and experiments it is impossible to determine the parameters of the developing forms, but on the basis of the aforementioned facts it seems quite probable that in the environment of the wind turbines rather special accumulation forms can develop. Those reefs can be interesting not just because of the special way of their development, but because of their potential effect on navigation. Although (anthropo-) geomorphologic concerns of this "impact assessment" are not based on measurements, but they are merely hypotheses, the authors believe that they can emphasize the importance of the issue, triggering further investigations into the topic which can prove or disprove the hypotheses.

In countries which have huge wind farms, the relatively old low-capacity turbines have been being replaced by new high-capacity ones, which can produce several times more energy in the same area. The cables, the fundamentals and the towers are left in the sea; new turbines are installed on the former structures. That way, investors spare the costs of laying submarine cables, building fundamentals and towers. At the same time, the number of new offshore wind farms increases dynamically as well, together with the increasing popularity of renewable energy utilization.

The first offshore wind farms were established in Denmark in the early 1990-s. The establishment of huge, high capacity offshore wind farms, like Horns Rev (80 turbines, 160 MW), or Nysted (72 turbines, 165.5 MW) have taken place since 2002. Further establishment of huge wind farms is also expected in the future, since there are plans for the establishment of 4,000 WM offshore capacity by 2030 in Denmark alone (*www.windpower.org*). There are similar plans in Germany too: the establishment of 27,820 MW of total capacity is planned on the German seas. Most of it (25,242.5 MW) will be situated on the North Sea. The greatest wind farm will have 980 turbines with a total capacity of 4,720 MW. At the same time more there are moderate plans for the Baltic Sea, where 2,577.5 MW of total capacity is planned (*www.offshore-wind.de*).

Those areas are suitable for offshore wind farms that are situated outside of the National Parks, navigation lines and military areas. In Denmark most of these territories are situated within 7-40 kilometres off the coasts, while the aforementioned German wind farms (mainly in the North Sea) are situated at a distance between 70-100 kilometres from the coasts. The infrastructure for the transportation of electric power is very expensive and there are significant losses during the transportation. An additional problem for laying the submarine and ground cables is that many coastal areas belong to national parks.

The establishment of offshore wind farms is of high importance, because in the land a wind farm with 25 turbines and 50 MW of capacity, cannot get licence due to environmental and landscape protection causes if its area exceeds 1.5-1.6 km^2 (*Munkácsy*, 2004). The first offshore wind farms in Germany started operation in 2006. On the basis of the plans for wind energy utilization for that region and the characteristics of the North-, and Baltic Sea coasts (water depth, development of the bars and lidos), the aforementioned hypotheses is not unfounded. It is supported by that most offshore wind farms were established only a few years ago. They are the newest types of practical wind energy utilization. For this reason there are no long time series of monitoring data available on their impacts on the environment. Therefore it would be reasonable to carry out detailed examinations on the questions raised in this paper, since – if there are real problems – extensive research, appropriate planning and realization could prevent anthropogenic landscape evolution processes in those coastal regions.

3. CONCLUSIONS

Wind turbines produce electricity in a clear and environment-friendly way, but in the meantime they can slowly alter their environment.

Onshore wind farms do not create any significant geomorphic forms. Despite their enormous weight, turbines do not cause mass movements, since territories which are hazardous from that aspect are banned. Levelled surfaces and roads created for the construction works are small in area and later they are integrated into the road network as parking places or recreation areas, or they are recultivated.

Offshore wind turbines can alter the mass movement processes of the sea bed significantly, which can affect navigation in those areas.

The degree of the alteration of former natural processes and the extent of new effects should be determined by further detailed studies.

It can be stated that the (anthropo-) geomorphologic effects of instruments of wind energy utilization are insignificant compared to those of fossil fuel exploitation or the utilization of hydropower.

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