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Some aspects of the growing penetration of wind energy in the Polish power system

***Abstract**. According to the Energy Policy of Poland by 2030 the national power system will have to acquire 12 times more electricity from wind energy than in 2011. This challenging policy goal entails a number of significant consequences. The article presents global and Polish state of the art in the field of growing penetration of wind energy in the power system. Furthermore, it discusses selected technical, economic, social, legal and regulatory aspects of wind energy integration in the Polish power system. The aim of this article is to present that wind power deserves a broad and in-depth considerations before any binding political decision are taken to meet Poland's EU 2020 obligations. It also calls for reviewing the criteria used for valuing the real costs of wind power option in Poland.*

***Streszczenie.** Według Polityki Energetycznej Polski do 2030 roku Krajowy System Elektroenergetyczny będzie pozyskiwał 12-stokrotnie więcej energii z wiatru niż w 2011 roku. Artykuł prezentuje przegląd wybranych informacji na temat światowego i polskiego dorobku nauki i techniki w zakresie rosnącej penetracji energii wiatrowej w systemie elektroenergetycznym. Przedstawione zostały wybrane aspekty techniczne, ekonomiczne, społeczne, prawne i regulacyjne związane z integracją energii elektrycznej z wiatru w polskim systemie elektroenergetycznym. Celem artykułu jest pokazanie, że energetyka wiatrowa zasługuje na szeroką i dogłębną analizę, która powinna odbyć się przed podjęciem wiążących decyzji politycznych w celu osiągnięcia przez Polskę celów 2020 UE. Wezwano również do dokonania przeglądu kryteriów stosowanych do oceny rzeczywistych kosztów opcji rozwoju energetyki wiatrowej w Polsce. (**Wzrost udziału energii wiatrowej w polskim systemie energetycznym**)*

Keywords: wind energy, Polish power system, renewable energy sources
Słowa kluczowe: energia wiatrowa, polski system elektroenergetyczny, odnawialne źródła energii

Introduction

The increasing penetration of wind energy in the power system is associated with a number of technical, economic, social, legal and regulatory issues, having different impact on the functioning of the power system, both in negative and positive ways.

In Germany the wind power installed currently exceeds 31 GW, accounting for over 16% of the capacity installed in the power system [1]. The development of energy storage technologies and the expansion of the power grid is dynamic. The country is the undisputed leader in Europe in terms of installed capacity of wind power plants. In 2012, Poland's neighbour was the third producer of wind energy in the world (behind China and the USA). Berlin plans to increase the installed capacity of wind power plants from 27 676 MW in 2010 to 45 750 MW in 2020 (an increase of 65%) [2]. It can be expected that in the light of the decision of the nuclear power decommissioning, the share of wind power in the overall capacity installed in Germany will be increasing. In 2050 German government aims to acquire 80% of electricity from renewables [3].

Wind farms in Denmark provide about 25% of power to the power system. Plans of the transmission system operator (TSO) assume, however, an increase of the wind power penetration to 50% [4]. Danish TSO estimates that in the near future, wind generation will exceed the total demand for energy in the system over 1000 hours per year.

In 2012 Spain was the fourth largest producer of electricity from wind energy in the world [5]. At the end of 2010 the penetration of wind power capacity was 20% [6]. In terms of the amount of energy wind power accounted for 15.9% of total electricity generation [7]. On 9 November 2010, 43% of total daily energy needs were met by the wind. This involved the use of 75% of the wind farms' power – 20 676 MW [2, 8].

The aim of this article is to present that wind power deserves a broad and in-depth considerations before any decisive political decision are taken to meet Poland's EU 2020 obligations. It also calls for reviewing the criteria used for valuing the real costs of wind power option in Poland.

General characteristics of wind power in Poland

As shown in fig. 1, the wind power pentration in the Polish National Power System (NPS) has been dramatically growing in the recent years. Despite the still relatively low penetration of wind power generation in the NPS, which in December 2012 amounted to 6.7%[1], wind energy development is often seen as a threat to power quality and system stability. Some papers stress the need for unnecessary investments and incurring additional costs of conventional power to allow the balance of the system [9].

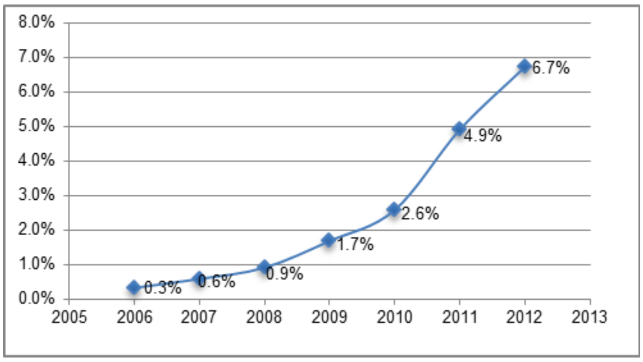

Fig. 1. Wind power penetration in the Polish National Power System

In spite of diverging opinions of Polish political, social and academic leaders on the importance of wind energy in the future energy mix, the perspectives of development of Polish power system will be unarguably determined by the growing penetration of wind energy. According to [10] high wind power penetration rate will be possible only in two cases: when there will be excess transmission capacity of electricity to neighboring power systems, or large scale energy storage will be possible (for instance, in pumped-storage hydroelectricity). It appears that in the case of Poland, only the first condition may be satisfied, since the total maximum power of cross-border synchronous connections of the Polish system with the neighboring countries is over 30% of total peak power [12]. It is becoming increasingly difficult to site new conventional overhead transmission lines, particularly in urban and suburban areas experiencing the greatest load growth.

[1] According to [11] as at 11th December 2012 the total installed capacity in the NPS was 37 669.8 MW, while the installed capacity of wind power was 2 534.2 MW.

Therefore the technical barrier to the development of cross-border trade in electricity generated from wind may be primarily internal network limitations of Polish system, not limitations of cross-border power connections.

In 2010 1 311 GWh of electricity in Poland were produced from wind, and in 2011 it was already more than 2 833 GWh that means an increase of over 116%. The share of wind energy in electricity production increased from 0.84% to 1.74%. As shown in tab. 1, the installed capacity of wind power (696 installations) as at 31.12.2012 amounted to 2 496.7 MW [13].

Table 1. The installed capacity of wind power in the Polish voivodships as at 31.12.2012

Voivodship	Number of installations	Power [MW]	Percentage of wind power installed in Poland
zachodnio-pomorskie	43	726.4	29.1%
kujawsko-pomorskie	210	281.9	11.3%
pomorskie	28	272.0	10.9%
wielkopolskie	94	259.3	10.4%
łódzkie	151	247.9	9.9%
warmińsko-mazurskie	22	201.5	8.1%
podlaskie	20	120.9	4.8%
mazowieckie	48	119.0	4.8%
opolskie	5	84.1	3.4%
dolnośląskie	6	62.3	2.5%
podkarpackie	22	55.6	2.2%
lubuskie	6	50.6	2.0%
śląskie	13	5.7	0.2%
świętokrzyskie	12	4.4	0.2%
małopolskie	11	3.0	0.1%
lubelskie	5	2.1	0.1%
TOTAL	696	2496.7	100.0%

Source: own calculations based on [14]

Wind power is concentrated in the north of Poland. Almost one third of installed capacity of wind turbines is located in Western Pomerania (zachodniopomorskie voivodship). More than 50% of power is concentrated in three regions, namely in zachodniopomorskie, kujawsko-pomorskie and pomorskie voivodships. As far as the total installed capacity in the power system in each voivodship of Poland is concerned, the penetration of wind power capacity in the northern part of Poland (19%) exceeds the level of penetration of wind energy in the power system of Germany (16% in 2010).

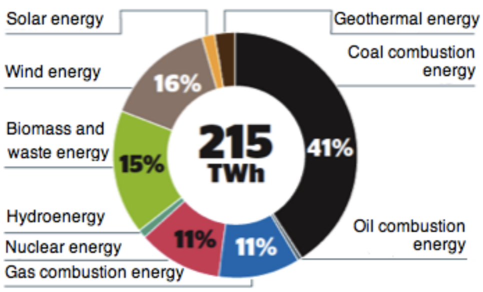

Fig. 2. Electricity production in Poland in 2030, broken down by technology of obtaining energy [15]

According to the register of promissory concessions issued by the Polish Energy Regulatory Office valid as at 31 December 2011 wind power investors are going to install 169 wind farms, whose power amounts to 3 570.679 MW. Wind power promissory concessions correspond to 98.5% of the planned capacity in all RES installations [13]. The implementation of all promissory concessions issued would mean an increase in the installed capacity of wind power up to 5 912 MW – an increase of over 150%. The penetration of wind power in the NPS would then increase to 13.6%.

As shown by the forecasts of the International Energy Agency in fig. 2, in 2030 approximately 16% of electricity in Poland will be acquired from wind. This would correspond to 34.4 TWh of energy. The Polish power system will acquire 12 times more energy from wind than in 2011 [16]. This will inevitably entail a significant increase of wind penetration in the Polish power system.

Costs due to growing share of wind power may be incurred as follows:

1. To keep additional generation capacity in readiness (to meet demand if wind is unavailable);
2. To obtain additional flexibility from generators or demands to maintain energy balance.

Technical issues of the growing penetration of wind energy in the Polish power system

The relationship between the development of wind power and power quality in Poland is considered predominantly in terms of volatility and losses of power, voltage fluctuations as well as flicker and harmonics. Changes of parameters of transmission and distribution systems due to the large number of wind turbines in the northern part of Germany are becoming another challenge for maintaining stability of operation of the Polish power system. The general overview of the impact of technical issues of the growing penetration of wind energy in the Polish power system is given in tab. 2.

Table 2. Impact of technical issues of the growing penetration of wind energy in the Polish NPS on local power system and economy
Source: own elaboration

Technical issues of predominantly macroscopic character	Issues of predominantly microscopic character (impact of wind power on local power system and economy)
Under-developed power system	Higher energy losses Need for investments in centralised traditional technologies Limited power connections available Untapped potential of grid control (U, f) High cost of connection Slower competitive energy market creation
Insufficient capacity of interconnectors	Higher domestic demand for back-up power Lost benefits of international energy trading
Loop flows	Need for reactive power compensation and voltage control Additional power losses Distorted energy market accounting
Delayed Smart Grid development	Poorer active load management Lower reliability and power quality Slower build-up of distributed sources sector Higher risk of outages Slower development of prosument market segment Lower environmental benefits

Changes of the active and following changes of the rective power of wind turbines result from the variations in the speed of wind. Changes in both types of power necessitate back-up power of conventional energy sources, which is the basic argument of opponents of wind as a significant source of energy in the Polish power system, who indicate that wind is uncertain and unpredictable [9].

Recent papers stress the growing predictability of wind power. For instance, [17] finds that during periods of peak demand for electricity in the UK in 2009, conventional power plants have used 85% of their power, while wind turbines used 35% of their capacity. This implies that wind farms can and do play a crucial role in ensuring the continuity of energy supply. [17] stresses that wind is less variable than what is commonly believed. By 90% of the analysed time hourly fluctuations of wind power in Germany, Denmark and Finland do not exceed 5% [18]. Hourly volatility of wind power, depending on the area of wind power dispersion is presented in tab. 3. Up to date volatility of wind power across Poland has not been thoroughly analysed.

Table 3. Hourly volatility of wind power depending on the size of the area on which wind turbines are dispersed

Area surface	Example	Hourly volatility of wind power generation
Small (<50 000 km^2)	Denmark	±30%
Medium (ca. 300 000 km^2)	Poland	±20%
Large (>1 000 000 km^2)	Scandinavia	±10%

Source: own elaboration based on [19]

Supporters of wind energy show that improving forecasting techniques can effectively solve the problem of volatility of wind power. Forecasting is applicable only in case of a short time horizon and does not solve the problem of unavailability of wind power in completely windless periods (energy production based on less than 1% of installed capacity). According to [20] in the 21-year history of wind measurements in England and Wales, the longest windless period of time lasted 11 hours. On the other hand in 2002 in Denmark the wind did not blow for 58 hours [21]. However, in 2000-2002 there was no time when the wind would not allow for power generation in any of the Scandinavian countries. The obvious solution to the problem of wind power changes is to diversify energy sources. In general the harnessing of wind power in the Polish power system is desirable since it may be an important source of renewable energy [22].

One of the main arguments of opponents of increasing wind power penetration in the Polish power system is the need for necessary back-up power in other sources of energy, which would guarantee the stability of the power system. So far, there has been no comprehensive study, which would clearly describe the relationship between the amount of wind power and the size of the necessary reserve capacity in other sources of energy. There are, however, analyses of foreign power systems. Certain authors, such as [23] believe that a gas turbine with a capacity of 100 MW is able to stabilise operation of 500 – 1000 MW of wind power. On the other hand, according to [24] the inclusion of 1 MW of wind power capacity should entail an increase of 0 to 0.00333 MW of additional spinning reserve, and an increase of 0 to 0.0233 MW of additional non-spinning reserve.

According to [25] the amount of reserve capacity needed for wind energy is determined predominantly by the characteristics of the power system, including the size of the system and the correlation between wind power production and peak power demand. Required reserves of non-wind power as a back up for wind farms for Poland nowadays can be estimated for 1-15% of the wind power installed. Comparison of data from various sources on the required back-up wind power is presented in table 4.

Table 4. Necessary conventional back-up power for wind power according to different sources

Wind power penetration	Necessary back-up power	Source
Any	3%	[24]
Any	10-20%	[23]
10%	1-15%	[25]
20%	2-18%	[25]

Source: own elaboration

It is important to note that the active power losses in the Polish power system may be minimised by the connection of wind power. Such a case is possible when the wind farm would generate reactive power equal to the power consumed in a given node. However, the possibilities of capacitive reactive power generation in wind turbines are limited. Wind power plants with squirrel cage induction machines are usually receivers of inductive power, and in wind power plants with Doubly Fed Induction Generator (DFIG) reactive power is usually maintained at the level close to zero. It is worth noting, however, that in view of the great regulatory potential of DFIG, wind power plants are able to contribute to minimisation of the power losses in the Polish power system [22].

Another technical issue concerning the growing wind power penetration in the Polish power system refers to voltage fluctuations. They concern, however, single wind power plants or wind farms rather than the whole power system. Rapid voltage changes are mainly caused by switching on or off of wind turbines [22]. The highest voltage fluctuations occur during switching off a wind turbine operating at full load. Voltage changes occur also as a result of slow changes in the power generated by generators. Adjusting taps in transformers in the main power supply station, to which wind turbines are connected, can compensate them. However, this occurs after a delay of a few to several minutes. What is more, voltage fluctuations may be caused by the variation of reactive power consumed by asynchronous generators, which are currently the most common type of wind generator used in wind power plants. In the event of voltage fluctuations caused by changes in reactive power compensation FACTS technologies (e.g. SVC / STATCOM) can be used. It is of paramount importance to stress that properly selected and installed protective relaying for electrical power engineering in the immediate vicinity of wind farms guarantee a quick and effective elimination of abrupt voltage interruptions.

During continuous operation of wind power plants rapidly changing wind power resulting from wind shadow effect on tower and turbine structural properties can cause voltage flicker [26]. However, it has been proved that voltage flicker accompanying wind turbines operation does not cause damage to receivers [10]. Still, in the case of weak power grids, large voltage fluctuations can be a significant inconvenience for electricity receivers. Voltage flicker can be then limited through the use of speed control systems of wind power generators.

Currents and voltages generated by wind turbines can be non-sinusoidal. Their non-sinusoidal waveforms can be decomposed into higher harmonics, which are components at frequencies that are multiples of the grid frequency. In the case where the power of a device retrieving a distorted current is large, distortion in the grid voltage may occur. Each connected receiver will be then powered by a distorted (non-sinusoidal) voltage. Many devices cannot function correctly under these conditions and even may be damaged or destroyed. However, the higher harmonics are not a major problem for wind turbines in Poland [27]. Modern electronics systems installed in virtually any type of wind turbines with high power (over 1 MW), do not generate higher harmonics that would exceed the threshold limit values.

Connecting wind farms to the grid results in significant changes in load current flow in the grid adjacent to the wind farm. [28] considers changes in load current flow as the most serious and most difficult barrier to installation of new wind power connections in Poland due to difficulties in planning and implementation of network investments and extensive nature of the changes, which often apply to neighbouring grids' operators. The second type of network limitations in Polish NPS are short-circuit power levels in selected nodes. The problem can concern not only exceeding the limit values of short-circuit power. If the short-circuit power level is too low, it makes the system more sensitive to disturbances and sudden changes of energy generated. Additional problems are connected with accuracy of calculation models in the mapping of wind generation sources.

The problem of international dimension for Polish NPS are loop flows from German wind farms. Such unscheduled flows of electricity may occur as a result of the increasing penetration of wind power causing serious limitations of cross-border electricity trade, electricity imports from Germany in particular, as well as safety of Polish power system. Loop flows are caused by the inconsistency between market mechanisms for cross-border trade and laws of physics. In the region of Central and Eastern Europe unscheduled flows are caused mainly by the exchange between the north and the south of Germany, and to a large extent by the uncoordinated exchange a within the single market for electricity between Germany and Austria. As shown in fig. 3, by 2015, these flows are expected to increase (blue figures).

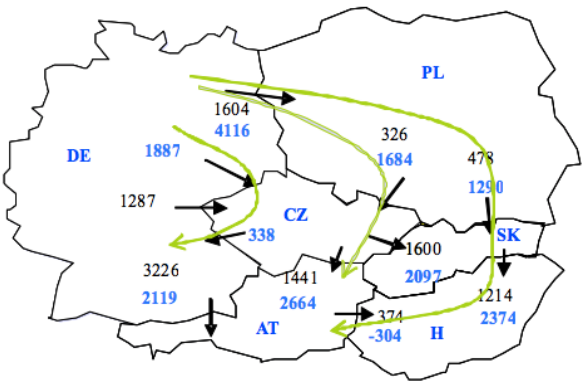

Fig. 3. The results of load flow power flows caused by increased penetration of wind power for 2015 (EWIS project) [29]

Reducing the possibility of loop flows from Germany can be reached by several technical measures:
• installation of phase shifters, i.e. transformers, which allow for voltage phase lag or lead of one circuit over the other,
• implementation of Flow Based Allocation methods of cross-border transmission capacity in the region,
• development of grid infrastructure and investment in generation capacity,
• changes in the mechanism of compensations between TSOs,
• implementation of the grid code in scope of allocation of transmission capacity and congestion management [30].

The growing penetration of wind power in Poland may increase the scale of the negative impact of wind farms on the power system, but also creates new opportunities for transmission and distribution system operators for the provision of services that used to be considered an exclusive domain of conventional power plants.

It is expected that active power control of wind farms, which is not exploited nowadays in Poland, in the near future not only will be necessary, but just as natural as the control of conventional power plants involved in the regulation of frequency and cross-border power trading by working with power below the power attainable [22]. Opportunities for provision of system services by wind power will increase with the development of new energy storage technologies. New system services offered by wind power plants will include aggregating a number of wind farms, which should allow for:
• control of active power to provide secondary frequency regulation services. This may result in a lower required back-up power reserve.
• adjustment of reactive power in order to stabilise grid voltage within a selected zone operated by the TSO. This should help to reduce grid power losses [31].

What is worth noting, introduction of the aforementioned system services can be applied not only to new wind turbines, but also those already existing. For instance, virtual power plant may be established, allowing for provision of services similar to those provided by conventional power plants, but on the basis of decentralized energy sources.

Economic and social issues of the growing penetration of wind energy in Polish power system

By 2020 the biggest Polish energy companies will spend approximately 12.6 billion zloty on wind power (approximately 3 billion euro) [32]. Their strategies involve investments in on-shore wind turbines with a total capacity of about 2 000 MW. Polish Energy Group (PGE) plans to build stand-alone wind farms with a capacity of 500 MW, and the same amount will be bought from wind farm developers. Tauron is going to achieve a total power of 800 MW of wind power by 2020. Enea plans to purchase wind power projects with a capacity of 300-350 MW. Energa will seek to increase wind power by 40 MW.

By 2020 a total of 11 500 MW of new wind generation capacity will be installed in Poland, of which about 1 500 MW will be offshore wind farms [33]. The total amount of funds that will be spent by public and private investors is estimated to exceed 22 billion zł (approximately 5.2 billion euro). The scale of investments can be illustrated by a comparison with the average annual investment in the production of machinery and equipment in Poland between 2009 and 2010, which amounted to 1.5 billion zł (0.35 billion euro) [33].

As seen investments needs of wind energy are rather well estimated. However, this accounting does not necessarily reflect other possible benefits due to increase wind power penetration. Such elements as capability of a new wind plant to increase reliability of the power system, to decrease the need of grid investments, to reduce grid losses, decrease of the operating costs in the existing power system or to flexibly follow demand are poorly measured in economic terms.

Economic risk is considered as one of the main investment barriers. It is mainly due to unstable short-term public support schemes - that is at present the case observed in Poland caused by political rumours around green certificate. On the other hand the increase in installed capacity of wind power is accompanied by rapid development of forecasting techniques of wind power variability, which allow for more effective risk management of both wind farm managers, as well as transmission and distribution system operators. Increasing predictability and ubiquity of wind turbines making use of decentralized energy resources is proving around the world that renewable energy technologies are becoming more and more economically viable.

Considering economic values of wind power, alike other renewable technologies, this sector must find its market position among other energy options in Poland considered as perspective e.g. nuclear energy, LNG, shall gas. In medium-term perspective that position shall be entirely market based e.g. deprived of any public support.

Citizen's support to different technologies is also of concern especially amid the climate change discussions and facing even more stringent CO_2 emission EC policy. Wind energy is the most popular renewable energy source in the Polish society, as indicated by 85,46% of respondents in a nation-wide survey [34]. Wind energy is much more preferred than for instance nuclear power. 72% of Poles surveyed believe that wind power has no detrimental impact on human health. 82% of respondents claim wind power development contributes to Polish technology development.

Legal and regulatory issues of the growing penetration of wind energy in Polish power system

Current legal framework for wind power investments is of general character. Each investment is subject to separate environmental impact assessment run at regional level. Proposals of some members of the Parliament aimed at introduction of a rule of 3 km distance from wind power plants to human habitats regardless of wind power capacity or rotor size have not been widely recognised.

In 2014 a new law on renewable energy is planned to be adapted in Poland, changing the rules of public support for wind power investment. It is expected that more stress will be put on small scale RES investments (including micro-wind turbines) rather than large scale ones, which have been most used up to date, especially by large Polish power companies.

Regulations of the power system in Poland in the Transmission Grid Code do not fully use regulatory opportunities that are offered by wind turbines. For example, island operation of generating units is possible only on the island of devices of the wind plant's owner, provided that it has been ascertained in the contract with the grid operator. However, operation of wind turbines on an island is possible in case of modification of control systems already installed. Furthermore, Polish grid codes do not engage wind farms in the process of possible restitution of power system after blackout.

Some other factors influencing absorption of renewable energy that require intervention from the energy regulator are presented in table 5.

As far as short circuit operation is concerned, regulations of Polish grid codes are similar to the ones in other EU member states (e.g. Spain). However, because of the relatively small number of wind turbines such regulations do not yet have practical application [36]. Regulation of active and reactive power of wind turbines presumed in Polish transmission and distribution grid codes is limited to the right of the operator to cut off the wind farm in case of emergency. It is expected that Polish system regulations will be subject to significant changes with increasing penetration of wind energy in the National Power System.

Regulation faces in Poland an urgent need to take the lead in proposing dynamic pricing and setting standards for Smart Grid communication and cybersecurity that directly pertains to wind power as well.

Table 5. Factors influencing absorption of renewable energy

Impact	Threshold	Mitigation options
Change in renewable generation output	Generation subject to fluctuation>20% of peak demand	Purchase additional controllable output
Unpredictable instantaneous reduction in generation output	Potential instantaneous loss >2% of peak demand	Purchase additional frequency control
Unpredictable short-notice reduction in output	Potential loss >3% of peak demand in an hour	Purchase additional reserve services

Source: [35]

Conclusions

Wind power is one of the most realistic options that shall be seriously considered in Poland's energy strategy up to 2050.

Up to know the country-wide discussion on this theme has been dominated by technical aspects not always fairly presented to the citizens. The other prevailing issue raised has been for years the system of public support for renewables. In this respect major mistakes have been made e.g. support to co-firing or large hydro that are desperately tried to be rectified nowadays.

Public assessment of renewables, including wind power, is not fair and true, as being for years under strong impact of different lobbies and generally lacking profound analysis.

The technical problems, *inter alia* those addressed in this paper, due to steadily increasing wind power installed in the Polish NPS are rather typical and similar to those encountered and then more or less successfully overcome in wind power leading countries.

They should not be raised as a barrier against further wind power development unless they are thoroughly investigated and analysed.

The real problems of the wind power are not technical, but, no doubt, of economic nature. Therefore to come to the right technically feasible and cost effective solutions affecting Poland for tens of years requires immediate undertaking serious research on wind power in the broad context on the EC and national climate-energy policy. Such criteria as energy costs in the long-term period, up to 2050, creation of new jobs, environmental concerns, innovation boost in industry, creation of competitive energy market should also be taken into account apart from the arguments persistently put forward by the energy sector.

It is fairly clear that difficulty and urgency of taking crucial decisions now are at least partly due to lack of consistent policy in the past, dating from late 1990'. The issue of re-valuing wind power is of primary importance as the political decisions taken shall then be supported by proper allocation of national development priorities in order to ensure effective use of the EU funds envisaged for 2014-2020.

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