Concept of Energy Supply from Renewables for Greenhouse Roses Cultivation in Poland

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Abstract

Nowadays, worldwide problem is the struggle with global warming. The main source of the CO_2 are the fossil fuels. Due to this fact, Europe is trying to reduce the generation of energy from conventional sources with alternative ones. European Union members has to meet the requirements of the reducing the CO_2 emission and use the alternative ways of energy production. There is a significant amount of different ways to replace the conventional energy sources, possibly extracting the energy from nature as biomass, sun, geothermal and water, is an amazing concept.

The main goal of this thesis is to find the alternative ways of energy supply for the Greenhouse Roses Cultivation in Poland. Electricity and Heat necessary to run the farm are currently obtained from fossil fuels. In terms of sustainable development, it is still better to produce roses than to import them from abroad, due to the emission from transport. Firstly, will be presented the system describing electricity and heat demands, money that owner of the Greenhouse yearly spend for the energy, and emission of GHG. Followed by alternative ways of Energy production defined as Gasification of wasted roses and crops from the surrounding farms. At the beginning, the calculation of the energy production from wasted roses and crops was made leading to the next step, which was the description of the heat production based on gasification process, estimation of costs of such system. Last step will be the economic analysis of the current system and the system based on biomass gasification and comparison between the two.

1. Introduction

Today's energy production is mainly based on the fossil fuels. Their's destructive impact for the environment is commonly knows. However it is difficult to find alternative fuel with high energy potential as have, for instance, coal or petroleum oil and at the same time high availability of the source and quite low cost. This is the main reason why the fossil fuels have an advantage over renewables. However, today the awareness of the environment is growing. More and more people want to prevent environmental catastrophe and popularity of the renewable energy sources are rising. To reduce the GHG emission, alternative ways of energy production need to be found, with not only reducing the pollutions, but impact of mining and transportation for the environment need to be considered.

Gasification process is an example of the clean energy generation. To compare with the combustion, in gasification wider range of feedstock can be used. Despite the fact, that such process is still under the development, already large number of power plant generating clean energy, existing around the world. Using the biomass as a feedstock for the gasification is very common nowadays. Different types of biomass can be used as wood, crops or even municipal wastes. What contribute to the reduce CO_2 emission and resolve the problem with the landfilling wastes.

The object of problem is a Greenhouse Roses Cultivation in Poland, which consuming large amount of the energy from fossil fuels what has destructive impact for the quality of the air. The purpose of this work is to replace the conventional energy sources by the renewables through the gasification process of biomass. Feedstock that will be used are wasted roses and crops. Analysis of the current energy system and proposal of the system based on renewable with necessary equipment and economic analysis will be provided. Alternative way of energy production for the greenhouse is necessary in order to reduce the GHG emission from combustion process of coal and at the same time it would minimize the costs of the energy inputs. The question is if such investment is profitable and what will be the payback period. The aim of this work is also to increase popularity of such clean energy source among local farmers.

Fossil fuels are the main source of CO_2 emission. Dependently on the type of fuel different pollutants are emitted into the atmosphere. The cleanest conventional energy source is natural gas. The petroleum oil and coal contribute the most to air pollution. Burning coal, especially in the old and inefficient power plant located in Poland emits undesirable gaseous as: Sulphur dioxide, nitrogen oxides, carbon oxide, carbon dioxide and moreover, dust which contains heavy metals as: lead, zinc, cadmium, such gaseous together with the ones emitted from transportation sector are the main reason of the low emission and smog in the bigger cities. However, not only transportation and energy sectors contribute to the bad quality of the air. Manufacturing, cutting down the forests and lack of awareness of mankind are the cause of this problem too.

Due to this fact, European Union is fighting for the dissemination of concept of sustainable development, what means improvement the quality of life without any significant influence for the environment and ecological processes. Such concept is appealing; however following this idea is associated with many adversities, especially related to people's lack of care about the environment. The fossil fuels have an advantage over the renewable ones because of energy density and wide availability. Unfortunately, the formation process takes very long time. Predictions for the future saying that conventional energy sources will run out soon. The only solution to make the original source last longer is to enter to the market less expensive and alternative ones. Carbon originally has been present at our planet since early beginning. However, it was isolated and hidden below ground in order to make our atmosphere rich in oxygen. Burning the fossil fuels contributes to the significant rising the CO2 concentration in atmosphere. According to scientific, if this trend continue, the greenhouse effect lead to the climate change within century period of time and it will have a huge impact at our planet and living organism (ex. human, animals, food production or water supply), which is a global problem.

Energy Sector in Poland in significant part based on fossil fuels. Primary energy consumption in 56% is a coal. The electricity is, generated in 88% from coal. There was popular sentence associated with the polish energy sector, repeating by polish government: “Poland is a coal”. Coal mining achieved the highest level in 1980 – 195 million tons. After that, decreased due to the difficulties of extracting from the deeper layers, nevertheless extraction is still high: 2009 – 77.4 million tons. Today’s Poland need to deal with the problem of GHG emission, which main source is coal. It is not possible to make the Polish energy sector in 100% independent from coal, however emission can be reduced by the increasing the efficiency of the power plants, using the Carbon Capture Technologies or increasing energy production form the renewable sources. The solar prospective in Poland is low to compare with others countries. Large potential has wind power, especially in the northern part of the country, total energy produced from wind accounts for 173.5 MW and hydro power plants. Because Polish agriculture is highly developed, extraction energy from biomass has prospective. So far, there is just one biomass power plant established in 2013 and it is the largest plant in Europe producing electricity from the combustion process of biomass with the installed power capacity 205 MWe. Polish government has plans to implement new projects to decrease the dependency on fossil fuel as and at the same time improve the unfriendly environmental image of Poland in Europe due to the use of coal as a main energy source in national energy production.

2. Methods and Materials

In the study current system and system based on renewable was described. The description of current system based contains the following calculation:

The luminous flux and efficiency of lamps

$$\Phi V(lm) = P(W) \times \eta(\frac{lm}{W})$$

Where: ΦV(lm) is the luminous flux of the lamps, P(W) – power of lamp in Watts, η(lm/W) is a luminous efficiency of LED lamps using in Greenhouse.

In a form of graph, the electricity demands is presented for individual months. Due to the difference of electricity consumption between winter and summer periods, appropriate calculations connected with the amount of energy consumed by lamps and energy used by others processes taking place in the greenhouse was estimated.

Heated space design heat load

Design heat load of a space is calculated in accordance with the following equation:

$$\Phi_{HL,i} = \Phi_{T,i} + \Phi_{V,i} + \Phi_{RH,i} \text{ [W]}$$

where:

$\Phi_{T,i}$ – heated space design heat loss *i* through transmittance, transmission heat loss [W], $\Phi_{V,i}$ – heated space design ventilation heat loss *i* , ventilation heat loss [W],

$\Phi_{RH,i}$ – thermal input surplus necessary to compensate effects of weakening heating of heated zone *i* , heating-up capacity [W].

The following equation for calculating design heat loss of heated space and through transmittance has been given:

$$\Phi_{T,i} = (H_{T,ie} + H_{T,iue} + H_{T,ig} + H_{T,ij}) \cdot (\theta_{int,i} - \theta_e) \text{ [W]}$$

where:

$H_{T,ie}$ – transmission heat loss coefficient from heated space *i* to external environment *e* through building casing [W/K],

$H_{T,iue}$ – transmission heat loss coefficient from heated space *ie* to environment through unheated space *u* [W/K],

$H_{T,ig}$ – transmission heat loss coefficient from heated space *i* to the ground *g* in certain circumstances [W/K],

$H_{T,ij}$ – transmission heat loss coefficient from heated space *i* to adjacent space *j* heated to significantly different temperature, i.e. adjacent heated space in the same part of a building or in adjacent part of a building [W/K],

$\theta_{int,i}$ – design internal temperature of a heated space *i* [°C],

θ_e – design external temperature [°C].

Design heat loss factor through transmittance to environment through building casing

The transmission heat loss coefficient $H_{T,ie}$ is calculated in the following way:

$$H_{T,ie} = \sum_k A_k \cdot U_k \cdot e_k + \sum_l \Psi_l \cdot l_l \cdot e_l \text{ [W/K]}$$

where: A_k – building element surface area *k* [m^2],

U_k – thermal transmittance of building element *k* [W/m^2·K],

Ψ_l – linear thermal transmittance of the linear thermal bridge *l* [W/m·K],

l_l – linear thermal bridge length *l* between internal and external space [m],

e_k, e_l – correction factors on the grounds of orientation, taking into consideration climate impacts, such as : different insulations, moisture absorption through building elements, wind velocity and air temperature, if the impacts were not taken into account before when determining factor U_k

Approximate correction factors are given in National Annex to PN-EN 12831:2006 [33]: e_k = 1,0, e_l = 1,0, therefore equation (5.3) is simplified to:

$$H_{T,ie} = \sum_k A_k \cdot U_k + \sum_l \Psi_l \cdot l_l \text{ [W/K]}$$

In heat loss through transmittance calculations heat bridges can be taken into account with **simplified method**. It is accepting heat transmittance factor corrected value:

$$U_{kc} = U_k + \Delta U_{tb} \text{ [W/m}^2 \cdot \text{K]}$$

where: U_{kc} – corrected thermal transmittance of building element *k*, taking into account linear heat bridges [W/m^2·K],

ΔU_{tb} – correction factor depending on type of building element [W/m^2·K]

Heat loss through transmission to the ground factor

The transmission heat loss coefficient $H_{T,ig}$ is calculated in the following way:

$$H_{T,ig} = f_{g1} \cdot f_{g2} \cdot (\sum_k A_k \cdot U_{equiv,k}) \cdot G_w \text{ [W/K]}$$

Where:

f_{g1} – correction factor, taking into account external annual temperature fluctuation impact (according to national annex to PN-EN 12831:2006 [33] its approximate value is1,45),

f_{g2} – temperature reduction factor, taking into account average annual external temperature and design external temperature difference,

A_k – building element surface area *k* touching the ground [m^2],

$U_{equiv,k}$ – equivalent heat transmittance factor of building element [W/m^2·K].

G_w – groundwater impact factor.

Temperature reduction factor is determined in accordance with :

$$f_{g2} = \frac{\theta_{int,i} - \theta_{m,e}}{\theta_{int,i} - \theta_e} \text{ [-]}$$

where $\theta_{m,e}$ – average annual external temperature [°C].

Design ventilation heat loss is defined by the following equation:

$$\Phi_{V,i} = H_{V,i} \cdot \left(\theta_{int,i} - \theta_e\right) \text{ [W]}$$

where: $H_{V,i}$ – design ventilation heat loss coefficient [W/K],

$\theta_{int,i}$ –design internal temperature of heated space *i* [°C],

θ_e – design external temperature [°C].

Design ventilation heat loss coefficient is defined by the following relation:

$$H_{V,i} = V_i \cdot \rho \cdot c_p \text{ [W/K]}$$

where: V_i – ventilated air flow rate of heated space *i* [m^3/h],

ρ – air density in temperature $\theta_{int,i}$ [kg/m^3],

c_p – specific heat capacity of the air in temperature $\theta_{int,i}$ [J/kg·K].

Assuming stability of density and specific heat of the air as function of temperature and introducing to equation (5.14) ρ = 1,2 kg/m^3, c_p = 1005 J/kg·K, [26, 28], the following simplified equation may be assumed:

$$H_{V,i} = 0{,}34 \cdot \dot{V}_i \text{ [W/K]}$$

where: $\dot{V}_i$ – heated space volume flow of ventilated air i [m^3/h].

Surplus value can be determined in a precise way under the dynamic calculation procedures or calculated in a simplified way taking into account building type and heating time proportionally to heated spaces surface area, in accordance with the following equation:

$$\Phi_{RH,i} = A_i \cdot f_{RH} \text{ [W]}$$

where: A_i – heated space internal surface area i [m^2],

f_{RH} – heating factor.

Heating factor f_{RH} depends on the assumed temperature drop in time of heating weakening and heating time, in which the required internal temperature is to be obtained. Heating factor values are given in national annex to PN-EN 12831:2006

GHG emission

For the heating system, the emissions of the GHG was calculated from the equation:

E = B × W

Where E is Emission, B – Fuel consumption and W is Emission factor per unit of spent fuel. The emission factor was obtained according to the calculations for the combustion of coal by Polish National Center of Balancing and Emission Management.

Pollution	**Unit of the indicator**	**Fixed grate**				**Mechanical grate**
		Nominal thermal power of the boiler [MW]				
		≤ 0.5	**≤0.5÷≤ 5**	**≤ 0.5**	**≤0.5÷≤ 5**	**≤0.5÷≤ 5**
		Natural sequence		**Artificial sequence**		
SO_x/SO_2	**g/Mg**	16000 × s				
NO_x/NO_2		2200	1000	2000	3000	3200
CO		45000		70000	20000	10000
CO_2		1850000	2000000	1850000	2000000	2130000
TSP		1000 × A^r	1500 × A^r			2000 × A^r
benzopyrene		14				3.2

Tab1. Emission Factors for the coal

Where, A^r it is the Ash content expresses in [%], s – Sulphur content expresses in [%]

Amount of Energy and power of furnace

$E = M \times Q^r_i \times \eta$

Where E is Produced energy, M – Amount of used culm, Q^r_i – Culm heating value and η is furnace efficiency.
Annual power of furnace:

$P = (M/\text{amount of hours in year}/3600) \times Q^r_i \times \eta$

Primary and Final Energy Consumption

Final energy indicator determines annual demand for final energy per unit area:

$$EF = \frac{Ef}{A}$$

Where: EF – Final energy indicator, Ef – Final energy , A – Usable area

Primary energy indicator determines annual demand for non-renewable primary energy per unit area.

$$EP = \frac{Ep}{A}$$

Where: EP – Primary Energy indicator, Ep – Primary Energy, A – usable area

Depending on the type of fuel, the value of the final energy demand is multiplied by the coefficient of primary energy generation w_i

$$Ep = Ef \times wi$$

The individual types of fuel correspond with different coefficient of primary energy generation:

Way of energy supply	Type of energy carrier	wi
Local energy production in the building	heating oil	1.1
	natural gas	
	coal	
	lignite	
	solar power	0.0
	wind power	
	geothermal power	
	Biomass	0.2
	Biogas	0.5
Heating form plant with cogeneration	Coal or natural gas	0.8
	Biomass	0.15
Heating from heating plant	Coal	1.3
	Gas or heating oil	1.2
System power grid	Electric Energy	3

Tab.3 Coefficient of primary energy generation

Energy conversion efficiency is calculated from equation: $\eta = \frac{EF}{EP}$

Where: η - energy conversion efficiency, EF – final energy indicator, EP – primary energy indicator

To estimate the energy potential of wasted roses appropiate calculations was made, taking into account the weight, moisture content, heating value and average efficiency of the gasification process. The same procedure was carried out for crops, in order to find amount of this material necessary to cover the decoupling thermal energy.

Description of the system based on renewable based on selection of appropiate gasification equipment together with the cost estimation.

At the end the economic analysis was made in order to compare both systems and estimate the possible pay back time for such investment.

3. Results

Area of Greenhouse cover 7ha and is separated into two independent running farms. The case study includes 3.5 hectares area. According to the owner 20% out of 10 mln roses produced every year are wasted. During the night in the period between November-April, 1936 LED lamps provide the light essential for the roses growth. The luminous flux of all of the lamps is equal 196 300 000 lumens.

The electricity consumed every year, reaches amounts of 3290.859 MWh and costs owner €245016.94. As was mentioned before electricity is mainly used for the providing light in the period between November-April because nights are much longer during the wintertime, and roses need artificial light for the proper growth.

The surface of the walls and roof of the greenhouse: - A_k = 50875 m^2. Heat transfer coefficient for glass - U_k = 0.8 W/m^2K. Coefficient of thermal losses from the heated room to the surrounding through the glass walls - $H_{T,ie}$ = 40700 W/K. Transmission heat loss - $\Phi_{T,I}$ = 1831500 W. Ventilation heat loss - $\Phi_{v,i}$ = 53550 W. Coefficient of design ventilation heat loss - $H_{v,I}$ = 1190. Temperature inside - Q_{int} = 298 K. Outside temperature - Q_e = 253 K. Steam of ventilation air volume - V_i = 3500 m^3/h. Excess heat output - Φ_{rhj} = 1085000 W. Floor area of the greenhouse - A_j = 35000 m^2. Heating coefficient - F_{RH} = 31. Heat load - Φ_{hl} = 2970050 W what is 2.97005 MW

Furnace EkoFire has power 5MW and burns ever year 3000t of coal type culm 31. The emission of the GHG was calculated for this amount of coal and account for: CO_2 – 6390t, SO_x/SO_2 – 38.4t, NO_x/NO_2 – 9.6t, CO – 30t and TSP – 96t.

To provide cover electricity demands 568660.4kg of coal is needed. Knowing that 1GJ of coal produce 94600g during electricity production, 12510.53 GJ will produce 1344881.846 kg of CO2. According to the estimates presented above, the calculations of the emissions resulting from the combustion process of coal the total CO2 emission to cover the energy demands for the greenhouse is: 7734881.846 kg

Amount of energy produced annualy by furnace working with efficiency 80% is 14666.67 [MWh] and boiler works with average power 1.67428 [MW], and average power during winter time is 4.1857 [MW]. Usual temperature inside furnace reach 500-800ºC, water leaving the furnace has temperature of 85ºC.

Primary Energy Consumption from coal per square meter and per year period of time is equal 0.4609 MWh whereas Final Energy per square meter is 0.419 MWh. The energy conversion is equal 90%. For the Primary Energy Consumption associated with electricity, the Final Energy Indicator is equal 0.94 $[\frac{MWh}{m^2 \times year}]$ and the Final Energy Indicator: 2.82 $[\frac{MWh}{m^2 \times year}]$. The energy conversion is 33%.

2-3 mln pieces of roses are wasted every year. According the calculations the weight of wasted roses is around 60t and contain 285.6 MWh of energy. Taking into account that efficiency of the gasification process is 71%, the amount of energy that can be obtained from thermochemical conversion of wasted roses is 202.78 MWh. The missing part of the energy to cover the heat demand can come from crops. Calculations shows that around 5342.6 tons of crops are needed to cover the heat demands. According to the calculations of CO_2 emission importing roses from different countries, for instance, Portugal would be more sustainable. Amount of CO_2 emitted by 240 tracks to transport 10 mln pieces of roses is 1147440 kg and the total CO_2 emitted by greenhouse is 7784881.846 kg.

System based on gasification of biomass as wasted roses and crops from the surrounding, needs to consider appropriate steps. First, one is the receiving and storage. In the case of greenhouse wasted roses are collected at the farm, and crops will be imported from the agricultural area located near to the greenhouse. Biomass will be storage in silo buffer. Next step is the processing of the biomass. Mainly chopping and drying, to get rid of undesirable moisture. When biomass is prepared, conversion process occurred. This step will take place in the boilers – fluidized bed gasifier with operating temperature between 790-1400ºC with the 5MW capacity and gasification efficiency around 80%. Produced gas need to be cleaned from impurities using the ash removal, quench, bag filter, wet scrubber and heat exchanger. Gasification system produces power and steam in gas turbine combined-cycle configuration.

Economic analysis show that cost of the electricity is €245016.94 per year and the cost of energy necessary to provide heat is €473700. All together owner of the greenhouse need to spend every year €718716.94. The gasification system together with necessary equipment would cost €1747325.88. The investment by itself is profitable for owner; however the operating equipment costs are high €899283.26/year. It means that the alternative energy supply system wouldn't be profitable without co-financing from government.

Conclusions

Greenhouse roses cultivation has a vast energy demand what contribute to the CO2 and GHG emission in Poland. Due to the European Union restriction, alternative ways of energy production must be applied.

Greenhouse energy demands reach the highest peak in the period from 1st of November until the end of April, because winter period cannot provide a proper amount of natural light, artificial one must be provided for the proper roses growth. Differences between this periods are huge: 3142.635 MWh – for period November – April and 148.224 MWh for period May – October.

Electricity is provided from the PGE power plant in Rzeszów, which has modern and efficient electricity generating system powered by natural gas with the cogeneration. However, the losses for processing and transmission are greater than electricity consumption. Nevertheless, the fuel that runs the power plant in Rzeszów is natural gas; it means the electricity production in power plant has a less harmful impact to the environment than the process of burning the coal in the greenhouse to provide heat.

Heated space design heat load are 2.97 MW and are calculated for the winter period when the average temperature outside is -20°C. Such calculations give information about heat demands in the winter period and the power of the thermal system that is required to cover energy needs.

The amount of coal burning every year is massive, the quantity of the GHG emission indicate that combustion of coal has a destructive impact on the environment, especially the amount of CO_2 emits into the atmosphere every year.

Every year 3000t of coal is used with the heating value 22MJ/Kg. Furnace annually produce 14666.67 MWh and works with average power 1.67428MW. Average power during the winter period accounts for 3.34856 MW; it means that the stove does not use its power potential, which is 5MW, however in Poland temperature can sometimes drop to -30°C, due to this fact thermal system needs to have higher potential than the average power.

Calculations of the primary and final energy from coal indicate that energy conversion is equal to 90% what is higher than the energy conversion for electricity (33%). Such difference results from the fact that electricity production is connected with significant losses for the transmission and processing.

Energy potential from wasted roses is not that great. According to the calculation, the Energy that can be obtained from the number of roses that are wasted per year is just 285.6 MWh. However, it is not just about the energy potential, but also the problem with the utilization of wasted roses could be resolved.

Moreover, the fact that Greenhouse is located in the agricultural area where a significant amount of farmers is willing to get rid of crops. Missing part to fulfil the heat demand can be obtained from the gasification of crops. According to the estimates apart from 60t of wasted roses, 5342.6t of crops is needed. According to calculations, transporting roses from different countries would be more profitable regarding sustainable development. However in calculations are not assuming the energy demands for the cold storage, especially in case of transporting from hotter countries.

Economic analysis says that the amount of money that owner spending per year for the coal and electricity is €718716.94. The cost of investment for the gasification of biomass is estimated at €1747325.88. The investment itself is not that big, but the annual operating cost is high. Due to this fact, the investment is not profitable for the owner. However, taking into account the growing coal prices tendency, rising the popularity of the renewable energy sources and European Union restriction on CO_2 emission, is highly likely to get some co-financing from the Polish Government. Such an investment would bring profits not only to the greenhouse but surplus electricity would be used by local farmers to power their homes. This is an attractive idea, however, requires additional research and findings. Such an idea would be a good option for the new greenhouse, where the owner has to choose thermal system anyway.