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Carbon dioxide emission reduction by heating poultry houses from renewable energy sources in Central Europe

Jacek Kapica *, Halina Pawlak, Marek Ścibisz

University of Life Sciences in Lublin, Poland

A R T I C L E I N F O

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A B S T R A C T

The production of thermal and electrical energy is related to the emission of greenhouse gases, which are believed to cause climatic changes. The activities of the international community show an increase of ecological awareness. In the Central European countries the share of renewable energy in overall energy production is relatively small. One sector where some progress can be made is agriculture. This paper presents simulation results of CO_2 reduction potential by replacing conventional heating system for a poultry house with a hybrid solar–wind system. Heat requirement for 2400 birds was calculated. Simple models for solar collector, wind turbine and heat storage tank are presented. The system is modelled in a Matlab/Simulink environment and various system configurations are analysed for climatic conditions typical for Central Europe. The solar collector area was varied between 0 and 80 m^2, wind turbine diameter was varied in the range of 0–20 m and 1 to 4 heat storage tanks. Apart from percentage of CO_2 emission reduction two other indicators are introduced: renewable energy utilisation ratio and weighted CO_2 emission reduction — renewable energy utilisation coefficient. The results show that larger systems provide higher CO_2 reduction but the energy utilisation ratio decreases.

1. Introduction

Operation of the industry, including production of thermal energy and electricity is related to the emission of greenhouse gases, which are believed to cause climate change (Fuhrer, 2003; Janzen, 2004; Jang, 2013; Pasgaard and Strange, 2013; Butcher et al., 2014 and Cheng et al., 2014). This problem has been perceived in recent years by the international community. Already in 1992 in Rio de Janeiro the Earth Summit has decided to protect the climate and reduce greenhouse gas emissions in the world. It was the first global conference when the attention was drawn to the need to improve the efficiency and sustainability of the industry (United Nations, 1992). On this basis, in 1997 in Kyoto an agreement has been made which legally obligates countries to protect the climate (United Nations, 1998).

The agreement became the foundation of the work carried out in the European Union. In 2008 the European Council published a document setting out the objectives of European countries in the area of climate protection. The EU objective is to reduce greenhouse gas emissions in 2020 by up to 30% as compared to 1990 (Commission of the European Communities, 2008).

The activities of the international community show an increase of ecological awareness of the population, but at the same time it is needed to search for environmentally sound technological solutions in all areas of life. The biggest area in which reduction of the greenhouse gas emissions is possible is the industry, including the energy industry. Hence the creation of new technical solutions in the field of energy should be correlated with the improvement of environmental conditions. This can be achieved by improving existing plants or create new solutions, including the use of renewable energy sources. The sustainable energy development can be achieved in three areas (Lund, 2007): energy savings, efficiency improvements in energy production and replacement of fossil fuels.

An attractive alternative to conventional energy sources is renewable sources (Busko et al., 2012). Also in considering the need of carbon dioxide reduction, a wider use of unconventional sources will have to be introduced (Budzianowski, 2012; Lee and Zhong, 2014; Luthra et al., 2015).

The energy from renewable sources supports about 14% of the world energy demand (IEA, 2012). European data from Eurostat (Eurostat, the statistical office of the European Union, 2014) indicates a 14.1% share of Renewable Energy in the 27 EU member states plus Norway in the year 2012. For individual countries this share ranges between 3.1% for Luxembourg up to 64.5% and 51.0% for Norway and Sweden respectively. For the Central European Countries (Czech Republic, Hungary, Poland, Slovakia) the share is in the range of 9.6% to 11.2%. The numbers show that there is still a lot of investment to be made to increase the share of renewable energy. This motivated the authors to seek simple solutions which can help to decrease carbon dioxide emission within the agricultural sector.

Animal production is responsible for greenhouse gas (GHG) emission (Herrero et al., 2009; De Boer et al., 2011; Bell et al., 2014), reaching

* Corresponding author at: ul. Głęboka 28, 20-612 Lublin, Poland.
E-mail address: jacek.kapica@up.lublin.pl (J. Kapica).

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22% of global total emission of which nearly 80% comes from the livestock production (including transport of livestock and feed) (McMichael et al., 2007). Some sources (Goodland and Anhang, 2009) assign even as much as over 50% of global GHG emission to livestock products.

Livestock emission takes place in various ways. Methane warms the atmosphere strongly (CO_2 equivalent equals 25 in a 100 year timeframe and 72 in a 20 year timeframe), however its lifetime is approximately 12 years compared to over 100 years in the case of CO_2 (IPCC, 2007). The source of methane is enteric fermentation and manure (Zong et al., 2015; Philippe and Nicks, 2015). Even more warming potential is accredited to nitrous oxide — with CO_2 equivalent equal to 289 in a 20 year timeframe. Its main source is manure and soil management. As the meat and dairy production is expected to grow, action is needed to decrease emission from animals, primarily by modifying the food ingredients (Hawkins et al., 2015). Another way in which the agricultural sector impacts the environment is changes in land use, especially destroying natural forests (Kim and Kirschbaum, 2015) to provide land to produce more livestock thus reducing tonnage of carbon stored per area unit.

On the other hand, the livestock production can be influenced by the climate change (Nardone et al., 2010) as it is tied to the climate natural resources (Lee et al., 2014). These facts have motivated many researches to search for solutions targeted at lowering the emissions (Franks and Hadingham, 2012; Beukes et al., 2010; Dalgaard et al., 2011; Johnson et al., 2007; Vergé et al., 2007; Guo and Zhou, 2007; Smith et al., 2007; Glenk et al., 2014; Blandford et al., 2014; Eory et al., 2013; Winiwarter et al., 2014 and Snyder et al., 2014).

The health condition of birds in breeding poultry is highly dependent on the temperature in the house. In summer, appropriate steps should be taken to avoid overheating and heat stress (Lin et al., 2006 and Renaudeau et al., 2012). On the other hand, in winter low outdoor temperatures (at times even as low as −30 °C in Central European countries) require heating of the poultry houses as the recommended temperatures for broiler houses are in the range of 21–32 °C and 10–30 °C for breeder houses (ASHRAE, 2011).

Agriculture and Food Development Authority states that in poultry production 84% of energy is used for heating (EAGASC, 2011). Overall energy use in agriculture is constantly growing (Pawlak, 2012 and Wise et al., 2014). The increasing prices of fossil energy sources are appealing for an increase in the use of renewable energy. In many countryside locations in Central European countries like Poland the widely used source of thermal energy is coal — first because of its lower price compared to other fossil fuels and secondly, because of unavailability of natural gas (as relatively cheap fossil fuel) in many areas.

According to (Alterra — Stichting DLO, 2011) economy is the main factor which the farmers consider when making investment in renewable energy system. The farmers also want to contribute to the renewable energy sources, be less dependent on the possible energy price change in the future and to diversify their income sources.

Numerical modelling is a tool that can help in assessing properties and behaviour of various systems allowing easy analysis of numerous configurations of the system. In the real-world system it would be very difficult, if not impossible, to carry out experiments on so many variations of the system configurations. In such a case the computer model of the real structure becomes the object on which observations are made.

Table 2
Wind and solar energy data for Lublin (NASA, 2013).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly averaged insolation incident on a horizontal surface (kWh m^{-2} d^{-1})											
0.96	1.68	2.78	3.85	5.03	4.97	4.84	4.45	2.90	1.74	0.95	0.73
Monthly averaged wind speed for surface with 0.5-m broadleaf shrubs (10%) with bare soil (m s^{-1}) at 20 m											
3.18	3.94	3.11	3.05	2.96	2.89	2.88	2.95	3.24	3.13	3.02	3.06

The modelling techniques are used in many science areas. In agriculture they can be employed to analyse: performance of agricultural machines (Ampatzidis et al., 2014; Coen et al., 2008 and Ebrahimi et al., 2013), agronomic operations (Van't Ooster et al., 2014 and Bochtis et al., 2014), production management (Tedeschi et al., 2011 and Reynoso-Campos et al., 2004), production economy (Valdivia et al., 2012 and Xin and Li, 2011) possibility of greenhouse emission reduction (Crosson et al., 2011) and other areas of agricultural production and systems (Wallach et al., 2014; Rosenzweig et al., 2013; Rossing et al., 2007). One of the tools used in numerical modelling and analysis of various systems is the Matlab environment, widely used in the area of agriculture (Giusti and Marsili-Libelli, 2015; Menesatti et al., 2014; Zhang et al., 2011; Papadopoulos et al., 2011; Cool et al., 2014 and Odegard and van der Voet, 2014), including modelling of the renewable energy systems (Kıyan et al., 2013; Woinaroschy, 2014; Da Silva and Fernandes, 2010; Nakoul et al., 2014; Taghavifar and Mardani, 2014 and Sefeedpari et al., 2014). As a useful tool, this programming environment has been used to simulate the operation of the system presented in this paper.

The obvious way to use renewable energy sources to heat the farm buildings is the production of biogas from animal litter (Lynch et al., 2013), however it would be interesting to evaluate the usefulness of other sources like solar and wind energy. This paper presents simulation results of poultry house heating with solar and wind energy in various proportions. Also a heat reservoir has been included in the system configuration. The two different energy sources were chosen in order to test their complementarity and interoperability. This was achieved using indicators such as percent of reduction of the CO_2 emission, renewable energy utilisation ratio and an indicator which combines these two. Also, the assessment of what size of wind turbine and solar collector will be needed to supply all the heat needs of the broiler house for 2400 birds has been made.

2. Model assumptions and methods

The input data used for the calculations are for Lublin, Poland but the conclusions will be valid for a large area of Central European countries. Table 1 presents the temperatures and Table 2 — wind and solar energy potential in Lublin.

As can be seen from the tables, there is a significant difference in average temperatures between winter and summer: 21.1 °C in average values and 69 °C between absolute minimum and maximum. This correlates well with solar energy: greatest amount in the summer months and very low value in winter. There is no considerable difference in wind energy potential throughout the year with slightly higher speeds in autumn and winter months as compared to June–August speeds.

Table 1
Average, absolute maximum and absolute minimum temperatures in Lublin in the years 1981–2010 (IMGW, 2013).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average temperature (°C)	−2.9	−2.0	1.9	8.0	13.5	16.1	18.2	17.6	12.9	8.0	2.5	−1.5
Absolute maximum temperature (°C)	12.0	16.9	19.9	25.7	30.8	32.2	34.3	35.3	29.5	24.0	18.5	14.8
Absolute minimum temperature (°C)	−33.7	−26.4	−22.8	−7.0	−4.1	1.7	5.2	3.8	−1.9	−7.6	−18.1	−22.2