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The small hydroelectric power stations as an element of the multifunctional development of rural areas

Abstract. Poland's accession to the EU has caused a necessity of harmonising Polish with the union law also in the field of energy law. It also enforces achievement of 7,5% share of energy from alternative sources in the total energy consumption in 2010. Execution of this international commitment will require more economic and legal support from the state. The development of alternative sources of energy creates chances of development of rural areas where these kinds of installations are being mostly located. This article presents an analysis of the economic efficiency of energy production on an example of 5 small hydroelectric power stations. The analysis is based on a comparison of full unit costs and unit revenue from energy sale. Bigger stations proved economically efficient while for the smaller the break even point is associated with an average water flow of 153 million m^3/year.
Key words: alternative source of energy, economic efficiency, electric power, small hydroelectric power stations

Renewable energy market

One of the most essential aims of the Polish energy policy is to assure the reliability of fuel and energy deliveries, the increase of economic competitiveness as well as the reduction of a negative influence of the energy sector on the environment. The problem can be solved, among others, through increasing the renewable energy resources exploitation that will contribute to the reduction of national dependence on the imported energy carriers and also result in a reduction of harmful gas and dust emissions to the atmosphere [Obwieszczenie Ministra Gospodarki… 2006].

The rapid growth of exploitation of renewable energy resources, noticeable in Europe and the United States since the end of eighties in the last century, results from their utility for the local communities as well as for the national economy, which yields them significant benefits. To the most important benefits belong, among others, an increase of the level of energy security, creation of new workplaces and promotion of regional development, a decrease in emissions of greenhouse gases, especially sulphur (SO_x) and nitrogen (NO_x) oxides. The positive effects of the energy production from renewable sources, which include small hydroelectric power stations, apply mainly to rural areas, where these kinds of installations are being mostly located. One of the reasons why the Fundacja Wspomagania Wsi (Rural Development Foundation) worked out Program Odbudowy Małej Retencji (Programme for Reconstruction of Small

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Retention) was the positive influence of the small hydroelectric power stations on the water regime in rural areas. Investors (private entrepreneurs, companies or communes) within the framework of this programme could apply for funds to be spent on reconstruction of damaged mills and hydroelectric power stations. The value of a preferential loan could reach even 50% worth of the capital expenditure [Fundacja… 2007].

In Polish conditions the renewable energy sources play a crucial role in the energy balance in the area of some communes or even of some provinces. They can also contribute to an increase of the level of energy safety and, especially, to an improvement in the energy supply in the areas of a underdeveloped energy infrastructure. Agriculture could be probably the biggest consumer of electricity from renewable sources and then also housing and the public transport. Using these resources, especially in areas afflicted with unemployment, gives a chance of creation of new workplaces. Besides, boggy rural areas or the ones with strongly polluted soils which are not fit for cultivation of edible plants, can be designated for founding plantations of energetical plants.

A chance for the renewable energy development is provided by the European Parliament and Council directive of the 27th of September 2001 on promotion of electric energy from renewable sources in internal market [Directive… 2001]. This directive determines for the UE-15 countries a quantity aim of a 21 % share of the gross energy produced from renewable sources in the total energy consumption in 2010. The quantitative aim for Poland, defined in the Accession Treaty, is 7.5%. For realization this purpose production of energy from alternative carriers should grow till attainment of level defined in Directive in 2010 (table 1).

Table 1. Amounts and shares of energy from alternative sources in the total energy consumption in years 2005-2014

Year	Consumption of energy from alternative sources	
	[TWh]	[%]
2005	3,12	2,2
2006	3,72	2,6
2007	4,61	3,2
2008	5,80	4,0
2009	7,74	5,5
2010	11,10	7,5
2011	11,18	7,5
2012	11,33	7,5
2013	11,48	7,5
2014	11,63	7,5

Source: [Obwieszczenie Ministra Gospodarki i Pracy… 2005]

According to the guidelines set forth in the Polish energy policy for years up to 2025 the aim defined in the directive is to be realized especially on the basis of technologies that use the biomass (energetical plants, firewood, wood production and agricultural waste as well as biogas), water and wind. It is confirmed by the data juxtaposed in table 2 which show power

installed by particular technologies using alternative sources of energy in years 2002 through 2004.

Despite the new investments in the field of renewable energy leading to a growth of the installed power (from 2002 to 2004 this growth totaled 104.5 MW, i.e. 11.5%), the share of electric energy from renewable sources is lower than assumed. This is partly caused by the rapidly growing gross electricity consumption (from 138 810 GWh in 2001 to 144 831 GWh in 2004, i.e. 4.3% [Obwieszczenie Ministra Gospodarki… 2006]). Therefore the fulfilment of the international commitment will require more economic and legal support from the state.

Table 2. Power installed in power stations producing electric energy from renewable sources in Poland, MW

Installed power by source	Year		
	2002	2003	2004
Biogas (total)	15.0	18.0	22.0
agricultural biogas	n. a	1.0	2.0
landfill gas	15.0	15.0	17.0
sewage gas	n. a	2.0	3.0
Biomass (total)	1.1	16.6	51.9
industrial power stations and thermal-electric power stations	n. a.	15.5	50.5
other power stations	1.1	1.1	1.4
Hydroelectric power station (total)	840.0	873.0	881.0
installed power ≥ 10 MW	630.0	637.0	638.0
installed power <10 MW	210.0	236.0	243.0
Wind power stations	59.0	60.0	65.0
Total	915.1	967.0	1019.6

n. a. – data not available
Source: [Obwieszczenie Ministra Gospodarki … 2006]

The basic act regulating energy market in Poland is the act from 10th April 1997 Prawo energetyczne (Energy Law) [Obwieszczenie Marszałka… 2003]. It includes, among others, provisions for promoting and supporting production of electricity from renewable and associated energy sources. This promotion is specific because it statutorily obliges the energy suppliers to purchase every offered to them amount of electricity derived from renewable sources and at the same time to purchase or to produce themselves from renewable sources at least a certain percentage of the total offer in consecutive years instead of introducing a system of granting by the state allowances and other incentives. The essential step taken with an object of supporting development of renewable sources was the introduction, with the act of 4th March

2005 [Ustawa… 2005], of a property law resulting from a testimony of the origin of electricity produced from renewable sources.

The most important and essential consequence of the regulations passed in this bill was dividing revenues from the sale of energy produced from renewable sources in two categories:

- revenues from the electricity sales that a producer gets for the sold energy; the price of energy produced from renewable sources is the same as that produced from a conventional carrier;
- revenues from the property law sales resulting from the testimony of a renewable origin; a renewable energy producer gets a payment from the power station that purchases the property law resulting from the testimony of origin.

The testimony of origin is a confirmation that a particular amount of electricity has been produced from a renewable energy source. The testimonies are registered in the producer's inventory account in the register of testimonies kept by the Energy Stock Exchange (ESE)**.** The moment the testimony is registered in the producer's account, the property law resulting from that testimony comes to existence. However it is transferable. The turnover of the property laws to the testimony of origin takes place in the energy stock exchange market during and off session. All transactions, no matter during or off session, are registered by ESE. The first session of property law trading took place on 28th December 2005. The average prices of property laws traded in and off session transactions in 2006 and 2007 (registered by ESE) are shown in figure 1. The picture shows that the price of property laws between transactions sessions nos. VII and IX grew rapidly. It must have been caused by the increased demand in the end of the year because of the necessity of obligatory property law purchase. In December the price stabilized at a level slightly lower than the statutory charge for missing property law. The price of property laws in off-session transactions between January 2006 and April 2007 did not change a lot. The price grew in that period by 18.5 PLN (which is 9.6**%).** In April 2007 was the price of property laws in off-session transactions in session transactions by 27 PLN (11.4%) lower than price of property laws traded in session. That difference resulted from the fact that the prices were fixed on the basis of long-term contracts between the producers of energy from renewable sources and the big power stations. Producers are inclined to sign this kind of contracts because they give them a guarantee of stable incomes.

Total volume of renewable energy confirmed by a testimony of origin in 2006 was 3 579 132 MWh, while in first fourth months of 2007 it was 1 334 924 MWh.

To fulfill the statutory duty conventional power stations have to purchase or produce the energy from renewable sources in accordance with a prescribed percentage for a given year. The confirmation of the fulfillment of this duty is a purchase of the property laws to testimony of origin. The testimony of origin is written off the sum of obligation for a given year the moment an energy company buys the property law to it. Every entity participating in ESE can become an owner of the property law resulting from the testimony of origin without the obligation to purchase electricity confirmed by the testimony of origin (electricity and property laws could be purchased separately by two entities).

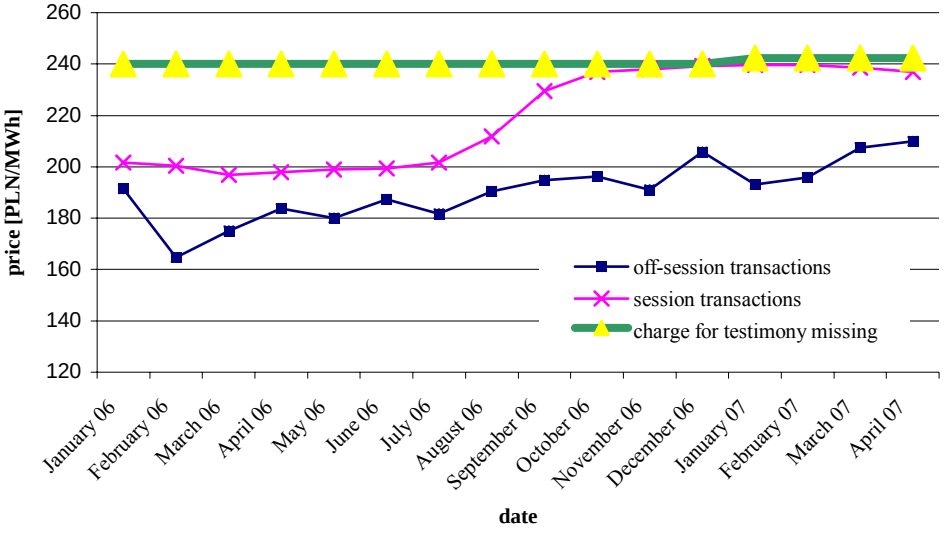

Figure 1. Weighted average price of property laws traded in and off session, registered in months between January 2006 and April 2007.
Source: own research based on [Towarowa… 2007]

Energy companies which do not buy nor produce themselves required amount of renewable energy property rights are statutorily obliged by the end of March next year to pay a surcharge adequate to the amount of the missing testimonies of origin. This surcharge is a part of revenues of the National Fund of Environmental Protection and Water Economy.

The payment is determined by multiplying a unit surcharge of 240 PLN/MWh (in 2006; in the following years updated on the basis of the consumer price index in the previous year; according to an announcement of the chairman of the Office of Energy Regulations the unit surcharge in 2007 is 242.40 PLN/MWh) by the amount of the missing testimonies. The surcharge is supposed to be higher than the market price of testimony of origin and can be treated as a maximum price practicable.

The system of tradable testimonies of origin contributed to a considerable economic revival in the market of renewable energy. The consequence of this mechanism is a higher price (because of the cost of purchased testimonies of origin) of energy from renewable sources than the price of energy from conventional sources. Increased costs of power stations are being transferred to final consumers, that is to general public. This mechanism is justified economically only when the social benefits from replacing traditional energy carriers (among others reducing emission of harmful gases and dust to the atmosphere as well as the amount of ashes to store) are higher than the social costs.

Costs and revenues of small hydropower plants

The aim of the research was to determine the relation between the hydraulic and engineering parameters of investigated hydropower stations (average stream flow, installed power), the level of full unit costs and the unit revenue from the sale of electricity. The data basis have been the book entries in a company operating five cascaded power stations located in the northern-central part of Poland. All of the analyzed objects are situated in the same river basin and belong to one owner (a limited liability company). Table 3 shows the technical parameters of the analyzed stations. Four of these stations can be classified as small hydroelectric power stations (with installed power <5 MW); only the station no. 2 exceeded this limitation.

Table 3. The technical parameters of the analyzed objects

Parameter	Unit	Station				
		I	II	III	IV	V
installed power	kW	2294	6669	2410	872	781
average water head	m	13.8	44.8	13.9	4.5	4.21
average flow	m^3/s	5.4	5.5	5.8	5.4	5.5
lowest flow	m^3/s	2.36	2.42	1.97	2.03	0.5
highest flow	m^3/s	12.07	12.43	13.49	12.61	36.85
average annual energy production	MWh	3980	15000	5000	1570	1340

Source: own research

The analysis covers a period from V 2003 (date of establishment of the company) to VII 2006. The research was based on the information about:

- monthly flows, amount of produced energy, amount of energy used for internal needs and work time;
- annual total costs and revenues from energy sale.

First of all a relation between the installed power and the unit revenue from energy sale has been determined (figure 2). The average of annual revenues in 2004 and 2005 has been used in the analysis. Data from 2006 have been excluded because of the changes in the system of accounts between the renewable energy producer and the buyers, which occurred in 2006 (the previously mentioned mechanism of tradable property laws). In that period (2004 and 2005) the company was paid 0.23 PLN for 1 kWh. After the changes of 2006 a new contract was signed with the energy receiver, according to which the company gets 0.12 PLN for each kWh as a revenue from electricity sale and 0.20 PLN/kWh as a revenue from the property laws sale. The testimony of origin price is stabilized and independent of stock exchange quotations. This practice is very common because it guarantees that the producer has a stable (independent of the

stock exchange price fluctuations) revenue and a warranty of quick sale of the testimonies. A dependence of the unit revenue from the installed power capacity on the installed power has been observed in the analyzed period. It can be described by equation:

$$P = 0{,}0281M + 422{,}7$$

where:

P – unit revenue from electricity sale per 1 W of installed power (price level 2004/2005), PLN/year/W,

M – installed power, kW.

Linear correlation coefficient for these variables R = 0,884

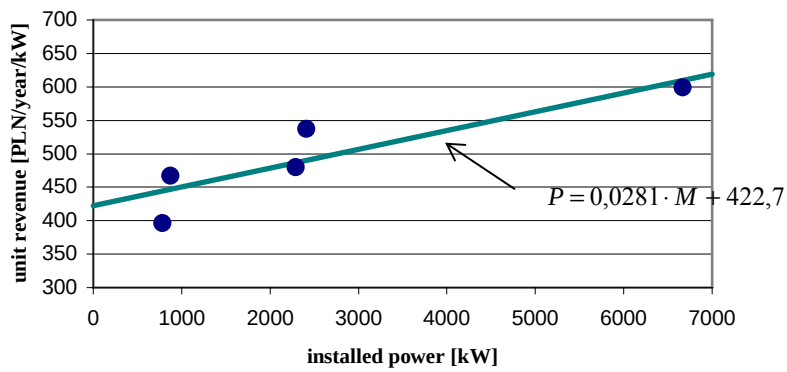

Figure 2. Relation between the unit revenue from installed power and the installed power
Source: own research

In order to determine the influence of stream flow on the revenue from the energy sales all three years 2004, 2005 and 2006 have been analysed. The revenue obtained by the company in 2006 has been included but uniformly counted at the 2005 prices. The results are shown in figure 3. It has been investigated whether the revenue from a unit flow depended on the flow volume.

It can be observed that the unit revenue is practically independent of the flow volume. Whereas the factor that strongly influences the unit revenue is the water head level. In the case of power stations with low water head h=4÷4,5 m the relation between P [PLN/m^3/year] and the average flow Q [m^3/s] can be described as a linear equation in form of $P=0{,}50 \cdot Q+1804$. However, in the case of objects where h=14 m the same relation has a form of $P=0{,}93 \cdot Q+5912$. The value of regression coefficient can be treated as a unit average annual revenue from 1 million m^3/year of average water flow.

The next step was to analyze the relation between the installed power (M) and the annual cost (the average annual cost in 2004-2006) K_c per unit of installed power [PLN/yr/kW] (figure 4). In this case the linear correlation coefficient was R=-0,790. From the analysis illustrated by

the chart in figure 4 it follows that with an increase of the installed power the unit cost decreases. It is an example of the so called economy of scale.

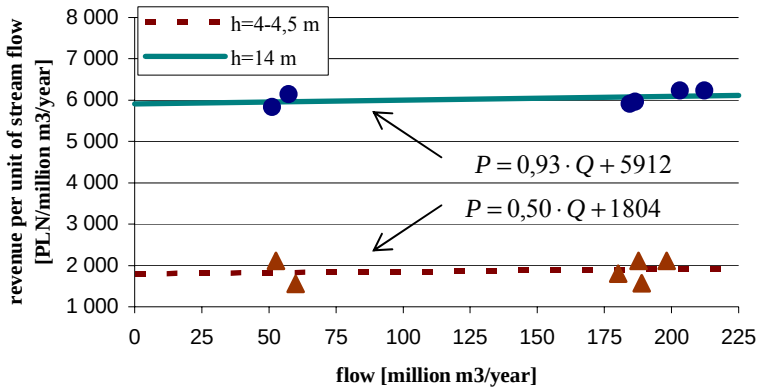

Figure 3. Relation between unit revenue from energy sale and the average stream flow and water head
Source: own research

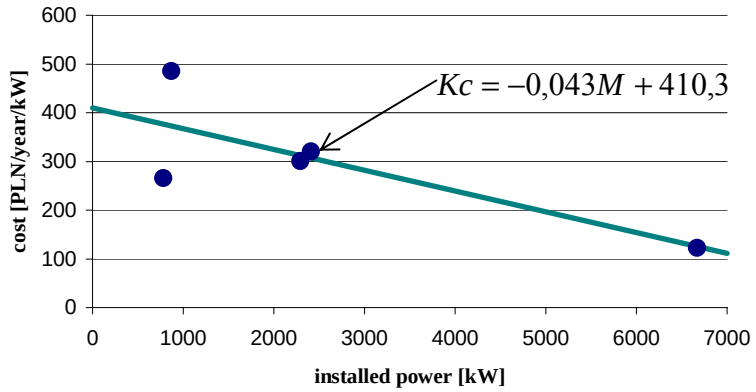

Figure 4. Relation between the unit annual cost per 1 W of installed power and the installed power
Source: own research

In the last stage of research was the influence of the average stream flow and water head on the unit cost investigated (figure 5). In this case also declining curves have been obtained. Their shape is much dependent on the water head level. In the case of smaller objects this

dependence can be described by equation $K_c=-5,8 \cdot Q+2770$, whereas for the bigger ones it becomes $K_c=-4,7 \cdot Q+4932$, where K_c stands for an annual cost (price level 2004/2005) in PLN/million m^3/year and Q stands for flow in million m^3/year.

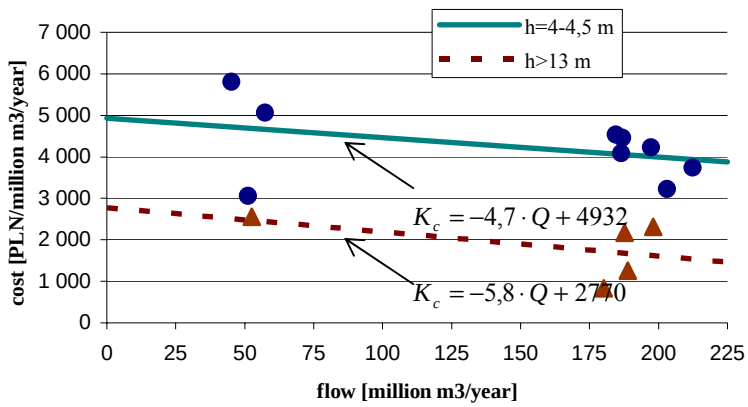

Figure 5. Relation between the unit annual cost per million m^3/year of water flow and the unit stream flow as well as the water head
Source: own research

Those results of research indicate that there is a considerable influence of the installed power on the economic efficiency obtained by a particular power station. In the case of smaller objects (below 100 kW) the revenue per unit coming from the energy sale exceeds slightly the costs (the benefit/cost factor ≈1). Together with the growth of installed power the revenues per unit of installed power grow as well, while the costs diminish. Consecutively in the case of the biggest of analyzed objects the benefit/cost factor is 5.5.

The research results indicate that the objects with water head of more than 13 m (objects I-III) are distinguished by a substantial economic efficiency. In the case of those stations the unit costs per million m^3/year are always lower than the unit revenue obtained from the sale of energy. The difference between those two values is growing with the increase of stream flow which is caused by a decreasing tendency of the unit cost function and the constant (or even a little growing) unit revenue function. In the case of smaller objects, with water head within the range of 4-4.5 m, the break even point for costs and revenues comes with the flow volume of 153 million m^3/year. This flow level indicates that in dry years the small hydroelectric power stations with low water head could prove to be economically inefficient. It should be remembered that in the calculation only the revenues from the energy sale have been taken into consideration without counting the revenues from the sale of property laws to the testimonies of origin. If we take into account the second source of revenue it will cause the profitability frontier in the case of the power stations with lower water head move to the direction of lower flows. Moreover, when evaluating this kind of investments from the social viewpoint it is

necessary to take into consideration the social benefits resulting from the replacement of hard coal with natural sources in the energy production.

To the most important benefits belong:

- reduction of the harmful gaseous and dusty emissions to the atmosphere
- creation of additional workplaces
- increase of tourist attractiveness of rural areas
- possible improvement of water regimes
- reduction of necessity of building high voltage electricity supply lines which visually pollute the landscape and give rise to electromagnetic fields of high capacity.

Taking into consideration those social benefits can considerably influence the estimate of macroeconomic efficiency of energy production from renewable sources.

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