Wind Energy

Energija vetra

First wind turbine in Serbia

Nippon-komerc from Belgrade announced on October 9, 2003 that it had installed the first grid connected wind turbine in Serbia. The power of the generator is 11 kW, the diameter of the rotor blade is 13 m, and the manufacturer of the wind turbine is Danish company Gaia wind.

Prvi vetrogenerator u Srbiji

Firma Nipon-Komerc iz Beograda instalirala je i 9. oktobra 2003. godine povezala na električnu mrežu prvi vetrogenerator u Srbiji. Snaga generatora je 11 kW, a prečnik elise je 13 m. Proizvođač vetrogeneratora je danska firma Gaia Wind.

The Energy of the Wind

Wind energy has recently become an economically feasible (although site specific) alternative to conventional sources of energy. The energy contained in the motion of air has always attracted attention of researchers. Therefore the control of wind potential to meet human energy needs is a concept several thousand years old. Sails and later wind mills were the only means of conversion of wind energy into mechanical work. Among the many challenges that confront modern society, one stands for its grandeur and power – the race around the world. An event of this kind involves sailing boats only, illustrating in a suggestive way the power of the wind. Now as well as in the future, the energy of the wind has proven to be one of the most important renewable energy sources. The main reasons are:

- Unlimited energy supply
- Possibility of conversion into electrical energy by means of wind turbines
- The cost of electricity generated by wind power reduces in proportion to increasing wind energy use
- Environmentally-friendly method of energy generation
- Small requisite land

Energy crises, significant reduction of fossil fuel resources and enormous increase in pollution across the planet have stimulated growth of wind turbines production in the last 30 years at an almost equal pace as the computer industry. Increased wind turbine reliability and the in-roads into world markets would mean that the future for the technology is bright.

Energija vetra

Energija sadržana u kretanju vazdušnih masa - vetru - oduvek je pobuđivala pažnju istraživača koji su želeli da je korisno upotrebe.

Jedra, a kasnije i vetrenjače bili su jedini način za pretvaranje energije vetra u mehanički rad. Od svih izazova koji stoje danas na raspolaganju savremenom čoveku postoji jedan koji pleni svojom uzvišenoću i snagom. To je trka oko sveta. Pored svih mogućih prevoznih sredstava jedino se u jedrenju odrzavaju trke oko sveta što na slikovit način govori o moći vetra. Sada, a i u budućnosti energija vetra se pokazala kao najozbiljniji obnovljiv izvor energije pri dostignutom razvoju tehnologije. Osnovni razlozi za to su:

- neizmerna količina energije
- mogućnost pretvaranja u električnu energiju pomoću vetrogeneratora
- pad cena vetrogeneratora i prateće opreme srazmerno sve većoj upotrebi energije vetra
- ekološki potpuno čist način pretvaranja energije
- mala zauzetost zemljišta

Energetske krize, smanjenje zaliha fosilnih goriva i enormno zagađivanje planete uticali su da se industrija za proizvodnju vetrogeneratora (VTG) poslednjih 30 godina razvijala u svetu skoro istom dinamikom kao i industrija računarske opreme, a danas se smatra vrlo stabilnom i perspektivnom.

After 2001 the growth rate has increased significantly, and continuing trend of considerable growth is predicted for the whole world market. By the end of 2001 there were 56 000 wind turbine installations around the world, with total capacity of 25 GW. Just last year capacities increased by 52%.

The highest number of wind projects Germany has, followed by the U.S.A and Spain.

Overview of installed wind energy capacities in the world (MW)

Country	**Beginning of 2001.**	**Beginning of 2002.**
Germany	6 113	8 753
U.S.A	2 555	4 245
Spain	2 402	3 335
Denmark	2 297	2 417
India	1220	1 507
The Netherlands	448	483
Great Britain	409	485
China	340	399

Po predviđanjima mnogobrojnih eksperata, očekuje se dalji intenzivan rast instalisanih kapaciteta, a trendovi daljeg povećanja ekonomičnosti, kao i sve ozbiljnije pogoršanje stanja životne sredine, potvrđuju takve pretpostavke. Do kraja 2001. godine u svetu je instalisano 56.000 vetrogeneratora sa kapacitetom od 25 GW. Prošle godine je povećanje kapaciteta iznosilo 52%. Nemačko tržište ima i dalje najveći udeo, tržište SAD drži drugo, a Španija je došla na treće mesto.

Pregled zemalja sa najviše instalisanih kapaciteta u svetu [MW]

Zemlja	**Početak 2001.**	**Početak 2002.**
Nemačka	6.113	8.753
SAD	2.555	4.245
Španija	2.402	3.335
Danska	2.297	2.417
Indija	1.220	1.507
Holandija	448	483
Velika Britanija	409	485
Kina	340	399

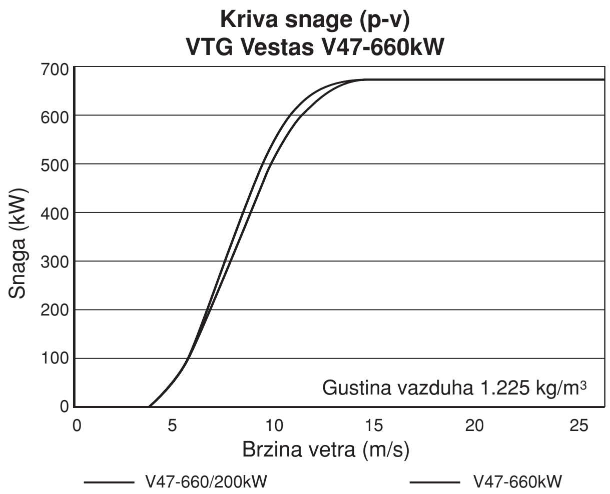
Energy deficit and the inevitable exploitation of renewable, environment protecting energy sources will force Serbia and Montenegro to start investing in wind energy research and development for electricity generation purposes.

Technology of the wind turbine power production

The basic wind energy conversion device is the wind turbine. The wind turbine transforms kinetic energy of the moving air by means of rotating blades, gear mechanism and electricity generator.

Energy generated by the wind is proportional to the third power of the average velocity. However, the wind turbine cannot transform the whole transmitted energy obtained through the interaction of the wind with the blades. Albert Betz has shown in 1919 that the maximum kinetic energy that may be transformed into mechanical energy of the wind turbine is 59%, while the maximum efficiency of the wind

Figure 9. Entrance-exit characteristic of 660 kW wind turbine
Slika 9: Ulazno-izlazna karakteristika vetrogeneratora nominalne snage 660 kW



Energetski deficit i neminovnost upotrebe ekološki čistih izvora energije primoraće i Srbiju i Crnu Goru da počne da investira u razvoj i eksploataciju energije vetra.

Tehnologija korišćenja energije vetra

Pretvaranje energije vetra u elektičnu energiju vrši se pomoću vetrogeneratora.

Vetrogenerator pretvara kinetičku energiju vazduha koji se kreće (vetra) pomoću lopatica rotora (elise), prenosnog mehanizma i elektrogeneratora u električnu energiju.

Energija dobijena iz vetra zavisi od srednje brzine vetra i to tako što je proporcionalna trećem stepenu brzine vetra.

Vetrogenerator ne može da transformiše celokupnu kinetičku energiju vetra koji struji kroz površinu koju obuhvataju kraci rotora. Albert Dec je 1919. godne dokazao da se

turbine is approximately 40%. The main practical characteristic of the wind turbine is the change in power production with wind speed. Figure 7 is an example of power vs. wind speed characteristic for a single speed machine in increasing wind.

Modern wind turbines generate electricity at wind speed as low as 2.5 m/s, and for safety reasons the operation of the wind turbine is halted when the wind velocity reaches 25 m/s. In order to have an economical power generation of electricity, an annual average velocity of the wind of 6 m/s is required.

Due to the friction between wind motion and the ground and the internal viscous forces in the air mass, the wind speed increases with increasing altitude. The wind speed is further influenced by the topography of the land such as roughness of the terrain, presence of natural and artificial impediments etc. In order to view the wind energy in its proper

maksimalno 59% ukupne kinetičke energije vetra može pretvoriti u mehaničku energiju rotora vetrogeneratora. Proizvođači vetrogeneratora uglavnom daju krivu izlazne snage u zavisnosti od brzine vetra kao što se vidi na slici 7.

Moderni vetrogeneratori počinju da proizvode električnu energiju već pri brzini vetra od 2,5 m/s, a zaustavljaju se iz bezbednosnih razloga pri brzini od 25 m/s. Vetrogenerator može da obezbedi ekonomičnu proizvodnju struje ukoliko je srednja godišnja brzina vetra veća od 6 m/s.

Usled trenja između struje vazduha i tla, kao i unutrašnjeg viskoznog trenja brzina vetra raste sa povećanjem visine iznad tla. Jasno je da na profil brzine vetra utiče hrapavost terena, prisustvo prirodnih i veštačkih prepreka kao i drugi topografski elementi. Pošto se ovi parametri razlikuju od lokacije do lokacije potrebno je prilikom izbora lokacije voditi context, it is important to have at least an approximate estimate of wind energy's strategic potential. Most estimates use the same basic steps: define the climatic and physical characteristics – average wind speed and areas where turbines can be placed; estimate the space available for development from the results of the previous step and finally using current technology estimate the energy yield which can be derived. The second step has major influence on the final outcome and is most difficult to perform accurately. On the other hand, even minor errors in location choice may have negative effects on the overall cost effectiveness.

Small and very small turbines (up to 3 kW approximately) usually use a direct-drive system, which offers the advantage of omitting the gearbox, and utilizing a generator that can operate at the rotational speed of the rotor. Such products can be utilised for remote communications, electric fences, domestic systems, leisure craft etc. Wind turbines rated at several dozens of kW generate three-phase electrical current, and are usually connected to utility grids.

Medium size turbines produce electricity of several hundred volts at the frequency of 50/60Hz. By means of transformers the voltage is raised to 10 - 30 kV so that electrical grids may transmit it.

Although the wind industry has demonstrated technical and commercial feasibility of units of about 1.5 MW, larger wind turbines have been built but the present generation of megawatt machines may well be close to the economic limit of up-scaling. All of these units are connected to the utility grids. In some land based and offshore applications larger generating units are desirable. The most cost effective use of wind turbines is the so-called wind farm, which comprises a large number of individual units. The largest offshore wind farm is the 17 MW Dronten wind farm in Denmark, although there are mainland farms of several hundred MWs.

Cost effectiveness of wind energy use

The price of modern turbines is in the range between 700 and 1000 euros per installed kW. The cost of wind turbines and wind plants has fallen substantially during the last fifteen years, and this trend is continuing. Energy prices have fallen even faster, due to lower

računa da se dosegne što povoljnija srednja godišnja brzina vetra. Od toga direktno zavisi količina proizvedene električne energije. Čak i male greške u odabiru najpovoljnije lokacije u dugogodišnjem bilansu proizvodnje daju značajna umanjenja isplativosti investicije.

Mali i vrlo mali vetrogeneratori snage do 3 kW prave se direktnim povezivanjem elise i elektrogeneratora bez prenosnog mehanizma (reduktora) čime im se smanjuje cena. Mali vetrogeneratori namenjeni su individualnoj upotrebi i najčešće služe za punjenje akumulatora tamo gde ne postoji električna mreža, a energija se obično koristi za osvetljenje i TV prijemnik.

Vetrogeneratori srednjih snaga do nekoliko desetina kilovata daju trofaznu struju i obično se priključuju na niskonaponsku distributivnu mrežu.

Na izlazu vetrogeneratora dobija se naizmenična trofazna struja napona 690 V i frekvencije 50/60 Hz. Pomoću transformatora se napon podiže na 10 - 30 kV što odgovara naponu srednjenaponskih mreža.
Svi vetrogeneratori većeg kapaciteta (od 10 kW do 3 MW) koriste se kao elektrane, što znači da proizvedenu energiju predaju elektroenergetskom sistemu. Najčešće primenjivani moderni vetrogeneratori su kapaciteta od 500 kW do 3 MW mada se grade i veći. Najekonomičnija primena vetrogeneratora je njihovo udruživanje na pogodnim lokacijama u takozvanu farmu vetrenjača. Takva elektrana može da ima kapacitet od nekoliko MW do nekoliko stotina MW koji obezbeđuje više desetina vetrogeneratora.

Ekonomičnost korišćenja energije vetra

Na osnovu dosadašnjih iskustava u gradnji vetrogeneratora došlo se do orijentacione vrednosti investicija od oko 700 do 1000 E po instalisanom kW. Vetrogenaratori, a samim tim i farme vetrenjača su znatno pojeftinili u poslednjih desetak godina i ta tendencija će se i dalje nastaviti. Na taj način je i cena električne energije dobijene iz vetro-

U SAD u državi Ajova počeo je sa realizacijom projekat izgradnje farme vetrenjača snage od 310 MW koja će se sastojati od 180 do 200 vetrogeneratora snage od 1,5 do 1,65 MW.

A realization of the project is underway in the state of Iowa, U.S.A., to build a $323 million, 310-megawatt wind farm in northwest or north-central Iowa that would have 180 to 200 1.5 to 1.65 MW turbines.

wind turbine costs, higher efficiency and availability, and lower operation and maintenance costs. Wind turbine prices fell by a factor of at least three from 1981 to 1991, and energy prices have halved in the last 9-10 years. Initial investment accounts to about 75% to 90% of the total expenses and comprises the cost of the wind turbine or wind farm, including the price of connecting roads if necessary, and the price of commercial utility grid connection. The windiest locations - on hilltops, often remote from a grid connection, or costal locations where deep piling into silt is needed, tend to incur above average costs. Operational costs vary between countries and between wind farm sites. The price of wind turbines is in the range of 600 - 900 euros per installed kW. The efficiency of wind turbines increases with wind speed so that high tower installations are required.

The calculation of wind-generated electricity costs follows procedures which are reasonably standardized across the power industry. The International Energy Agency (IEA) has published guidelines in the form of a “Recommended practice” for wind energy, and these are similar to those used for other renewables as well as for thermal plants. The IEA document advocates the use of net or real costs, i.e. net of inflation, interest rates and test discount rates. This has become a common practice by now. The wide range of interest rates and other factors must be acknowledged and so indicative low, average and high prices are used. The assumptions are set out in Table , and the data applies to machines in the size range of 600-750kW. It is assumed that installation costs increase with wind speed above 7m/s by 8% per m/s. Energy production has been derived assuming that availability and other losses account for 10% of the gross energy, although actual losses may be less, as availability levels of 98% and above are achieved for many turbines, but the guaranteed level is usually 95%.

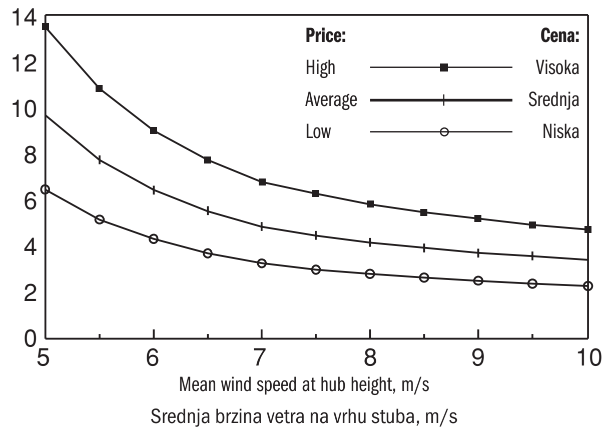
Table 3: Summary of assumed wind-generated electricity prices (in Eur)

Price parameter	Low	Average	High
Installed cost, ECU/kW at 7m/s (hub height)	700	850	1000
Real interest rate, %	5	7.5	10
Construction period, years	0.5	0.50	0.5
Amortization, years	20	20	20
Running costs, fixed, euros/kW/yr	12	18	24
Running costs, available, cents/kWh	0.2	0.3	0.4

generatora drastično smanjena. Na to je dodatno uticalo i smanjenje operativnih troškova i rast efikasnosti i pouzdanosti. Obzirom da kod korišćenja energije vetra, kao i kod mnogih drugih obnovljivih izvora energije, nema troškova goriva, posle investicione izgradnje jedini troškovi su operativni i troškovi održavanja. Investicioni troškovi se kreću od 75% do 90% ukupnih troškova. Investicioni troškovi su troškovi izgradnje vetrogeneratora ili farme vetrenjača, uključujući troškove izgradnje pristupnih puteva ukoliko je potrebno i troškove priključivanja na elektroenergetski sistem. Obično su lokacije sa povoljnim uslovima za gradnju farme vetrenjača udaljene od drumskih i energetskih magistrala i to povezivanje utiče na povećanje investicionih troškova. Cena vetrogeneratora se kreće od 600 do 900 E po instalisanom kW. Sa povećanjem brzine vetra raste koeficijent korisnog dejstva što postavlja zahtev za podizanjem visokih stubova.

Finansijski efekti u značajnoj meri utiču na odluku o investiranju u proizvodnju električne energije pomoću vetrogeneratora. Iako cena električne energije iz vetra zavisi od raznih institucionalnih faktora, referentne vrednosti se mogu izračunati primenom preporučene prakse za proračun cena električne energije, od strane Međunarodne agencije za energiju. Zbog širokog opsega kamatnih stopa mora se izračunati visoka, srednja i niska cena električne energije. Osnovne pretpostavke su date u tabeli a podaci se odnose na klasu vetrogeneratora kapaciteta 600 - 750 kW. U kalkulaciju se ušlo sa pretpostavljenim rastom investicionih troškova od 8% po priraštaju brzine vetra za svaki m/s, iznad 7 m/s. Količina godišnje proizvodnje električne energije redukovana je za gubitak od 10%, iako, zbog visokog stepena pouzdanosti od 98%, stvarni gubici mogu biti i manji.

Figure 10. Electricity price, cE/kWh
Slika 10: Cena električne energije, cE/kWh



The obtained energy prices are presented in Fig, where it may be noticed that at wind speeds of 6m/s, the price varies in the range 0.045 - 0.09 euros/kWh.

Government support for the nuclear and coal industries means that the real generaling costs are higher than apparent. Direct comparisons between prices of wind energy and electricity from conventional sources ignore the fact that, in many instances, renewable electricity-generating technologies deliver energy closer to consumer than centralized generation, hence the transmission losses are minimal.

The electricity prices quoted earlier do not include so-called “external costs” of electricity generation - those associated with damage to health and the environment. These are not borne by the electricity generator or consumer, and are not included in the price of electricity. External costs are for simplification purposes divided into three broad categories:

- Hidden costs borne by governments, including energy industry subsidies and Research and Development costs
- Costs of the damage caused to health and the environment by emission other than CO_2
- Costs of global warming attributable to CO_2 emissions

It is generally agreed that the price of wind-generated electricity has decreased much faster than the price of energy obtained from other sources, and such trend will continue.

A number of factors cause a steady fall in the cost of wind energy systems:

- The trend is towards larger machines as they can produce electricity at a lower price.
- Lower infrastructure costs
- Possible reductions in the cost of raw materials
- Increased efficiency of wind turbines

Effects of wind energy on the environment

Energy industry is one of the main sources of global pollution through the emission of global warming agents as well as

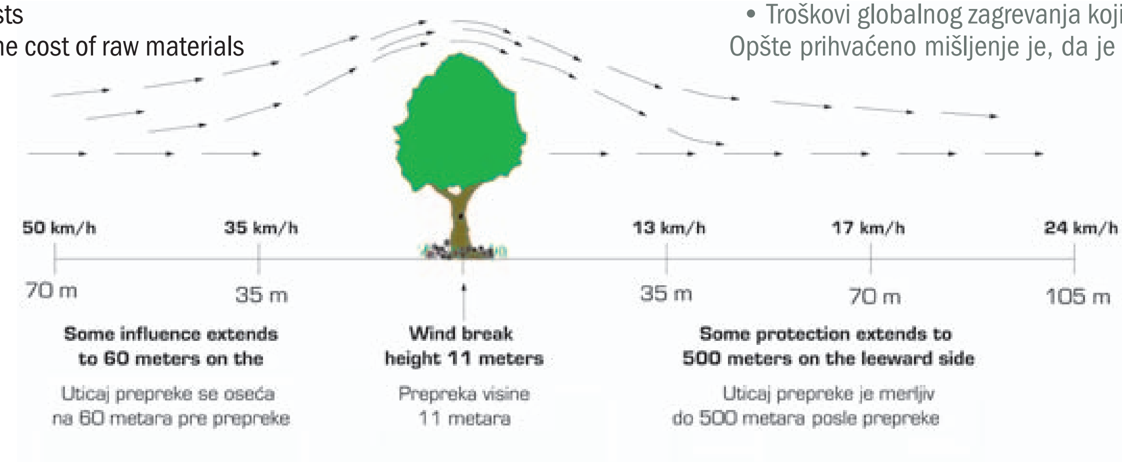


Tabela 3: Pretpostavke pri proračunu cene električne energije proizvedene vetrom (Euri)

Parametar cena	niska	prosečna	visoka
Investicioni troškovi [E/kW] pri vetru od 7 m/s u visini rotora	700	850	1000
Realna kamatna stopa [%]	5	7,5	10
Period investicione izgradnje [god.]	0,5	0,5	0,5
Period amortizacije [god.]	20	20	20
Fiksni operativni troškovi [E/kW/god.]	12	18	24
Varijabilni operativni troškovi [ct/kW/god.]	0,2	0,3	0,4

Dobijene cene su date u dijagramu gde se može videti da pri brzini od 6 m/s, cena varira u opsegu od 0,045 do 0,09 E/kWh.

Državna podrška proizvodnji nuklearne energije i proizvodnji uglja širom Evrope i Amerike čine da se troškovi električne energije dobijene iz ovih izvora prikazju manjim od realnih. Takođe, energija iz vetrogeneratora se obično proizvodi bliže potrošačima čime se smanjuju gubici u prenosu električne energije i ovako dobijena energija ima povećanu konkurentnost.

Prilikom razmatranja cene električne energije iz vetrogeneratora treba razmotriti i uticaj eksternih troškova. Eksterne troškove je teže kvantifikovati ali su oni vrlo realni i mogu se podeliti u tri kategorije:

- Skriveni troškovi koje snose vlade, uključujući subvencije industriji za proizvodnju električne energije i istraživačke i razvojne troškove, porezi, oslobađanja od poreza,
- Troškovi nastali usled emisije štetnih gasova (ne uključujući CO_2) koji utiču na zdravlje i životnu sredinu,
- Troškovi globalnog zagrevanja koji se pripisuju emisiji CO_2.

Opšte prihvaćeno mišljenje je, da je cena električne energije dobijene od vetra padala mnogo brže od cena dobijenih iz drugih izvora, kao i da će se taj trend u budućnosti i nastaviti.

Faktori koji izazivaju permanentni pad cena vetrogeneratorskih sistema su:

- trend izgradnje većih turbina
- opadanje infrastrukturnih troškova
- povećanje efikasnosti vetrogeneratora
- smanjenje troškova sirovina od kojih se izrađuju vetrogeneratori.

through generation of waste. Specific effects of the electricity industry on the environment may be classified into three categories:

- Emission of global warming agents (without CO_2)
- Emission of CO_2
- Waste generated through the process of electric energy generation (radioactive waste, ashes, oils, gypsum etc.)

The environmental imperative for renewables and energy conservation is now beyond dispute, since protection of the environment has become a global movement. A global trend is also to build energy systems which no longer threaten to change the global climate without invoking the long and short term hazards of nuclear power, so that such systems would rely on far-reaching energy efficiency measures and substantial use of the renewable energies. In this scenario, wind energy could contribute substantially since wind farms, as many companies have realized, exhibit economic and ecological advantages.

The target of the European Union has increased from planned 20 000 MW to 40 000 MW of wind energy capacities by 2010. Each unit (kWh) of electricity produced by wind turbines displaces a unit of electricity, which would otherwise have been produced by a fossil fuel-burning power station.

Among all the renewable sources of energy wind energy is ranked as one of the least expensive for reducing emissions of CO_2 and other air and land polluting agents.

A modern 600 kW wind turbine in the average will, depending on the site, prevent emission of some 20 000 - 36 000 tones of CO_2 from conventional sources during its design life.

Uticaj vetrogeneratora na životnu sredinu

Energetika je jedan od najvećih globalnih zagađivača, gledano kroz emisiju zagađujućih materija i otpad koji se stvara kao posledica proizvodnje. Štetni uticaji na životnu sredinu od proizvodnje električne energije, mogu se podeliti na tri grupe:

- emisija štetnih gasova (bez emisije CO_2)
- emisija CO_2
- otpad koji nastaje u procesu proizvodnje (radioaktivni, pepeo, gips, ulja)

Narastanje brige o zaštiti životne sredine, postaje svetski pokret. Rezultat delovanja ogleda se u konkretnim aktivnostima na globalnom nivou: borba protiv zagađenja, borba protiv globalnog zagrevanja i klimatskih promena, borba za racionalnije korišćenje resursa.

Prilikom planiranja novih kapaciteta, mnoge energetske kompanije se odlučuju za farme vetrenjača zbog toga što njihova primena ima ekonomskog i ekološkog smisla. Evropska Unija je zbog izgradnje vetrogeneratorskih kapaciteta intenzivnije od očekivane uradila reviziju strategije čime je povećala cilj sa 20.000 na 40.000 MW instalisane snage vetrogeneratora do 2010. godne.

Svaki kWh proizveden obnovljivim izvorima energije, zamenjuje isti koji bi s druge strane trebao da bude proizveden u elektranama na fosilno gorivo, što ima za posledicu redukciju negativnih uticaja na životnu sredinu, a naročito emisije CO_2 u atmosferu.

Među svim obnovljivim izvorima energije, energija vetra je rangirana kao jedna od najjeftinijih opcija za smanjenje emisije CO_2, ali i emisije drugih zagađujućih materija.

Moderni vetrogenerator od 600 kW će tokom svog radnog veka na prosečnoj lokaciji, u

Table 4 below summarizes some of the emissions avoided owing to wind energy deployed in the EU as of December 1997:

Parameter	**Quantity**
Installed capacity	4 425MW
Energy produced	8.8 TWh/year
Avoided CO_2 emissions	7 800 000 tons/year
Avoided SO_2 emissions	26 000 tons/year
Avoided NO_x emissions	22000 tons/year

Wind energy has many positive environmental facets and one of the principal market drivers for wind energy is that it is clean, renewable and sustainable means of generation.

Urbanization, waste and land pollution are factors that considerably raise concern of agricultural land preservation. Almost 99% of the land area on which a typical wind farm is situated is physically available for use as before. There is no evidence that wind farms interfere to any greater extent with livestock farming. On the other hand hydroelectric plants require large areas of, in many cases, high quality land areas.

Negative effects of wind energy installations do exist, although they are negligible compared to the positive effects. Moreover, in assessing the negative effects considerable influence is exerted by subjective elements, poor interpretation and inadequate information.

Visual effects, noise, electromagnetic interference and birds, which often collide with structures, are relatively insignificant negative side effects of wind turbines and may be easily reduced and avoided.

Energy requirements of Serbia and Montenegro

In order to asses the amount of quality wind for cost effective exploitation and conversion to electrical energy, it is necessary to take care of, besides the wind characteristics, the following: the fossil fuel reserves, price of energy generated by fossil fuel power plants, environmental effects, imported oil and gas assets, energy consumption structure and trends etc. Total megawatts of power plant applications in Serbia and Montenegro amount to 9 GW, of which 66.7% is generated by thermal power plants. The annual power

zavisnosti od vetrovitosti mesta i stepena iskorišćenja kapaciteta, sprečiti emisiju za otprilike 20.000 do 36.000 tona zagađujućih materija.

Radi sticanja relativnih odnosa, predstavljen je u tabeli primer procenjenog smanjenja emisije zagađujućih materija u decembru 1997. godine, na nivou EU.

Tabela 4: Procenjeno smanjenje emisije zagađujućih materija u EU kao posledica primene energije vetra.

Parametar	**Količina**
Instalisani kapaciteti	4425 MW
Proizvedena energija	8,8 TWh/god.
Izbegnuta CO_2 emisija	7.800.000 tona/god.
Izbegnuta SO_2 emisija	26.000 tona/god.
Izbegnuta NO_x emisija	22.000 tona/god

Negativni trendovi u korišćenju fosilnih goriva nameću značajna istraživanja u cilju iznalaženja efikasnih načina korišćenja obnovljivih izvora energije. Energija vetra, već pri sadašnjem stanju tehnologije, zbog neiscrpnosti vetra i široke rasprostranjenosti na svim svetskim meridijanima, može značajno doprineti stabilnosti i raznolikosti u energetskom snabdevanju, uz istovremeno smanjenje štetnih atmosferskih emisija.

Urbanizacija, otpad, zagađenje tla su faktori koji bitno aktuelizuju problem očuvanja poljoprivrednog zemljišta. Stoga pri valorizaciji neke tehnologije nije nebitan parametar neophodno zaposednuto zemljište. Termoelektrane zaposedaju velike površine zemljišta (za objekte, deponiju pepela). Površina se znatno uvećava kada se uključe površine zaposednute površinskim kopovima uglja, odlagalištima jalovine i transportnim putevima.

Kod hidroelektrana, velike površine zemljišta, često najplodnijeg, potapaju se i bivaju izgubljene za poljoprivredu. Farme vetrenjača su izuzetno ekonomične po pitanju iskorišćenja zemljišta. Veći deo zaposednutog zemljišta na kome je izgrađena farma (oko 99%) može se za vreme eksploatacije koristiti za poljoprivredu.

Negativni uticaji vetrogeneratora na životnu sredinu postoje ali su ti uticaji zanemarljivi u poređenju sa pozitivnim elementima. Takođe u toj proceni postoje subjektivni elementi, neinformisanost kao i loša interpretacija.

European Wind Energy Association - EWEA announced at the June 2003 conference a revision of its wind power targets set in 1997. EWEA originally planned 40 000 MW installed by 2010 and 100 000 MW by 2020. New goals are 75 000 MW by 2010 and 180 000 MW by 2020.

Evropska asocijacija za energiju vetra (EWEA - European Wind Energy Association) je na junskoj konferenciji 2003. godine revidirala ciljeve u primeni energije vetra. 1997. EWEA je planirala da do 2010. godine u Evropi bude instalirano vetrogeneratora kapaciteta 40.000 MW, a do 2020. godine 100.000 MW. Novi planovi su da se do 2010. godine instalira 75.000 MW, a do 2020. godine 180.000 MW.

production in Serbia and Montenegro was 35 TWh yielding an average efficiency factor of 475 for all available capacities in the country.

By the end of 2003 Germany plans an offshore wind turbines installation of 20 000 MW total power in the North and Baltic seas.

The average efficiency of wind turbine installations is in the range of 20%-40%, depending on the wind stability, the ability of the utility grid to take in wind-generated electricity and other technical and meteorological factors. Objectively, this means that 1 MW capacity of modern wind turbines corresponds in energy quantitative sense to about 0.5 MW generated by hydro or thermal power plants. However, on average, availability of the wind is at its peak when the wind energy requirements are the highest. So in the qualitative sense, the energy of the wind should be rescaled by about 20% in comparison with the energy generated by thermal power plants, an important fact that should be taken into account when assessing the electrical energy price produced in the wind generators.

In spite of actions undertaken to increase efficiency and transfer capacities and revitalize production, Elektroprivreda Srbije (The Serbian Power Company Utility of Serbia) experiences energy shortage since 1997. The shortage in 2002 was around 5.5 TWh, which accounts for over 10% of the gross national production, which in 2002 amounted to almost 40 TWh. The problem of disparity in energy production was resolved by importing expensive electrical energy and by applying restrictive distribution measures. Assuming that the domestic wind energy resources exceed 3 GW, putting into use 2000 to 3000 1MW scale wind turbines may solve this problem. Further on, it will be shown that Serbia and Montenegro have wind energy potential in the range of 8 - 15 GW, which is much higher than the current disparity between the production and consumption needs. Considering the increase in energy demand based on the expected industrial growth an imperative demand for exploitation of wind resources. There has been a striking development on the northern European markets with installations in Germany of around 200 MW per annum in the early 1990's. Almost 50% of the European capacities are in Germany, where 1132 MW were installed by early 1996, while in June of 2003 around 15000 wind turbine units of 12 500 MW total power shared 5% of the complete production market in this country.

Models for assessing wind energy resources

No comprehensive evaluation of wind energy resources has been performed so far in Serbia and Montenegro. Based on the experience of other

Vizuelni efekat, buka, ometanje radio telekomunikacija i uticaj na ptice su relativno beznačajne negativne karakteristike vetrogeneratora i mogu se lako izbeći ili umanjiti.

Energetske potrebe Srbije i Crne Gore

Da bi se dao odgovor na pitanje o količini kvalitetnog vetra koji bi se mogao na ekonomski isplativ način konvertovati u električnu energiju, potrebno je, pored karakteristika vetra, voditi računa o: rezervama fosilnih goriva, ceni električne energije iz fosilnih goriva, očuvanju životne sredine, količinama naftnih derivata i gasa koje uvozi naša zemlja, trendu rasta i strukturi potrošnje energije i slično.

Ukupna raspoloživa snaga na pragu elektrana u elektroenergetskim sistemima Srbije i Crne Gore iznosi oko 9 GW, pri čemu 66,7% čine termoelektrane. Godišnja proizvodnja električne energije u SCG je u toku 2002. godine iznosila oko 35 TWh. Na osnovu ovih podataka se izračunava da je srednji faktor iskorišćenja proizvodnih kapaciteta u SCG 47%.

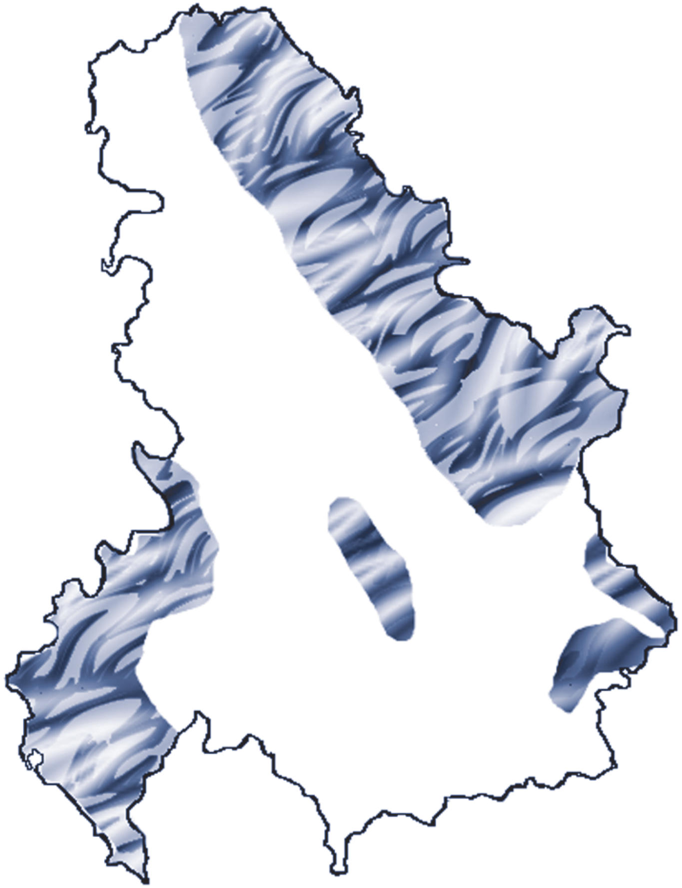
Prosečni faktor iskorišćenja kapaciteta vetrogeneratora je u opsegu 20% do 40%, zavisno od stabilnosti vetra, sposobnosti mreže da preuzme električnu energiju i od drugih meteoroloških i tehničkih parametara. Ovo znači da objektivno 1 MW proizvodnih kapaciteta u prosečnom vetrogeneratoru u kvantitativnom energetskom smislu odgovara oko 0,5 MW instalisanih u prosečnoj hidro ili termoelektrani. Međutim, energija koju proizvodi vetrogenerator je vršnog karaktera, jer vetra prosečno najviše ima onda kada je potrošnja najveća, što znači da kvalitativno energiju vetra treba valorizovati sa oko 20% u odnosu na energiju koju generišu termoelektrane što svakako treba imati u vidu pri formiranju cene električne energije proizvedene u vetrogeneratorima.

Nemačka planira da do 2030. godine u Severnom i Baltičkom moru instalira vetrogeneratore ukupne instalisane snage oko 20.000 MW Za ostvarivanje ovih planova biće potrebno oko 20 milijardi evra.

I pored preduzetih mera u pogledu povećanja energetske efikasnosti i revitalizacije proizvodnih i prenosnih kapaciteta u EPS-u se od 1997. god. permanentno javlja deficit u električnoj energiji. Taj deficit je u 2002. godini iznosio oko 5,5 TWh što čini preko 10% ukupne nacionalne potrošnje, koja je u 2002. iznosila skoro 40 TWh. Debalans u proizvodnji i potrošnji električne energije je u proteklom periodu rešavan uvozom skupe električne energije i restriktivnim merama u isporuci električne energije. Prevazilaženje elektoenergetske krize moglo bi se rešiti kupovinom i montažom 2000 do 3000 vetrogeneratorskih jedinica prosečne snage 1 MW, uz uslov da je naš tehnički iskoristiv vetropotencijal veći od

European countries it is useful to analyze currently installed capacities and wind resources in the European Union member states. Considering the ratio of installed capacities and the available land, Denmark holds the leading role in the European market, which currently has 3 GW of installed capacities contributing with 20% share of the total Danish energy production. Considering the fact that Germany and Denmark have ample experience in the wind energy field, as well as well documented projects for assessment of the wind energy potentials, it seems appropriate to draw conclusions and establish analogies between the wind resources of these two countries on one side and Serbia and Montenegro on the other.

Figure 11. Regions in Serbia and Montenegro with favorable wind speed conditions
Slika 11: Oblasti u Srbiji i Crnoj Gori pogodne za korišćenje energije vetra



The wind potential of Denmark is based on the main land and offshore wind resources. Besides the already installed wind energy capacities of 3 GW, the Danish government has approved construction of additional 4GW by the end of 2010, and long term plans (by the year 2020) include installation of 10 GW so that the share of the wind energy industry will amount to 50% of the total national energy market. Based on this information, and confirmed on the web pages of the Danish Energy Agency, the wind energy resources of Denmark are around 20 GW (= 20 000 MW), which is evenly distributed between the land and offshore

3 GW. U daljem tekstu biće pokazano da Srbija i Crna Gora imaju tehnički iskoristiv vetropotencijal u rasponu od 8 do 15 GW što je znatno više od našeg trenutnog deficita u električnoj energiji. Ako se uzme u obzir i rast potreba za električnom energijom srazmeran pretpostavljenom privrednom rastu, dolazi se do imperativnog zahteva za aktiviranjem vetro potencijala.

Model za procenu vetroenergetskog resursa

U Srbiji i Crnoj Gori nisu sprovedena opsežnija namenska merenja vetra u cilju određivanja globalnog vetropotencijala. Na osnovu modela koji se bazirao na iskustvenim podacima drugih zemalja korisno je analizirati trenutno stanje instalisanih kapaciteta i procenjenog vetropotencijala u zemljama Evropske Unije.

Oko 50% vetroenergetskih kapaciteta je koncentrisano u Nemačkoj, koja je početkom 1996. godine imala instalisano 1132 MW da bi u junu 2003. godine oko 15.000 vetrogeneratorskih jedinica ukupne instalisane snage od 12.500 MW učestvovalo sa oko 5% u ukupnoj proizvodnji električne energije u ovoj zemlji.

Vodeću ulogu u Evropi i svetu u pogledu odnosa izgrađenih vetrogeneratorskih postrojenja prema površini ima Danska (koja trenutno ima instalisano oko 3 GW u vetrogeneratorima koji učestvuju sa oko 20% u ukupnoj nacionalnoj proizvodnji električne energije).

Obzirom da Nemačka i Danska imaju najveće iskustvo u oblasti vetroenergetike, kao i verifikovane procene svog globalnog vetroenergetskog potencijala kroz značajna izgrađena vetroenergetska postrojenja, prirodno je pokušati uspostaviti određenu sličnost i analogiju između njihovih vetroenergetskih potencijala i potencijala SCG.

Vetropotencijal Danske je sadržan u kopnenim i morskim priobalnim vetrovima. Pored izgrađenih 3 GW u vetrogeneratorima, Vlada Danske je odobrila gradnju novih 4 GW do 2010. godine a dugoročni planovi (do 2020.) su izgradnja ukupno 10 GW koji bi proizvodili oko 50% nacionalnih potreba za električnom energijom. Na osnovu ovih planova koji se temelje na realnim vetroenergetskim resursima, može se zaključiti da su vetroenergetski resursi Danske oko 20 GW. Ovaj podatak je potvrđen i na internet sajtu minstarstva za energetiku Danske. Oni eksplicitno tvrde da je njihov tehnički iskoristiv vetroenergetski potencijal: P = 20 GW = 20.000 MW, od čega je oko 50% koncentrisano resources. This information has been further verified by means of sophisticated and reliable methods through direct measurements.

Analyzing the wind atlas of Serbia and Montenegro, a product of the Hydrometeorological institute of the former Yugoslavia, the wind potential is lower than the one in Denmark. However, considering the fact that the total land area is twice the size of Denmark, it may be assessed that the total wind energy potential is about the same as in Denmark.

On the other hand, the wind resources of the mainland Germany are around 64 000 MW, an information provided by the German Ministry of Economics. A parallel analysis of wind speeds in Germany and Serbia and Montenegro indicates that values of the annual average wind speeds for the two countries are almost the same. Assuming that the wind speeds in Serbia and Montenegro are 10% to 20% lower than in Germany, it may be inferred that the corresponding wind energy potential is 40% lower, which taking into account the area of available land, yields a value of 11 GW (= 11 000 MW). Hence, taking into consideration these comparative analyses, a value of 8 GW - 15 GW comes up as the global wind energy potential of Serbia and Montenegro. This means that if the wind turbines operate at efficiency level of 20%, the amount of produced electricity may be around 17 500 GWh/year (= 17.5 TWh/year).

The main technical difficulty of integrating wind energy installations in the main power utility system is contained in the very nature of the wind. Namely, as the wind is highly intermittent generation source, and has a low level of compatibility, the problems related to planning and regulation of the wind energy sector come up. Based on the preliminary studies, the wind energy sector may contribute to the total power industry with 20%, which could be increased by improving connections with the main distribution system and by installation of appropriate accumulation systems.

Existing power generating units offer favorable conditions for integration (embedding) of wind power facilities. Reversible hydro power plant Bajina Bašta enables accumulation of the wind-generated electricity. Also, stable operation of hydropower plants, mainly –erdap, may provide an efficient and stable power generation in case of large output fluctuations of wind-generated electricity. Hence, existing power generating structure of Serbia and Montenegro allows relatively easy integration of the wind power industry into the main energy system.

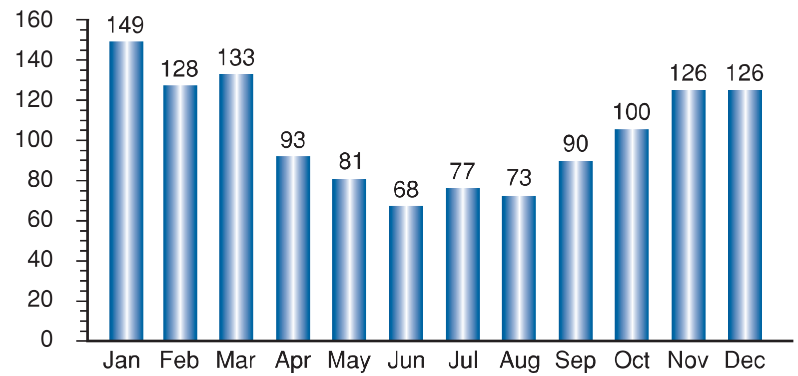
Embedding of wind power utilities into the main system would significantly reduce the

u morskim, a 50% u kopnenim vetrovima. Ovaj podatak može se uzeti kao pouzdan jer je rezultat dugogodišnjeg iskustva i opsežnih merenja koja su korigovana na osnovu praktičnih iskustava.

Analizirajući mapu vetrova SCG koju je formirao hidrometeorološki zavod bivše SFRJ vetrovi u SCG su slabiji nego u Danskoj tako da iako imamo skoro dvostuko veću površinu može se proceniti da je tehnički iskoristiv vetropotencijal na kopnu SCG oko: P = 20 GW = 20.000 MW. Ministarstvo za ekonomiju Nemačke je u studiji o vetroenergetskom potencijalu kopnenih vetrova u Nemačkoj iznelo podatak da je ukupni iskoristivi vetropotencijal kopnenih vetrova u Nemačkoj oko 64.000 MW instalisane snage vetrogeneratora.

Analizirajući vetrove Nemačke i SCG može se konstatovati da su intenziteti srednjih godišnjih brzina vetrova jako slični. Pod pretpostavkom da su brzine vetrova u SCG 10 do 20% manje nego u Nemačkoj, može se usvojiti da je vetroenergetski potencijal manji za 40% što uzimanjem u obzir i površine SCG dovodi do vrednosti od: P = 11 GW = 11.000 MW. Dakle, na osnovu uporednih analiza može se zaključiti da je globalni tehnički iskoristiv vetroenergetski potencijal u Srbiji i Crnoj Gori: P = [8 ÷15] GW = [8.000 ÷ 15.000] MW, odnosno, ako bi vetrogeneratori radili sa faktorom iskorišćenja od 20% mogli bi proizvesti električnu energiju od 17.500 GWh/god. ili 17,5 TWh/god.

Figure 12. Typical average wind speed variation (in % of average annual wind speed)
Slika 12: Tipična mesečna varijacija srednje brzine vetra (u procentima srednje godišnje brzine vetra)



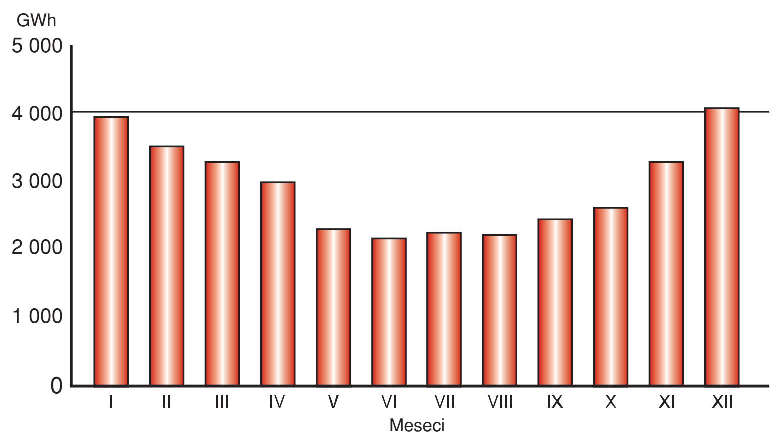
load on the transmission system, since wind power generation is situated closer to consumer loads. Moreover, transmission losses would be reduced. This provides a saving for the Power Company and consequently for its customers.
Since wind is highly intermittent power generation source, it is important to analyze correlations of annual wind speed fluctuations with consumer demands. Typical seasonal variations of the average wind speed and data of Elektroprivereda Srbije (Serbian Power Company) on annual power consumption are presented in Figures 12 and 13.

Areas potentially suitable for wind energy applications in Serbia and Montenegro

There are several locations convenient for wind energy applications:
1. Offshore locations in Montenegro in the 20 km long coastal region from Ulcinj to Herceg Novi covering an area of around 1000 km^2. The mean wind speeds in this area are above 7 m/s having power in the range 400 - 600 W/m^2. Projected installation capacities are from 1000 to 1500 MW. There are a number of high ridges and mountainous locations in this area where, at altitudes of 50m, the average wind power may exceed 1000 W/m^2.

2. The eastern parts of Serbia - Stara Planina, Vlasina, Ozren, Rtanj, Deli Jovan, Crni Vrh

Figure 13. Monthly power consumption at EPS in 2001
Slika 13: Mesečna potrošnja električne energije u EPSu 2001. godine



Osnovni tehnički problem integracije vetrogeneratora u elektroenergetski sistem je sadržan u samoj prirodi vetra. Vetar kao stohastički izvor ima mali stepen kompatibilnosti pa se javljaju problemi u planiranju i regulaciji elektroenergetskih sistema koji imaju veliko procentualno učešće vetrogeneratora u ukupnoj proizvodnji električne energije. Prema studijama koje su se bavile analizom maksimalnog učešća vetrogeneratora u ukupnoj proizvodnji prosečnog EPS-a , pokazalo se da je tehnički maksimum učešća vetrogeneratora u ukupnoj globalnoj proizvodnji električne energije oko 20%. Ovaj stepen participacije vetrogeneratora podrazumeva postojeće konfiguracije elektrenergetskih sistema. Pojačanjem interkonekcije i izgradnjom akumulacionih sistema ovaj procenat se može povećati.

Elektroenergetski sistemi SCG su strukturno povoljni za integraciju vetrogeneratora. Postojanje reverzibilne hidrolektrane Bajina Bašta omogućava preuzimanje viška električne energije u uslovima pojačanog vetra odnosno proizvodnje vetrogeneratora. Takođe, stabilni hidropotencijali (Đerdapske hidroelektrane) mogu da obezbede efikasnu regulacionu rezervu i time stabilan rad sistema i u uslovima velike varijacije u proizvodnji vetrogeneratora. Dakle, postojeća struktura električnog proizvodnog sistema u SCG omogućava uključenje vetrogeneratora u elektroenergetski sistem.

Što se tiče prenosnog sitema, on bi priključenjem vetrogeneratora bio u značajnoj meri rasterećen jer se vetrogeneratori priključuju po pravilu na distributivne sisteme. Osim rasterećenja bili bi smanjeni i gubici u prenosnoj mreži na račun decentralizacije proizvodnje. Obzirom da je vetar stohastički izvor, važno je analizirati u kojoj meri se poklapaju godišnje fluktuacije vetra i zahtevi potrošača za električnom energijom. Na slikama 12 i 13 je prikazana tipična sezonska varijacija srednje brzine vetra i tipičan dijagram potrošnje električne energije na godišnjem nivou EPS-a.

Analiza regiona u SCG pogodnih za izgradnju vetrogeneratora

U Srbiji i Crnoj Gori postoje potencijalno pogodne lokacije za izgradnju vetrogeneratora:
1. Crnogorsko primorje, odnosno pojas morske obale od Ulcinja do Herceg Novog u širini oko 20 km, odnosno površine od oko 1000 km^2. U ovoj oblasti vetrovi su srednje brzine veće od 7 m/s, snage 400 ÷ 600 W/m^2. Na ovom prostoru je moguće izgraditi vetrogeneratore kapaciteta od 1000 do 1500 MW. U ovom predelu postoji dosta lokacija sa visokim grebenima i brdima na kojim srednja snaga vetra na visini od 50 m može biti i preko 1000 W/m^2.

2. Istočni delovi Srbije - Stara Planina, Vlasina, Ozren, Rtanj, Deli Jovan, Crni Vrh itd. U ovim regionima postoje lokacije čija je srednja brzina vetra preko 6 m/s. Ova oblast pros-

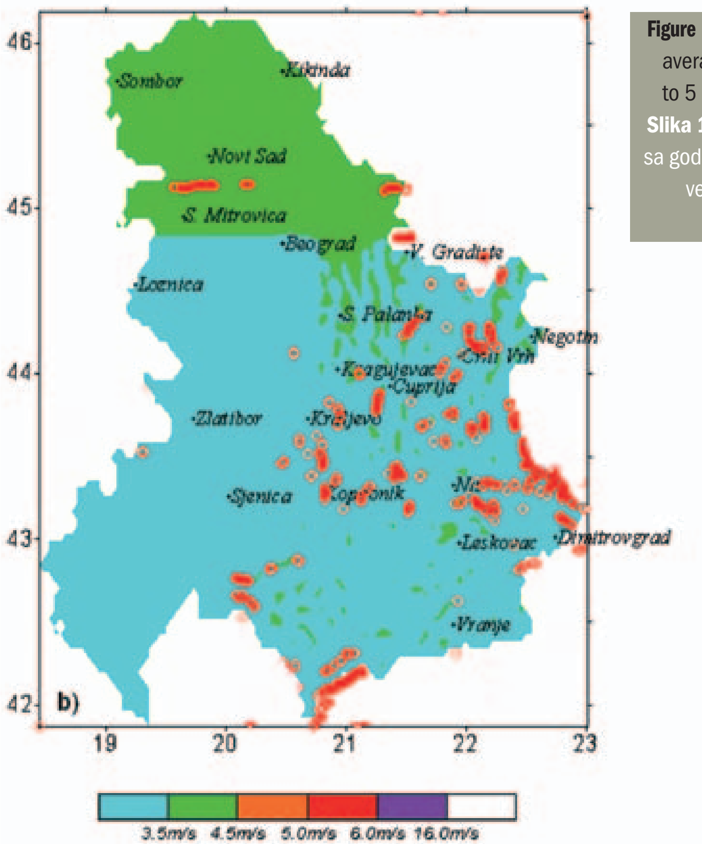


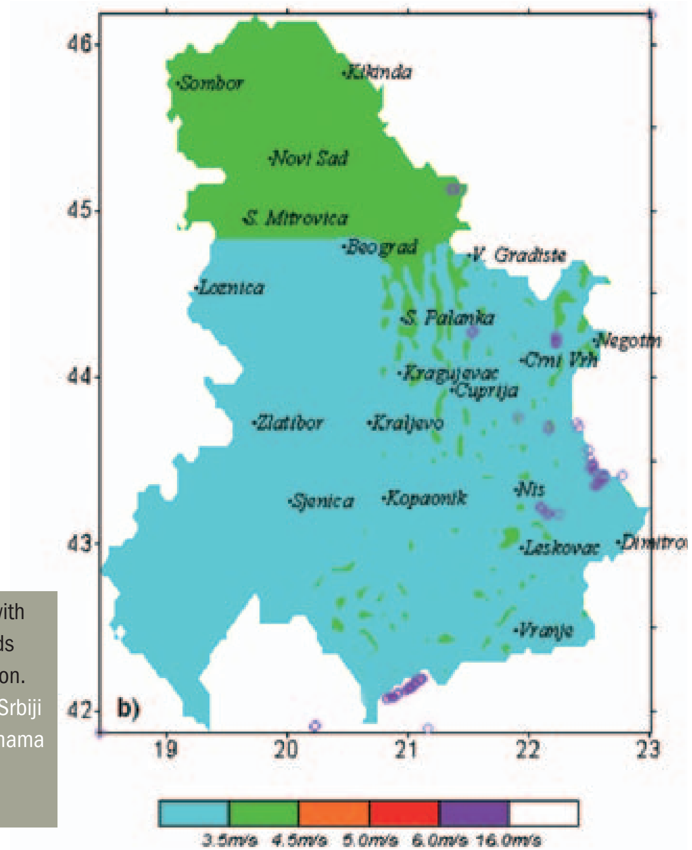
Figure 14. Serbian map with the average wind speeds of 4.5 to 5 m/s on 50m elevation.
Slika 14: Karta lokacija u Srbiji sa godišnjim srednjim brzinama vetra od 4,5 do 5 m/s na visini od 50 m.

etc. The average wind speed at some locations in this region is above 6m/s. This area covers approximately 2000 km^2 allowing 2000 MW of projected installed power.

3. Zlatibor, Žabljak, Bjelasica, Kopaonik, Divčibare are mountinous regions where further measurements of the wind speed variability are necessary to determine suitable locations for wind power facilities.

4. The area north of the Danube river, Panonia valley, also offers locations for exploitation of wind energy. The region extends on the area of 2000km^2 and offers favorable civil infrastructure: roads, utility grids, large consumer areas etc. The projected capacity for this region is around 2000 MW.

Figure 15. Serbian map with the average wind speeds of 6 m/s on 50m elevation.
Slika 15: Karta lokacija u Srbiji sa godišnjim srednjim brzinama vetra većim od 6 m/s na visini od 50 m.



torno pokriva oko 2000 km^2 i u njoj bi se perspektivno moglo izgraditi oko 2000 MW instalisane snage vetrogeneratora.

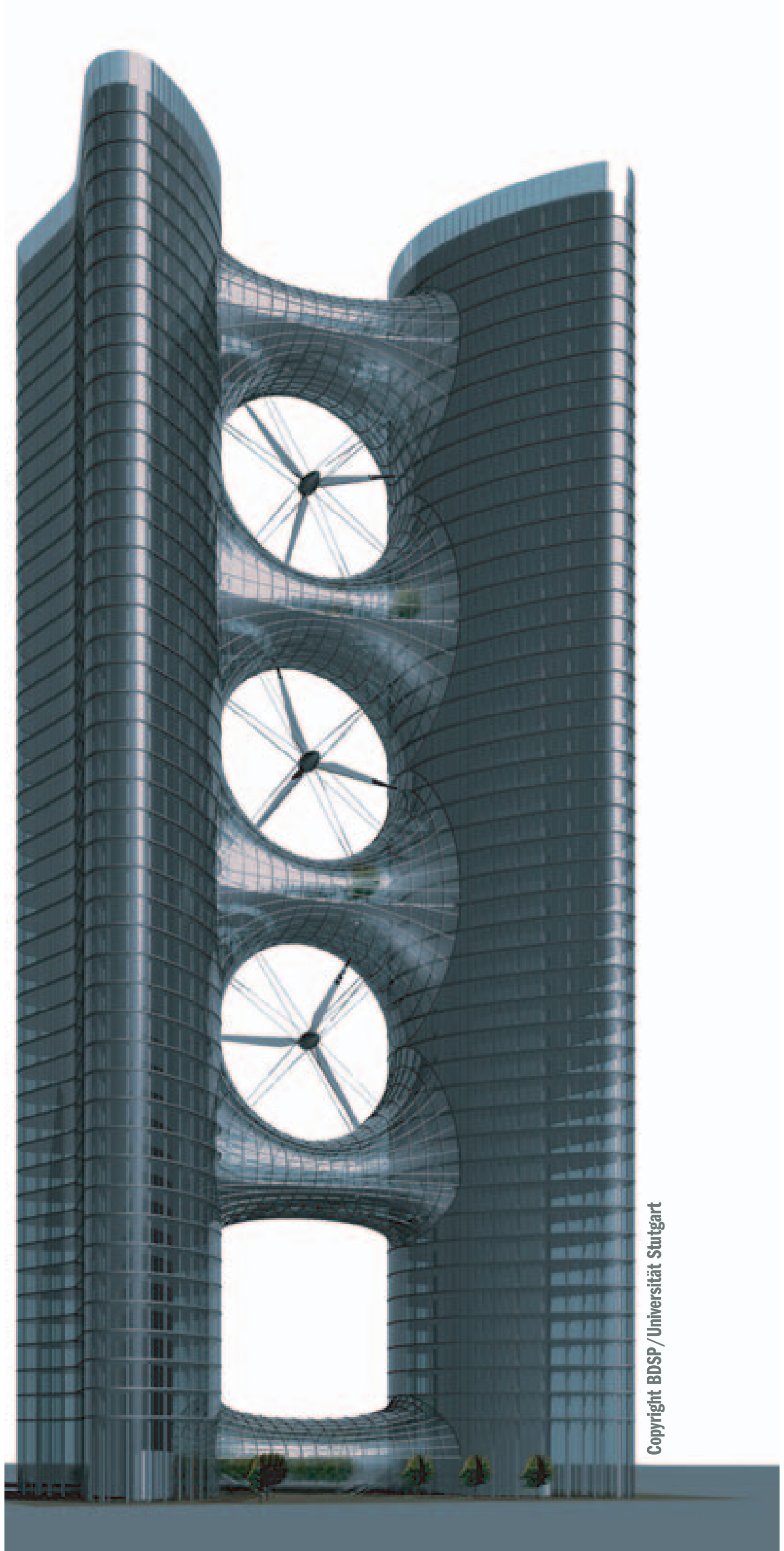
3. Zlatibor, Žabljak, Bjelasica, Kopaonik, Divčibare su planinske oblasti gde bi se merenjem mogle utvrditi pogodne mikrolokacije za izgradnju vetrogeneratora.

4. Panonska nizija, severno od Dunava je takođe bogata vetrom. Ova oblast pokriva oko 2000 km^2 i pogodna je za izgradnju vetrogeneratora jer je izgrađena putna infrastruktura, postoji električna mreža, blizina velikih centara potrošnje električne energije i slično. U perspektivi bi se u ovoj oblasti moglo instalirati oko 1500 do 2000 MW vetrogeneratorskih proizvodnih kapaciteta.

Conclusion

The last twenty years have witnessed a dynamic development of wind technology. During this time-span, it has evolved from an industry that makismaking small, simple and sometimes unreliable machines into a technology, which can compete with the well-established conventional forms of power generation. It has volume production of medium sized machines in the 600 kW range, while there are a number of designs in the megawatt range with commercial prospects. The increase in available rated capacity is striking and has seen a very rapid development since 1990. The arrival of the largest units is timely as the industry prepares for major offshore developments. There are no doubts that the widespread extent of wind power industry will place it as one of the most important renewable energy fields.

As far as Serbia and Montenegro are concerned, exploitation of renewable energy resources is a primary target, which requires cooperative action of energy experts, politicians and engineers. The fastest way to overcome the current shortage in electrical energy production is restrained energy consumption and construction of new facilities for exploitation of renewable energy resources.



Zaključak

U proizvodnji električne energije nijedan izvor energije nije imao tako dinamičnu ekspanziju u poslednjih dvadesetak godina. Savremeni verogeneratori dostižu snagu od 5 MW i više, a po ekonomičnosti su izjednačeni sa klasičnim izvorima energije. Konkurentnost im se značajno povećava pogotovo kada se u poređenja uvrsti uticaj na životnu okolinu. U narednom periodu može se očekivati da će energija vetra kao najznačajniji obnovljiv izvor zauzeti značajno mesto u ukupnom svetskom energetskom bilansu.

Za Srbiju je primena obnovljivih izova energije primarni cilj oko koga treba da se okupe stratezi energetskog razvoja, političari i stručnjaci. Pri sadašnjem konstantnom deficitu električne energije najbrži put u praćenju potrošnje energije je štednja i gradnja postrojenja za eksploataciju obnovljivih izvora energije.