Combustibility of biomass from wet fens in Belarus and its potential as a substitute for peat in fuel briquettes

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SUMMARY

Peatland drainage has caused enormous environmental problems at global scale; in particular, ongoing greenhouse gas emissions and soil degradation. In Belarus, which is rich in peatlands and a hotspot of emissions from drained peatlands, several thousand hectares have already been re-wetted but are not used productively. Moreover, vast areas of wet (undrained) peatland that are designated for nature conservation are in need of mowing and biomass removal. Plants such as common reed (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*) and sedges (*Carex* spp.) which frequently dominate these areas could be harvested and used as fuel, potentially as a substitute for peat. In this study we analysed the yield and combustibility of late harvests in March/April 2009 and 2010. The yields of 3.7–11.7 t DM ha^{-1} were within the range reported from other studies on wetland plants. Concentrations of Cl, S, N, P, C, Ca, K, Mg and Na, as well as water and ash contents, indicated similar or better combustibility when compared to other straw-like (graminaceous) plants such as *Miscanthus*. The full replacement of peat fuel by biomass from wet peatlands in Belarus would require an area of 680,000 ha, i.e. 'only' half of the peatland that has been drained for agriculture.

KEY WORDS: biofuel; nature conservation; reed; re-wetting; paludiculture

INTRODUCTION

Mires formerly covered about 15 % of Belarus, extending to almost three million hectares. Approximately 1.5 million hectares have now been drained (Tanovitskaya 2011) and, as a result, the country is ranked eighth in the world for national greenhouse gas emissions from peatlands (41 Mt CO_2 per year; Joosten 2009). The drained peatlands are used for agriculture (72 %), forestry (26 %) and peat extraction (2 %) (Tanovitskaya 2011). The output of 26 peat ‘factories’ is used mostly as fuel for heating and power generation, and regarded as important for domestic energy security.

The continuous CO_2 emissions from peat degradation, augmented by emissions from peat fires, could be avoided by raising peatland water levels. By 2011, around 36,000 ha of peatland had been re-wetted but most of this area was not used productively (Tanneberger & Wichtmann 2011). Productive 'wet' land use (paludiculture) could provide, for example, renewable fuels to replace fossil ones, and thus generate both income and further carbon savings. It could also arrest the dense overgrowth of abandoned open fens by tall reed and shrub vegetation, which is one of the most important nature conservation problems in Belarus. Moreover, the resumption of traditional mowing of wet fens could reinstate habitats for much of the threatened flora and fauna.

To newly establish or revive the use of biomass from wet peatlands for fuel production, it is essential to assess potential biomass yields and combustion characteristics. Expected yields strongly influence the outcome of feasibility and profitability calculations, whilst characteristics such as water and ash content determine fuel quality and any requirements for special combustion techniques. For example, water contents above 20 % substantially reduce the heating value of biomass and may cause serious storage problems (Wichtmann & Schulz 2011). Straw-like (graminaceous) biomass is usually regarded as a problematic fuel because of its high S and Cl concentrations (leading to high HCl and SOx emissions, deposit formation and boiler corrosion), high K, Mg, Na and Ca concentrations (causing low ash melting temperatures), and high ash content (Hartmann *et al.* 2003). Straw-like biomass harvested in late winter has lower water and ash contents and, thus, better combustibility (Hadders & Olsson 1997, Heinsoo *et al.* 2011). This is mainly due to leaching-out of K, Cl and other ash components from the dead standing biomass by precipitation. Leaching experiments with straw have shown that 150 mm of precipitation is sufficient to reduce the Cl concentration by 75–80 % and the K concentration by 60–70 % (Hernández Allica *et al.* 2001). Additionally, the loss of N- and K-rich leaves (Granéli 1990, Landström *et al.* 1996) and the recycling of nutrients into the rhizomes (e.g. 80 % of the August K content; Granéli 1990) lowers the elemental concentrations in above-ground biomass.

Most studies on yields and combustibility of straw-like energy plants (e.g. *Phalaris arundinacea*, *Miscanthus*) have been conducted on mineral soils. Heinsoo *et al.* (2011) indicate that there are differences between mineral and peat soils in this context, but studies from the latter are scarce. This article provides data on potential yields and combustion characteristics of winter harvested biomass from a re-wetted peat extraction site (Dakudauskaje) and a wet abandoned peatland (at Sporava). It also assesses the potential for replacing peat fuel briquettes with biomass briquettes produced from wet peatlands in Belarus.

METHODS

Study sites

Biomass was sampled at two peatlands in Belarus (Dakudauskaje and Sporava; Figure 1). The four study sites were delineated on the basis of a field survey of dominant vegetation types suitable for biomass harvesting, which was carried out in late March and early April 2009 and March 2010 (Wichtmann & Tanneberger 2009).

The Dakudauskaje site is dominated by the common reed *Phragmites australis* (Table 1). Dakudauskaje is located in Hradna region, Lida district. The peatland extends to 7,811 ha, of which 3,583 ha has been excavated. Some excavated areas have already been re-wetted, and re-wetting is planned for the remainder. The water table is currently 1.2–1.5 m below the soil surface, and peat fires occur frequently. The study site is a patch of approximately 100 ha that was excavated and re-wetted about 15 years ago. As is typical for the

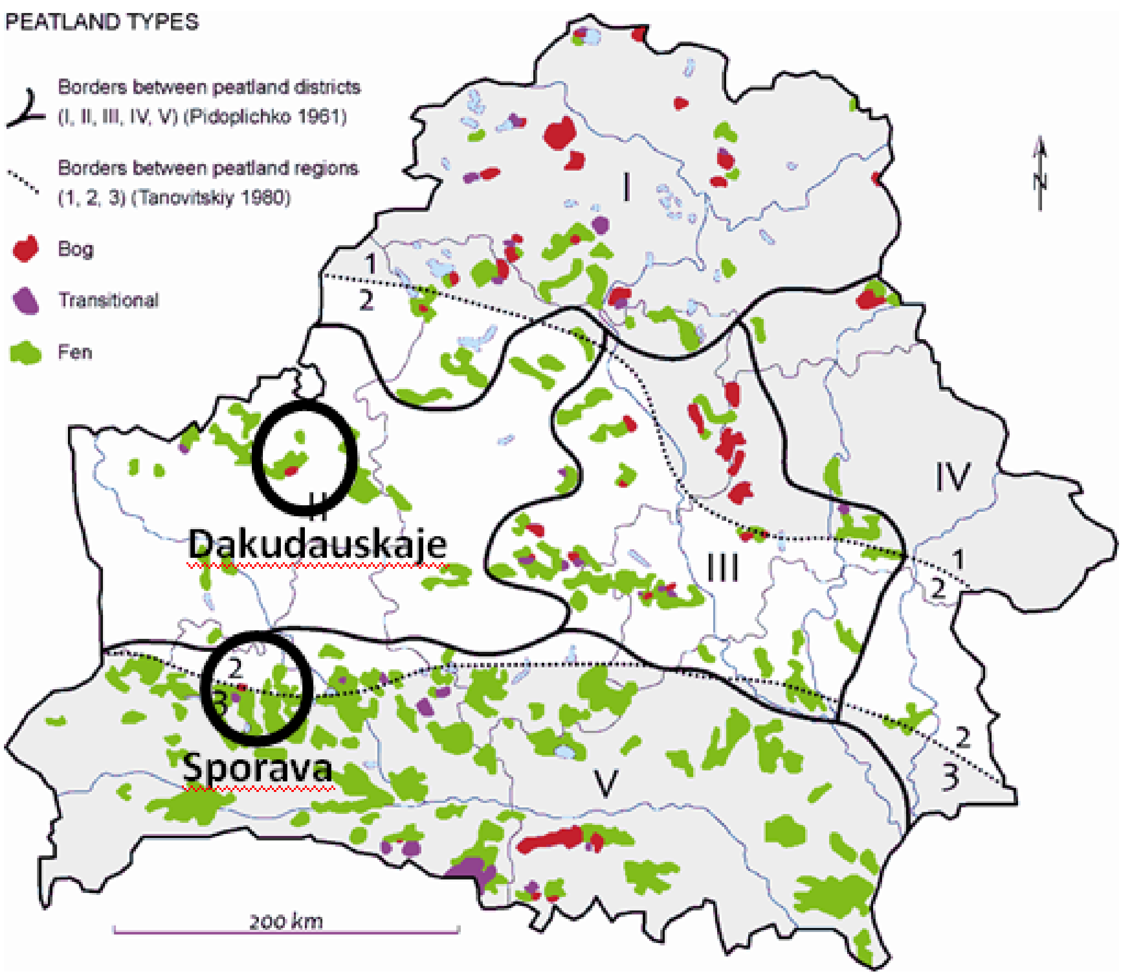

Figure 1. Locations of the Dakudauskaje and Sporava peatlands (circles) in Belarus. Peatland types are indicated in red (=bog), green (=fen) and purple (=transitional). Modified after Bambalov & Rakovich (2005); map: S. Busse.

Table 1. Locations and characteristics of the four study sites. The *Phalaris arundinacea* site (Sporava) burned in 2009. Otherwise, none of the sites had been disturbed for at least five years.

Site	Co-ordinates	Location	Water level during sampling*	Other plant species	Year of re-wetting
Phragmites australis Dakudauskaje (D)	53° 49′ 15″ N 25° 24′ 32″ E	south of Lida, near Lidziejka River	2009 and 2010: 55–60 cm	*Salix cinerea*, *Equisetum fluviatile*, *Carex* spp.	2001
Phragmites australis Sporava (S)	52° 20′ 32″ N 25° 17′ 22″ E	5 km south of Zdzitava, south of Jasielda River	2009 and 2010: 35–50 cm	*Carex riparia*, *Carex elata*, *Typha angustifolia*	~1995
Phalaris arundinacea Sporava (S)	52° 25′ 23″ N 25° 15′ 48″ E	near Zdzitava	2009: 3–5 cm 2010: 30–50 cm	*Carex elata*, *Typha latifolia*, *Lythrum salicaria*, *Peucedanum palustre*	never
Carex spp. Sporava (S)	52° 25′ 38″ N 25° 05′ 24″ E	*ca*. 4 km from Vysokaje	2009: 10–20 cm 2010: 35–40 cm	*Carex lasiocarpa*, *Potentilla palustre*	never

* above soil surface

majority of cutover areas 5–15 years after re-wetting, large reed beds have developed. The Lida peat factory, which is located close to the peatland, has been trialling the production of mixed briquettes (peat with straw) for several years.

The three Sporava sites have vegetation dominated, respectively, by (1) common reed (*Phragmites australis*), (2) reed canary grass (*Phalaris arundinacea*) and (3) sedges (*Carex* spp.) (Table 1). Sporava is located in Brest region, Beriosa district. Situated in the floodplain of the Jasielda river, it is one of the largest (*ca*. 20,000 ha) and least modified floodplain mires in Europe. The vegetation is dominated by sedge communities and wet meadows with associated reed beds, willow thickets and agricultural grasslands. Parts of the area are used for haymaking and cattle grazing, but much of it has been abandoned during the last 20 years. Rapid and, presumably, accelerating overgrowth by bushes is currently causing loss of open mire habitat at an estimated rate of 5 % per year (Wichtmann & Tanneberger 2009). The Sporava peatland includes an extensive area of suitable breeding habitat for the Aquatic Warbler *Acrocephalus paludicola* (a globally threatened songbird) and an internationally significant proportion of the *Caricetum elatae* plant community, both of which are in urgent need of vegetation management.

Biomass sampling and analysis

Samples were taken from 2–20 randomly selected 0.16 m^2 plots per study site, in March/April 2009 and March 2010. At each plot, all above-ground biomass was harvested by cutting the plants 5 cm above ground/water level. The fresh weight of each sample was determined in the field, and its dry weight after oven drying (to constant weight) at 80 °C for 48 hours. In 2009 the plot samples were mixed to form a single combined sample from each site, but each plot sample was analysed separately in 2010. The equipment and methods used for the chemical analyses are summarised in Table 2. The biomass harvested in 2009 consisted of plant biomass and remnants from the previous season(s). In 2010, regrowth of biomass at the same plots was sampled. Unexpectedly, it was impossible to repeat all of the 2009 sampling at some of the sites due to the presence of thick ice and snow in 2010.

Table 2. Methods and equipment for biomass analyses.

Attributes measured	Methods	Instruments
C, N, S	Dry combustion according to DIN ISO 15104 (2010) and DIN ISO 15178 (2001)	Elemental analyser Vario EL III, Elementar Analysesysteme Hanau, Germany
K, Mg, Ca, Na	Microwave digestion with HNO_3 and H_2O_2 and atomic absorption spectroscopy	Microwave 1500, MLS GmbH Start, AAS ContrAA 300, Analytik Jena Germany
P	Microwave digestion with HNO_3 and H_2O_2, and photometric measuring of orthophosphates	UV/VIS spectral photometer Cecil CE 102. 1000 Series, Analytik Jena, Germany
Cl	HNO_3 extraction according to Islam *et al.* (1983)	Ion-selective electrode (ISE), Monokrystaly Turnov, Czech Republic
Ash content	Loss on ignition at 550 °C, DIN ISO 14775 (2010)	Muffle furnace, Heraeus instrument

RESULTS

The mean yield in 2009 was highest at the *Phragmites australis* (D) site (11.7 t DM ha^{-1}) and lowest at the *Carex* spp. (S) site (7.0 t DM ha^{-1}) (Table 3). In 2010, the yields at all *Phragmites* sites were much lower (3.7–4.6 t DM ha^{-1}), and representative samples could not be collected from the *Phalaris arundinacea* and *Carex* spp. sites.

The water contents of *Phragmites australis* and *Phalaris arundinacea* were similar at the two harvest dates (*ca*. 30 wt % in 2009 and *ca*. 16 wt % in 2010). In contrast, the *Carex* spp. biomass was much wetter in 2009 (*ca*. 60 wt %) than in 2010 (7 wt %). The within-site variability was high.

Except for N concentrations, which were substantially higher at all study sites in 2010, the elemental concentrations differed only slightly between sites, plots and years (Table 4). There were almost no differences between sites in the concentrations of elements affecting ash melting (K, Ca, Mg and Na), although conspicuously higher Ca concentrations (0.32 wt % d.b. = dry biomass) were measured in *Carex* spp. (Table 5).

Table 3. Mean yields (in t DM ha^{-1}) and water contents (in weight % w.b. = wet biomass) of winter harvested plant biomass from wet peatlands in Belarus. D: Dakudauskaje; S: Sporava; *N*: number of samples. Standard deviations are given in brackets.

Study site	*N*		Yield (t DM ha^{-1})		Water content (wt % (w.b.))	
Year	2009	2010	2009	2010	2009	2010
Phragmites australis (D)	8	16	11.7 (5.9)	4.6 (2.9)	-	14.7 (8.4)
Phragmites australis (S)	9	20	9.8 (3.9)	3.7 (4.72)	29.0 (17.5)	15.1 (9.1)
Phalaris arundinacea (S)	8	6	9.6 (1.9)	-	30.3 (11.4)	16.3 (7.6)
Carex spp. (S)	8	2	7.0 (1.9)	-	58.2 (15.3)	7.2 (1.5)

Table 4. Concentrations of ash and chemical elements in winter harvested plant biomass from wet peatlands in Belarus. Mean values and (standard deviations) are given in wt % (d.b.). D: Dakudauskaje; S: Sporava.

Study site	*N*		Ash		C		Cl		S		N		P	
Year	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Phragmites australis (D)	1	4	4.1	4.4 (0.5)	46.9	45.0 (0.7)	0.01	0.03 (0.02)	0.09	0.10 (0.01)	0.43	0.63 (0.07)	0.03	0.04 (0.01)
Phragmites australis (S)	1	6	4.6	5.7 (1.7)	46.6	44.4 (1.2)	0.05	0.05 (0.02)	0.09	0.11 (0.02)	0.49	0.65 (0.14)	0.04	0.04 (0.01)
Phalaris arundinacea (S)	1	3	4.3	3.0 (0.3)	46.7	46 (0.1)	0.01	0.01 (0.005)	0.13	0.12 (0.02)	0.61	0.91 (0.25)	0.06	0.07 (0.02)
Carex spp. (S)	1	2	5.3	5.6 (0.7)	47.1	45.2 (0.5)	0.01	0.03 (0.001)	0.10	0.13 (0.02)	0.72	0.95 (0.13)	0.06	0.07 (0.02)

Table 5. Concentrations of elements affecting ash melting (K, Ca, Mg and Na) in winter harvested plant biomass from wet peatlands in Belarus (2010). Mean values and (standard deviations) are given in wt % (d.b.). D: Dakudauskaje; S: Sporava.

Study site	*N*	K	Ca	Mg	Na
Phragmites australis (D)	4	0.09 (0.02)	0.08 (0.01)	0.04 (0.01)	0.03 (0.01)
Phragmites australis (S)	6	0.11 (0.03)	0.08 (0.04)	0.02 (0.003)	0.02 (0.01)
Phalaris arundinacea (S)	3	0.12 (0.05)	0.11 (0.03)	0.05 (0.01)	0.02 (0.003)
Carex spp. (S)	2	0.15 (0.02)	0.32 (0.02)	0.06 (0.01)	0.03 (0.004)

DISCUSSION

Yields and water content

Summer yields are usually substantially higher than winter yields for the same plant species (Table 6). Seasonal losses of 18–24 % for *Phalaris arundinacea* on peat soils (Heinsoo *et al*. 2011) and of 25 % for *Miscanthus* (Lewandowski *et al*. 2003) have been reported. For *Phragmites australis*, assuming a mean summer yield of 6–24 t DM ha^{-1} and a loss of 30 %, the mean winter yield would be 4.2–16.8 t DM ha^{-1}. While our 2009 values are in the upper range of possible yields at a late harvest date, our 2010 values are at the minimum (Table 3). One possible reason is the composition of the biomass, as the 2009 harvest contained material from several years whereas the 2010 biomass originated in a single year. Studies of *Phragmites australis* in Sweden indicate that winter cutting may increase summer productivity by improving the light climate in spring (Granéli 1989). Traditional double wale (two-year-cutting) cycles are recommended for peat soils with low nutrients (Haslam 2010). Other possible reasons for the low 2010 values are the

Table 6. Mean yields of *Phragmites australis*, *Phalaris arundinacea* and *Carex* species on wet peat soils.

Plant species	Mean yield (t DM ha^{-1})	Harvest time	Reference (Country)
Phragmites australis	11.7 (2009) 4.6 (2010)	Mar/Apr	this study (Belarus)
	10	Jan-Mar	Bleuten *et al*. 2009 (Netherlands)
	6.9–23.8	Aug	Schulz *et al*. 2011, Steffenhagen *et al*. 2008 (Germany)
	6-16	Aug	Hanganu *et al*. 1999 (Romania)
Phalaris arundinacea	9.6	Mar/Apr	this study (Belarus)
	5/7/6	Jul/Oct/March	Heinsoo *et al*. 2011 (Estonia)
	8/7.9	Sep/Apr	Mander *et al*. 2012 (Estonia)
Carex spp.	7.0	Mar/Apr	this study (Belarus)
Carex acutiformis	4.2–7.6	Summer	Grzelak *et al*. 2011 (Poland)
Carex riparia	5.3–11.1	May/Sep	Schulz *et al*. 2011, Steffenhagen *et al*. 2008 (Germany)

severe frost and high water table before or at the harvest date (Table 1), which destroyed parts of the biomass and hampered sampling. Weather conditions and water levels presumably strongly affect yields in wet and re-wetted peatlands. Further factors influencing biomass yields such as site conditions (medium water tables, nutrient conditions) and genotypes of plants have not yet been investigated in Belarus.

Biomass with water contents above 20 % (w.b.) is in danger of self-ignition and decomposition by fungi and, thus, requires additional drying (Eckl 2003). The water content of winter harvested biomass is lower than that of summer harvested biomass (Hadders & Olsson 1997, Heinsoo *et al.* 2011). Values measured in this study were in the range 29–58 % (w.b.) in 2009 and 7–16 % (w.b.) in 2010 (Table 3). Therefore, only the 2009 biomass would require substantial additional drying and the 2010 biomass could be further processed without drying. This problem could be avoided by choosing more favourable dates for harvesting. Possible reasons for the high 2009 values are wet weather conditions preceding sampling, and cutting of moist plant parts close to the soil/water surface. In 2010, cutting was high due to high water levels. To reduce the water content of biomass from wet peatlands, cutting should be high (above the water level, usually by 10–30 cm, Haslam 2010). After harvesting, the biomass should be processed immediately and any loose material stored in a dry place (Wichtmann & Tanneberger 2009). In wet peatlands, it is not feasible to conduct drying on the ground, as is usual in grassland management and haymaking. Because traditional drying in hay stacks is very labour-intensive, it is advisable to use a well-aerated piece of ground outwith the peatland for any drying that is needed.

Combustibility

The characteristic elemental composition of plant biomass affects its combustibility and suitability for certain combustion techniques. The elemental concentrations of *Phalaris*, *Phragmites* and *Carex* spp. were quite similar across the sites and years of this study. Ash concentrations in the different biomass samples were 3–5.4 % and in the same range as those of straw and *Miscanthus*, but not as low as those of wood (Table 7; Barz *et al.* 2011). Concentrations of Cl were below the recommended <0.1 % limit for problem-free combustion (Obernberger *et al.* 2006). The concentration of S was 0.09–0.13 % and thus slightly higher than that of straw and *Phragmites* in other studies (Eder *et al.* 2004, Kitzler *et al.* 2012, Paist *et al.* 2007). The mean concentration of N was 0.55 % in *Phragmites*, but in *Phalaris* (0.76 %) and sedges (0.84 %) slightly exceeded the critical value of 0.6 wt. % given by Obernberger *et al.* (2006), as well as typical values for straw and *Miscanthus*. The

Table 7. Concentrations of ash, Cl, S, and N of peatland plants in comparison to other biofuels (wt % (d.b.)).

Type of biomass	Ash	Cl	S	N	Harvest time	Soil	Reference (Country)
Phragmites australis	4.7	0.04	0.10	0.55	Mar/Apr	re-wetted fen	this study, mean of 2009/2010 (Belarus)
	5.12	0.20	0.04–0.05	0.24–0.30			Eder *et al.* 2004 (Austria)
	7.47	0.15	0.07	0.47	Feb/Mar		Kitzler *et al.* 2012 (Austria)
	3.2	0.1	0.04	0.3			Paist *et al.* 2007 (Estonia)
Phalaris arundinacea	3.65	0.01	0.13	0.76	Mar/Apr	re-wetted fen	this study, mean of 2009/2010 (Belarus)
	8.0	0.05	0.1	0.6			Kastberg & Burvall 1998 (Sweden)
	3.23	0.19	0.17	0.96	Jul/Oct/Apr	mineral/ organic	Heinsoo *et al.* 2011 (Estonia)
Carex spp.	5.4	0.02	0.12	0.84	Mar/Apr	re-wetted fen	this study, mean of 2009/2010 (Belarus)
	4.0	0.1	0.18	1.41	autumn	fen	Zeng *et al.* 2013 (Germany)
Miscanthus	5.4	0.3	0.1	0.4			Hohmann 1995 (Germany)
Rye straw	4.8	0.4	0.085	0.55			Hartmann *et al.* 2003 (Germany)
Wood (spruce)	0.6	0.005	0.015	0.13			Hartmann *et al.* 2003 (Germany)

concentrations of elements that may cause low ash melting temperatures (K, Na, Ca and Mg) were very low (0.02–0.15 %) except for Ca in *Carex* spp. biomass (0.32 %). Concentrations in straw were much higher (K 1.68 %, Na 0.05 %, Ca 0.36 % and Mg 0.06 %; Hartmann *et al*. 2003, Obernberger *et al*. 2006). We conclude that late (March/April) harvesting ensures good combustibility by allowing substantial loss of critical elements through precipitation-induced leaching. However, the use of *Phalaris*, *Phragmites* and *Carex* spp. as biofuels requires special techniques. Grate or fluidised bed combustion would be suitable because it can accommodate higher ash contents. The very low Cl concentrations and moderate S and N concentrations should not lead to serious emissions problems.

Yield and combustibility are strongly related to harvest date, for which an optimum should be sought. It is suggested that biomass from wet peatlands should be harvested for combustion in January/February (i.e. a little earlier than in this study). For *Phalaris* in Estonia, Heinsoo *et al.* (2011) suggested harvesting in late autumn, when higher yields and combustion attributes similar to spring values (except for ash) were attainable. *Carex* spp. has similar attributes and so should be suitable for an earlier winter harvest. *Phragmites* for thatching is most usually harvested in December/January after culms have hardened and leaves have completely fallen off (Haslam 2003). Further research is needed to optimise yields and combustibility of biomass from wet peatlands.

Potential of biomass

Irregular mowing of at least 1,000 ha of *Phalaris* vegetation and 6,000 ha of *Carex* spp. vegetation is required to maintain the protected area at Sporava. Assuming a (conservative) mean yield of 5 t DM ha^{-1}, 7,000 t of biomass could be harvested annually from an area of 1,400 ha. However, harvesting every part of this area once in five years (e.g. one-fifth of the total area per year) will presumably be sufficient to maintain the desired Aquatic Warbler habitat conditions.

At Dakudauskaje, about 300 ha of *Phragmites* is currently available for harvesting. In an ongoing co-operative project with the Lida peat briquette factory, the proportion of peat in the briquettes is being gradually reduced in favour of above-ground biomass harvested from wet peatlands, and the combustibility of the mixed briquettes is being investigated. Since reedbeds are advancing onto areas where peat extraction has recently ceased, biomass may increasingly be used as a diluent for peat and eventually replace it.

More generally, there is great potential in Belarus for the replacement of peat briquettes with biomass from wet peatlands. To substitute the total quantity of fuel peat extracted annually in Belarus (recently some 3.5 million tonnes, N. Bambalov and V. Rakovich pers. comm.), 680,000 ha of wet peatland must be harvested (assuming a mean yield of 5 t DM ha^{-1} and a calorific value of around 17 MJ kg^{-1}). This is approximately 23 % of the total peatland area. According to Kozulin (2011), another 260,000 ha of (mainly) extracted peatland and 250,000 ha of agriculturally degraded peatland may be re-wetted in the future.

CONCLUSIONS

1. The potential yield and combustibility of biomass from wet and re-wetted peatlands are such that it is a suitable substitute for other fuels.

2. To fully replace the fuel peat that is currently extracted in Belarus with biomass from wet peatlands, around 680,000 ha of paludiculture would be required.

3. This is approximately 50 % of the peatland area that has already been drained for agriculture in Belarus.

4. Implementing paludiculture at this scale would substantially reduce the country's greenhouse gas emissions and establish a sustainable use of peatlands.

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