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The Potential of Straw for Energy Purposes in Poland

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Abstract

The paper presents the results of studies aimed at determining the potential of the use of straw for energy in Poland. The results of this analysis have been presented in a dynamic approach for the years 1975–2011, and in a territorial (by voivodship) approach for the years 1999–2011. These studies demonstrate that since 1983 straw harvests have exceeded the requirements of agricultural production. During the years 1983–1990, the average surplus over agricultural consumption amounted to 4 971 thousand tons, and recently, during the years 2007–2011, already 15 190 thousand tons. The quantity of these surpluses varies greatly by region, as it depends on the structure of land tillage, crop structure, farm size, as well as the type of livestock and the manner of husbandry. The greatest potential for using straw for energy-related purposes was noted in the following voivodships: Wielkopolskie, Lubelskie, Zachodniopomorskie, and Kujawsko-Pomorskie.

Keywords: straw for energy, renewable energy sources

Introduction

Poland is seen in the EU as a country with great potential opportunities for biomass production for energy purposes. This is due to the fact that the agricultural area (AA) per capita in Poland is 0,41 ha, and in the EU-15 countries the respective figure stands at 0,19 ha.[1] The results of analyses and estimates conducted by some foreign experts indicate that from 1,0 to 4,3 million hectares of land can be used for energy production in Poland (*Estimating the Environmentally…* 2007; Kołodziej and Matyka 2012).

According to the Agricultural Census conducted in 2010, the total land area was 15,5 million hectares, of which 10,4 million hectares were cultivated. By analyzing the structure of the main crops on arable land (cereals, maize and rapeseed, all of which can provide straw for energy purposes), it was determined that the total area of these crops amounted to 8,592 million hectares. The largest share in the structure of crops were cereals (73,5%) and rapeseed (9,1%). The crop structure varied regionally in particular provinces, but the largest group of plants is always a type of cereal whose share reaches 75% in the crop structure. This is obviously beneficial, when considering the possibilities for the use of straw in power generation.

Straw for energy is included in the European policy of renewable energy sources use.[2] In Poland, industrial use of straw for energy purposes is regulated by the current legal status of biomass energy law[3] and Regulation of the Polish Minister of Economy on electricity produced from a renewable energy source.[4] Estimates of straw's potential in Europe have been carried out by the Joint

1. [In the journal (in both Polish and English texts) European practice of number notation is followed—for example, 36 333,33 (European style) = 36 333.33 (Canadian style) = 36,333.33 (US and British style). Furthermore in the International System of Units (SI units), fixed spaces rather than commas are used to mark off groups of three digits, both to the left and to the right of the decimal point.—Ed.]

2. See: Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union L 140, 05/06/2009, p. 16–62.

3. See: Ustawa z dnia 10 kwietnia 1997 r. — Prawo energetyczne. DzU z 1997 r. nr 54 poz. 348.

4. See: Rozporządzenie Ministra Gospodarki z dnia 18 października 2012 r. w sprawie szczegółowego zakresu

Research Centre (Edwards et al. 2005) as well as by scientific projects (Zheliezna and Eleftheriadis 2011). However, these analyses of straw resources do not seem to be sufficiently complete because of scale inconsistencies or the modelled types of assortments. This applies especially in case studies conducted for larger European countries such as Germany, France and Poland, which have a high theoretical potential for this resource.

Poland has abundant bioenergy resources including the agricultural and food industries as well as forest timber waste. Cereal crops dominate arable agriculture, producing straw in large quantities. The straw potentials have to be estimated for a wide range of plants: wheat, barley, triticale, rye, oats, mixed cereals, maize, rapeseed and turnip rape. This broad list takes into account all kinds of plants leaving straw mass, which is potentially usable for energy purposes.

Estimates of the availability of straw must take into account its primary uses in agriculture for soil fertilization (Madej, Fotyma, and Duer 2004; Scarlat, Martinov, and Dallemand 2010), animal husbandry (Edwards et al. 2005; Scarlat, Martinov, and Dallemand 2010) and carbon-based improvers of the soil (Kuś, Madej, and Kopiński 2006), which is now seen as one of the processes of climate change mitigation (Kozyra, Doroszewski, and Nieróbca 2009). A significant proportion of the straw resources are also used for mound covering, bedding mat preparation in horticultural farms, insulation of buildings and in the food industry, especially mushroom production.

As Gradziuk (2012), Igliński et al. (2011) mentioned, since 1983 there has been an overall surplus in straw that differs from a few million tons nationwide to a peak of about 10 million tons between 1995 and 2001. An effective way to manage this surplus has to be sought and one of the possible solutions could be for energy generation purposes. Taking into account that Polish energy plants are basically fuelled by coal and that its heating value ratio to straw biomass is roughly equal to 1,5, straw could not only heat houses and buildings in agricultural areas, but could also be used in local furnaces at a community level or even bigger power plants.

1 Material and research methodology

Our analysis used published and unpublished information from the Central Statistical Office (Polish name: Główny Urząd Statystyczny (GUS)). The following published materials were used:

- statistical journals
- statistical bulletins on the production of major agricultural and horticultural crops
- census data on agricultural land use, crop area, and livestock numbers

Among the unpublished materials, we used specially commissioned GUS material showing agricultural production in the spatial system. On this basis, we were able to establish the general area and straw harvest of basic cereals (wheat, rye, triticale, barley and oats, including grain mixtures) in the years 1975–2011 in Polish agriculture. In these materials, however, there is no data on the harvests of straw originating from rapeseed and agrimonia, and therefore there was a need for an estimate valuation. Production of straw from these crops was calculated on the basis of seed stock. It is assumed that the ratio of seeds to straw is 1:1.

The selection of those particular plants resulted from the fact that the basic cereal straw with grain mixtures, and that of rapeseed and agrimonia represent about 99% of the total production of straw in Poland, and is suitable for energy purposes. To evaluate the possibility of using straw for energy purposes, the straw harvest was reduced by its use in agriculture. Based on previous studies, it was assumed that straw is primarily supposed to meet the needs of livestock production (bedding and feed), and fertilizer purposes (ploughing into the soil)—in order to maintain a sustainable balance of soil organic matter. Calculations are made according to the following formula:

$$N = P - (Z_s + Z_p + Z_n), \tag{1}$$

where:

N—surplus straw for alternative (energy) use,

obowiązków uzyskania i przedstawienia do umorzenia świadectw pochodzenia, uiszczenia opłaty zastępczej, zakupu energii elektrycznej i ciepła wytworzonych w odnawialnych źródłach energii oraz obowiązku potwierdzania danych dotyczących ilości energii elektrycznej wytworzonej w odnawialnym źródle energii. DzU z 9 listopada 2012 r. poz. 1229.

P—straw production of basic cereals and rapeseed and agrimonia,
Z_s—straw demand for bedding,
Z_p—straw demand for animal feed,
Z_n—straw demand for ploughing into fields.

In GUS materials, there is no data on the distribution of straw, and therefore the information had to be estimated. Demand for feed and straw bedding was calculated on the basis of livestock numbers and annual norms for individual species and groups of use, as follows:

$$Z_s = \sum_{i=1}^{n} q_i s_i \text{ and } Z_p = \sum_{i=1}^{n} q_i p_i, \tag{2}$$

where:
Z_s—straw demand for bedding,
Z_p—straw demand for animal feed,
q_i—population of the individual species and group use,
s_i—normative demand for bedding straw for individual species and group use,
p_i—normative demand for animal feed and straw for individual species and group use.

In recent years, mainly due to a decrease in the areas of grassland and perennial legumes, which are essential for the recovery of stocks of organic matter in the soil, and a further decrease in the stocking density of farm animals and the associated lower production of manure, there is concern that in some areas the balance is a negative value. The increase or decrease in the organic substances can be measured by determining the coefficients of their reproduction or degradation. In the event of the loss of organic matter, one of the possibilities of increasing the humus content is ploughing in straw. Such a decision requires the conducting of a balance calculation. In our studies the calculations were based on the coefficients of reproduction (w_{ri}) and degradation (w_{di}) of organic matter in medium grade soil.

Knowing the sowing area of particular groups of plants and the amount of manure produced (based on animal populations—adequate norms (o), the balance of organic matter was determined by the following formula:

$$S = \sum_{i=1}^{n} r_i w_{ri} + \sum_{i=1}^{n} d_i w_{di} + \sum_{i=1}^{n} q_i o_i, \tag{3}$$

where:
S—the balance of organic matter,
r_i—area of cultivation of plant groups increasing organic matter content,
d_i—area of cultivation of plant groups reducing organic matter content,
w_{ri}—reproduction rate of organic matter for a given group of plants,
w_{di}—organic matter degradation factor for a given group of plants,
q_i—quantity of livestock in actual numbers by species and age groups,
o_i—manure production norms in tons/year by species and age groups.

Such calculations were conducted in this study. The occurrence of a negative balance of organic matter means that a certain amount of straw needs to be ploughed in, in order to maintain a sustainable balance of humus. It was assumed that 1 ton of dry manure is equivalent to 1,54 tons of straw, and hence the need for ploughing straw was calculated as follows:

$$Z_n = 1{,}54 \cdot S, \tag{4}$$

where:
Z_n—straw required for ploughing in,
S—balance of organic matter.

Based on the collected material, it was only possible to determine the potential energy use of straw nationwide. In order to present the data in a spatial form, we commissioned relevant statistical data from GUS for an additional fee. On the basis of such data, we estimated straw surpluses for particular voivodships for the years 1999–2011.

Tab. 1. Straw supply balance in the years 1975–2011 in thousands of tons

Year	Straw production of 4 grains with mixes (P)		Rapeseed straw Production (P)	Straw Production Total (P)	Straw Bedding (Z_s)	Straw Feed (Z_p)	Straw Bedding and Feed (Z)	Straw Plowed in (Z_n)	Straw surplus (N)	
	total	of which wheat							total	of which wheat
1980	21606	4698	572	22178	16778	13294	30072	0	0	0
1981	22377	4226	496	22873	15510	12585	28095	0	0	0
1982	22985	4324	433	23418	15749	12715	28464	0	0	0
1983	26934	5272	554	27488	14428	12217	26645	0	843	421
1984	30457	6568	911	31368	14654	12156	26810	0	4558	2279
1985	28601	6786	1073	29674	14620	11842	26461	0	3213	1607
1986	29321	7493	1298	30619	14560	11502	26061	0	4558	2279
1987	29106	7995	1186	30292	13969	10960	24929	0	5363	2582
1988	28092	7518	1199	29291	13885	10623	24508	0	4783	2392
1989	30889	8517	1586	32475	13926	11026	24952	0	7523	3762
1990	31875	8942	1206	33081	13622	10534	24156	0	8925	4463
1991	28676	8237	1043	29719	13229	9400	22629	0	7090	3545
1992	20495	6277	758	21253	12480	8464	20944	0	309	155
1993	23785	7208	594	24379	11060	7787	18847	0	5532	2766
1994	22675	6764	756	23431	10963	7476	18439	0	4992	2496
1995	27690	8136	1377	29067	10773	7056	17828	0	11239	4068
1996	25852	7614	449	26301	9972	6768	16740	0	9561	3807
1997	25494	7461	595	26089	10141	6962	17103	0	8986	3731
1998	28336	8735	1099	29435	10364	6999	17363	0	12072	4368
1999	27096	7242	1132	28228	9904	6657	16561	0	11666	3621
2000	21004	6802	958	21962	9160	6165	15325	0	6637	3319
2001	29084	7428	1064	30148	8939	5867	14805	0	15343	3714
2002	24308	7438	949	25257	8990	5521	14511	0	10746	3719
2003	21297	6287	793	22090	8931	5507	14436	0	7654	3144
2004	26590	7914	1633	28223	8433	5358	13791	0	14432	3957
2005	26589	7017	1450	28039	8824	5374	14197	0	13842	3509
2006	20450	5648	1651	22101	8977	5511	14487	0	7615	2824
2007	24054	6654	2130	26184	8863	5585	14447	0	11737	3327
2008	26801	7420	2106	28907	8232	5624	13856	0	15051	3710
2009	29195	7832	2497	31691	7890	5520	13410	0	18281	3916
2010	26832	7526	2229	29061	7712	5390	13102	0	15959	3763
2011	25748	7471	1862	27610	7554	5132	12686	0	14924	3736

2 The results of the study

The study showed that since 1983 straw collection has begun to exceed straw demand resulting from agricultural production. In the years 1983–1990, average annual surplus over consumption in agriculture amounted to 4 971 thousand tons, and in recent years (2007–2011), the surplus amounted to 15 190 thousand tons. The increasing surplus of straw is due to a decrease in livestock farming, and thus decreasing demand. A negative phenomenon, but typical for agriculture, was the occurrence of fluctuations in the harvests of straw, which was not without impact on the surplus figures. Thus in 2000, straw production amounted to only about 6.6 million tons, and in 2001 more than twice as much, namely 15,3 million tons. The balance of straw in the country

in the years 1975–2011 is shown in figure 1, which shows the trend of production and surplus of primary cereal straw with mixtures of wheat and rape in the years 1984–2011.

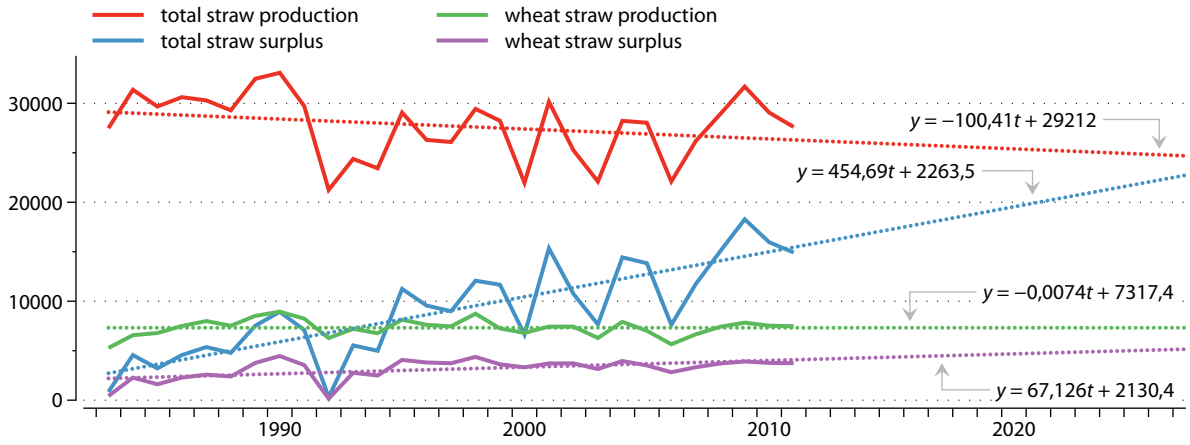

Fig. 1. Trends in the production of and surpluses of straw for use for power-and energy-related purposes in Polish agriculture during the years 1984–2027

An analysis by province showed that possible alternative use of straw is much smaller, because in some provinces part of the surplus should be used for ploughing in, to maintain a sustainable balance of organic matter in the soil. Thus in 1999 the difference was 3,2 million tons, and in 2011 approximately 5 million tons. This means that decisions on the possible alternative use of this material must be preceded by a calculation of the local balance of straw. An analysis of the obtainable amounts on the sub-provincial level (county) will allow us to obtain more reliable results.

In this paper however, the balance of surplus straw is drawn up on the voivodship level. This results primarily from a lack of reliable figures on the county level. The volumes of surplus straw are varied regionally, as they depend on the structure of land use, crop structure, the size of farms and the structure and methods of livestock farming. The biggest potential for the use of straw in energy generation was found in Wielkopolskie, Lubelskie, and Zachodniopomorskie voivodships. Limited possibilities of straw for energy purposes were seen in Podlaskie and Podkarpackie voivodships, where deficits have occurred in recent years. In drawing up the balance calculations for the country, it was not assumed that straw could be transported from other provinces, and in case of deficit, farmers would reduce its normal use or replace it with other similar materials, such as hay. This does not mean, however, that at the local, municipal and even county levels, straw could not be used for energy purposes in these regions. Nevertheless, this requires taking accounts in the micro-scale; and then it would be possible to determine with greater precision the demand for straw for agricultural purposes, considering the various ways animals are bred (bedding or non-bedding) and how they are fed (concentrate feeds vs. high forage rations).

The main problem is the real availability of existing surplus straw. The area structure of farms in Poland is very unfavorable as it is dominated by small farms. This reduces substantially the possibility of using high-performance, large-sized presses for straw, which in turn determines successfully an economically feasible supply of biomass. Hence, in the presented study we attempt to assess the economic potential of the one which would guarantee the economic viability of the project, and which depends on the organization of an efficient system of collection, storage and transport. It is assumed that potential suppliers of straw should be sought in such regions which satisfy the following conditions:

- areas that will have a significant surplus of straw over the needs stemming from agricultural production, with a view to at least 2020
- areas characterized by a favorable structure of holdings (a significant number of large farms — more than 50 ha)

As pointed out earlier, Polish agriculture is characterized by unfavorable area structure of farms, dominated by small farms. Of the total of 1 562 000 farms, 87% have an area of less than 15 hectares

Tab. 2. Area structure of farms by voivodship in Poland in 2010

	Total		Up to 15 ha		Over 50 ha		Total		Up to 15 ha		Over 50 ha	
Voivodship	***n***	**%**	***n***	**%**	***n***	**%**	**thousands of ha**	**%**	**thousands of ha**	**%**	**thousands of ha**	**%**
Dolnośląskie	63462	100	52792	83	2792	4,4	968	100	254	26	499	52
Kujawsko-pomorskie	67914	100	49048	72	2390	3,5	1087	100	310	29	362	33
Lubelskie	189874	100	173436	91	1455	0,8	1417	100	870	61	173	12
Lubuskie	23516	100	18821	80	1426	6,1	451	100	88	20	274	61
Łódzkie	134448	100	122320	91	658	0,5	1004	100	658	66	80	8
Małopolskie	162275	100	159793	98	364	0,2	664	100	493	74	75	11
Mazowieckie	237658	100	208792	88	1927	0,8	2017	100	1141	57	243	12
Opolskie	28 479	100	21939	77	1413	5,0	519	100	112	22	270	52
Podkarpackie	145172	100	141992	98	671	0,5	693	100	453	65	131	19
Podlaskie	86013	100	63742	74	1232	1,4	1070	100	428	40	142	13
Pomorskie	42840	100	32013	75	2040	4,8	808	100	189	23	396	49
Śląskie	77627	100	74048	95	655	0,8	455	100	246	54	105	23
Świętokrzyskie	103130	100	99249	96	304	0,3	551	100	421	76	33	6
Warmińsko-mazurskie	44403	100	28155	63	3134	7,1	1056	100	176	17	538	51
Wielkopolskie	123893	100	97195	78	3555	2,9	1790	100	582	33	637	36
Zachodniopomorskie	31901	100	22541	71	3134	9,8	955	100	120	13	666	70
Poland	1562605	100	1365876	87	27150	1,7	15503	100	6541	42	4624	30

Source: Own study on the basis of the National Agriculture Census

of farmland. Farms with an area of over 50 ha numbered just over 27 000, or 1,7% of the total, but their total area amounted to more than 4,6 million ha. The structure of Polish farm areas on the voivodship level is shown in table 2.

For the calculation of the economic potential it has been assumed that the said potential depends on the average size of farms. For such calculations, indices averaged for each province were used. For provinces with the most favorable structure of the area (e.g., Opolskie Voivodship) the rate stands at 70%, which means that the economic potential is 70% of the technical potential. The list of indicators are shown in table 3.

The calculations show that in 2007–2011, on average, the economic potential of straw for energy use in the country amounted to 5,6 million tons (tab. 4). The biggest alternative potential use of straw was found in areas in the north and south-west of the country. Limited possibilities of straw use for energy purposes are found in the Małopolskie, Podkarpackie, Świętokrzyskie voivodships, and a total absence of surplus in Podlaskie Voivodship. A differentiation of surplus straw for alternative use in the country in the period 2007–2011 is illustrated in figure 2.

Tab. 3. Indices of surplus straw use for energy purposes by the size of average farm

Average farm size in ha	Index in %	List of voivodships
Up to 6	20	Małopolskie, Podkarpackie, Świętokrzyskie, Śląskie
6–10	40	Lubelskie, Łódzkie, Mazowieckie
10–15.	50	Podlaskie, Wielkopolskie
Over 15	70	Dolnośląskie, Kujawsko-Pomorskie, Lubuskie, Opolskie, Pomorskie, Warmińsko-Mazurskie, Zachodnio-Pomorskie

Tab. 4. Straw surpluses and economic potential for energy purposes by voivodship in the years 2007–2011 in thousands of tons

	Surpluses						Economic potential					
Voivodship	2007	2008	2009	2010	2011	2007–2011	2007	2008	2009	2010	2011	2007–2011
Dolnośląskie	409	432	679	698	969	637	286	302	475	489	678	446
Kujawsko-Pomorskie	740	1011	1145	990	988	975	518	708	802	693	692	683
Lubelskie	598	1950	1443	558	1077	1125	239	780	457	223	431	426
Lubuskie	218	118	458	415	244	291	153	83	321	291	171	204
Łódzkie	800	827	1006	683	828	829	320	331	402	273	331	331
Małopolskie	208	553	528	174	542	401	42	111	106	35	108	80
Mazowieckie	357	776	1009	710	599	690	143	310	404	284	240	276
Opolskie	570	795	602	962	599	706	399	557	421	673	419	494
Podkarpackie	67	354	226	−57	63	131	13	71	45	0	13	28
Podlaskie	−419	−303	−354	−336	−393	−361	0	0	0	0	0	0
Pomorskie	751	706	670	878	626	726	526	494	469	615	438	508
Śląskie	525	548	511	362	672	524	105	110	102	72	134	105
Świętokrzyskie	363	314	272	93	263	261	73	63	54	19	53	52
Warmińsko-Mazurskie	791	696	838	1378	862	913	554	487	587	965	603	639
Wielkopolskie	992	849	2754	2616	1318	1706	496	424	1377	1308	659	853
Zachodniopom.	565	542	1057	634	634	686	396	379	740	444	444	481
Poland	7536	10166	12843	10760	9890	10239	4263	5210	6762	6384	5414	5607

Fig. 2. Straw surplus for energy production in Poland

Summary

These studies demonstrate that since 1983 straw harvests have exceeded the requirements of agricultural production. During the years 1983–1990, the average surplus over agricultural consumption amounted to 4 971 thousand tons, and recently, during the years 2007–2011 — already 15 190 thousand tons. The increasing straw surpluses are caused by a decrease in livestock, and by the same token, by diminishing demand. An unfavorable phenomenon, albeit common for agriculture, were straw harvest fluctuations, which certainly bore an impact on the levels of surpluses. As an example, in 2000 they amounted to only 6 627 thousand tons, but nearly doubled in 2001 — 15 343

thousand tons. The quantity of these surpluses varies greatly by region, as it depends on the structure of land tillage, crop structure, farm size, as well as the type of livestock and the manner of husbandry. The greatest potential for using straw for energy-related purposes was noted in the following voivodships: Wielkopolskie, Lubelskie, Zachodniopomorskie, Kujawsko-Pomorskie, Mazowieckie, Warminsko-Mazurskie, Pomorskie, Łódzkie, and Śląskie. There is very modest potential for using straw for energy-related purposes in Podlaskie and Podkarpackie voivodships, and deficits have been recorded during certain years. In preparing the balance on the national scale, a transfer of straw from other voivodships in the event of a deficit has not been foreseen; the farmers decrease consumption standards or employ other raw materials instead, such as hay. However, this does not mean that on a local scale (township or county) in these regions straw could not be employed for energy-related purposes. This would however require making calculations on a micro-scale, and it would then be possible to define the requisition of straw for agricultural purposes with greater accuracy, at the same time taking into account various methods of animal husbandry (litter and non-litter systems) and nutrition (nutritive or bulky fodder).

References

Edwards, R.A.H., M. Šúri, T.A. Huld, and J.F. Dallemand. 2005. GIS-Based Assessment of Cereal Straw Energy Resource in the European Union. http://iet.jrc.ec.europa.eu/remea/gis-based-assessment-cereal-straw-energy-resource-european-union.

Estimating the Environmentally Compatible Bioenergy Potential from Agriculture. 2007. *EEA Technical Report*. Luxembourg: European Environment Agency; Office for Official Publications of the European Communities.

Gradziuk, P. 2012. Pozyskanie i wykorzystanie słomy na cele energetyczne w ciepłownictwie i energetyce zawodowej w Polsce. In *XI Koknferencja "Odnawialne źródła energii obecnie i w nowej perspektywie po 2013 roku"*. Płońsk: Mazowiecki Ośrodek Doradztwa Rolniczego. Oddział Poświętne w Płońsku.

Igliński, B., A. Iglińska, W. Kujawski, R. Buczkowski, and M. Cichosz. 2011. "Bioenergy in Poland." *Renewable & Sustainable Energy Reviews* no. 15 (6): 2999–3007. doi: 10.1016/j.rser.2011.02.037.

Kołodziej, B., and M. Matyka. 2012. *Odnawialne źródła energii. Rolnicze surowce energetyczne*. Poznań: Państwowe Wydawnictwo Rolnicze i Leśne.

Kozyra, J., A. Doroszewski, and A. Nieróbca. 2009. "Zmiany klimatyczne i ich przewidywany wpływ na rolnictwo w Polsce." In *Kierunki zmian w produkcji roślinnej w Polsce do roku 2020*, edited by A. Harasim, 243–257. Puławy: Instytut Uprawy Nawożenia i Gleboznawstwa – Państwowy Instytut Badawczy.

Kuś, J., A. Madej, and J. Kopiński. 2006. "Bilans słomy w ujęciu regionalnym." In *Regionalne zróżnicowanie produkcji rolniczej w Polsce*, edited by A. Harasim, 211–226. Puławy: Instytut Uprawy Nawożenia i Gleboznawstwa – Państwowy Instytut Badawczy.

Madej, A., M. Fotyma, and I. Duer. 2004. *Kodeks dobrej praktyki rolniczej*. 3rd ed. Warszawa: Fundacja Programów Pomocy dla Rolnictwa.

Scarlat, N., M. Martinov, and J.F. Dallemand. 2010. "Assessment of the Availability of Agricultural Crop Residues in the European Union. Potential and Limitations for Bioenergy Use." *Waste Management* no. 30 (10): 1889–1897. doi: 10.1016/j.wasman.2010.04.016.

Zheliezna, T.A., and I. Eleftheriadis. 2011. "Agricultural Residues." In *Biomass Resource Assessment Handbook Harmonisation of Biomass Resource Assessments, Best Practices and Methods Handbook*, edited by M. Vis, 103–128. Saarbrücken: VDM Verlag Dr. Müller.