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THE PERSPECTIVE OF SOLAR AND WIND ENERGY UTILISATION IN THE COPPER ELECTROREFINEMENT

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PERSPEKTYWA WYKORZYSTANIA ENERGII SŁOŃCA I WIATRU W ELEKTRORAFINACJI MIEDZI

STRESZCZENIE: Odnawialne źródła energii (OZE) pozwalają na wykorzystanie energii promieniowania elektromagnetycznego Słońca w formie bezpośredniej lub poprzez produkty fotosyntezy, energię kinetyczną wiatru, wody itd. W przypadku fotosyntezy, której akumulowana energia jest później pośrednio wykorzystywana w biogazowniach oraz w innych systemach OZE trzeba mieć świadomość niskiej 3–6% wydajności tego procesu. Proponujemy rozważenie zastosowań uwzględniających ograniczenia wynikające z natury OZE w technologiach akceptujących te uwarunkowania. Rozważania opieramy na przykładzie energochłonnego procesu elektrorafinacji miedzi, w którym zużywane jest 300 400 kWh (1,08 1,44 GJ) energii elektrycznej na wydzielenie tony (10^3 kg) miedzi. Zapewnienie ciągłości procesu można osiągnąć poprzez nowe rozwiązania technologiczne lub w najgorszym przypadku przez wspomaganie energią ze źródeł konwencjonalnych. Nie można wykluczyć, że efektem tych działań będą rozsiane po całym kraju niewielkie instalacje rafinujące miedź, spełniające wymogi środowiskowe i sprzężone z nimi wytwórnie specjalistycznych stopów miedzi. Podejście nie powinno być ograniczone do elektrorafinacji miedzi. Przy źródłach OZE można będzie lokować inne technologie, a nowe rozwiązanie staną się inspiracją do multidyscyplinarnych innowacji.

SŁOWA KLUCZOWE: odnawialne źródła energii, elektroliza, elektrorafinacja, miedź, innowacyjne technologie

Introduction

The European non-ferrous metals industry has larger economic significance than it would be indicated by the employment, capital and trade statistics[1]. The copper, which finds versatile applications in the economy is obtained from fossil minerals and recycling[2]. Naturally, it occurs in the form of oxides and sulphides. Only small quantities of copper are in the native form[3].

Procedure for the obtainment of crude copper consists of several energy-consuming steps involving flotation and metallurgical processes[4]. Even though the resulting crude blister copper contains 98.5 to 99.5% pure metal, it still requires further purification. In the energy-consuming process of electrolysis in acidified copper sulphate solution, due to the electric current with a low voltage and high density, the metal from which the anodes are made is "transferred" to the cathodes. During the electrolysis lasting 9–15 days, pure copper (99.95 99.99%) is deposited on the cathode and the silver, gold, nickel, platinum-group-metals and other metal and metalloid compounds are left in the slimes[5].

Industrial electrolysis baths are rectangular boxes made from polymer-concrete, which provides hermeticity, strength, good electrical insulation and high resistance to aggressive chemicals[6]. Thereby optimization of the electro-refining process allows energy consumption of 300–400 kWh (1.08 to 1.44 GJ) per tonne of copper (10^3 kg)[7].

Despite the economic fluctuations, the demand for copper grew dramatically over the last hundred years, driving the rate of production nearly exponentially[8]. However, from the economic point of view, the copper processing

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[1] Joint Research Centre, *Best Available Techniques (BAT) Reference Document for the Non Ferrous Metals Industries (Final Draft)*, 2014, p. 1–1242.

[2] International Copper Study Group, *Sustainable Development*, www.icsg.org [16-07-2015]; S. Northey, N. Haque, G. Mudd, *Using sustainability reporting to assess the environmental footprint of copper mining,* "Journal of Cleaner Production" 2013 no. 40, p. 118–128.

[3] S. Northey, N. Haque, G. Mudd, op. cit.

[4] Joint Research Centre, op. cit.; S. Northey, N. Haque, G. Mudd, op. cit.

[5] J. Marcinowski, *Główne przyczyny uszkodzeń wanien elektrolitycznych stosowanych w hutnictwie miedzi,*, "Przegląd Budowlany" 2010 no. 81, p. 124–127; G. Cifuentes, J. Hernández, N. Guajardo, *Recovering Scrap Anode Copper Using Reactive Electrodialysis*. "American Journal of Analytical Chemistry" 2014 no. 5(15), p. 1020; International Copper Study Group, *The World Copper Factbook*, 2014, p. 1–63; R. Marković et al., *Behaviour of non standard composition copper bearing anodes from the copper refining process*, "Journal of Hazardous Materials" 2010 no. 182(1), p. 55–63.

[6] J. Marcinowski, *Główne przyczyny uszkodzeń wanien elektrolitycznych stosowanych w hutnictwie miedzi*, "Przegląd Budowlany" 2010 no. 81, p. 124–127.

[7] Joint Research Centre, op. cit.

[8] S. Northey, N. Haque, G. Mudd, op. cit.

has certain disadvantages. The use of copper products has negative impact on the environment, often imperceptible to the consumer[9]. If the overall cycle of metal (from mining to recycling) is taken into the account, the scale of the environmental impact extends from local (water consumption and toxic waste) to global (climate changes)[10]. In the global perspective, the energy demand and related to it CO_2 emission contributes to global warming[11]. Despite the implementation of new technologies to copper processing, the current dimension of the environmental effects of this sector and no liability for their formation makes the situation difficult to maintain in its present form. Consequently, companies engaged in mining, refining and recycling are under growing pressure to reduce negative environmental impact[12].

The way how society uses and exploits its resources, is an important factor ensuring the sustainable development, which became one of the strongest incentives shaping the progress of industry in mining and processing of minerals and metals[13]. One of the ways to achieve better efficiency in the use of raw materials is dematerialisation – the reduction of energy and materials needed to perform economic functions. This process complements the reuse of materials and forms a closed loop, allowing to achieve smaller and lighter products with longer lifespan, which could be recycled[14]. Such an approach can contribute to limiting production of primary copper, thereby reducing the energy expenditure, and as a result CO_2 emission. Improving the circulation of the material is still not sufficient to fully secure the society from the harmful effects of the copper production. It is impossible to propose a concept solving all of the problems, separated from comprehensive analysis. Therefore an integrated, innovative approach bonding various ideas and solutions is necessary. An exemplary voice in the discussion may be the use of renewable energy sources (RES), such as wind and photovoltaics for supplying electric energy-dependent stage of copper refining – electrorefining.

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[9] Ibidem.

[10] D. Giurco, J.G. Petrie, *Strategies for reducing the carbon footprint of copper: New technologies, more recycling or demand management?*, "Minerals Engineering" 2007 no. 20(9), p. 842–853.

[11] W. Kuckshinrichs, P. Zapp, W.R. Poganietz, *CO_2 emissions of global metal industries: the case of copper*, "Applied Energy" 2007 no. 84(7), p. 842–852.

[12] D. Giurco, J.G. Petrie, op. cit.

[13] International Copper Study Group, *Sustainable Development*, www.icsg.org [16-07–2015]; R. van Berkel, *Eco efficiency in primary metals production: Context, perspectives and methods*, "Resources, Conservation and Recycling" 2007 no. 51(3), p. 511–540.

[14] T.E. Norgate, S. Jahanshahi, W.J. Rankin, *Assessing the environmental impact of metal production processes*, "Journal of Cleaner Production" 2007 no 15(8), p. 838–848.

Data, methods and assumptions

In Poland, the electrorefinement of copper is carried out in two smelters owned by KGHM Polska Miedź – "Głogów" and "Legnica" works[15]. Thus, a case study was conducted – surroundings of Legnica were taken as a hypothetical localisation for the considerations. The productivity of wind farm in Taczalin (Legnica county) was estimated to be 2.66 $GWh\times MW^{-1}$ (9.58 $TJ\times MW^{-1}$) of installed power[16]. Data presenting wind velocity around Legnica on an hourly basis for the years 1985–2004, taken from SoDa[17] were averaged to daily values and compared with measurements conducted by the Institute of Meteorology and Water Management.

The methodology for calculations of energy generated by renewable energy sources was adopted from[18]. Electric power generated by the wind turbine was calculated according to the formula (1), while the yield of electric energy for photovoltaic system by means of formula (2).

$$P(TW) = \begin{cases} 0 \text{ if } v < v_1 \\ P(v) \text{ if } v_1 \leq v < v_r \\ P_r \text{ if } v_r \leq v < v_2 \\ 0 \text{ if } v \geq v_2 \end{cases} \quad (1),$$

where:

$P(TW)$ –	power generated by wind turbine, MW
$P(v)$ –	power curve of turbine depending on wind velocity
v_1 –	start velocity at which turbine starts to generate electric energy, $m\times s^{-1}$
v_2 –	critical velocity at which operation of turbine has to be suspended, $m\times s^{-1}$
v_r –	velocity from which turbine operates at nominal power, $m\times s^{-1}$

Equation (1) form is determined by the work specificity of a particular wind turbine model. The reference used was Vestas V90 turbine with nominal power P_r = 2 MW. According to the information on the turbine it was assumed that: $v_1 = 4\ m\times s^{-1}$, $v_2 = 25\ m\times s^{-1}$, $v_r = 12\ m\times s^{-1}$[19].

$$E(PV) = \frac{GHI * P * P_R}{GHI_{STC}} \quad (2),$$

where:

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[15] KGHM Polska Miedź, *Smelting and refining*, www.kghm.com [30-07–2015].

[16] WSB Parki Wiatrowe, *Projekty. Park wiatrowy Taczalin*, www.wsb parkiwiatrowe.pl [29-07–2015].

[17] SoDa, *Time Series of Solar Radiation Data from MACC RAD*, www.soda pro.com [31-07–2015].

[18] G. Notton, S. Diaf, L. Stoyanov, *Hybrid photovoltaic/wind energy systems for remote locations*, "Energy Procedia" 2011 no. 6, p. 666–677.

[19] Vestas Wind Systems, *V 90 2.0 MW*, www.vestas.com [28-07–2015].

E(PV) – yield of electric energy from PV (photovoltaic) system, kWh (MJ)
GHI – value of solar radiation incidence on a surface, $kWh \times m^{-2}$ ($MJ \times m^{-2}$)
P – nominal power installed in a PV system, kW
P_R – degree of efficiency (adopted as 0.8)
GHISTC – standard conditions, at which photovoltaic modules are examined, $1\ kW \times m^{-2}$

Within the further analysis, variability of energy production from both sources in a shorter time horizon have been assessed – calculated as the average monthly energy yields for the years 2005–2014. The last step in the analysis of energy resources of wind and the Sun was to evaluate the variability of electric energy production in daily terms.

For photovoltaic farm, the estimated cost is assumed to be 3.9–4.8 million PLN/MW_p[20]. However, in the case of wind power plants on land, the cost is higher and oscillates at 5–7 million PLN/MW[21]. Economic considerations, were conducted on the basis of assumptions shown in the table 1.

Table 1. Assumptions in the economic calculations

Assumed parameter	Unit	Value
Copper production	$t \times day^{-1}$ ($kg \times s^{-1}$)	9000 (104.17)
	$t \times h^{-1}$ ($kg \times s^{-1}$)	53.57 (14.88)
Energy consumption	$MWh \times t^{-1}$ ($MJ \times kg^{-1}$)	0.4 (1.44)
	$MWh \times h^{-1}$ ($MJ \times s^{-1}$)	21.43 (21.43)
Purchase from grid energy price	$PLN \times MWh^{-1}$ ($PLN \times GJ^{-1}$)	350 (97.22)
Resale to grid energy price	$PLN \times MWh^{-1}$ ($PLN \times GJ^{-1}$)	150 (42.22)
Green certificate price	$PLN \times MWh^{-1}$ ($PLN \times GJ^{-1}$)	180 (50)
Average increase in energy prices	$\% \times year^{-1}$ ($\% \times s^{-1}$)	2.5 (7.93×10^{-7})
Wind park initial cost	$PLN \times MW^{-1}$	5 800 000
PV farm initial cost	$PLN \times MW_p^{-1}$	4 500 000
Wind park yearly maintenance	% of initial cost	2
PV farm yearly maintenance	% of initial cost	1.5
PV farm efficiency decrease	$\% \times year^{-1}$ ($\% \times s^{-1}$)	1 (3.17×10^{-7})
Wind turbine efficiency decrease	$\% \times year^{-1}$ ($\% \times s^{-1}$)	1.6 (5.07×10^{-7})
Maintenance cost increase	$\% \times year^{-1}$ ($\% \times s^{-1}$)	1.2 (3.81×10^{-7})

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[20] B. Szymański, *Farma fotowoltaiczna podstawowe fakty*, www.solaris18.blogspot.com [09-07–2015].

[21] Centrum Informacji o Rynku Energii, *Energetyka wiatrowa w Polsce*, 2010, p. 1–52.

It has been assumed that electric energy obtained from the hybrid system (wind park plus photovoltaic farm) will be utilized to cover current demand for energy in the copper manufacturing process. Covering the demand generates savings in the amount equal to the cost of purchasing electric energy from the grid, while the resale of surpluses is associated with income equal to the price of resale of electric energy to the grid. The considerations also include the decrease in efficiency of energy sources and an increase in the cost of their maintenance.

In the first stage of the considerations, an analysis of how the structure of the hybrid system (the share of capacity installed in wind turbines and photovoltaic panels) affects the degree of coverage of current demand. The next stage was to determine how simple return period of financial outlays is shaped, depending on the installed power in the individual power plants. For this purpose, the cost of generating a single MWh of energy from a given hybrid system was calculated, with a 25 year of investment duration. In the subsequent stage, average profit arising from the generated unit of electric energy, was calculated. Such profit is calculated as the sum of the savings arising from electric energy not purchased for the production process and surplus energy resold to the grid. System optimisation was single-objective – the shortest simple payback time (SPT). A variety of methods exist for optimising these systems[22], but for performed analyses their implementation was not necessary.

Results

Comparing data for wind speed near Legnica in hourly basis for the years 1985–2004 with measurements carried out by the Institute of Meteorology and Water Management, gave correlation coefficient of 0.85. This value indicates partial compatibility of data sources. It should however be kept in mind that the correlation coefficient value was influenced by i.a.: a mesh of satellite measurements (spatial resolution of 50 kilometres), averaging daily values by Institute of Meteorology and Water Management on the basis of four readings (for satellite based on 24) and increasing roughness of the terrain around the weather stations (leading to the reduction of wind velocity and changes in its character).

Figure 1 shows the energy yield from the photovoltaic plant and wind turbine for particular periods of time, according to equations (1) and (2).

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[22] W. Zhou, et al., *Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems*, "Applied Energy" 2010 no. 87, p. 380–389.

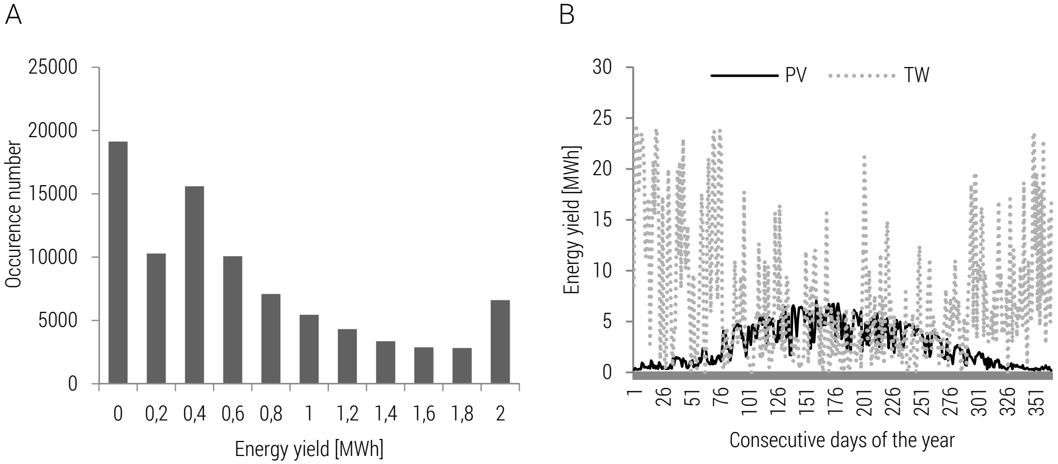

Figure 1. Electric energy yields obtained from components of the hybrid system

(A) The histogram of hourly energy yield from wind turbine with capacity of 2 MW between 2005 and 2014 (B) The average daily yield of electric energy from the photovoltaic system and wind turbine calculated per 1 MW of installed power in 2005.

Variability and complementarity of wind and solar sources are shown on the multi-annual, monthly and daily basis. Figure 2 presents the variability of annual sums of obtained electric energy from photovoltaic farm with a power of 1 MW and wind turbine with nominal power of 2 MW.

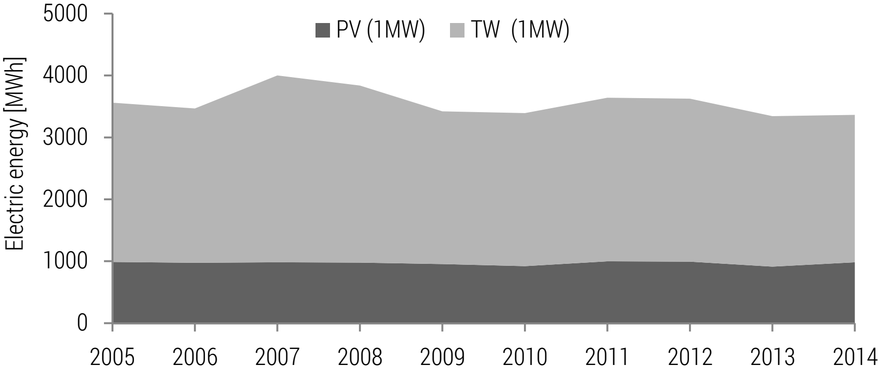

Figure 2. Multi-annual variability of energy yield from photovoltaic system and wind turbine

Turbine power was recalculated for 1 MW. In the analysed period, the energy yield of photovoltaic farm was relatively stable at approx. 970 MWh×MW^{-1} (3,49 TJ×MW^{-1}) while in the case of wind turbine approx. 2600 MWh×MW^{-1} (9,36 TJ×MW^{-1}).

Multi-annual variability of the wind turbine work is much clearer than in the case of the photovoltaic installation. The average monthly energy gains over the years 2005–2014 are summarized in figure 3.

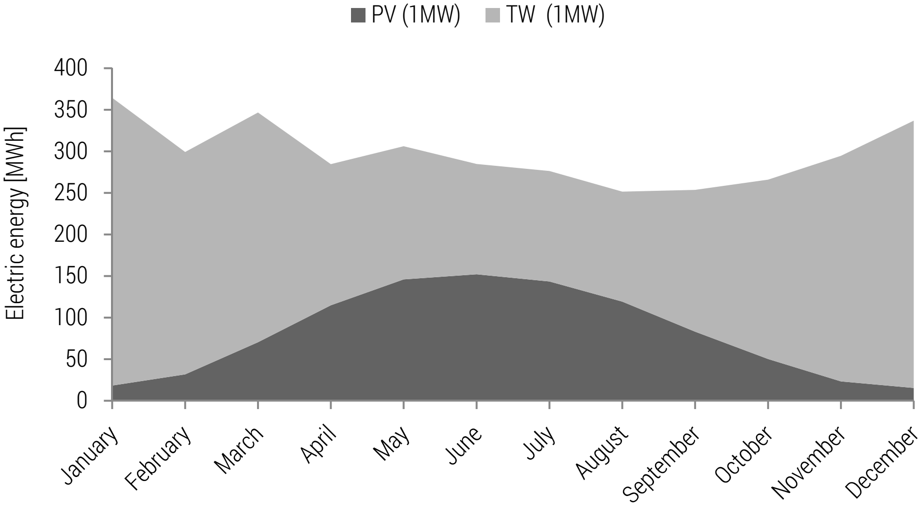

Figure 3. Annual variability of energy yield from photovoltaic system and wind turbine

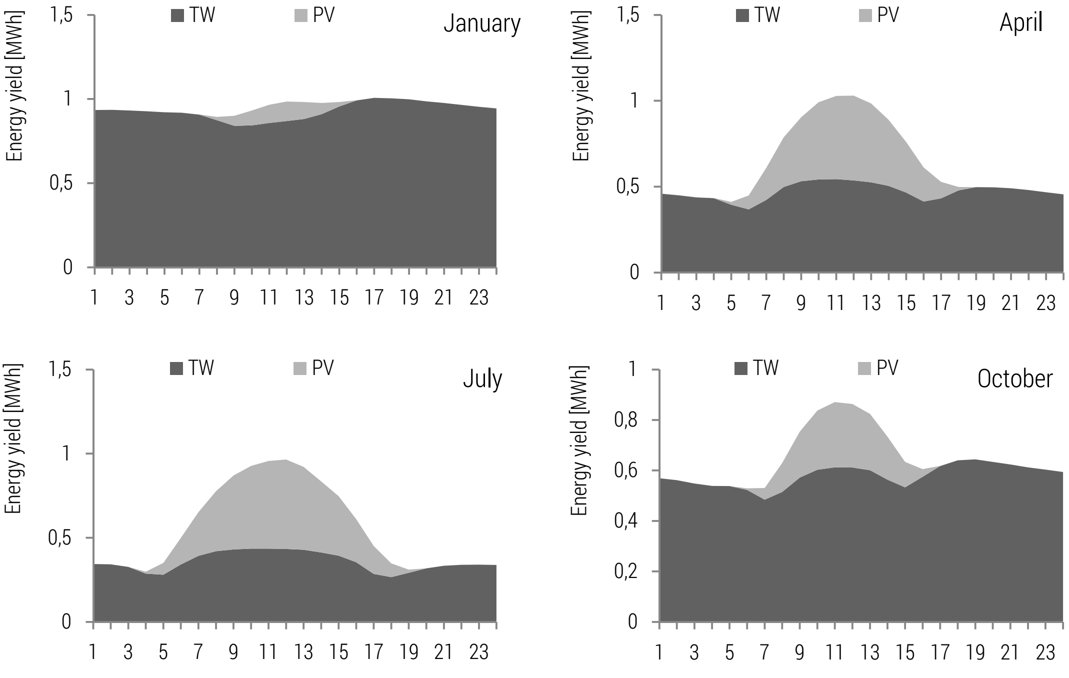

Figure 4. Statistical hourly energy yield from the wind turbine and photovoltaic farm in the individual hours of the day in selected months

The results of calculations aimed at assessing the variability of electric energy production in daily terms are shown in figure 4, where statistical values of generated electric energy are presented in the consecutive hours of a day.

Figure 5 illustrates the values of correlation coefficients between the recovery of energy from the photovoltaic system and wind turbine in the particular months. As can be seen only in November-February, the correlation between these energy sources is advantageous from the recipient point of view.

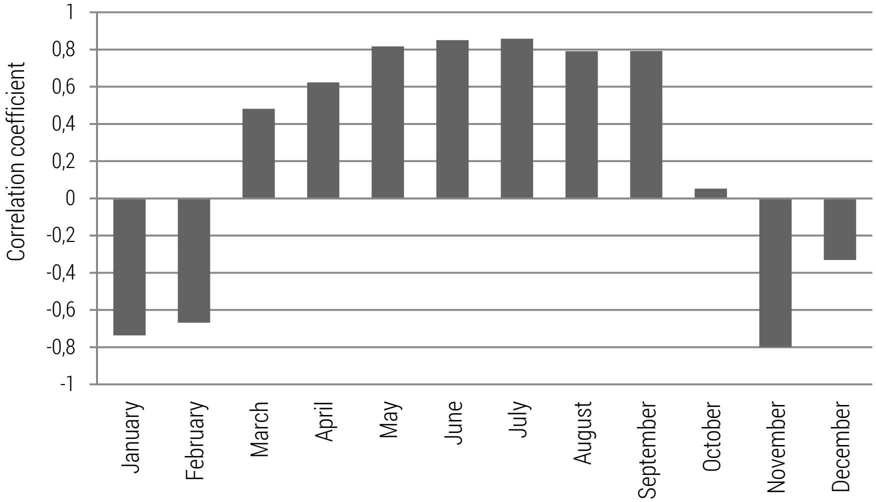

Figure 5. The correlation coefficient for hourly energy yields from photovoltaic system and wind turbine

Analysis of the structural influence of the hybrid system (the share of installed power in wind turbines and photovoltaic panels) on the coverage of current demand is visualized in figure 6A. The results of the calculations of the cost of generating single MWh of energy from given hybrid system, with the 25-year period of the investment, depending on the installed power in the individual power plants are shown in figure 6B. The average profit from the generated unit of electrical energy is expressed as the sum of the savings arising from electric energy not purchased for the production process and surplus energy resold to the grid. It is presented in figure 6C. Profit from generated energy, decreased by the cost of obtaining it is the size of the income from a single megawatt hour of electric energy. Thus, we get the answer to the question, what configuration of the hybrid system will allow to generate electric energy which value, from the point of view of economics, will be the most advantageous. The results of the calculations are shown in figure 6D.

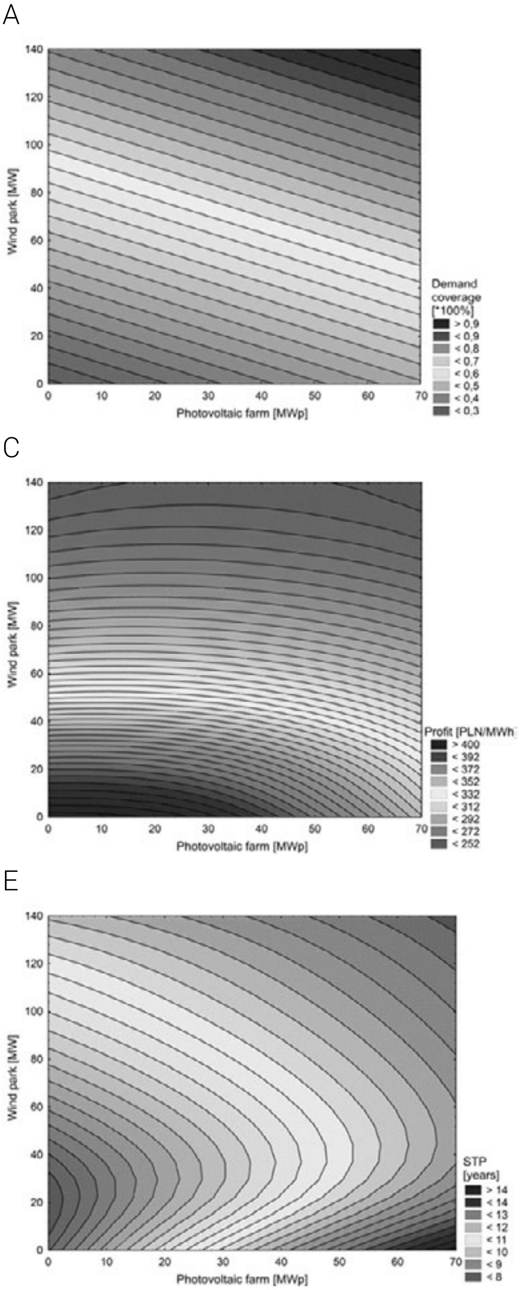

Figure 6. Analysis of the profitability of the considered investment

(A) Coverage of the demand for electric energy depending on the nominal power of the various energy sources. (B) The cost of obtaining 1 MWh of energy from the perspective of 25 years of work of energy sources with the selected nominal powers. (C) The average profit from the savings and resale of energy for energy sources with given powers (figure does not include green certificates). (D) Income from a unit of electric energy produced, which is the difference between profit and the cost of obtaining it. (E) The average simple payback time (SPT) – not taking into account the green certificates.

The length of the payback time of financial outlays results both from the extent to which the sources cover the requirements, as well as their initial and maintenance costs. The values of a simple payback time of financial expenses, excluding the green certificates are presented in figure 6E.

Discussion

Renewable energy sources are an attractive topic of media. Often the discussion about their use does not include the realities and limitations. Annual energy carried by the Sun rays in Poland has a value of approx. 950–1250 kWh×m^{-2}. In the use of this energy, limited efficiency of converters and their impact on the environment (recycling) must be considered[23]. For example, the energy balance of biomass production, based on the photosynthesis process is dependent on the time of day and year, and its yield is estimated to be 3 to 6%[24]. Another example would be biodiesel production technology, in which beneficial energy balance is affected by the use of straw, which is not anticipated final product. Additionally, adverse environmental effects should be taken into account, involving the unsolved problem of processing waste material – glycerol[25].

However, critical look at the RES does not relieve from the discussion and exploration. In recent years, due to the scale effect, dynamic development of manufacturing plants, optimization of production processes and implementation of programs aimed at the development of renewable energy sources, a systematic drop in investment expenditures incurred by both the small and large renewable energy sources is being observed.

From a national perspective, Legnica is located in an area where wind conditions are not promising for the development of wind energy. However, making decisions based on a summary map of wind speeds in Poland turns out to be wrong, and this fact is confirmed by the rapid development of wind parks in the areas of rural municipalities located near Legnica[26].

The production curve of electric energy from wind and photovoltaic plants indicates high instability of these sources (figure 1), which may result

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[23] H. Lorenc, *Atlas klimatu Polski*, Warszawa 2005, p. 21–24.

[24] X.G. Zhu, S.P. Long, D.R. Ort, *What is the maximum efficiency with which photosynthesis can convert solar energy into biomass?*, “Current opinion in biotechnology” 2008 no. 19(2), p. 153–159.

[25] T.K. Dobek, M. Dobek, O. Šařec, *Ocena efektywności ekonomicznej i energetycznej produkcji pszenicy ozimej i rzepaku ozimego wykorzystanych do produkcji biopaliw*, “Inżynieria Rolnicza” 2010 no. 14, p. 161–168.

[26] Regionalna Dyrekcja Ochrony Środowiska we Wrocławiu, *Farmy wiatrowe w województwie dolnośląskim*, www.bip.wroclaw.rdos.gov.pl [29-07–2015].

in incomplete coverage of demand for a given time. In the global perspective (eg. the country) when a group of wind parks and solar farms spread over a large area is analysed, a positive effect is observed, resulting from the spatial distribution, which leads to smoothing of the production curve[27]. However, from the perspective of a single recipient, that uses such sources located in small area, the only solution is to resize the system and simultaneously store the surplus energy. When the electric energy sources are able to complement themselves in the energy production, it can be spoken of complementarity. This term can be considered both in time (variation in wind and sunlight per year) and space (eg. stronger winds on the coast of the Baltic Sea and larger amounts of sunlight in the Voivodship of Lublin on a national scale).

Due to the relatively spotty nature of the analysed hybrid system, only the time complementarity has been analysed. As an example of a perfect time complementarity, the situation can be considered, in which a first source operation is described by the sine function while the second source operation is the sine function, but shifted in phase by π/2. As can be seen, the energy sources are clearly complementing each other in terms of energy yield per year (figure 3). In these time series, the correlation coefficient is at the level of 0.91. Appropriate configuration of installed power in both of these sources could allow smoothening of the statistical curve of energy yield per year. However, its adaptation to the curve of electric energy demand should be kept in regard. The issue of energy yield from the photovoltaic system is more intuitive than in the case of wind turbines. It exhibits variability considerably clearer and perceptible by the human in both the year and the day scale (figure 4). Generation of electric energy in photovoltaic system is based on the direct conversion of solar radiation to the electric energy. Thus, when the sunlight does not reach module plane, the photovoltaic effect does not occur and electric energy is not generated. In summary, photovoltaic and wind energy sources annualised show a strong negative (favourable) correlation (figure 5). In daily terms, this situation occurs only during November-December.

It can be observed that the degree of the demand coverage is increasing much faster in the case of a wind park than photovoltaic farm (figure 6A). Each additional megawatt of power installed in wind turbine, averagely contributed to covering additional 0.48% of the demand, while in the case of solar energy it was about 0.2%. This situation is mainly due to the hours in which electric energy is statistically obtained from different sources, and the

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[27] J. Jurasz, J. Mikulik, *Wpływ dystrybucji przestrzennej na stabilność źródeł fotowoltaicznych*, in: A. Kotowski, K. Piekarska, B. Kaźmierczak (eds), *Interdyscyplinarne zagadnienia w inżynierii i ochronie środowiska*, Wrocław 2015, p. 179–191; J. Kleissl, *Solar energy forecasting and resource assessment,* 2013, p. 21–406.

amount of energy generated per a megawatt of installed power: 970 MWh×MW^{-1} (3.49 TJ×MW^{-1}) – PV and 2600 MWh×MW^{-1} (9.36 TJ×MW^{-}1) – TW (figure 2).

It is noteworthy that for the wind conditions occurring in analysed location and assumed structure of energy consumption and its costs, generation of energy from the photovoltaic system is much more expensive (figure 6B). Due to the adopted assumptions as to the price of resale and purchase of energy, the highest profit is generated by energy sources that allow covering the current demand to the maximum extent without generating unnecessary surplus energy. Thereby, a threshold value of requirement coverage is 50%, beyond which profit from the energy starts to diminish (figure 6C). As can be seen, the installation consisting of a wind park with a capacity of 40 MW and a photovoltaic farm with a capacity of 10 MW, which will cover an average of 10 to 50% of electric energy demand, will generate the greatest income (figure 6D).

Calculated income translates directly into a simple payback time of financial outlays, which at best is 8 and at worst for over 14 years (figure 6E). Taking into account the price of green certificates assumed in table 1, the payback period is reduced averagely by three years, and is still not less than 6 years.

The considerations have been conducted on the example of the cathode copper production for situation covering industrial-scale production. In conventional technologies requiring continuous supply of electric energy technical thought contributed to the improvement of this process. However, the question must be asked – would it be possible to conduct this process in conditions of changeable supply of energy generated by RES. Asking the question should inspire the professionals to answer.

Due to scattering of renewable energy sources, the idea of small production systems powered by RES can be discussed. Technically design might differ from the standard solutions. Small installations could be more easily supervised, and the possible release of harmful gases would not be concentrated in small areas. The intermediates could be processed on the spot into small batches of special products. Creating small installations taking into account the limitation of RES could become an impulse of progress. However, this approach requires proof and should be tested in future works. It should be proven whether the unit processes comprising the entire scheme would not lead to energy consumption higher than expected savings. Also different aspects of transportation and its impact on economics and environment should be considered.

The discussion started with the issues related to the electrorefining of copper, but the problem is open to broadly understood energy consuming technologies. The continuation of research on innovative technologies absorbing the changing energy supply will be required. Specialists chemists, physicists, biologists, etc. should propose a list of issues. It may begin with the electrochemical processes, the production of nitrogen fertilizers, and so on.

Conclusions

Innovative solutions, based on the synergy of many disciplines are in the modern world, one of the most widely used tools to resolve problems within almost every sector of the economy. In the case of above analysis, the keynote was the use of electric energy generated from renewable energy sources (wind and sun) in the copper production processes. Conceptually, all generated energy should be spent on the needs of the production process, but the changeability and instability of these energy sources enforce certain oversizing of the system and coming to terms with the fact of periodic occurrence of energy surpluses and shortages. Although in the current economic realities and technological conditions, the production of copper using energy from renewable sources seems to be difficult to implement, the initial solution could be supporting it with conventional energy. Expected innovative technologies should allow to carry on the processes depending on the changeable energy supply without adverse impact on product quality. This is the challenge to be taken by modern science[28].

The contribution of the authors in the article:

Tomasz Głąb, MSc – contribution to the concept of the paper, discussion and preparation of the technological-chemical

Jakub Jurasz, MSc Eng – contribution to the concept of the paper, discussion and preparation of the economical

Prof. Janusz Boratyński, Ph.D – concept of the paper and discussion

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[28] A similar concept, proposed by other authors appeared online in the "Journal of Cleaner Production" during technical preparations of above manuscript http://dx.doi.org/10.1016/j.jclepro.2016.09.040. Whereas our similar paper concerning utilisation of RES in chlor-alkali industry appeared in "Przegląd Naukowo-Metodyczny 'Edukacja dla Bezpieczeństwa'" 2016 No 1 (30), p. 1180-1198.

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