Drewno 2016, Vol. 59, No. 198
DOI: 10.12841/wood.1644-3985.162.09

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WOODEN BIOMASS POTENTIAL FROM APPLE ORCHARDS IN POLAND

A side product emerging during apple orchard cultivation is pruned biomass, which may be used for energetic purposes. As Poland is the third largest producer of apples in the world, it is crucial to estimate the annual energetic potential of branches from apple tree pruning. In this paper, the theoretical, technical and economic potential of cut branches for energy production with distribution according to provinces (Voivodeships) is determined. Based on literature reviews and our own measurements the amount of produced branches was estimated to be 3.5 Mg·ha^{-1}·year^{-1}. It was shown, that the energetic potential of pruned biomass from apple trees in Poland is in the range of 7.9-12.5 PJ·year^{-1}. Moreover, the abundance of that potential depends on the province and for a single Voivodeship, may vary from 0.04 PJ·year^{-1} up to 4.8 PJ·year^{-1}.

Keywords: wooden biomass, apple orchard, pruning, energetic potential

Introduction

Based on a report from 2013, Poland delivered almost 3.1 m Mg of apples to the fruit market [ARR 2014]. Such a high apple production placed Poland in 3rd place in the world behind the USA (5 m Mg) and China (25 m Mg). The production of such a large amount of apples also requires significant orchard areas being cultivated effectively. To maintain good fruit productivity pruning must be performed every year. Usually, the pruning takes place during the winter and spring period (in the months from January until April) depending on the local climate, weather conditions or apple variety [Badowska-Czubik et al. 2012; Mika 2012; Sanford and Schultz 2013]. During pruning, manual scissors, electric shears or mechanical discs are used to cut useless or sick branches and

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form the appropriate shape of the tree [Romański et al. 2014]. The cut branches are put on the ground for further treatment/utilisation. Currently, the most popular solutions of pruning management are (fig. 1):

– pushing out of the rows and burning on site in the orchards,
– mulching in-situ (chipping) with the use of agricultural machinery.

a) biomass mulching b) biomass removal c) biomass burning

Fig. 1. Typical processing of the pruned biomass in the orchard

These actions, however, require energy input, machinery use and extra labour costs without giving any direct benefits to the entrepreneur [Niederholzer et al. 2007]. It should be noted, however, that the mulched biomass bring some minerals and elements back to the soil, which support the tree growing and cultivation process diminishing the use of fertilizers [Kadiata et al. 1998, Cowie et al. 2006, Gabrielle and Gagnaire 2008]. On the other hand, the chipped prunings can contain pests, small rodents, fungi and bacteria which may have negative effects on fruit tree productivity and can cause further development of diseases harmful to the trees [Ritchie et al. 2012, Duca et al. 2016]. Contamination of the prunings with pesticide residues raises a concern about the persistence of these chemicals, which may not be completely removed through weathering. So, leaving the infected pruned biomass in the orchards brings a risk of the accumulation of heavy metals and persistent organic pollutants [Boschiero et al. 2015]. Therefore, leaving prunings in the orchards may lead to a long-term lowering of fruit productivity and consequently, financial losses. The conversion of pruned biomass into usable heat, however, seems to be an economically feasible option for the orchard owners [Silvestri et al. 2011].

Considering the above, to provide additional economic profits to apple producers, the collection of biomass in orchards for energy production is proposed [Dyjakon et al. 2014]. The biomass gained in the orchards may be an attractive renewable source of energy for the local power engineering market, including households, institutions, and small factories or decentralized heating systems. Such direction of local biomass utilisation in local markets leads to the development of decentralized heating systems and a sustainable energy management. Moreover, the combustion of an orchards biomass in small and middle size capacity boilers, decreases the use of fossil fuels and at the same time limits the emission of pollutants to the environment [Cotana et al. 2009, Silvestri et al. 2011]. However, to enable the development of this so-called Pruning to Energy (PtE) strategy, it is also necessary to create biomass storage and distribution market connecting the fuel delivery company (orchards enterprise) and the final consumer. Currently, the biomass produced in fruit plantations is not used widely to produce bio-energy. This is because of unsolved technical problems in harvesting, or a lack of information on the quantity and quality of the residues. Knowing the amount of residual biomass available in orchards allows for the planning of logistics operations at a local community level, and achieving a cheaper and functional supply chain.

In literature, there is no data related to the potential of biomass from apple tree pruning in Poland. Only a total technical potential of pruning residues of permanent plantations and other biomass, like olive trees, vineyards, fruit trees, grass and shrubs in Europe was assessed [Pudelko et al. 2013]. Because of the importance of the Polish fruit market both at a national and international level, it is very important to determine the potential of cut branches from fruit trees in the given regions of Poland, especially from apple orchards.

Apple orchards in Poland

For many years fruit orchards cover areas over 250 000 hectares, which is ca. 2% of the surface area of the country. However, in the last decade. this area has been rising, reaching a stable value at a level of 350 000 hectares (fig. 2).

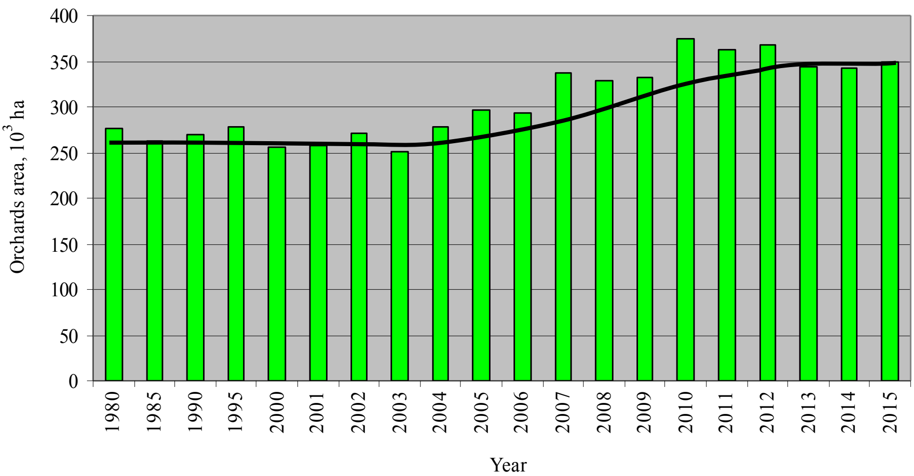

Fig. 2. Area of orchards in Poland in years 1980-2014 [GUS 1980-2015]

In Poland, large varieties of fruits are cultivated and the most popular are apples, currants, strawberries, blueberries, cherries and sweet cherries (fig. 3).

Amongst the fruit tree plantations, which may be a source of woody biomass for energetic applications, the largest area is covered by apple orchards (193 440 ha), cherry orchards (33 669 ha), plum orchards (18 204 ha), sweet cherry orchards (10 880 ha) and pear orchards (10 680 ha).

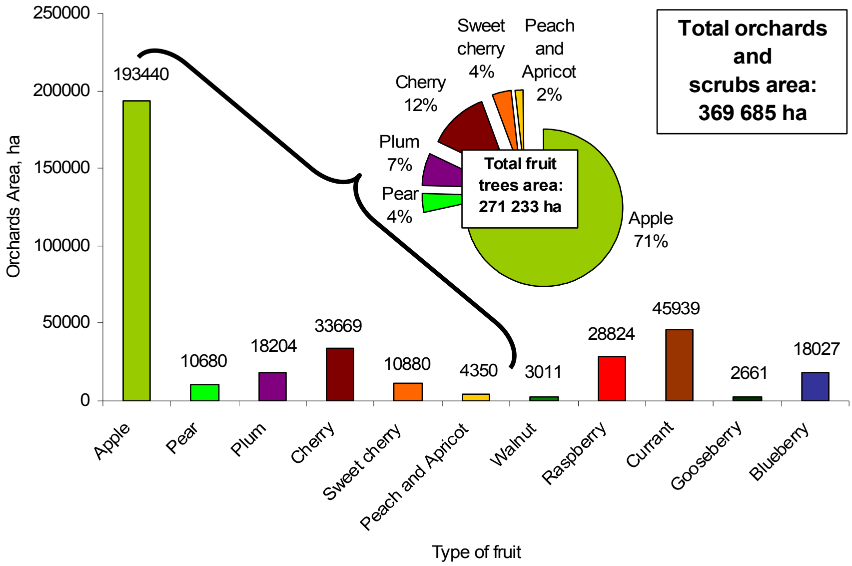

Fig. 3. Orchards and scrubs area in distribution to fruit type in Poland [GUS 2014]

The total fruit tree orchards cover more than 270 thousand hectares, of which 71% are apple trees (fig. 3). Such significant values of the area together with the high apple productivity of over 3.1 m tonnes, places Poland in third position in that market in the world (after USA – 5 m Mg and China – 25 m Mg).

To obtain high productivity and quality of the apples, suitable cultivation, including regular soil fertilisation, spraying against pests and pruning of branches is required. To allow for tree growth and assure the fruits get proper access to sunlight, the pruning process in the winter-spring period is obligatory. During the pruning, the employees cut the superfluous and infected branches and put them on the ground. The woody biomass needs to be removed from between the rows and disposed of. Both the pruning itself and the removal of the cut branches is time-consuming and costly for the orchard owners. It does not have any direct financial benefits for the company either. However, the pruned biomass has an energetic value and may be used for energy production. Moreover, it is a renewable source of energy that is able to support the achievement of the 15% goal for green energy production in Poland that is required by the EU Directives until 2020. Therefore, it is important to estimate the potential of this kind of biomass in Poland with the identification of the regions with highest accessibility to that source of energy.

Research methodology

The aim of this study was to obtain data about the biomass potential derived from the pruning of apple tree orchards in Poland that could be used for energetic purposes. The mass of harvested biomass assumed for the elaboration of the potential energy map of pruning in Poland was determined, based on data coming from questionnaires completed by the orchard owners [EuroPruning 2014], direct measurements in orchards and literature review. In the case of our own measurements, the research was performed on an orchard farm (area over 150 ha) characterised by various apple varieties and a regular cultivation oriented on fruit production. The estimation of the pruning potential was based on the mass (and moisture) measurements of the manually collected cut branches in the winter-spring period. For each apple variety, ten random trees were selected. The mass of pruned biomass was determined using a dynamometer with an accuracy of 0.05 kg. The moisture content was defined according to the PN-EN 14774:2010 standard.

The available energy potential from the biomass pruning was divided into three groups taking into account the theoretical, technical and economic potential.

The determination of the amounts of biomass from apple orchard pruning is complex, because the value of pruned/harvested biomass depends on many factors, like:

– orchard type (traditional, intensive),
– orchard size,
– type of roots/tree,
– age of the orchard,
– apple variety,
– cultivation and management strategy,
– orchard location,
– climate and weather conditions,
– plants intensity.

Such multi-dimensional dependence of biomass potential in apple orchards makes a very accurate calculation impossible. The amount of cut branches varies from year to year and old orchards (with higher pruning potential) are being replaced by young ones (with a very low initial pruning potential).

As a result, some assumptions in the analysis have to be defined in order to calculate the resources of the kind of biomass from apple trees in Poland. One of the most important parameters is the mass of pruned biomass (branches) gained from one hectare of an apple orchard. Table 1 presents the values of harvested biomass in orchards based on our own measurements performed in orchards, as well as the estimated values taken from literature and questionnaires fulfilled by the orchards owners.

Table 1. The amount of pruned biomass from apple orchards

Apple tree variety	Orchard age years	Amount of trees trees·ha^{-1}	Amount of pruned biomass kg·tree^{-1}·year^{-1}	Amount of pruned biomass Mg·ha^{-1}·year^{-1}	Moisture content %wt.
Golden[b]	21	1250	3.0-3.2	3.7-4.0	46.5
Boskoop[b]	21	1250	1.9-2.7	2.4-3.4	43.5
Champion[b]	24	1250	2.0-2.5	2.5-3.2	45.7
Jonagold[b]	21	1250	1.7-2.4	2.1-3.0	45.3
Melaroza[b]	28	1250	1.0-1.4	1.2-1.8	39.5
Spartan[b]	24	1250	5.1-5.5	6.3-6.9	37.4
Golden-Delicious[b]	20	1666	4.7-5.1	7.8-8.5	42.9
Jonatan[b]	42	570	8.1-8.5	4.6-4.9	43.7
Lobo[b]	20	1666	4.5-4.9	7.5-8.1	42.5
Idared[b]	42	570	5.9-6.3	3.4-3.6	41.9
Earle Geneva[c]	12	1666	2.7-3.3	4.5-5.5	44.6
Lobo[c]	22	1250	4.8-5.6	6.0-7.0	46.5
Spartan[c]	43	570	4.0-4.7	2.3-2.7	42.8
Golden-Delicious[c]	18	1666	3.5-4.1	5.8-6.8	44.1
Idared[c]	35	833	1.2-1.5	1.0-1.2	42.3
Mix[c]	11	3300	0.9-1.0	3.1-3.3	n.a.
Elstar[a]	4-17	n.a.	2.5-3.6	4.7-6.8	n.a.
Golden[d]	23	1250	3.1	3.87	db.
Gala[d]	10	1923	1.15	2.21	db.
Mix[d]	n.a.	2375	2.35	5.57	n.a.
Mix[d]	n.a.	785	3.7	2.9	n.a.
Mix[d]	n.a.	n.a.	n.a.	3.0-3.7	n.a.
Golden-Delicious[d]	n.a.	n.a.	3.58	6.2	n.a.
Gala Royal[d]	15	n.a.	n.a.	9.8	n.a.
Golden[d]	10	n.a.	n.a.	3.4	n.a.
Dallago[d]	11	n.a.	n.a.	2.8	n.a.
Idared[d]	n.a.	2190	1.42	3.11	n.a.
Jonagold[d]	n.a.	2190	1.59	3.48	n.a.

Mix – the variety of apple is not identified.
[a]Data from literature (orchards in Poland) [Rabcewicz et al. 2007].
[b]Own measurements: orchard farm (above 150 ha) in Dolnośląskie Voivodeship.
[c]Data based on the questionnaires fulfilled by owners of the apple orchards [EuroPruning 2014].
[d]Data from literature (orchards in Europe) [Bilandzija et al. 2012; Janic et al. 2012; Broekema 2013; Grella et al. 2013; Magagnotti et al. 2013; Zivkovic et al., 2013; Boschiero and Zerbe 2014].

The differences in the values presented in table 1 result from the varying age of the apple trees, variety of the apples, year of cultivation as well as the plants intensity. For further calculations, the average value of raw biomass material (as received) from annual pruning is assumed to amount to 3.5 $Mg\cdot ha^{-1}\cdot year^{-1}$ (fig. 4). Our own measurements of different apple varietities showed that the average moisture content in the pruned biomass (as received) is ca. 40-45% and the higher heating value (HHV) is ca. 18.0-19.3 $MJ\cdot kg^{-1}$. Similar HHV values might be found in literature, as well [Boschiero and Zerbe 2014].

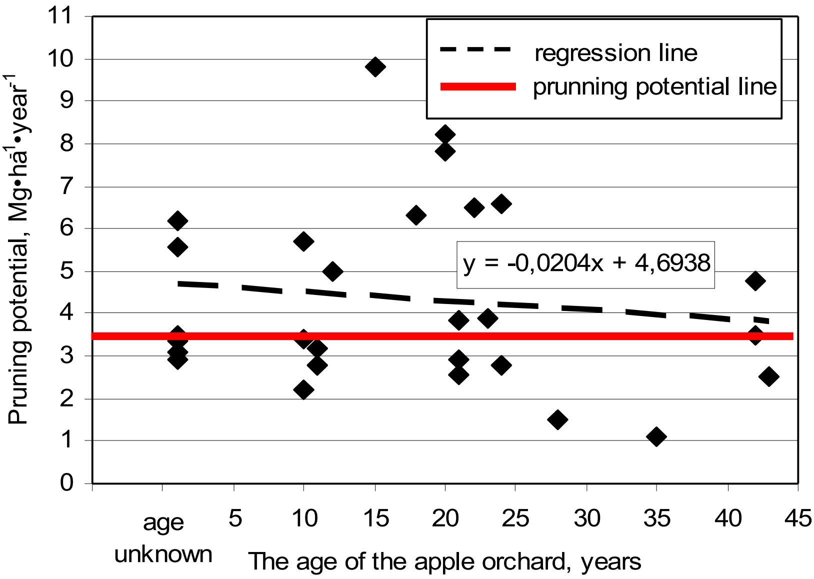

Fig. 4. Pruning potential in apple orchards (based on table 1)

Energetic potential of pruned biomass from apple orchards in Poland – Results and discussion

The pruning potential for energetic purposes may be assessed in terms of theoretical, technical or economic possibilities.

The annual theoretical energetic potential is determined as a total amount of biomass available in the apple tree orchard areas in Poland multiplied by the high heating value of the pruned biomass. The result is the amount of energy (expressed in $MJ\cdot year^{-1}$) that could be gained from apple orchards without recognition of the collection possibility, real functionality of the orchards, technical capabilities or profitability of these activity etc.

The technical potential represents the achievable energetic potential taking into account an actual available technology, system performance, topographic limitations, environmental and land-use constraints. The technical potential disregards the economic constraints and profitability of the process or technology. In relation to this issue, the harvesting efficiency of the existing technology is assumed as 85%. It means, that 15% of the pruned biomass is not picked-up (collected) by the machinery, but remains in the orchards. The main reasons for this are the technical limitations of the machinery and irregularity of the terrain. Similar values were obtained during tests performed in orchards within the EuroPruning project (www.eurpruning.eu) and by other researchers, as well [Magagnotti et al. 2013, Spinelli et al. 2014]. Another depreciating factor is connected to the fact, that many small orchards (up to 2 ha) might be not cultivated properly or pruned regularly at all. Therefore, the percentage share of this area (6.04%) is excluded from consideration of the technical potential (fig. 5). Consequently, the area considered for calculation is smaller, and the amount of the harvested wooden biomass will be lower than in the theoretical potential.

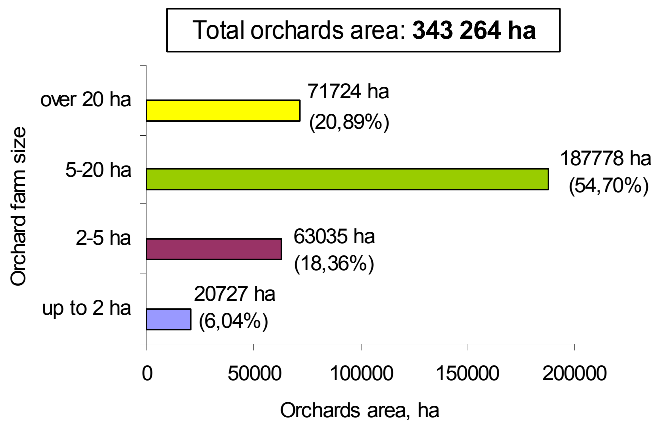

Fig. 5. Characteristic of covered area in distribution to the orchards size in Poland [GUS 2014]

In turn, the economic potential considers the possibility of the performance of the enterprise in terms of financial benefits and business rationality. To harvest wooden biomass in the orchard, specific machinery is required. Actually, there are two technical solutions on the market: chipping and baling. As a result, the additional investments in harvesting machinery and other equipment are necessary. Only for bigger orchards or groups of producers is it assumed to be profitable to buy such machinery. Thus, it is assumed that for economic calculations, only orchards with an area larger than 5 ha are considered. As a result, the calculated area for economic feasibility is reduced by 24.4% (fig. 5) compared to the theoretical potential. In effect, the accessible orchards area for determination of economic potential will be the lowest one (in comparison to the theoretical and technical potential). It this case, the harvesting efficiency (85%) must be taken into account, as well.

Assuming additionally, that the average high heating value of the pruned biomass is HHV=18.5 MJ·kg^{-1}, the theoretical, technical and economic potential of pruned biomass in Poland is determined (tab. 2). The distribution of the local energetic potential of the wooden biomass from apple orchards in the administrative regions (Voivodeships) is shown in figures 6-8.

Table 2. The biomass potential from pruning of the apple orchards in Poland

Voivodeship	Apple orchards area	Theoretical potential	Technical potential	Economic potential
	ha	TJ·year^{-1}	TJ·year^{-1}	TJ·year^{-1}
Dolnośląskie	2653	172	137	110
Kujawsko-pomorskie	4003	259	207	167
Lubelskie	23192	1502	1199	965
Lubuskie	2225	144	115	93
Łódzkie	19368	1254	1002	806
Małopolskie	7985	517	413	332
Mazowieckie	74572	4829	3856	3103
Opolskie	658	43	34	27
Podkarpackie	4842	314	250	201
Podlaskie	1650	107	85	69
Pomorskie	2253	146	117	94
Śląskie	1005	65	52	42
Świętokrzyskie	22825	1478	1180	950
Warmińsko-mazurskie	3553	230	184	148
Wielkopolskie	7377	478	381	307
Zachodniopomorskie	15279	989	790	636
Total	193440	12525	10004	8049

In Poland, the total theoretical potential of wooden residues after regular pruning of apple trees in orchards is 12.5 PJ·year^{-1} (tab. 2). However, this energetic potential is not distributed equally across the country (fig. 6).

The highest potential is in Mazowiecke Voivodeship reaching a value of 4.8 PJ·year^{-1}. It is a significant amount of biomass energy and represents almost 40% of the national potential of pruned biomass from apple orchards. The next Voivodeships with significant potential are: Lubelskie, Łódzkie, Świętokrzyskie and Zachodniopomorskie. Their joint potential is calculated at 5.2 PJ·year^{-1} (ca. 42%). The lowest potentials are determined for Opolskie and Śląskie Voivodeships giving together only ca. 0.11 PJ·year^{-1}, which is less than 1% of the investigated national potential from apple tree pruning.

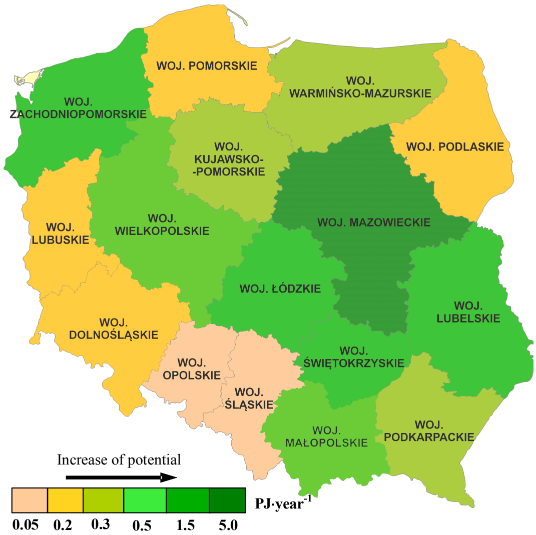

Fig. 6. Theoretical potential of the pruned biomass in Polish Voivodeships

The technical potential of biomass from orchard pruning is naturally lower than the theoretical potential and is calculated at 10.0 PJ·year^{-1}. The highest energetic potentials are found in the Voivodeships (fig. 7): Mazowieckie, Lubelskie, Świętokrzyskie, Łódzkie, and Zachodniopomorskie, respectively. These five regions are responsible for more than 80% of the technical potential of this kind of renewable energy from apple orchards in Poland.

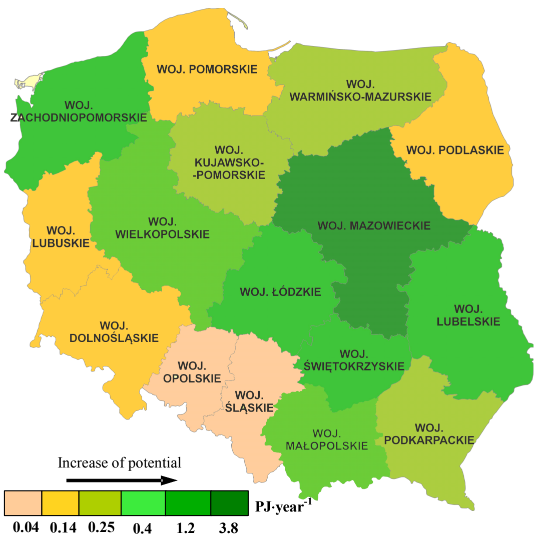

Fig. 7. Technical potential of the pruned biomass in Polish Voivodeships

From a practical point of view, however, the most important role is the economic potential, which for Poland is calculated at 8.0 PJ·year^{-1}. The highest shares are in the same Voivodeships, as for the previous theoretical and technical potentials (fig. 8). It should be noted that, although the economic potential is almost 40% lower than the theoretical one, this value is still high and may play an important role for the local biomass market, especially for the feeding of small (domestic) and middle size boilers. Moreover, it opens new business opportunities for both apple producers and companies in the sectors of logistics, heat technology and agricultural services, at the same time providing new job opportunities.

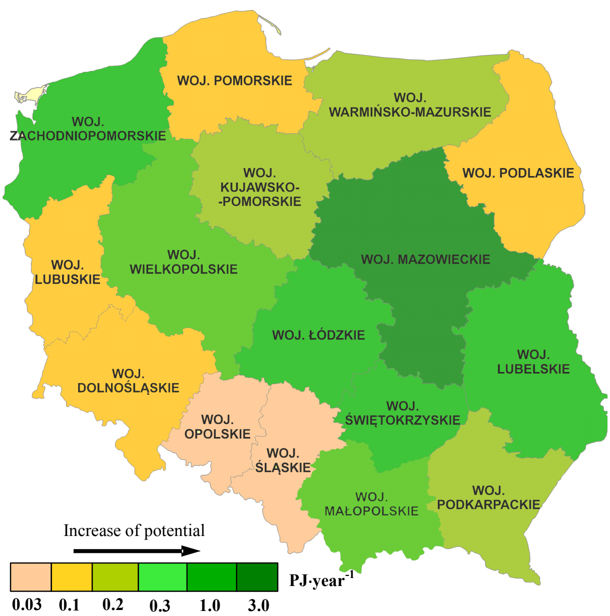

Fig. 8. Economic potential of the pruned biomass in Polish Voivodeships

It should be highlighted that the allocation of wooden biomass residues from orchards for energy production also has influences on environmental aspects and decreases the need for fossil fuel combustion. If the economic potential of bioenergy from apple tree pruning is compared to the energy coming from typical bituminous coal combustion in households boilers (HHV = 26 MJ·kg^{-1}, moisture content W = 12.5%) [Kruczek 2001], then around 0.31 m Mg·year^{-1} of coal may be saved. Moreover, when considering the reaction of stoichiometric carbon combustion (1 kg C + 2.67 kg O_2 = 3.67 kg CO_2) and the carbon content in the bituminous coal in the amount of c = 65%, then a reduction of CO_2 emission of 0.75 m Mg·year^{-1} may be achieved.

Conclusions

Wooden biomass from apple tree pruning in orchards may be a good alternative and renewable source of energy for heat production in small and middle size boilers on the local market.

In Poland almost 200 000 hectares of apple orchards are cultivated. As a result of apple tree pruning, the generated average amount of wooden biomass is calculated as 3.5 $Mg \cdot ha^{-1} \cdot year^{-1}$. Assuming the high heating value HHV = 18.5 $MJ \cdot kg^{-1}$ of this biomass the energetic potential of apple orchards in Poland is, as follows: theoretical 12.5 $PJ \cdot year^{-1}$, technical 10.0 $PJ \cdot year^{-1}$, economic 8.0 $PJ \cdot year^{-1}$. The highest energetic potential of apple orchard pruning residues is in the Mazowieckie Voivodeship. In the case of economic potential, the amount of energy from this Voivodeship is ca. 3.1 $PJ \cdot year^{-1}$. The lowest potential is in Opolskie Voivodeship and is only 0.03 $PJ \cdot year^{-1}$. The economic potential indicates that this kind of biomass might be available locally, depending on the possibilities, orchard area and access to the harvesting technology.

Nevertheless, the energetic potential of pruned biomass in Poland is significant (especially in the selected regions) and may lead to an increase of sustainable development of the local community and usage of local renewable energy sources as well as a reduction of emissions to the environment, mainly CO_2.

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Acknowledgements

This scientific paper is co-financed by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312078, and by funds on science in the years 2013-2016 granted by the Polish Minister of Science and Higher Education (Grant Agreement Nr 2896/7.PR/2013/2 from 18.11.2013) on the realisation of the international project EuroPruning: "Development and implementation of a new and non-existent logistics chain for biomass from pruning".

Submission date: *15.02.2016*

Online publication date: *24.11.2016*