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Aspects of using wood biomass for energy production

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Abstract. This article presents the most important aspects relevant to forest-derived biomass utilization for the purposes of energy production by professional energy providers. The issues discussed here are divided into four groups: environmental, social, economic and technological aspects of biomass utilization in energy production. The environmental part focuses on the effects of intensive use of leftovers from timber harvest on forest ecosystems as well as the problem of ash utilization. Economic and social problems include the costs of energy production from timber, consequences of intensified fuel wood demand for the state of the timber and paper industry as well as the impact on the labor market. The technology section of the article covers questions related to the harvest and transport of forest-derived biomass.

We conclude that, before regarding it as an energy source, wood should be mainly used for the production of timber due to the necessity and difficulty of considering all of the above-mentioned diverse aspects of energy production. Wood should be used for the production of energy only after its usage as timber products and their recycling.

Keywords: fuel wood, energy policy, climate policy, timber industry

1. Introduction

Wood had been a primary source of energy and construction material up until the middle 19th century. Its economic significance was changed by the industrial revolution, when there was a rise in demand for fossil fuels. The advance of industrial processes resulted in the production of new construction materials substituting wood.

The situation changed when negative effects of industrialisation on the natural environment were observed. From 1970s, protection of the natural environment became especially important, which was reflected in such reports as the Rome Club Report (1972) as well as numerous documents and international agreements, such as the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change (1992) or Kyoto Protocol (1997).

The above-mentioned international initiatives opened up new roads for further development, which would allow balancing economic development with respectful protection of the natural environment and human needs. Balancing various needs is possible within a framework of sustainable development, although from time to time the probability of its implementation while maintaining the current tempo of economic development accompanied by the constant growth of human needs, including energy demand, is being questioned.

Although there is no certain estimate of direction or the scale of climate change, this issue is difficult to ignore, which prompts the necessity to replace fossil fuel energy sources by energy from low-emission renewable energy sources[1]. A similar movement could be also observed in Poland from 2005, which resulted in a continuous growth of biomass quantity used for the production of electric ener-

[1] Energy use directly transforms into emission of greenhouse gases. Annual energy use by a of a developed country is from 150 to 300 GJ per capita, which corresponds to the emission of 8–20 tons of CO_2. In Poland, the average annual energy use is about 100 GJ/year per person (Gostomczyk 2010).

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gy as well as heat. Despite many organisational, economic and technological limitations related to the use of biomass for energy purposes, the energy sector became interested in the use of this type of fuel (Budzyński and Bielski 2004). Among the most important factors that resulted in this were the possibility to quickly adjust the technological process in coal stoves for burning biomass, as well as political support for such activities and also conviction in their large potential for the energy sector, which in Poland is estimated to be 895 petajoules (PJ or 10^{15} J; Jasiulewicz 2010).

In March 2007, the European Union (EU) Council adopted general targets for its energy and climate policy by 2020, or the so-called '20–20–20' targets:

– reaching a 20% reduction in EU greenhouse gas emissions from 1990 (30% in the case international agreement on this can be reached in the meantime);

– raising the share of EU energy consumption produced from renewable resources to 20%, including the increase to a minimum 10% use of biofuels within the general consumption of gasoline and diesel fuel used by transport around the EU;

– 20% improvement in EU's energy efficiency (Energy Policy 2009).

The European Parliament and Council Directive 2009/28/WE from April 23, 2009 is the directive supporting the use of energy from renewable sources, which amends and repeals the previous directives 2001/77/WE and 2003/30/WE. The Directive 2009/28/WE establishes, among others, a common framework for the promotion of renewable energy, defines obligatory national targets in relation to the overall share of renewable energy in the bloc's final energy consumption and also in relation to the share of the renewable energy in the transport sector, as well as criteria for the sustainable development of the biofuel and bioliquid market. On the basis of the above directive, Poland by 2020 has to produce a minimum 15% of energy from renewable sources within its final energy consumption (Directive 2009/28/WE).

The evaluation of forest biomass use for energy purposes indicates significant environmental benefits, especially through its effect on carbon balance. However, the detailed analysis, which takes into account economic and social aspects as well as costs, does not allow giving a straightforward positive rating to practices used by professional providers of energy originating from biomass sources.

The goal of this publication is to present, based on a literature review (including official documents), the most important conditions and effects of using forest biomass for energy purposes by professional energy providers such as industrial plants whose basic activities include the production and distribution of electric energy. The literature on this topic is quite extensive, so in order to present many discussed problems and aspects related to the examined questions more clearly, the publication divides the topics into four groups: environmental, social, economic and technological. The article covers the geographical area of Poland with several references to other European countries, where it appeared to be significant. The current study does not give a complete review of this complicated and diverse question; however, the goal of this article is to highlight the most important problems based on the analysis of the presented information (research results and estimates) covered by forest, agricultural, technical and economic publications during the last several years.

2. Potential production of wood from forests for energy purposes

Terrestrial ecosystems store about 2190 gigatons (Gt or 10^9 tons) of carbon, from which 1200 Gt is stored in forest ecosystems and only 32% of that is carbon found in forest vegetation. The remaining part is accumulated in soil mainly in boreal ecosystems (Dixon et al. 1994).

In 2010, countries of the EU harvested about 1 billion m^3 of wood biomass, from which 30% originated from places other than forests. About 57% of that wood was used for timber products (pulp and paper, lumber, particle boards and so on), and 43% reserved for energy purposes. According to Mantau et al. (2010), in 2020 and 2030, the wood biomass production will increase respectively by 5.4 and 11.2% in the above categories (the growth will be possible only in the event of increased biomass production from non-forest sources). It is also estimated that biomass use for timber products will decrease from 57% in 2010 to 44% in 2030. Such forecast covers the whole EU, while in specific countries the degree of biomass use for energy purposes will depend first of all on the wealth of its population (Gołaszewski et al. 2013).

In 2012, Poland produced about 170 terawatt hours (TWh or 10^9 kWh) of electric energy. Production of such an amount of energy only from wood burning would require using 54 million m^3 of wood (to compare, in 2012 Poland harvested 37.2 million m^3 of wood, including 34.9 million m^3 of large-size timber; Central Statistical Office 2012). It is predicted that in 2020, the share of energy produced from sources using biomass, including that produced from burning some forest biomass, would be 35%, which will utilise more than 8 million m^3 of wood (18.6% of wood harvested; Lis 2013).

Bartoszewicz-Burczy and Soliński (2013) evaluate that the market potential of forest biomass for energy purposes in 2020 will be 12.7 million tons (or about 16 million m^3 of wood), from which 6.4 million tons will come directly from forests and 6.3 million tons from the timber industry. Biomass originating from the timber industry includes (recalculated per 100 m^3 of wood coming from forest management practices) on average 10 m^3 of bark, 15 m^3 of small branches, 20 m^3 of wood pieces (cut-offs), 19 m^3 of wood dust and chips, and 36 m^3 of lumber, including 20–25 m^3 of final timber products from large-size lumber (Guzenda and Świgoń 1997). As evaluated by Ratajczak and Bidzińską (2012), the production of wood for energy purposes from forests, municipal management and agriculture in 2015 would be about 17.9 million m^3. According to Borecki and Dawidziuk (2011), the volume of timber used for energy purposes and originating from forests and the timber industry in 2020 and 2030 would be equal to about 9.0–9.5 million m^3 and 10.2–10.7 million m^3 respectively. Evaluation analysis of Dawidziuk and Neroj (2012) estimates that in 2031 and 2042, the available wood volumes (from forests and the industry) would be 10 and 11 million m^3, respectively. Zajączkowski (2013) values the wood market potential in 2021 to be 7.17 million m^3, and in 2031, 8.04 million m^3. Meanwhile, Borecki and Stępień (2013) indicate that according to the gross forecasted use of large-size lumber in 2061–2070 in the state and private forests of about 67 million m^3 annually, it would be possible to provide to the market annually about 16.8 million of wood for energy purposes.

Wood production, compared to production of wood substitutes used in the industry and other areas, does not require large energy inputs. Manufacturing one ton of construction timber requires about 580 kWh of energy, while for manufacturing bricks, the energy used is four times higher, cement — five times and plastic — six times higher. Production of 1 ton of aluminum uses on average 126 times higher energy inputs, compared to timber product manufacturing (Frühwald 2008). Moreover, timber sequesters carbon, and the added value of timber use by the timber industry is higher than in the case of wood burning. Timber products after their use are easily recycled, which allows the recapture of additional energy (Birler 1998).

Despite the considerable low share of carbon in timber, wood burning is of great interest for industrial energy manufacturers. However, the use of wood for energy purposes on a large scale brings many controversies related to the relevance and effectiveness of such solutions. Currently, the energy capacity of electric plants using wood biomass is constantly growing. From June 2010 to the end of 2011, the number of electric plants in Poland adapted for wood burning increased from 15 to 19, and their energy capacity grew from 252.5 MW to 409.7 MW (in the middle of 2010, those plants produced 11.1% of energy, and by the end of 2011 — 13.3%). During the first half of 2012, the number of electric plants using biomass increased to 22, and the share of energy produced by them to 14% (Lis 2013).

3. Environmental aspects of forest biomass use for energy purposes

During the times when forest biomass was used as one of the dispersed renewable energy sources (for the needs of small households mainly in rural areas), it did not cause controversies, as such activities presented a natural, accepted and historically shaped wood utilisation method. The change in justifying the use of wood for energy production occurred simultaneously with increasing interest in such a type of fuel by professional energy providers. Numerous questions related to the effects of such use of wood on the natural environment started to appear. Currently the discussion concentrates on evaluation and comparison of combined benefits resulting from CO_2 sequestration by forests (which in the EU equals 870 million tons of CO_2 annually, and corresponds to 10% of total greenhouse gas emissions produced by industries) and long-term carbon storage in timber products in relation to benefits received in the result of burning biomass as a low-emission source of energy (MCPFE 2011).

Understanding the significance of forests for mitigating climate changes helped to recognise two new functions of forestry, which include:

– capture and storage of atmospheric CO_2 in wood and forest soil, which constitutes a part of sustainable forest management activities that foster existing and growing potential of forests in this area;

– substitution of coal by wood biomass used for energy purposes, which replaces non-renewable high-emission energy sources, as well as long-term carbon storage in timber products, which also substitute such industry materials, which are characterised by high energy consumption processes (steel, concrete, aluminum, plastics) (Streck et al. 2010).

However, the above-mentioned positive forest functions are accompanied by problems related to ash utilisation. Chemical properties of ash produced as a result of biomass burning limit possibilities for ash utilisation (such as production of cement). However, after suitable processing and stabilisation, wood ash can be used as a source of valuable elements, which could be returned to the forest ecosystem (Kowalkowski and Olejarski 2013, Oesten 2012).

Another problem is linked to intensive collection of harvest waste. However, scientists are divided in their opinion whether such activity depletes biological elements from the forest environment. While analysing the mineral content of wood, Rykowski (2012) acknowledges that there is no indication that intensive forest biomass harvesting significantly diminishes the nutrient content of forest sites and limits tree growth. With some small differences between coniferous and broadleaf species, wood is mainly built of carbon (about 50.1%), oxygen (about 43.4%) and hydrogen (about 6.0%), and the main source of these elements is atmosphere. The remaining part (about 0.5%) consists of such elements as nitrogen, phosphorus, potassium, magnesium and calcium, which in the forest ecosystem originate from the duff layer. Those elements contribute to soil productivity and along with water regulate tree growth. They regulate this in a way of building tree crown, the size of which (biomass or developed assimilation area of leaves) determines the amount of absorbed CO_2, water and solar energy, and therefore carbon, oxygen and hydrogen affecting timber production. Considering the above, silvicultural activities should concentrate on building and shaping tree crowns as well as single tree competition for space and light. Nutrient absorption by a tree (which in a pine forest ecosystem equals on average 50 kg of nitrogen, 5 kg of phosphorus, 14 kg of potassium, 10 kg of calcium and 3 kg of magnesium per 1 hectare) is compensated from the dead material of the duff layer. Therefore, moderate tree harvest and timber removal outside of the forest ecosystem do not cause its degradation and do not decrease the productive potential of the site. Such activities, however, significantly change the life conditions of many organisms by simplifying the trophic structure of the ecosystem and by weakening associations between species resulting in a less stable ecosystem that is more susceptible to internal and external calamities. Therefore, timber production cannot be viewed without the consideration of forest ecosystem sustainability (Rykowski 2012).

A different view is presented by Kowalkowski and Olejarski (2013). They point out that in forests with intensive thinning, with short rotation and with total removal of harvest debris together with bark and roots, for several years the forest ecosystem is irreversibly depleted in large amounts of nutrients. The research conducted by Gornowicz and Pilarek (2013) shows that in the case of harvesting trees inside the bark, the decrease of some of the most important biological elements in the forest environment amounts to 312.7 kg/ha of nitrogen, 30.3 kg/ha of phosphorus, 53.7 kg/ha of potassium, 328.5 kg/ha of calcium and 39.0 kg/ha of magnesium. The authors estimate that during the whole cycle of timber production when trees are taken away together with their roots, up to 524 kg/ha of nitrogen, 55 kg/ha of phosphorus, 121 kg/ha potassium, 438 kg/ha of calcium and 54 kg/ha of magnesium could be removed from the nutrient cycle. Those amounts when compared to nutrient depletion during the traditional timber harvest would be higher on average of 65.5% (from 33% in the case of calcium to 125% in the case of potassium).

As shown by Kowalkowski and Olejarski (2013), the raw ash produced as a result of burning ‘primary fuel’ originating from forests is a heterogeneous product of burning forest biomass. It is characterised by the high ability to aggressively enter into chemical reactions with the elements of the forest environment. It has a damaging effect on soil flora and fauna as well as on humans. It cannot be considered as a fertiliser directly applied to forests. However, its use is possible after suitable processing through granulation with the highest possible homogenisation, which decreases the amounts of small fractions and converts aggressive oxides into hydroxides and carbonates. The final product should contain variable nutrients, so its application would not be damaging, its nutrients should be released during the long-term period (from 5 to 25 years) corresponding to the conditions of a given site, and also it should be of low reactivity in a soil environment.

Currently in Poland, fly ash produced during biomass combustion is transported to mines and old quarries, stored at specialised repositories or with the consent of the local administration it could be used for the recultivation of communal landfills. In other countries, such as Sweden and Finland, wood ash after special granulation is used as a fertiliser in forests (Sadowski 2013).

4. Economic aspects of forest biomass use for energy purposes

Low energy value as well as large dispersion and related to that high costs of wood biomass transportation lead to the fact that wood combustion by professional energy providers in market conditions is unprofitable even during the process of combined combustion with fossil fuels (bituminous and brown coals). Financial instruments (so-called green certificates) used in countries of the EU, including Poland, which support the use of biomass significantly change the above situation (Bird & Bird 2011). The system of green certificates is a market mechanism, which requires energy companies dealing with providing electrical energy to end users to obtain a certain number of certificates of origin indicating the generation of electric energy from renewable energy sources or to pay a substitute fee (Ministry of Economy 2013). As a result of such an operating system of support, unit income value of professional energy providers using biomass fuel in 2010 reached the value of 450–470 PLN/MWh while unit energy price was only 200 PLN/MWh, with the remaining amount coming from the sale of the certificates of origin (green certificates) (Bird & Bird 2011). At the same time, timber market equilibrium has been affected, which mostly concerned paper, cellulose and particle board producers that utilise wood products, which are also of interest to energy providers. Such a situation affected many European countries. As an example, subsidies in Great Britain allow the energy sector to pay more than 92 euros per ton of wood (Bernasiński 2011). In Austria, during the period from 2001 to 2005 as a result of competition between producers of pellets and the paper–cellulose industry, the prices of wood dust increased almost twice. The price of pellets themselves has also hiked (on average from 183 euros/t to 265 euros/t) mainly as a result of high demand from heat plants and simultaneous shortage of round timber (Uslu et al. 2010).

Despite the difficulties of using biomass for energy production, its use in Poland is predicted to grow. It could be explained by the lack of natural conditions for further dynamic expansion of energy production from other renewable sources, such as water or geothermal energy and also high environmental costs of wind energy or energy produced from conventional sources[2]. The outcome of biomass price increase as a result of larger demand could be seen in growing energy prices for end users. In 2013, the average price of electric energy sold was 182 PLN/MWh (Information 2014).

The level of energy prices after 2013 would be affected by the distribution of allowances for CO_2 emission. In 2013–2020, Poland will receive in total about 404.6 million tons of the European emission allowances for existing producers, while in 2008–2012 that amount was about 1025 million tons (205 million tons/year). Based on the data on CO_2 emissions by the Polish electric energy sector in the future and also on the forecasts of prices of emission allowances in 2013–2020, it is estimated that already in 2014 the bulk price of energy from conventional energy sources could increase by about 30–35 PLN/MWh, and in the following years due to low annual allocation of emission allowances, the energy price will grow even more intensively (Bird & Bird 2011).

Currently the costs of production of 1 GJ of chemical energy enclosed in plant biomass are 1.5–2.5 times higher than the costs of 1 GJ of energy produced from coal. It could be explained not only by the price of biomass itself, but also by the costs of transportation, which depend on the distance to the place of fuel extraction. It is assumed that the distance from the producer or distributer of biomass to the consumer should not be larger than 30–35 km and in extreme situations not above 60 km (Lorenz and Grudziński 2009). Such distances are not too big considering that the annual demand for biomass for an 81 MW WP-70 boiler cofiring 20% of biomass is about 16–20 thousand tons, while an average forest area with the radius of 30 km produces annually about 8.5 thousand m^3 of fuel wood, or about 5–6 thousand tons of wood (Furtak 2004).

During the period until 2030, as a consequence of introduction of the EU climate policy in its current state and related to that wider use of biomass and other renewable energy sources, there is expected growth in investments for the expansion of new production facilities by about 60 billion PLN. The average costs of electric energy production will also increase, which will directly result in an increase of household and enterprise expenses by 8–12 billion PLN annually. As a consequence, it could be expected that the total gross domestic product (GDP) in 2020 will be 7.5% lower compared to a hypothetical situation with no support for renewable energy sources. In 2030, the decrease could even reach 15% (EnergSys 2008). While Bukowski and Śniegocki (2011) estimate that in 2020, the GDP will be 1.1–1.7% lower compared to the scenario without '20–20–20' targets, at the same time production in energy-intensive sectors will decrease by 1.9–4.4% and the unemployment rate will increase by 0.4–0.5%.

The 'Report 2030' prepared by EnergSys (2008) forecasts that by 2030, investments supporting renewable energy sources could increase by 58 billion PLN, and the price of electric energy by about 60%. According to another prognosis (Jurdziak 2012), the increase in wholesale energy price will be even higher and looking at the base scenario with no effect of allowance purchase, the price would grow by 100% until 2020 (from about 200 PLN/MWh to about 400 PLN/MWh). If the price of allowance purchase is considered, the energy price may reach about 580 PLN/MWh. In the case where power transmission and distribution costs are included, households will have to pay 600–800 PLN/MWh, which is 50 to 100% higher than in 2008. Assuming that a real household's available income will grow by 30% until 2020 (with the growth rate of 3.3% per year), the share of expenses for energy appliances can increase from 10% in 2008 to 18.7%.

The above estimates concern only professional electric energy providers, since the comparison of energy costs from different sources indicates that using wood in individual heating systems is still a least expensive way of producing heat, especially when split firewood is used. The price of firewood with a moisture content of 20% is 230 PLN/m^3 and the price of electric energy is 21.9 PLN/GJ, while the price of heat produced by a boiler with 80% efficiency is 27.3 PLN/GJ. When pellets and briquettes are used (moisture content 10%), and sold at the price level of 700 PLN/m^3, the prices of electricity and heat would be 41.2 PLN/GJ and 51.5 PLN/GJ. Those prices are significantly lower than the prices of energy produced from other sources. When fuel oil is used, the price reaches 90.29 PLN/GJ, coal — 29.64 PLN/GJ, liquefied gas — 114.07 PLN/GJ and electric energy — 121.11 PLN/GJ (Wach 2007).

Considering the advantages and disadvantages of wood use by large energy providers, it should be recognised, that with the unsatisfied demand for wood for industrial purposes, at least part of the wood that is being burned could be more

[2] External costs of electric energy production in Poland are the highest in the EU and reach 5.5–18 eurocents per 1 kWh (data from 2006). Incorporating those costs into the price of electric energy would result in its increase by 70–250%. Most significantly, they manifest in higher expenses on health protection, deteriorating infrastructure, higher costs of water purification and degradation of the natural environment (Graczyk 2010).

effectively utilised in the timber processing industry (higher total economic and social benefits). Czemko (2011) estimates that harvesting and processing of 10 thousand m^3 of large-size pine lumber wood with an average price of 202 PLN/m^3 (2010), would lead to the following economic consequences:

– From 10 thousand m^3 of wood (ecological renewable material) could be produced 117 thousand m^2 of floor surfaces and 1600 m^3 of yearly use industrial pellets.

– Total value of products produced from that timber would be 6.6 million PLN (328% of raw timber value), and an added value of 4.6 million PLN.

– Total employment during the processing of 10 thousand m^3 of wood would be on average 49 people.

– Value of residuals from timber processing would be about 0.37 million PLN; they could be used for the production of particle boards or as a source of energy corresponding in their energy value to 1800 tons of bituminous coal.

The European Panel Federation (EPF) estimates that processing one ton of dry wood in the paper industry on average takes 124 work-hours, the production of other wood products 54 work-hours, while the production of electric energy only 2 work-hours (EPF 2005). The added value of industrial timber processing equals 4176 PLN, and its combustion — 472 PLN (Czemko 2012).

According to EPF, the added value of wood products, even when the energy value at the end of the wood life cycle is not considered, is equal on average to 1044 euros per ton of dry raw material, while the value of timber used exclusively as fuel reaches 118 euros/ton.

One of the negative social and economic effects of the promotion of using wood for energy purposes is the shift of market equilibrium towards small- and medium-size timber and relocation of particle board production from Europe to ‘cheaper’ countries. For a dozen years, there was observed a shift of wood processing units to countries outside the EU (among others to Ukraine, Russia and also to China). If such a trend would continue, it could bring harmful effects on employment in the production of particle boards in EU countries and also weaken furniture production, which is easily affected by competition from cheap competitors outside Europe (EPF 2005). This problem could be especially stressful for furniture producers in Poland and national export (EU-Consult 2011).

5. Social aspects of forest biomass use for energy purposes

Labour market changes could be observed as a result of increased use of biomass in the production of energy. According to the EurObserv’ER report (a consortium monitoring the development of various sectors of renewable energies in the EU), in 2009 the solid biomass sector generated the largest number of jobs among energy producing sectors (280 thousand in the whole EU). Its turnover reached 26 billion euros and beneficiaries included small- and medium-size enterprises, including forest and agricultural sectors (EurObserv’ER 2011). Zielińska (2011) gives an estimate according to which the increased share of energy from renewable sources of 20% could generate more than 600 thousand jobs, and in the case where average energy efficiency would be improved by EU countries by 20%, an additional 400 thousand jobs would be generated. Currently, the EU sector of ‘green technologies and services’ employs 3.5 million people.

Daly et al. (2011) note that an investment of 1 billion euro could allow the creation of 21.5 thousand jobs in renewable transport, 25.9 thousand in energy efficient modification of buildings, 29.0 thousand in nature protection (Natura 2000 areas) or 52.7 thousand jobs in renewable energy. In the EU budget plan for 2014–2020, the implementation of ‘green budget’ at the level of 14% of the total EU expenses (annual investments at the level of 14.7 billion euros according to current propositions of the European Commission) would allow the four sectors listed above to create more than half a million jobs. At present, investments within the framework of the common agricultural policy and cohesion policy, which cover about 78% of the actual budget (140 billion euros annually), generate a little above than two times more jobs. If such investments within those two policies could be replaced by investments in ‘green sectors’, the effect of job creation would grow more than threefold (320%).

The Institute for Sustainable Development (2009) evaluates that if the efficiency of renewable energy sources is secured, it would require the employment of at least 25 thousand people, and half of them should be of special qualification. Such an estimate does not consider the multiplier effect — additional jobs created in the non-traded sector (internal service and agriculture). The inclusion of the agricultural sector into the sector of renewable energy production through an energy-oriented management of about 0.5 million ha would allow employing another 44–70 people (with the average being 10–14 people/100 hectares).

Moskalik et al. (2012) estimate that in Poland, harvesting and processing of medium-size fuel wood employ about 2750 people, while another 1400 people could be employed for the production of small-size fuel wood. Additional jobs could be created for further timber processing such as the production of charcoal or fireplace wood. The authors also cite research results of Danielson and Hektor (1992) as well as Strindberg (1998) according to whom the utilisation of 100 thousand m^3 of logging waste (which includes collection, chipping, transportation, burning and administration) requires the engagement of 25 people per year. Forest harvesting using chainsaws and heavy equipment or just heavy equipment generates respectively, 73 and 35 jobs annually per every 100 thousand m^3 of timber.

Effective management of forest resources should give a special priority to forest products with a higher added value, creation of new jobs and contribution to improved carbon dioxide balance. The waterfall model, according to which wood is first of all used for the production of such products that after secondary use and recycling are in the end utilised for energy production and neutralised, could fulfil such criteria; see COM (2013) 659 and Oesten (2012).

6. Technological aspects of forest biomass use for energy purposes

The most important technological issues related to using forest biomass for energy purposes include the evaluation of energy efficiency of technologies used and the estimation of CO_2 quantities released from fuels used in processes of biomass preparation. From the point of biomass harvesting, logistic problems as well as processes improving its energy value and density should be of first priority.

Forest biomass could be utilised in different forms such as split firewood, wood chips as well as in the compressed form such as pellets or briquettes. In combination with the degree of wood processing, the unit costs of the final product and energy used per unit of biomass start to grow, while due to higher energy density, the costs of transportation and storage decrease.

Processing of forest biomass is done by compressing it into briquettes or pellets. In the first case, the energy value is equal to 19–21 GJ/t; moisture content 6–8%, ash content 0.5–1% of dry weight. The advantage of pellets is in their very low ash content (0.3–1% of dry weight) as well as a high energy value of 16.5–19.5 MJ/kg. However, the pellet production process is very energy consuming, since the production of one ton of final product uses about 1.3 tons of air-dry chips. Assuming that one ton of wood has a heating value at the level of 8.4 GJ/Mg (W = 50%), and energy expenditure including losses of chemical energy accumulated in biomass amount to approximately 3.2 GJ/Mg of final product, more than 25% of energy used for the processed fuel production is lost (Drobnik 2007).

The large variety of technological processes used makes it difficult to precisely estimate energy inputs necessary for processing forest biomass. In the study of Kusiak and Czechlowski (2009) conducted in the Puszcza Notecka forests, the total CO_2 emissions from technologies with a low level of mechanisation (chainsaw and tractor) were equal to 1.11 kg CO_2/m^3 of timber harvesting and skidding. Workforce productivity of the four-person crew was equal to 4.8 m^3 per hour, and hourly CO_2 emission was 2.64 kg. With the use of forestry machinery for harvesting and skidding, CO_2 emission was 2.22 kg per 1 m^3 of harvested timber, while carbon dioxide emission related to skidding was 1.49 kg. The total CO_2 emission of high mechanisation technology (harvester and forwarder) was 3.71 kg CO_2/m^3. The hourly fuel emission during harvesting was 19.41 kg, while fuel emission during skidding was 10.41 kg.

In the research of Gałęzia (2013), the total energy input for harvesting and transportation of chips to an electric energy facility was 109.72 MJ/m^3 (p), and CO_2 emission from harvesting and transportation of chips to an electric energy facility was 7.89 kg/m^3 (p). The total energy input necessary for harvesting, processing and transportation of tree branch bales to an electric energy facility was 313.56 MJ/m^3 (p), while CO_2 emission from those activities was 22.14 kg/m^3 (p).

Such results indicate that production of forest biomass either in the form of bales or chips is justifiable in terms of energy balance. Production of forest biomass in the form of chips is three times less energy consuming than production of bales. Combustion of energy chips in the boiler of an electric facility produces over 10 times more energy than the energy required for harvesting and transportation of biomass in the form of bales, while it is over 30 times higher than the energy required for harvesting and transportation of biomass in the form of chips (Gałęzia 2013).

In local electric facilities, the use of unprocessed biomass transported small distances up to 30 km away is more economically justifiable due to its costs and environmental effects (Piszczałka et al. 2007). Unprocessed biomass in the form of chips has low energy value depending on its moisture content (6–20 MJ/kg). It also has a low stowage factor (chips or bales), which indicates that the transportation of that material to longer distances is not justifiable due to high costs of transportation and its negative effect on the environment. Therefore, when biomass is transported long distances for co-combustion of biomass and coal in large electric power plants, such activity should be viewed with certain criticism. Such activities have a certain pretence in them, only in order to fulfil CO_2 emission norms (Jasiulewicz 2010).

It is estimated (Baum et al. 2012) that in Poland in the perspective to 2020 and further, production of energy from biomass would require collection, transportation, storage and additional transportation of up to 50 million tons of biomass annually. In order to avoid long-distance transportation of large biomass amounts, it is necessary to support the development of local biomass markets, balancing supply and demand as well as electronic logistics systems, which could minimise costs of harvesting, transportation and storage of biomass. An additional advantage of using biomass close to the place of its production is the possibility of using the existing heating infrastructure of small cities or the use of biomass in its raw state or after natural drying in local energy production (Baum et al. 2012; Oesten 2012). Municipalities, which promote such solutions and invest in required equipment, could use their land potential (areas with low value management activities, fallow lands, degraded grasslands, etc.) for production of biomass, which would make them more energy self-sufficient (Baum et al. 2012).

In practice, energy could be produced from various annual and perennial plants as well as hay. Taking into account the climate conditions of Poland, the area theoretically available for growing willows and poplars is about 1.6 million hectares. Assuming that the average yield on less productive soils is about 10 dry tons annually, such an area could produce about 16 million dry tons per year. With the energy value of such a dry material being about 20 GJ/t, it would be possible to receive about 320 million GJ/year of energy, which corresponds to 36% of energy produced from burning bituminous coal (888 million GJ) and 62% of energy produced from brown coal (514 million GJ) (data for 2008; Jasiulewicz 2009).

Diversifying agricultural production, especially of plant origin, by the cultivation of plants used for food consumption and for energy purposes, could improve the income of the population working in the agricultural sector and bring new life to rural areas. It should also enhance natural environment and sustainable development of rural areas. The use of new technologies oriented to combined heating systems utilising waste biomass from agriculture, industry, municipal management and forestry in local power plants could be one of the most efficient solutions for heating energy producers as well as suppliers of energy resources (Jasiulewicz 2010).

The establishment of a local system of biomass utilisation (for electric and heating energy) is very energy efficient (70–90% efficiency). Moreover, it leads to the rise of employment in rural areas (creating new jobs) and more comprehensive use of land and cash flow within local communities. Such activities could bring a new momentum to the local economy.

7. Summary

The use of wood for energy production at the industrial scale is a new trend in the response of the economy to the global threat to the environment. Due to its large-scale use, such activities provoke many questions and oblige us to reflect upon the direction of changes occurring in our contemporary globalised world.

In the conditions of changing climate along with the growing demand for energy, the use of renewable energy sources including biomass coming from forests becomes indispensable. Utilisation of wood as a source of energy at the industrial scale is a very complex process having far-reaching environmental, social and economic consequences. Benefits for climate change mitigation resulting from this process should not overshadow threats related to excessive exploitation of forest stands or ash utilisation. Biomass use for energy production purposes in a large degree positively affects and will affect the advance of agriculture and therefore should be considered as a vital element of agricultural policy. However, the wide use of forest wood biomass for the purposes of energy production could have negative consequences for the development of rural areas due to weakening various branches of the timber industry, which in different degrees contribute to economic development.

Due to the scale of wood biomass being used for energy production, the significance of wood is given a new meaning characterising forest economy as a sector supporting the implementation of climate policy. Climate change prevention policy still calls for careful consideration of all the gains and losses, so that its implementation would not conflict with the development of other wood utilisation methods and would not endanger timber, cellulose and paper industries.

Conflict of interest

None declared.

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Authors' contribution

PG – study conception and design, project leader, acquisition of data and literature, analysis and interpretation of data, drafting of manuscript; AK – additional literature and data acquisition, critical revision of the manuscript, manuscript proof-reading.

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