Environmental and Climate Technologies
2018, vol. 22, pp. 118–131
doi: 10.2478/rtuect-2018-0008
https://content.sciendo.com

The Assessment of Cost of Biomass from Post-Mining Peaty Lands for Pellet Fabrication

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Abstract **– Post-mining peaty lands were formed as a result of peat extraction on drainage wetlands areas. After peat extraction has finished, the biggest problem is to use these lands for other purposes. This type of soil is very heterogenic, poorly drained, with massive structure and poor contents of nutrients. Thus it is very problematic to grow traditional agricultural crops that have special requirements for soil fertility on those areas. The area of post-mining peaty lands in Belarus alone is about 200 000 hectares. One of the perspective directions of post-mining peaty land use is re-wetting and production of biomass for energy purposes. The goal of our research was to estimate cost of biomass of natural grass and willow wood from short rotation coppice (SRC) plantations which may be used as feedstock for pellet production. The dominant wetland species were common reed, cattail and sedges. SRC plantation was planted on degraded soils. The prime cost of biomass which was produced on the base of natural grass was from 10.4 euro per ton to 13.2 euro per ton, depending on technology. The prime cost of willow biomass was 24.1 euro per ton. Introduction of taxes will increase cost of biomass by approximately 60 %. The calculation of economic efficiency identified that biomass as a feedstock for pellet production on post-peat mining areas may be a profitable direction for peat factory function and providing the sustainable development of local communities. Additional profit may be obtained as a result of saving carbon quotas. The share of CO_2 emissions from fossil fuel for grass biomass production is about 2 % from the total volume of CO_2 during renewable biomass utilization for energy and for chips production from willow wood – 6 %. The diversification of biomass sources enables to use feedstock for a pellet line in the winter and spring which is in the heating season.**

Keywords **– Composite pellets; economy; prime cost; renewable energy; wetlands.**

1. INTRODUCTION

Post-mining peaty lands form on drainage wetlands areas. In the Republic of Belarus wetlands formerly covered about 15 % of the country's area, extending to almost three million hectares [1]. Wetlands have a very big value for greenhouse gas control [2]. After peat excavation is finished, the biggest problem is using these lands for other purposes. This type of soil is very heterogenic, poorly drained, with massive structure and poor contents of nutrients. As a result, soil conditions immediately after peat harvest has been completed are not favorable and it is impossible to grow any cultural plants for several years [3]. Nowadays, the area of post-mining peaty lands in Belarus alone is about 200 000 hectares and a problem is development of optimal methods for using these soils. One of the perspective directions is rewetting of post-mining peatlands that stimulate growth of common reed, cattail and others grasses which may grow in natural conditions, and also

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improve conditions for cultivation of other plants, including trees [4]. There is special term – paludiculture in nowadays practice [5]. Paludiculture (Latin 'palus' = swamp) are land management techniques that cultivate biomass from wet and rewetted peatlands under conditions that maintain the peat body, facilitate peat accumulation and sustain the ecosystem services associated with natural peatlands [6]. Biomass from the wetlands area may be used for renewable energy purpose. This direction of paludiculture has not only economical, but also ecological profit because it helps to stop peat oxidation and to improve peatlands fertility [7]. Paludiculture may be introduced not only in natural peatlands but also on the degraded peaty and peat post-mining areas. The dominant natural species on drained wetlands areas as a rule is the common reed. It is a tall, thin, highly productive grass which was mostly distributed in Europe [8]. Reed has a market interest in Europe and nowadays efforts to rewet and restore drained wetlands increased the reed growing area [9]. The perspective culture for peat post-mining areas is short rotation coppice (SRC) trees, including willow [10]. Short rotation coppice is a term used for fast growing trees that may reach the height of 4–5 meters in 3 years. The plantation of SCR trees may last over a period of 20–25 years with harvesting of wood every 3–5 years. The basic direction for SRC tree use is bioenergy [11]. Energy forest plantations nowadays have been introduced in Sweden [12], Poland [13], Germany [14] and other European countries.

Trees, common reed and other grasses are perspective sources of biomass from wetland areas that potentially may be used for different purposes, such as ethanol, biogas, pellet or briquette production. For instance, an experiment devoted to common reed using for bioethanol production was fulfilled in China [15]. The complex investigations concerning biomass pellets production prepared from six different biomasses: bamboo sawdust, eucalyptus sawdust, corn cob, rubber tree branches, palm fiber and lippia grass were fulfilled in Thailand [16]. The results identify that it is possible to produce pellets from biomass which were milled into small particles less than 5 mm by using the hydraulic press. Further investigation shows that manual hydraulic press may be also successfully used for bio-briquettes production from selected biomass wastes [17]. Agricultural products and residues may also be used for biogas [18].

The reclamation of post-mining peaty lands and their use for energy purposes has both environmental and financial profit. The problem is low fertility and a very large diversity of these type of soils. Our research has been focused on finding the best options for biomass production depending on environmental conditions. The purpose of our investigation was to estimate prime cost of biomass of natural grass and willow wood from SRC plantations which may be used as feedstock for pellet fabrication.

2. METHODS AND PROCEDURES

The experimental plots were established on degraded post-mining peaty soils situated around Lida peat Factory (LPF), one of the biggest companies for peat briquette production in Belarus. The soils in the area of experimental fields are different in terms of nutrients, depth of peat layer, level of peat decomposition, water regime and underground water level [19]. In accordance with these factors, several basic places were chosen for estimation of natural grass biomass.

The plantation of willow clone Jorr (*Salix viminalis*) has been planted on post-mining peaty soils with the following characteristics: pH – 6.05; peat decomposition – 65 %; contents of P_2O_5 – 20.25 mg/kg; NO_3 – 79.40 mg/kg; K_2O – 106.40 mg/kg.

The experiments were established in four randomized complete block design. The size of experimental plot for grass was 10 m^2 and for willow 50 m^2.

The average yield of grass biomass was about 10.5 DMg ha^{-1} and wood biomass 9 DMg ha^{-1} per year.

The biomass water contents and calorific value of dry biomass were estimated in a laboratory. Statistical analyses were done using *Statistica* 10 and *SigmaPlot* 11.2 programmers.

For biomass production from natural grass two basic technologies were estimated:

- Harvesting by tractor with trailed rotary mower and followed by drying and baling biomass in field, and transportation to pellet line (technology "A"). The average dimensions of bale after pressing are 4200·2400·1600 mm. In accordance with technology it is necessary to include additional milling (premilling) of hay before loading it into the pellet production line;
- Harvesting biomass by self-propelled harvester with simultaneous chopping and uploading, followed by transportation to pellet line and drying in the peat factory (technology "B"). The moisture contents in biomass after harvesting in accordance with this technology were 25–35 %.

In agricultural practices the special machines and equipment were used which were designed and adapted for wetlands areas [20]. For instance, the unique tractor MTZ-952 was designed for mowing and transporting, and a special harvester was designed on the base of FORTSCHRITTE 281 for grass chopping in accordance with technology "B".

These machines were equipped by twin wheels which let them successfully cross wetlands and to overcome different obstacles such as hills, ditches, pits and so on.

The calculation of CO_2 emissions and economy assessments of energy production from wetlands biomass are based on the result of life cycle assessment of biomass production which has been done in accordance with ISO 14040 standards [21], [22].

The standard methods were applied in our calculations. Emissions of carbon dioxide are calculated according to the formula:

$$M_{\mathrm{CO_2}} = 10^{-3} \cdot 3.667 \cdot E_{\mathrm{te}} \cdot K_{\mathrm{C}} = E_{\mathrm{te}} \cdot K_{\mathrm{CO_2}}, \quad (1)$$

where

3.667	Factor equal to the ratio of the molecular weight carbon-dioxide and carbon genus (44 and 12 respectively);
E_{te}	Consumption of fuel in total energy units;
K_C	Carbon content for a given fuel, kg/GJ;
K_{CO2}	Carbon dioxide emission factor for this type of fuel, t/GJ, which should be applied in the preliminary estimates of changes in the level of greenhouse gas emissions and compliance with the calculated fuel characteristics.

For biomass, the prime cost calculation depreciation (amortization) of equipment was calculated on the basis of current financial practices of LPF. As a rule, the period of use of machinery (tractors, sprayers, trailers, crushers of biomass, etc.) was calculated for 10 years. The amortization of capital equipment (buildings), like shelter for pellet line was calculated for 20 years. Basic costs have been based on the prices prevailing in Belarus: payment of workers – 2.5 euro per hour; fuel cost – 0.8 euro per litre; electricity cost – 0.1 euro per kW, land tax – 0.5 euro per hectare. Payment of workers per hour was calculated in accordance with the average salary for agricultural practice. The average monthly salary in the Belarusian industry is about 500 euro for a forty-hour work week. In agriculture, the average salary is a bit less in comparison with industry. Land tax in Belarus depends on the quality of soils. Post-mining peaty areas are poor lands with low fertility.

3. Results

Biomass which may be used for pellet fabrication should be up to special standards. The humidity of biomass should be 10–14 % with sizes of particles no more than 4 mm for production of the industrial pellets and no more than 1.5 mm – for production pellets of the first class. These standards may be gained both from wood and from natural wetlands grass. Nevertheless, different technologies of biomass production should be used depending on the field conditions. Technology "A" is a reasonable choice for rugged terrain with bushes, ditches, hummock and so on.

For this type of wetlands area, a unique tractor MTZ-952 was designed for mowing and transporting (Fig. 1). And special harvester on the basis of FORTSCHRITTE 281 was designed for grass chopping in accordance with technology "B". The twin wheels tractor is much more adapted for hard conditions of harvesting in comparison with FORTSCHRITTE 281.

Fig. 1. Twin wheels tractor MTZ-952 with a trailed rotary mower KDP-310 in the field.

Technology "A" consists from 7 basic operations (Fig. 2). The technological chain was divided on several unit processes and prime cost of all operations has been calculated. The prime cost of biomass of natural grasses which were prepared for pellet production on the base of this technology was 13.20 euro per ton. The biggest cost item is electricity consumption for milling. The length of grass after harvesting by mower may be 1 meter or more which are not up to standards for pellet production. It is necessary to use a lot of electric power for milling of biomass after mowing and baling. As a result, the share of milling in the prime cost structure was more than 50 %.

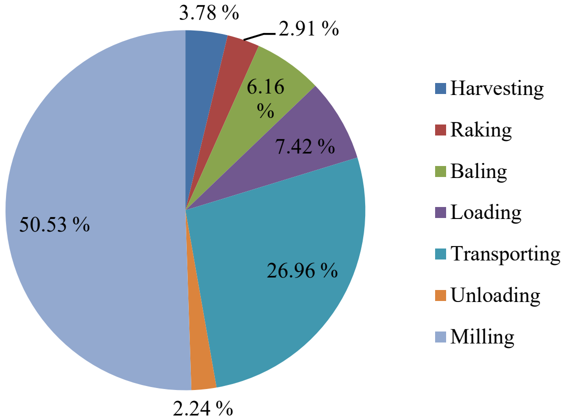

Fig. 2. The prime cost structure of biomass of grass (Technology "A").

The technology "B" is better for comparatively flat and dry plots of wetlands. Technological chain was divided on 5 basic unit processes (Fig. 3) and prime cost of biomass was 10.39 euro per ton.

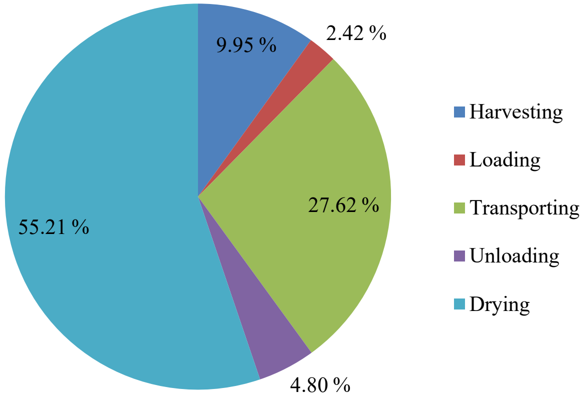

Fig. 3. The prime cost structure of biomass of grass (Technology "B").

The biggest cost item for technology "B" is drying. This item share was about 55 % in prime cost structure. Biomass drying is a necessary unit process for technology B, because the moisture of biomass for pellets must not be higher than 14 % but biomass moisture after harvesting by FORTSCHRITTE 281 was about 30 %. The drying module was assembled in the system of mini-peat factory (complex) that usually produced peat briquettes and the big share of cost was for amortization of drying equipment.

The calculation of the wood biomass cost has been made on the base of technology which was developed for SRC (short rotation coppice) willow growing [23]. Technological chain was divided in several sections and all operations were calculated and summarized (Fig. 4).

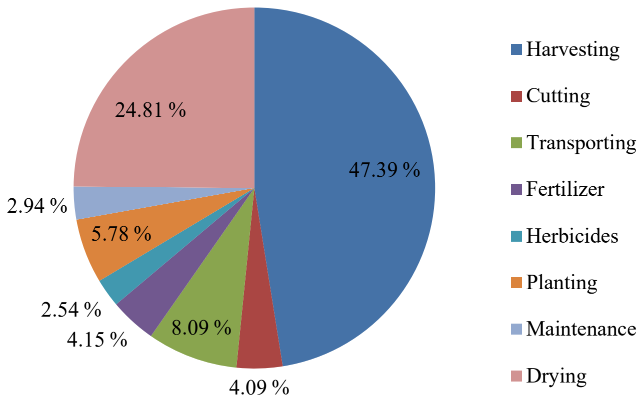

Fig. 4. The prime cost structure of willow wood.

In accordance with calculations, the prime cost of willow chips with humidity 14 % and size of fraction up to 4 mm was 24.1 euro per ton. The biggest share of prime cost in willow wood structure is related to harvesting (47.4 %). This fact may be explained by the high cost of special harvester for willow plantations (about 120000 euro) [24].

For the total economic assessment, the important aspect is calculation of greenhouse gases as a reason for climate change. In accordance with Kyoto protocol the emissions of greenhouse gases in the process of renewable biomass utilization for energy is not taking into consideration the definition of carbon quotas. Biomass, including grass residues and wood, it is "neutral" fuel for climate change. As a result of photosynthesis the plants may accumulate carbon dioxide and an equivalent volume of carbon dioxide can be emitted into the air during biomass combustion for energy production. It is necessary, however, to take into consideration that greenhouse gases may emit into the air as a result of fossil fuel use during the life cycle of biomass production. We should use diesel for planting and harvesting, electricity for drying or milling and so on. Of course greenhouse gases from fossil fuels should be included in carbon calculation and excluded from the total balance of greenhouse emissions of the life cycle of biomass. The basic greenhouse gas which is emitted into the air as a result of biomass production is carbon dioxide (CO_2).

The emissions of CO_2 as a result of firing 1 kg of fossil fuel are:

– Diesel – 2.6 kg;
– Gas (for electricity production) – 2.29 kg;
– Peat – 1.82 kg.

The structure of CO_2 emissions from fossil fuel for technology "A" is presented in Fig. 5.

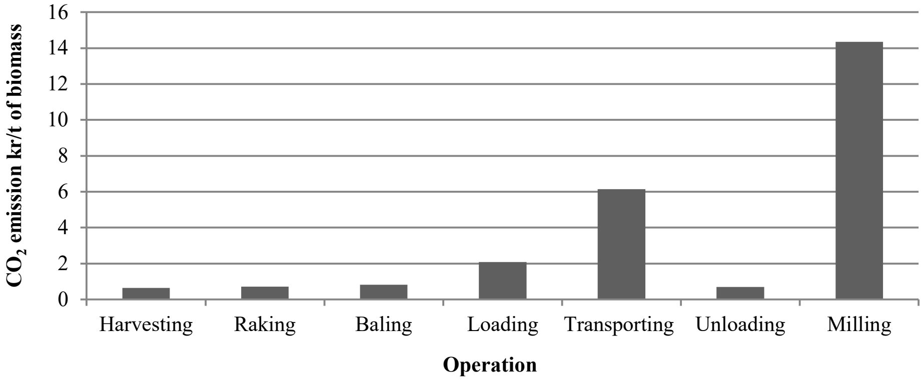

Fig. 5. The structure of CO_2 emission from fossil fuel (Technology "A").

The basic volume of CO_2 is released during transporting and milling of biomass. Transporting is an operation for transferring of biomass in the field and from field to the pellet line. Consumption of fuel (diesel) for the tractor MTZ-952 in transport regime is 6.0 l/hour and for the tractor with a trailed rotary mower KDP-310 – 6.5 l/hour. Emissions of CO_2 during the milling operation is connected with electricity consumption. The basic source of fossil fuel for electricity production in Belarus is natural gas. The total volume of CO_2 emissions from fossil fuel for technology "A" is 25.5 kg for production of one ton of biomass.

The structure of CO_2 emissions from fossil fuel for technology "A" is presented in Fig. 6.

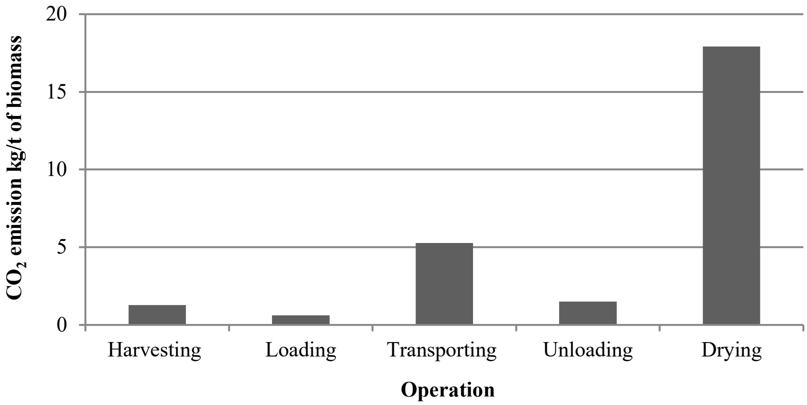

Fig. 6. The structure of CO_2 emission from fossil fuel (Technology "B").

The basic volume of CO_2 is released during drying. The humidity of grass biomass immediately after harvesting is 30–35 %. It is necessary to spend fossil fuel for drying because optimal humidity of biomass as for boilers operation as for pellet production should not be higher than 10–15 %. The factory uses peat for drying of biomass and total volume of CO_2 emissions from fossil fuel for technology "B" is 26.6 kg for production of one ton of biomass.

The basic volume of fossil fuel for wood chips production is connected with harvesting and transportation. Willow wood for energy is harvested every three years of life cycle of plantation.

The average volume of CO_2 emissions from fossil fuel for production of one ton of chips from willow wood is 78.7 kg.

4. DISCUSSION

The prime cost of biomass production for pellet depends on several factors, including yield of crops, technology of production and calorific value of biofuel. The yield of wetland grass biomass on our experimental plots varied from 8.1 to 14.0 DMg ha^{-1}. The significant fluctuation of wetland biomass productivity was also identified in other research and this aspect is directly connected with natural conditions of the area. For example, in China dry biomass yield of common reed was in the range of 3.8–36 Mg ha^{-1}, and location was the significant factor [15]. These results are comparable with results of our experiments. The yield achieved on non-agricultural land for reed canary grass in Scotland was from 4 to 7 DMg ha^{-1} [25]. During this period two harvests were taken and there was no additional fertilization, apart from the limited subsequent nutrient availability.

The productivity of giant reed is several times higher in comparison to common reed. Such, in Mediterranean climatic conditions, giant reed productivity showed a yield from 49 to 39 t ha^{-1} per year [26]. The technology chain of giant reed's cultivation consists from 25 unit processes including fertilizer and pesticides application. This is the reason for the significant difference in productivity between common reed and giant reed. The yield of willow wood on degraded peaty soils in our experiments was 8–10 of DMg ha^{-1} per year. The ordinary yield of willow for mineral fertile soils varies from 10 to 15 DMg ha^{-1} per year [27]. It is higher than yield of willow from wetlands in our experiments, but post-mining peaty lands are not suitable for ordinary agricultural crops and using of degraded soils for SCR crops also has a positive environmental effect.

Pellet production of high quality defines special requirements for feedstock. The key positions here are moisture and size of fraction of biomass. For biomass production from natural grass we tested 2 technologies, which may be used in practice depending on field conditions. The required standard of humidity of grass biomass for technology "A" was achieved in the field as a result of using rakes without special drying. Tearing is a special agronomy operation for grass drying. It is necessary to turn over grass not less than twice to get humidity at a level of no more than 15 %. Double tearing was admitted as an optimal technological process for our calculation. But the problem for technology "A" is the big size of biomass fraction. It was necessary to use additional milling and this constitutes as a large item in the structure of biomass cost (Fig. 1). In accordance with technology "B", the moisture of biomass for pellet production after the field was 25–35 %. It was necessary to dry biomass additionally before transferring it to the pellet production line. The cost of drying was not so high because the peat factory uses local resources (peat) for energy supply which is cheaper compared to gas or oil. In addition, drying was the basic item in prime cost structure (Fig. 2). The technology of SRC willow production required a special planter and harvester. Harvester for SRC plantations is a specific machine which cannot be used for other crops. It means that annual amortization costs for the harvester must be divided per hectare of plantation. Our calculations have been made for the base area of plantations – 100 hectares, but machine may harvest 3–5 hectares per day and 200–300 hectares per year. In that case, the rates of amortization and prime cost of biomass per hectare will decrease. Another big item in the structure of the prime cost of wood is also drying, because the moisture of willow wood after harvesting was 40–50 %.

Finally, in our experiments the prime cost of grass biomass was 10–13 euro per ton and wood biomass was 24 euro per ton. In our calculations taxes and indirect costs were excluded because biomass should be used for proper demands of peat factory for pellet production. In Belarus the producer should pay the following taxes: social protection fund (34 % of salary); value-added tax (maximal 20 % of proceeds); income tax (18 %). Indeed, taxes depend on proceeds, income and, consequently, on the market which is very unstable and cannot predicted for raw biomass in Belarus. The cost of wood chips may fluctuate from 30 till 55 euro per ton. There is no real market for grass biomass for energy. As a rule, producers sell grass biomass as hay or silage as forage for livestock. In the example of wood chips, if the market cost will be 50 euro per ton, the total taxes are 9–11 euro. Administrative costs for a peat factory constitute 20 % of the prime cost – 6 euro for ton of wood chips. As a result, the cost of biomass will increase by 60–65 % after taxes and administrative cost calculation.

For correct comparison of biomass prime cost it is necessary to take into consideration calorific value. The average calorific value of dry grass biomass obtained in our experiment was about 15.5 DMJ kg^{-1}. It is comparative to results of other researchers. For example, in experiments which were fulfilled in Latvia, the calorific value of reed biomass depended on the time of harvesting [28]. And the highest calorific value was observed for grasses which were harvested in spring – 19.0 $DMJ \cdot kg^{-1}$. The calorific value of dry willow wood in our experiment was about 18.5 MJ kg^{-1}, which is comparative with results of other experts [29].

The prime cost of energy unit which may be gained from grass biomass in our experiment was 0.78 €/GJ (Technology "B") and 0.99 €/GJ (Technology "A"). This is several times lower in comparison to energy costs for agricultural grass. Rosenqvist and Nilsson [30] calculated that the prime cost of energy from reed canary grass was 6.4–7.0 €/GJ, and from miscanthus – 7.9–8.4 €/GJ. The close results were obtained in Poland, Northern Ireland and other EU countries [31]–[33]. Prime cost of energy from willow wood in those experiments was about 4–5 €/GJ, which is 3 times higher in comparison to our results (1.5 €/GJ). In any case the prime cost for biomass produced from grass in the frame of technology "B" is lower than for technology "A" and cheaper in comparison with willow wood. Nevertheless, all methods of biomass production from wetlands areas are interesting. The tractor with twin wheels is more passable as compared to the FORTSCHRITTE 281 harvester. It is possible to mow natural grass from more wet areas. Willow plantations may be established in the areas which are not suitable for natural grass. Another advantage for using several sources of biomass is in regard to the logistical issue of pellet line supplying. The biomass after grass chopping should be used in several days, but it is possible to conserve hay and wood biomass for several months under a shelter. In that case it is possible to use feedstock for the pellet line in the winter and spring time.

In accordance with practical experience, the share of biomass feedstock in the structure of pellet prime cost is about 33 % [34]. It means that the projected prime cost of pellets for Lida Peat Factory that will be produced from biomass on wetland areas are 31.2 euro per ton (grass, technology "B"), 39.6 euro per ton (grass, technology "A"), and 72.3 euro per ton (willow wood). It is lower compared to the prime cost of pellets that was produced from the hay of agricultural crops 90–95 euro per ton [35]. Introduction of taxes will increase cost of pellets approximately by 60 % and the cost of pellets from grass is 49–63 euro per ton and from wood 115 euro per ton.

The market price for pellets is very flexible and depends on fossil fuel costs and other factors [36]. In Belarus the market cost of wood pellets is about 90–130 euro per ton. In Europe wood pellets prices are varied in the frame 100–150 euro per ton [37]. For example, an average price of pellets in 2017 in Finland was 187 euro per ton [38]. In USA pellets price market is gradually increasing and price in 2016 was about 305 euro per ton [39]. This data suggests that pellet production not only from grass but also willow wood biomass may be profitable in the future for peat factories.

Additional profit may be obtained as a result of saving of carbon quotas. In accordance with calculations, the share of CO_2 emissions from fossil fuels for grass biomass production is about 2 % from the total volume of CO_2 during renewable biomass utilization for energy. The positive balance of CO_2 for the life cycle of grass will be 1273–1275 kg per ton of biomass. The share of CO_2 emissions from fossil fuels for chips production from willow wood is about 6 % from the total volume of CO_2 during biomass utilization for energy. The positive balance of CO_2 for the life cycle of willow wood will be 1221 kg per ton of biomass. The cost of carbon quotas on the market varies from 20 to 25 euro per ton [40]. Therefore, the additional profit in conditions of emissions trading may be 25–32 euro for ton of grass biomass production and 24–30 euro for ton of willow wood production.

5. CONCLUSION

The field experiments were established in the area of post-mining peaty lands close to the Lida Peat Factory which is the biggest peat briquette company production in the region. Nevertheless, nowadays LPF faced to peat volume decreasing and in nearest future the problem should be more actual. As a result, some economic and social problems will arise. Decrease in peat briquettes production will dramatically change local living standards and employment opportunities. The sustainable functioning of LPF may continue on the basis of new and renewable sources of biomass. It was established that biomass from natural grass and willow wood may be added to peat for production of composite briquettes and pellets. The economic assessment shown that biomass production from wetland is perspective direction of renewable bioenergy. The prime cost of biomass which was obtained on wetland areas (10.4–13.2 €/ton of grass biomass, 24.12 €/ton of wood biomass) is lower in comparison to agricultural grass. The projected calculated prime cost of pellets which will be produced from wetland biomass is 31–40 euro per ton for grass and 72 euro per ton for willow wood. Introduction of taxes will increase the cost of pellets approximately by 60 % and the cost of pellets from grass is 49–63 euro per ton and from wood is 115 euro per ton. The market price of wood pellets is flexible and in Belarus it may vary from 90 to130 euro per ton, in Europe and USA 100–150 euro per ton and more. It means that pellet production from grass and willow wood biomass is a profitable direction for peat factories. Additional profit may be obtained as a result of saving of carbon quotas. In accordance with calculations, the share of CO_2 emissions from fossil fuels for grass biomass production is about 2 % from the total volume of CO_2 during renewable biomass utilization for energy and for chips production from willow wood – 6 %.

Different technologies of biomass production should be used depending on field conditions. Technology “A” is a reasonable choice for rugged terrain with bushes, ditches, hummock and so on. Technology “B” is better for comparatively flat and dry plots of wetlands. Willow plantations should be planted on comparatively fertile plots with a high level of peat decomposition and good water regime. The diversification of biomass sources enables to increase time of pellet production and to improve the logistics of pellet line supplying. The biomass after grass chopping should be used in several days, but it is possible to conserve hay and wood biomass for several months under a shelter. In that case it is possible to use feedstock for the pellet line in the winter and spring which is time that is in the heating season.

ACKNOWLEDGEMENTS

This paper is based on investigations performed within the "Wetland Energy"-project funded within the EU-Aid Programme (DC NV/2010/220-473).

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