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The Baltic potential for Heat or Energy plants using graminoid biomass from paludicultures

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Content

Introduction

Peatlands comprise a major global carbon store. Covering only 3% of the planet's surface, they store 500 Gt of the terrestrial carbon, twice the amount of carbon as in the world's forests. Intact peatland ecosystems (mires) act as a carbon sink and accumulate carbon though at present.

CO_2 emissions

Due to drainage and extensive agricultural usage, worldwide CO_2 emissions from peatland are about 2 Gt per year. 1m^3 of peat, equivalent to 140 kg of soil contains 81 kg of carbon. After oxidation it becomes about 0.25 ton of CO_2 [1] Carbon, stored in peat is continuously released in form of CO_2 emissions by oxidation and mineralization of peat after drainage and consequent drained utilisation in agriculture and forestry and peat extraction. The carbon foot print therefore is the carbon content of removed peat (actively by extraction, passively by wind and water erosion) and in-situ emissions caused by drainage (continuous mineralisation, and fires). Baltic States are among the top ten CO_2 emitters from dried mires in the EU (LV 5th place, EE 8 place, LT 9 place). With ~24,650 km^2 total peatland area being drained and degraded for agriculture, forestry, and peat extraction. To achieve the goals of the Paris Agreement, in 2018 the European Union adopted the Land Use, Land Use Change and Forestry or LULUCF Regulation. Under this regulation, GHG emissions from forest land, arable land and permanent grassland management will be counted against the Paris Agreement targets after 2020, and starting from 2026 the inclusion of GHG emissions from wetland management will also be mandatory [2] [3] [4].

N_2O emissions

Emission of N_2O from natural mires have been reported to be relatively low, varying on average from 0.01 to 0.3 kg N_2O-N/year. Drainage and altered water regime raises the median values of N_2O emissions from peatlands to 5.6–6.6 and even up to 29 kg N_2O-N/year in some deciduous forests on peat soils [4].

Paludiculture

Paludiculture (lat. '*palus*' = swamp), the cultivation of biomass on wet and reweted peatlands, is an innovative alternative to conventional drainage based peatland agriculture and silviculture. The paludiculture approach aims at plants that thrive under wet conditions, produce biomass of sufficient quantity and quality, and contribute to the conservation of peat and ideally to the formation of new peat.

Paludicultures on rewetted formerly drained peatlands, contribute to climate change mitigation in two ways: by reducing GHG emissions from drained peatland soils and by replacing fossil resources with renewable biomass alternatives [5].

Rewetting should secure long-term peat preservation and facilitate peat forming conditions. The basic principle of paludiculture is to use only that part of net primary production (NPP) that is not necessary for peat formation (which is ca. 80-90% of NPP). In the temperate, subtropical and tropical zones of the world, i.e. those zones where high production is possible, most mires by nature hold a vegetation of which the aboveground parts can be harvested without harming the peat sequestering capability. The quintessence of paludiculture is to cultivate plant species that: 1. thrive under wet conditions, 2. produce biomass of sufficient quantity and quality, and 3. contribute to peat formation [6].

Paludiculture potential in the Baltic States

The Database of Potential Paludiculture Plants currently has 1128 entries of which more than the half is analysed for their cultivation potential. [7]. Around 300 species are evaluated to have good and around 20 species to have very promising potential for future cost efficient cultivation. From these 20 species, a selected number is assumed to thrive well under the climatic and edaphic conditions in the Baltic countries.

These species include Common Reed (*Phragmites australis*), Cattail (*Typha lattifolia* and *T. angustifolia*), wet meadow grasses (e.g. Reed canary grass - *Phalaris arundinacia*, Sedges- *Carex* spp.) as biomass for energy generation.

Thermal utilization of paludiculture biomass is auspicious if close to harvesting areas a heat distribution grid is already installed and biomass combustion facilities are present. Furnace and exhaustion systems can be adapted to the demands of grass biomass so that a co-firing or even firing with pure paludiculture biomass is possible. A good example from the Baltics can be found in Estonia with the heat production plant in Lihula where grass biomass from managed areas in the Kasari river floodplain, Matsalu National park is used [9].
Paludiculture comes in to view as a feasible way to support the cutting of CO_2 emission from drained peatlands while providing an alternative income option for local farmers. Additionally, the Baltic States energy security gains another decentral source of domestic electrical and heat energy, beneficial especially in remote regions with weak infrastructural development [9].
In the Baltics there are available 450,668 ha of fully suitable areas for paludiculture implementation with theoretically minor potential restrictions. For example, agricultural paying agency fields (which have CPA payment claims) situated on drained peatland in nature conservation zones, or forest on wet peatland, exhausted peat mines or sites listed for future peat extraction. [9].

1. Current Baltic biomass fuel, heat, and energy production

Estonia

Estonia has total primary energy supply of 67.303 TWh in 2017, with renewables having a share of 18 % (12.329 TWh). Renewable energy supply is dominated by bioenergy (95%). Primary energy net trade is -4.097 TWh. Total renewable energy consumption in 2017 was 9.534 TWh with 5.564 TWh being biomass. Estonias electricity generation capacity in 2019 was 2,878 MW, 24% of those (694 MW) are renewable. Among renewables bioenergy is placed second with 9% (259 MW) [10].

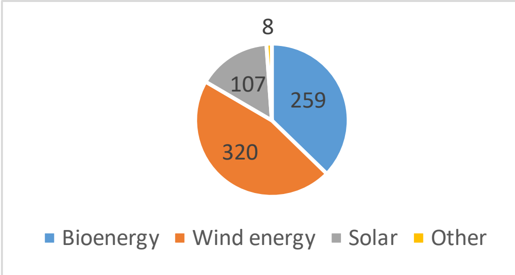

Figure 1: Composition of renewable energy capacity in Estonia in 2019 (MW) [10]

In 2018 non-renewables generated 10.371 TWh or 84%, renewables generated 1.989 TWh, the biggest contributor from renewables was bioenergy with 1.307 TWh or 11% [10].
Heat supply of Estonian towns and bigger villages is mainly based on central boiler houses and district heating systems. There were 4,053 boiler houses in Estonia in 2008, having the total heating capacity of 5.565 GW with annual production of 5.851 TWh energy. Usually only 50% of the installed capacity of the boilers is used. Out of the total number of boilers 810 boilers work with wood (total capacity 702 MW, generated heat 1.470 TWh) and 35 work with peat (total capacity 110 MW, generated heat 407 GWh) [11].

Latvia

Total installed electricity generation capacity of power plants in Latvia was 2,576 MW in 2012. [12]
For heat and electricity production in Latvia in 2017 13,944 GWh of energy resources were used (not counting wind and hydro power). This resulted in 11,333 GWh of energy being produced, from which 8333 GWh were heat energy and 3000 GWh were electric energy [12].
Latvia has a total primary energy supply of 49.326 TWh in 2017, with renewables having a share of 41% (20.224 TWh.) [78].
For energy production in Latvia mainly natural gas is used, however its amount in energy production sector is decreasing: 2010: –81%, 2016: – 60,1% and 2017: – 53,7% [12].

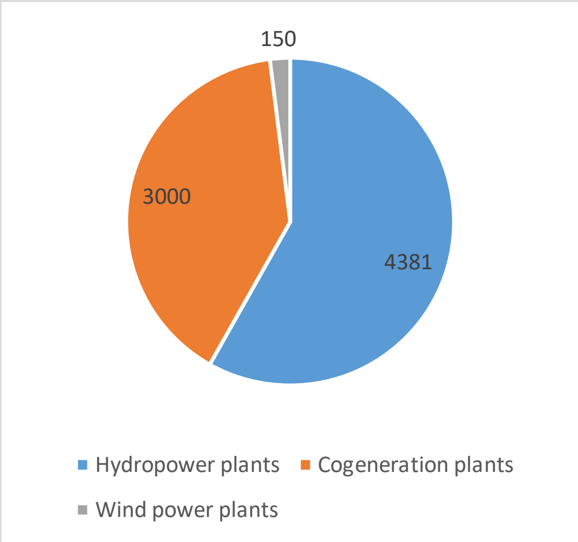

Figure 2: Total electricity production in Latvia (GWh) [12]

Latvia has a rather large share of renewables in its energy balance with leading role played by hydropower. Hydropower installed capacity in 2012 was 1,576 MW [13]. Three large hydropower plants (880 MW, 400 MW, and 260 MW) all installed at the largest of Latvia's rivers- Daugava, formed 53% of the total capacity and supplied 33% of Latvia's electricity in 2015 [14]. The average generation from 2000 to 2016 has been 2,830 GWh per year. The remaining electricity generation capacity is mostly natural gas (40%) supplemented with biomass and biogas.

District heating in Latvia is derived from natural gas and biomass. The amount of district heating produced with biomass has increased from 1,111 GWh in 2010 to 2,639 GWh in 2015 [14]. And Latvia has further plans to replace fossil fuel-based district heating with biomass [15].

Total electricity production in 2017 was 7,531 GWh. Out of that 4,381 GWh has been produced from hydropower plants, 3,000 GWh from cogeneration plants (including power plants), 150 GWh from wind power plants [12].

Further development of Latvian energy sector

In heat and electricity production sector in 2018, 15,944 GWh of energy resources were consumed for the production of heat and electricity and 12,416 GWh of energy was produced (of which 8,250 GWh of heat energy and 4,167 GWh of electricity), which is by 14.2% more than in 2017. The share of RES consumed in the energy and heat production sector in 2018 reached 41.0%. Over the period from 2013 till 2018, electricity production from biomass (firewood) cogeneration plants and power plants has increased from 319 to 570 GWh and from biogas cogeneration plants from 350 to 374 GWh. These are important indicators, given that mainly local RES are used: fuel wood, biogas and other biomass [16] [17].

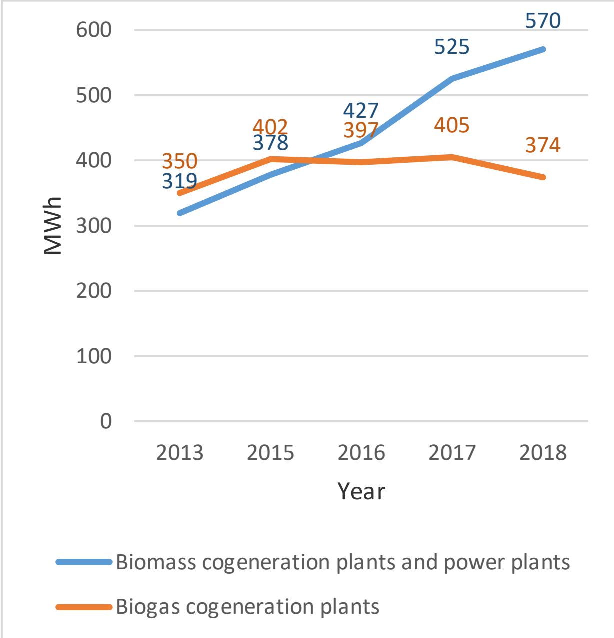

Figure 3: Bioenergy electricity production in Latvia [16].

Number of boiler houses: 633. Installed energy capacity: 2,360.2 MW. Heat energy produced, 2.3547 TWh [16]. Boiler houses that work on wood, peat and coal can theoretically switch to paludi biomass combustion or co-combustion.

Number of cogeneration stations: 175, Installed energy capacity: 1,269.7 MW, Electrical energy produced: 4,170 GWh, heat energy produced: 5,892.1 GWh [16].

Energy resources that can be substituted by paludiculture biomass

In total 14.03 TWh of energy resources were used in energy production sector in 2018, that can be partially substituted by paludiculture biomass with little to no change in combustion technology. These are:

- Coal 6 kt in cogeneration stations or boiler houses = 0.04037 TWh;
- Peat 10 kt = 0.0279 TWh;
- Wood 163,000 m^3 + 2.809,000 m^3 by households = 6.357 TWh;
- Wood residue 98,000 m^3 +126,000 m^3 by households = 0.167 TWh;
- Wood chips 5.849,000 m^3 +1.691,000 m^3 for industry heating = 6,828 TWh;
- Wood granules 10 kt + 111 kt by households = 0.5895 TWh;
- Straw 6 kt = 0.024 TWh.

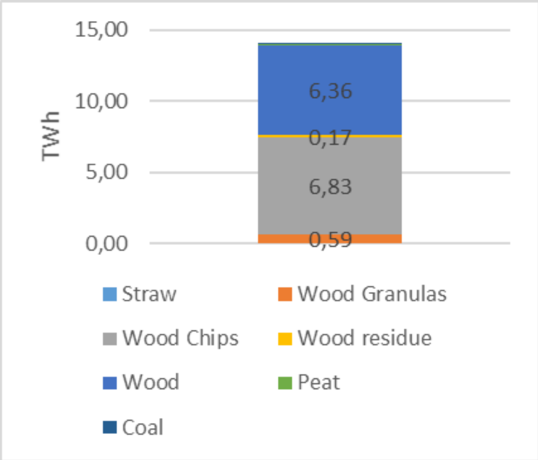

Figure 4: Opportunities for energy substitution based on resources used in Latvia's energy production sector in 2018 [16]

Lithuania

Total primary energy supply in 2017 was 83.561 TWh, renewables consisting of 24% or 19.944 TWh [18].

Energy import continues to heavily outweigh export with primary energy net trade being -65.577 TWh [18].

Installed electricity capacity in 2019 was 3,389 MW with just 2% (84 MW) being bioenergy. With the major share (2,539 MW) being non renewables. That being said the share of bioenergy in renewable energy supply in Lithuania in 2017 has amounted to 89% [18].

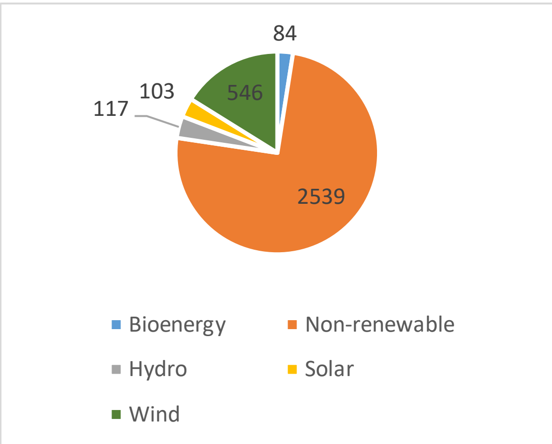

Figure 5: Installed electricity capacity in 2019 in Lithuania (MW) [18]

Lithuania's electricity imports have increased since Ignalina nuclear power plant shut down at the end of 2009. Industry generated 25% of the district heat in Lithuania which is significantly higher than in Latvia and Estonia (7% each). The public district heat was produced with biomass (61%) and natural gas (36%) in 2015 [15]. Due to unclear district heating reliability standards and out-of-date reservation procedure, district heating systems continue to have excess capacity. The total installed heat production capacity is above 10,000 MW, as compared to the maximum capacity of 2,997 MW needed in the district heating systems in 2015. At present the total capacity of wood-chip-fuelled boilers reached above 476.1 MW [19].

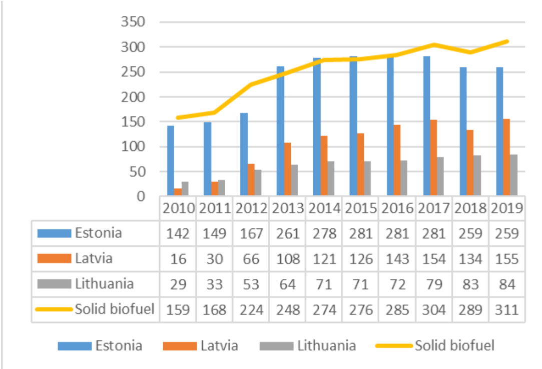

Figure 6: Electricity from bioenergy; installed capacity in the Baltic countries (MW) [21]

Perspectives of renewable biomass fuels

The Baltic countries supplied 22% of their primary energy demand (40.278 TWh of 197.222 TWh in 2015) from biomass and net exported 13.888 TWh of biomass in 2015. The largest consumers of biomass are the residential sector (15.278 TWh), electricity and district heating (13.888 TWh), and industry (5.555 TWh) where it is mostly used to generate electricity and steam for processes [15].

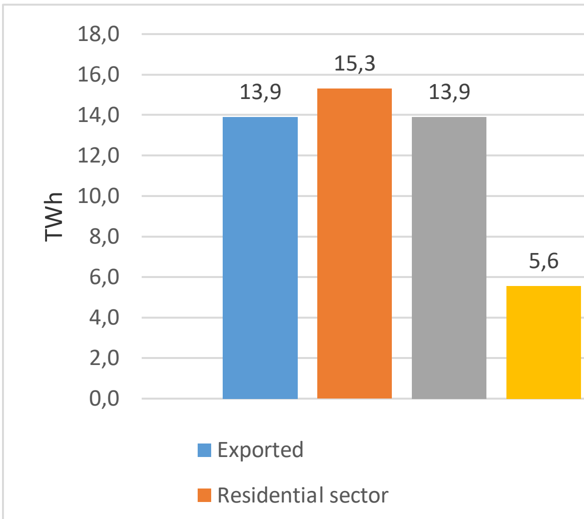

Figure 7: Biomass usage and export by the Baltics in 2015 [15]

Further plans for renewable energy

Estonia's strategy is to increase renewable energy to 50% of final consumption by 2030. With that 50% RES-Electricity by 2030 and 80% RES-Heating by 2030 [15].

Latvia's "Long-Term Energy Strategy of Latvia 2030" given suggestions include increasing the renewable energy share to 50% of final consumption by 2030 [15].

Lithuania's Government proposed an update to the National Energy Independence Strategy in 2017. The most important targets are: renewable energy 45% of final consumption by 2030; 90% RES-Heating by 2030; 45% RES-Electricity by 2030; 70% domestic generation of electricity by 2030 [15].

1.1. Wood usage

Estonia

In 2020, Estonia imported fuel wood at total value of 11.670 mil. €. In the same year Estonia's exports of fuel wood were valued at 200.218 mil € [74].

Estonian biomass balance, according to 2017 data:

Out of 5,131 thousand ton of primary biomass 2,074 thousand ton were used in Estonia for heat and power generation, additionally 828 thousand ton of by-products and wood waste were made into wood pellets and used for the same purpose.

Estonia's production of biomass based primary energy resources in 2017 (GWh): wood pellets- 5,709, firewood- 3,699, woodchips- 5,258, wood briquette- 174, wood scrap- 2,506, biogas- 50, other biomass- 384. From these resources Estonia exported 6,285 GWh while 11,595 GWh were used as a primary energy supply [22].

Latvia

In 2020, Latvia imported fuel wood at a total value of 81.490 mil. €. In the same year Latvia's exports of fuel wood were valued at 439.593 € [75]. The largest energy consumption in 2018 was in the wood sector, wood and cork products industry – 5.722 TWh or 50.6% of the final energy consumption in industry [16].

Latvian wood and wood products export (from all exports) has decreased from 37.4% in 2000 to 16.5% in 2015, but then grew to 18.2% in 2018. It was the second highest importance export material in 2018, amounting to 2,244 mil. € in 2018 [12].

In 2016 out of all wood products sawing materials amount to 24.1%, combustion wood is 15.1%, round wood is 27.9%, furniture is 6.1%, paper and cardboard are 5.5% [23].

Total primary energy resource usage as of 2017 were 53.07 TWh and 16.53 TWh from that was wood for combustion [12].

The usage of combustion wood steadily grew from 12.78 TWh in 2008 to 15.07 in 2016, to 16.53 TWh in 2017 [12].

In 2017, compared to 2016, the amount of fuel chips and firewood produced increased by 8.7% and 5.5%, respectively, and the amount of wood briquettes produced increased by 35%. In 2017, 0.17 TWh of wood briquettes were exported, which is 79.4% more than in 2016. As the total consumption of RES increases, Latvia's energy dependence on imported energy resources decreases (from 63.9% in 2005 to 47.2% in 2016) [12].

Production capacities in Latvia

The timber Production comprised 10.56 mil. m^3 in 2016 [24].

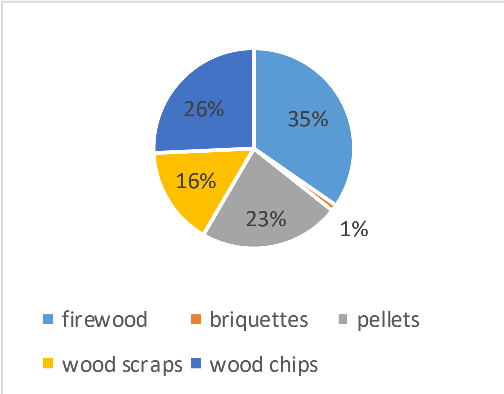

Figure 8: Types of energy-wood in total output (%) in 2015 [24]

In 2016 wood biomass consumption in energy production, measured in percentage was as follows: 30% was consumed by industry and construction (gradually growing from 12% in 2008), 43% was consumed by households (gradually decreasing from 73% in 2008), energy transformation sector (district heating boiler houses) had consumed 27%, (gradually growing from 15% in 2008) [24].

Lithuania

In 2020, Lithuania imported fuel wood at total value of 62.344 mil. €. In the same year Lithuania's exports of fuel wood were valued at 137.090 € [76].

In 2015 Lithuania had a gross felling of 6,700 cubic meters of solid wood volume [73].

In 2019 exports of domestically produced wood sawn, chipped, sliced or peeled were 16.3% of all wood export [25].

Forest biomass comprises 6,122 GWh and straw 27.7 GWh in the district heating sector in Lithuania, 2017 [26].

1.2. Grasses

Grasses is an underused energy resource in the Baltics. In Estonia the theoretical production of grass biomass is estimated at 2.2 mil. t dry matter and only 1/3 of this is used currently [9].
Upper bound of the biological potential calculated for graminaceous plants in Estonian climate is 14.0–16.2 t/ha DM [28].
In Latvia around 302,000 ha of agricultural land are not used and could make for approx. 2.4 mil t of biomass [79].
In Lithuania the theoretical production of grass biomass on less fertile soil, amounting to over 0.5 million ha, would be about 4 mil. t dry matter [77].

Lower calorific values of pellets from paludiculture biomass is comparable to that of wood making it attractive energy and heat production. A disadvantage is the higher ash content (3-7%), compared to wood pellets (<1%); although if compared to wood chips (0.5-4%) the ash content is not much greater [7] [8].

Reed Canary Grass (*Phalaris arundinacea*)

RCG has already been successfully grown in Latvia, however in recent years, a decreased market demand for reed canary grass biomass for fuel pellets and for animal bedding led to a drop of its production in Latvia from 1 160 ha in 2016 to 251 ha in 2018 [9] [2]. No current reliable data on Estonian and Lithuanian situation could be found.

Common Reed (Phragmites australis)

Reed already is a known resource in Latvia with aquatic reeds being frequently harvested.
116 natural and artificial water bodies (with the area of open water >100 ha and >3 % of the lake water body covered by reeds) are recognised as significant for the extraction of reeds with a total area of around 13,400 ha.
It is not recommended to harvest more than 50% of total reeds annually to allow proper regeneration of the stands. Consequently, the annually harvestable reed bed area in Latvia amounts approx. 6,460 ha and the amount of biomass to be obtained is approx. 32,000 t of reed dry matter per year. The reed obtained is not used exclusively for energy production, but also for other applications such as building materials production. The real energy potential for reed biomass in Latvia is around 150 GWh of thermal energy per year. The reeds on Lake Pape are mown in an area of approximately 900 ha by 6 companies. SIA “Royal Reed” rent 600 ha and annually exports 300,000 bundles, or about 12,600 t DM of reeds mostly to Denmark, Germany, the Netherlands [9].

1.3. Energy Security

The energy sector remains the most vulnerable national arena for Estonia, Latvia and Lithuania – an “Achilles heel” of the three Baltic states. The vulnerability stems from the fact that the energy sectors of the three states remain inextricably linked to and depended on Russia while they are virtually isolated from the rest of the EU, making them “energy islands”. This predicament is not only of concern to statesmen and strategists as energy effects almost every aspect of the Baltic states – the economy, industry and the wellbeing of citizens [20]. Even with the slowly changing situation, such as Estonia’s planned cutting of the linkage to Russia by 2026, a greater energy security and energy resource diversification is still needed.
Gas prices are particularly sensitive for households who depend on gas for heating in the winter months, making up 10% of total gas used in Estonia in 2011, 9% in Latvia, and 5% in Lithuania, which represents 10 to 15% of their post-tax income [20].
Self-sustainability in electricity consumption is obligatory for the security and maintenance of Baltic’s national interests.

Table 1: Baltic States electricity balance in 2014 (TWh) [29]

	Estonia	Latvia	Lithuania
Electricity production	12.444	5.058	n.a.
Electricity supply to transmis.grid	11.013	4.857	4.054
Renewable energy production	1.151	2.095	2.122
Electricity import	3.730	5.338	7.779
Electricity consumption	7.417	7.172	11.676
Net consumption	10.171	n.a.	10.715
Transmission grid losses	0.842	n.a.	0.870
Electricity export	6.484	3.023	0.156
Import-export Balance	**+2.754**	**-2.315**	**-7.623**

Latvia and Lithuania, having a negative Import-export balance will benefit from energy sources diversification and the increased usage of biomass [29].

2. Properties of paludi-culture biomass fuel

Wood as paludiculture

Wood has been traditionally used in the Baltics for energy generation. This type of biomass is plentiful with numerous heating plants for districts, businesses and private homes burning wood, wood chips and wood pellets. Trees suitable for combustion can be grown on wet peatland as well. Black Alder (*Alnus glutinosa*), Willow (*Salix* sp.), Downy Birch (*Betula pubescens*) are the tree species that grow well on this soil. Wet forestry for quality timber employs alder and birch, while alder and willow are also grown in short rotation coppices as fuel wood.
High water levels are essential when considering the utilization options in short rotation coppices or high quality timber production. Wood pellets net calorific value is ≥ 4.6 [kWh/kgDM] with ash content being 0.5-0.7% on average and occasionally rising to 2.0%.
Wood is not given focus in this work because of several reasons. Firstly, wood although preventing degradation of peatlands does not contribute to the formation of new peat, with willow even being an invasive species. Secondly, sustainable wood cultivation as paludiculture for combustion purposes leads to lesser economic benefits compared to grasses [9].

Grasses as paludiculture

Energy content properties of common reed and cattail from peatlands are excellent and comparable to wood. While being compared to the different EN-pellet standard classes (ENPlusA1, ENPlusA2, and ENB) sedge, reed canary grass and reed pellets display better lower calorific value. With ≥ 4.6 [kWh/kgDM] for standard wood pellet classes vs 4.08-5.05 for cattail, 4.83-4.89 for reed canary grass, 4.89 for sedges and 4.92 [kWh/kgDM] (5.03 from extensively used meadows [30]) for reed pellets [9] [28] [31].

Common Reed (*Phragmites australis*)

Common Reed is a cosmopolitan species which is abundant globally in the temperate zone under a broad range of environmental, climate and soil conditions. Together with high potential phytomass production and calorific values of dry biomass comparable to wood make it an auspicious renewable energy source [32].
Production amount: Biomass production of Common Reed under natural conditions of the lower Liptov region (central Slovakia) reached 12.70 tons of a dry matter per hectare with the calculated energy storage of 61.56 MWh/ha. In Lithuania the produced amount varies drastically from 9.48 to 35.92 t/ha (dry mass). [33] [34]. Reed yield in Estonia is 6.27 t/ha (dry mass) [9].

Cattail (*Typha* sp.)

Cattail in the Baltics is naturally growing in peatlands, overgrowing areas and on the lakes shores, in ponds, on riverbanks but extensive areas are not known. In peat extraction fields, cattail is regularly mown from the ditches to restrict its growth because their seeds are unwanted in peat.
Although cattail naturally begins growing on peat fields, it does not contribute to creation of peat as other paludiculture plants do. That reduces the usefulness of cattail for peat field restoration.
Cattail harvest from various literally sources is measured in a wide range of 4.3-22.1 t/ha (dry mass) [9] [35] [54].

Reed Canary Grass (*Phalaris arundinacea*)

This is the only paludiculture crop that currently can receive direct payments on the basis of being an agricultural crop as well. Reed Canary Grass (RCG) has a spring harvest of 6-8 t DM ha. Productivity measured in Lithuania is between 7.5 and 8.4 t/ha (dry mass). If a stand is well-established, RCG will sustain at one site for 10-12 years with no reduction in biomass yields [9].
A study finding indicates that 0.0989 kWh of input energy can produce as much as 1 kg dry matter of RCG in Estonian climate [28]. This gives an estimation of how much energy needs to be spent in order to produce 4.83-4.89 [kWh/kgDM].

Sedges (*Carex* spp.)

Sedges are mainly found growing around ponds and in peatlands with water level as high as 50 cm, but they are also drought-tolerant. Sedge productivity in Lithuania is between 3.2 and 7.1 t/ha (dry mass) [9].

Graminoid biomass from paludiculture plants has a series of important differences, compared to wood biomass and as such requires different handling practices during harvest and preparation for combustion. The main difference is the amount of micro, macro and trace elements that the plants take up during the growing process and how that affects their combustion. Below the most important and prevalent elements are mentioned along with a description of their function in a combustion process.

Elemental composition

The elementary (chemical) composition is divided into the main elements: carbon (C), hydrogen (H) and oxygen (O); secondary elements: nitrogen (N), potassium (K), magnesium (Mg), calcium (Ca), sulphur (S), silicon (Si), sodium (Na), phosphorus (P), chlorine (Cl) and trace elements.

The main elements (carbon, oxygen, hydrogen) are essentially responsible for the energy content (calorific value), expressed by the exothermal reaction of the carbon and the hydrogen with oxygen.

Nitrogen, sulphur and chlorine

These are so called "critical" components since they are involved in formation of environmentally harmful emissions, slagging and corrosion processes. High concentrations of nitrogen and sulphur lead to NO_X and SO_2 emissions, which can be further transferred into acid components. High chlorine concentrations can cause corrosion damage to the combustion plants components or further react into harmful substances such as dioxins and furans as well as causing HCl emissions.

Chlorine reacts with potassium and sodium to form relatively volatile and stable alkali chlorides. In addition, chlorine and sulphur present in the fuel participate in ash deposition to a large extent. Chlorine is also involved in low temperature corrosion through the formation of acid gases, while at the same time being a well-known inhibitor of combustion: the presence of chlorine will lead to depletion of radicals, highly reactive compounds that are essential in many combustion reaction mechanisms. Fortunately, in many straws and grasses, chlorine is completely water soluble and in sedges the amount of it decreases by 95% between August and February.

Almost all sulphur occurring in the fuel oxidises during combustion to sulphur oxides, SO_2 and SO_3, and variable quantities of these gaseous species will react with potassium to form potassium sulphate, K_2SO_4. This condenses on fly ash or on furnace and tube walls and will subsequently promote ash agglomeration. Therefore, sulphur plays a substantial role in the build-up of deposits in a boiler after the initial condensation of alkali species. Continued sulfation of ash deposits will increase the tenacity of the deposits, making them more difficult to remove. [36].

Potassium, magnesium, sodium and calcium

These elements will have an effect on the ash melting behaviour and can cause slag formation problems in combustion chambers. [37]. The oxides of alkali metals K_2O and Na_2O, which have influence on the ash-fusibility temperature in combination with other chemical compounds bring down the ash-fusibility temperature in general. [38].

Vaporization and subsequent chemical reaction of potassium (among other alkali elements) is responsible for much of the fouling, slagging, and corrosion problems that occur during combustion of grass fuels. Most of the potassium that is inherent to the fuel is volatile at typical boiler temperatures, and will exist in vapour form as potassium chloride (KCl), or potassium hydroxide (KOH) if chlorine is absent. Both KCl and KOH are highly reactive compounds and will readily combine with sulphur oxides to form potassium sulphate, a precursor species of several ash deposition mechanisms. Potassium and sodium form alkali silicates that melt at low temperatures (can be lower than 700^{o}C), thus providing a sticky surface for enhanced deposition. [39] Fortunately, much the same as chlorine, potassium is greatly water soluble [36].

Silicon

Silicon dioxide, also known as silica is the major constituent of the inorganic fraction in grasses. Silica shows little tendency to vaporise, and generally appears in the residual fuel fraction after thermal conversion. Silica will form compounds that melt at low temperatures when in the presence of certain elements, in particular the alkali metals potassium and sodium. Pure silica melts at around 1 700^{o}C, while a mixture of 32% K_2O and 68% SiO_2 will melt at as low as 769^{o}C. This decline in melting point is an important factor in the build-up of ash deposits in a boiler [36].

The above mentioned potassium, sulphur, silicon and chlorine also appear in other combustible biomass, mainly wood, but there they do not play such a prevalent role. The impact of these elements, though can be greatly mitigated and ultimately removed if proper biomass harvesting, treatment and subsequent combustion practices are maintained.

Harvesting

In Latvia grasses grown under paludiculture conditions can be mown 1-2 times a year. It is assumed that the same applies to Estonia and Lithuania [40].

Depending on desired fuel qualities, harvesting can be done during different seasons. If grass biomass is being turned into biogas or used as one of the substrates for ethanol production early summer harvest can be performed. If biomass is being turned to bales and burned in “cigar burners” or at furnaces where low temperature burning can be achieved, then summer and early autumn harvest also may be employed. If biomass is to be shredded and burned in conventional furnaces with the combustion temperature that is usually used for burning wood, it is best to harvest during winter or at the start of spring, when corroding elements and alkali metals had been washed out. If such harvesting is not possible it is important to get rid of harmful elements in biomass using conventional methods.

Reed, reed canary grass (RCG), sedges and cattail appear to have the same optimal time period when the plants need to be harvested in order to be used as fuel with best possible characteristics, that is with the least amount of corroding and ash slugging elements. As the nutrients are leached out with rains and frost, along with a portion of them retreating to the plants roots after the growth season, the late autumn to early/mid spring period appears to be the best harvesting time. Lower moisture of plants is also essential for reasons of logistic and energy savings, and ultimately for combustion purposes. It is suggested to harvest reeds in late winter or early spring, when also the moisture content of dead plants is the lowest (10% to 15%). The greatest moisture losses are from November to February [41]. Though for RCG it is suggested to harvest it by December, as the stocks often collapse afterwards and are then difficult to collect.

Counter to that the relative moisture content of summer (July-August) harvested reed is from 56% up to 69% (mostly in July), with the average of about ~60%. High moisture content reduces the heating value of fuel, increases the volume of flue gases, increases risks of corrosion, and deteriorates ignition and combustion [38].

Harvesting after growth season

One of the drawbacks of spring harvest is "winter loss". That involves leaf loss due to mowing and snow or gales as well as the leaching of mineral substances. At the spring harvesting of reed canary grass, the 'winter loss' of dry matter was 15% to 25% in Sweden. As biomass that was exposed to late autumn rains and winter frosts loses a great deal of elements harmful to combustion, including potassium, sulphur and chlorine, this kind of natural leaching is the preferable strategy.

Data gathered on the melting temperature of reed canary grass ash also indicate the advantage of spring harvested (March–May, 1,404 ℃) mass compared to summer/early autumn harvesting (July–October, 1,074 ℃) due to the leaching out mineral substances.

Reed ash testing confirms this as well: summer harvested reed ash cones initial deformation takes place at temperatures below 800°C and the complete fusion occurs at temperature lower than 1,200°C. The ash of winter harvested reed does not fuse down even at 1,330°C. The average ash-fusibility temperatures for summer and winter reed ashes was shown to differ by 200°C [38].

Sedges intended for combustion, by Belorussian data, are suitable for harvesting in March/April, as concentrations of elements that may cause low ash melting temperatures (K, Na, Ca and Mg) are very low (0.02–0.15%) [34].

It's hard to overstate the importance of the elevated ash melting temperature, as it enables regular wood combustors to take in paludi-biomass without the need of designing additional systems of keeping the temperature low so the slagging does not occur. The loss of corroding elements during winter also greatly rises the equipment lifespan and decreases the number and cost of repairs. Additionally, the ash content itself is also decreased in winter/early spring harvest. The ash content of reed harvested in winter is 2.1–4.4 %, compared to 4.1–6.2 %, in summer [34].

Leaching

The process of biomass loosing certain key substances (inorganic and organic) by means of rain, dew, mist, fog and frost is called leaching [36]. As was demonstrated in a study after the first rainfall, which was measured as 106 mm, the fusion characteristics of straw were substantially improved due to rain leaching out the elements. Straw was only cut after the rainfall. Beyond 199 mm of precipitation, only mild sintering of ash was observed up to the highest furnace temperature (1,550-1,650^{o}C). This raises the possibility of leaving biomass harvested in summer/early autumn in the field and letting precipitation do the necessary leaching [36]. As biomass in the previous example was cut after being leached by rain, it suggests that it does not require to be cut beforehand for the leaching to be effective. Such conditions are rather likely, if precipitation data from the three Baltic states is analysed: Annual average? precipitation in Latvia is 692 mm and has been steadily increasing since 1961 [42]. Monthly precipitation distribution in the Baltic states is very similar, so leaving biomass in the field for about two and a half-three months would most likely result in its exposure to the needed amount of rain.

3. Technical adaptation possibilities for production and utilisation of energy biomass from paludiculture

Potential paludiculture sites must be close to customers or processing facilities. Short transport ways are not only economically, but also ecologically beneficial. Especially existing decentral heat and energy grids that are located close to paludi-biomass production sites are favourable. [9].

Setting up the field

Before choosing a suitable field for paludiculture growth it must be assessed for any remaining draining infrastructure, such as ditches, pipes, channels, etc. If peat field has been degraded and excavated with no vegetation remaining there is a strong possibility that the upper layer of peat has mineralised and is no longer suitable for any kind of paludiculture activities. The assessment needs to be made and if the mineralization did indeed take place the upper layer of peat (can be up to 0.5 m thick) needs to be cut away, that can be done with conventional agricultural machinery [40] [43].

Harvesting and necessary equipment

For wet organic soils, the safest ground pressure considered in literature is ≤100 g/cm². However, machinery with ground pressure between 200 g/cm² and 300 g/cm² is generally accepted to be safe for wet soils, provided it is handled by an experienced operator.

The ground pressure of a vehicle can be lessened either by reducing its weight or by increasing the area over which it makes contact with the ground. Machinery used for harvesting in wet peatland can be divided into 4 groups, namely: adapted conventional agricultural machinery; small-sized machinery; specialised machinery with wheels; and specialised machinery with tracks.

Conventional agricultural machinery

Unfortunately for farmers using adapted conventional technology like light-weight conventional tractors (5t-8t empty weight) and baler combinations (e.g. round baler <2t) will keep the ground pressure too high. Ground pressure can be minimised with maximum mountable tire sizes on the tractors with low ground pressure values of 760-400 g/cm² are achievable. Additional mounting of twin tires reduces it down to 380-200 g/cm². Balers can be equipped with tandem axis and twin tires to reach values of 200-220 g/cm² [9].

Small-sized machinery

For harvesting wet sites this kind of machinery is widely available, but its usefulness is limited by low engine performance and small load capacity, which make harvesting time-consuming and expensive.

Wheeled machinery with balloon tires

These vehicles are large, low-pressure and usually treadles such as the Danish Seiga vehicle, are a proven technology for harvesting reed. Despite the low ground pressure of less than 100 g/cm², the use of Seigas can be problematic under some circumstances because they tend to float in open water more than 40 cm deep. Floating increases the risk of wheel-spin, which can damage engine performance and is no longer commercially manufactured; but is, nonetheless, suitable if available.

Tracked machinery

The use of tracked machinery effectively reduces ground pressure, and the area of contact with the ground can be further increased by lengthening or widening the tracks. Even though practical experience has shown that there is still a risk of disturbing the sward, tracked machines are a promising option for large-scale biomass harvesting on wet and rewetted peatlands because of their high performance (more power and cargo capacity).

Besides numerous conventional and small-scale machinery that is widely used in the Baltics, special machinery is also used. Of the ten companies in Estonia dealing with reed four used a small BCS 662 tractor. Three companies used a Seiga reed harvester. Besides these, self-made harvesters assembled from various machines were also used. Of the eight different harvesters, five were constructed so that a platform trailer was attached to the cutter to collect the crop. With the Seiga harvester and most of the self-made machines it is possible to collect bundled reed on the platform, from which the bundles are loaded onto a transport vehicle or dropped near the harvesting area [38]. Latvian and Lithuanian companies also employ self-made harvesters and Seiga harvesters to an extent.

Processing

The way energy is going to be extracted from biomass depends on the available technology, but the decisive factor is if the biomass was leached or not.

If the biomass was leached (mechanically or naturally) then it is possible to use more conventional technology that allows co-combustion with wood or combustion pure. This technology are the moving grate or fluidised bed furnaces as well as moving grate pellet furnaces.

If the biomass was not leached then there are several attractive ways how to use it, depending on the technology available. This include burning whole bales of biomass in bale burners, or cigar bale burners, shredding it and burning in specially designed grass combustion plants, or processing it further into biogas or ethanol.

Drying and storing

Different moisture requirements come with different combustion technology. If biomass is going to be burnt in regular moving grate combustion chambers, then the moisture content should not exceed 55%. Assuming that the biomass is harvested in winter or early spring and therefore naturally leached, and dried by frosts no additional drying is necessary. If it is not the case and biomass needs to be leached manually then drying afterwards is required. Drying biomass bales by storing them in a dry, well ventilated shed can reduce moisture from 40% to below 20% in a span of several months. Open air drying as well as using flue gas or boiler residential heat are also options to consider since they save on money and energy [46] [36].

For pelletizing biomass is required be at 15% of moisture or lower, since if the moisture is higher, pellets at the end of the process become brittle and break apart, producing large quantities of dust.

Biomass for production of biogas and ethanol may need drying, depending on the production method used. Biomass needs to be dried also for shredding, as wet biomass can lead to frequent bridging and clogging of grass in or on augers, screens, and chutes [34].

Shredding

All the described combustion technologies, excluding whole biomass burning, use a shredder for easier extraction of biomass energy, for preventing stocker blockage by bulky grass structure or in case of pellets, for press preparation.
An example of a bale shredder consists of a variable speed hydraulic driven floor drag chain on which a row of large bales can be loaded. The drag chain pushes the bales against a set of rolls with beater knives that will shred the bales and drop the shredded straw at the end of the unit.

Photo 1: Kirby Manufacturing bale shredder [44].

The capacity of the unit varies depending on loading time and chain speed, however capacities of up to 30 t/ha (for the shredding mechanism, assuming continuous loading) are quoted by the manufacturer.

Pelleting

Another conventional form of combustion for paludiculture biomass is the processing of pellets.
Pelleting of wood biomass is widely practiced and the same technology can be applied to paludi biomass. The 4.847 kWh/kg dry weight reached for reed granules, which was mentioned earlier, was made through the same processes of drying and pressing, as with granules from wood biomass. That would signal that the technology is comparable and the equipment used in wood granules production can be used to produce reed biomass granules and by extent other paludiculture granules without significant additions to the technology [33].

The amount of pellets that is possible to get is about 625 kg of pellets from 1 m^3 of reed harvested in winter, and 675 kg pellets from 1 m^3 of sedges harvested in summer [54].
Experiments to use pellets from reed and reed canary grass in small scale 50 kW fixed grate combustion system did not show any disadvantages compared to other biomass fuels such as wood chips normally used in the test facility. It can be assumed that pellets or briquettes produced from reed or reed canary grass could replace the wood chips by 100 % without major problems [37].

Pelleting technology

The different technological possibilities offer two choices:
First choice is the machine that encompasses both the shredder and the pelleter in one corpus. The advantages are such that it already embodies all the technology needed to successfully transform bales into pellets as the end product in a single sequence. An example of such is a PCM Green Energy MBA 1000 (seen on Photo 3.)

Photo 2: PCM Green Energy; mobile pelleting line - "MBA 1000" [47].

Work force needed to operate such a contraption is 2 people. Investment costs are 435,000 €. Main disadvantages of such an all-inclusive module are, as was described by a user: the unit needs constant maintenance, not enough technical support from the manufacturer, throughput of material is considerably lower than stated by manufacturing company and after initial money investment it would not be possible to break even after a period of as much as ten years. As was stated by the user of this particular PCM Green Energy MBA 1000 machine- other companies manufacturing similar units are plagued by the same problems [43].
Second choice is a self-made pelleting station. That means obtaining all the equipment separately, installing and connecting the production line. Based on several real life examples a complete stationery line for pelleting with throughput of 1-1.5 t/h

would cost about 96,000 € with second hand equipment.
By far the biggest power consumption in the pelleting line will be from drying the biomass if it was not air dried already, though it is necessary as pellets need to be in the 10-15% moisture range, otherwise they become more brittle and can start to break apart right after being formed. If biomass already comes to the plant dried the bale shredder, the hammer mill and the pelleter will amount to the biggest energy consumption. Using the hammer mill is necessary as one shredder is not able to cope with the fragmentation of biomass to chaff with a length of several millimetres. The efficient pelleting process depends on the quality and fragmentation [43].

4. Conventional Burning Technology

For reed, sedge, cattail and RCG biomass combustion purposes fixed bed combustion and fluidised bed combustion systems are suitable. Fluidised bed systems are more complex and require higher investment costs, an economic operation of the plants is only possible at high capacities-above 10 MW for bubbling fluidised bed systems and above 50 MW for circulating fluidised bed systems. For these reasons they are touched only briefly in this work.
If paludiculture is to be brought into decentralised or small scale boilers, for example in rural areas where paludi-biomass does not have to be transported through long distances the fixed bed combustion systems are favourable. The two main types of fixed bed combustion systems are underfeed stokers and grate firing systems. Underfeed stokers are relatively cheap, but only suitable as small-scale systems. Disadvantage of the systems is that underfeed stokers are limited to low ash content fuels such as wood chips due to ash removal problems [37].

Grate firing

Grate firing systems, such as moving grate or vibrating grate boilers can accommodate fuels with high moisture and ash content. [48]
Best case scenario of introducing paludiculture for energy in the Baltics is if the existing installations can be used for combustion without the need to import outside technology or do any costly improvements to them.
Wood biomass is an important energy resource in the Baltics and a number of companies are based there or have the production of biomass boilers there. In Estonia Tamult, in Latvia Komforts and in Lithuania Axis all are producing biomass fired boilers, grate furnaces, flue gas cleaners and other supplementary technology such as biomass transporters. Latvian Komforts produces moving grates front furnaces with output range from 500 kW till 12.5 MW (in single unit). These furnaces are designed to burn crushed biomass and biomass mixtures with 10-60% moisture. Over 80 moving grate front furnaces have been installed in Latvia alone in the last 20 years. Estonia has over 45 and Lathuania has 8 of such furnaces installed. Estonian Tamult has made over 40 furnace installations during its 14 years of operation to date. Axis has similar records. These installations, using a moving grate are capable of burning shredded paludiculture biomass or pellets as fuel.
With the amount of active installations by these companies in the Baltics and the fact that local manufacturing can accomplish any future biomass related projects, it gives a strong incentive for using these conventional installations for paludiculture biomass combustion.


Photo 3: Harvesting reed in winter [45].

A moving grate furnace installation will have the following operational equipment:

Fuel storage
Usually a chamber with one of the walls open for easier fuel unloading and/or mixing.

Moving floor
A system of hydraulic scrapers drawing the fuel forward to a frequency-controlled auger that delivers the fuel to the fuel supply conveyer that feeds the burner.

Fuel supply conveyer, hopper and stoker
Versatile conveyers, usually with a pair of chains and angular horizontal rails. Equipping the conveyer with a motor at every junction is necessary.

Moving grate furnace and hot water boiler
Schmid Energy Solutions furnace is provided as an example (see below), though it has combustion chamber water cooling which is not standardly employed across the industry, but other parts of the furnace are commonplace.

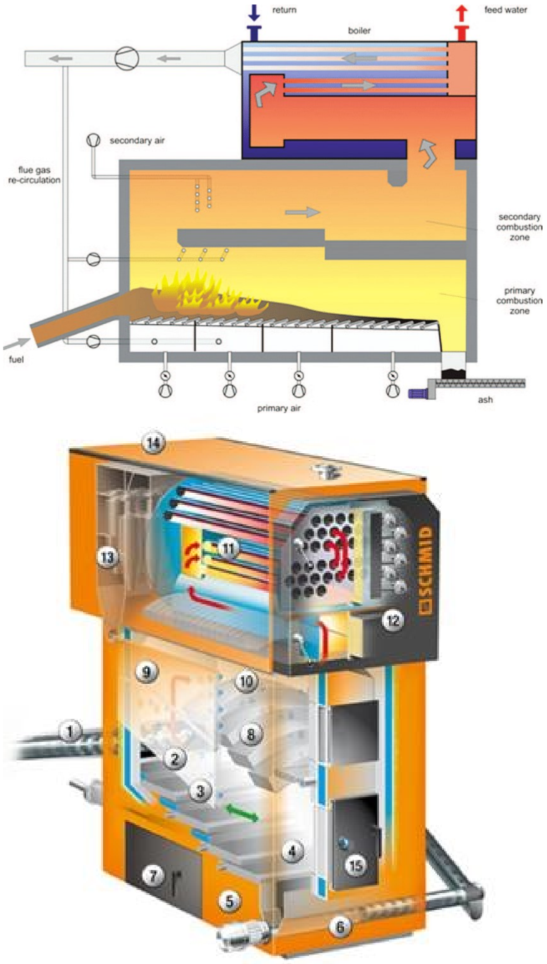

Figure 9: Schematic of a biomass grate furnace. Courtesy of TU-Graz and Schmid Energy Solutions. The numbered parts are as follows: 1. Fuel inlet – stoker screw. Depending on the fuel can be a hydraulic pusher instead of the screw; 2. Water-cooled combustion chamber; 3. Water-cooled moving grate (water cooled grates are employed if there is a problem of melting of the biomass ash on the grate); 4. De-ashing zone; 5. Under-grate de-ashing; 6. Automatic discharge of the grate ash; 7. Access to grate mechanism; 8. Radiation roof; 9. Refractory lining with defined heat transfer; 10. Secondary combustion chamber; 11. 3-pass heat exchanger; 12. Front door with automatic fire tube cleaning system; 13. Flue gas cleaning with multi-cyclone technology and automatic ash particles removal; 14. Flue gas fan (optionally to right, left, rear); 15. Grate door [50].

Ash removal system

Usually a screw conveyer that transports ash from the furnace and from the flue gas cleaning installations (like multi-cyclones) to the ash tank. The system rarely needs maintenance if the ash tank is emptied timely and the ashes are not melting together into big clumps of a size that can potentially block the conveyer.

Economiser

A heat exchanger that takes the remaining usable heat from the flue gases as they exit the boiler. Not always used as the heat of the escaping flue gases may be too little to warrant the installation of an economiser.

Multi-cyclone

An important step after the economiser is cleaning the flue gases so, if the flue gas recirculation system is employed, the fly ash particles do not damage the fan or if the flue gases are exhausted into the atmosphere, to lower the particle emission amount. Since fly ashes fall to the bottom of the multi-cyclone it needs to have an auger for ash transport to the tank.

Chimney

Free-standing, insulated chimneys are intended for combustion gas discharge from the boiler plant to the atmosphere.

Slagging

Slagging is the accumulation of molten ash on the walls of the furnace, gasifier, or boiler, as well as on the grate. It can be prevented by leaching as that rises ash melting temperature of paludiculture grasses. Slagging is detrimental as it reduces the heat transfer rate, and the combustion/gasification rate of unburnt carbon, causes mechanical failure and high-temperature corrosion. It is expected that the ash melting behaviour of leached paludiculture will not lead to slagging if it is used for combustion in moving grate or fluidised bed combustors [51].

In order to mitigate the formation of sludge and fouling there are several strategies besides natural leaching of biomass in field during winter. These strategies are:

1. Controlling furnace exit gas temperature in order to lower the average temperature in the convective heat transfer section. That can be accomplished by lowering the oxygen intake by the furnace. This method may have limited application because of impacts on boiler efficiency, capacity and possibly emissions [39].

2. In grate or fluidised-bed burners it is possible to change the composition of the ashes by adding stable metallic salts. These additives are meant to increase the melting point of the ash formed during combustion. However, with the use of most of these materials, chlorine is released in gas phase, thus not totally eliminating the corrosion effect [39].

Another drawback of this method is that additives appear to be only effective in systems where complete mixing is accomplished.

3. Using water-cooling on grates helps to lower the combustion temperature of the biofuel. Precise temperature control is needed to not overcool the grate and only relatively small amount of slugging or sintering mitigation is possible.

4. Mechanical leaching. If biomass cannot be sufficiently leached on field during a sensible time period mechanical leaching may be employed.

During handling, leaching, and dewatering loss of fuel should be anticipated. Laboratory tests indicate a potential loss from 13 to 15.5% for different grass fuels [36].

Though it is an additional economic burden to organise a mechanical leaching facility. The resources spent on establishing a line for leaching will greatly increase the initial costs of paludiculture preparation in addition to the costs of energy for drying biomass afterwards, so economically it is wiser not to employ this method.

Co-Combustion possibility

Operators should not mix non-leached paludi-biomass with woody biomass for conventional combustors, as even small percentages blended with woody biomass can result in serious fouling and slagging [36].

Leached wetland biomass on the other hand can be used through co-combustion with coal in conventional power plant applications. Co-combustion was proven successful for a 3 MW commercial district heating plant in Austria. The reed for combustion was harvested from February to March [52].

Fluidised Bed Combustion Systems

In fluidised bed combustion, the solid biofuels are suspended during the combustion process within a moving gas and particle stream, called the bed. The result is a turbulent mixing of gas and solids, which provides very effective chemical reactions and heat transfer.

Due to higher specific investment costs and technological complexity of the overall plant, fluidised bed combustion is used in larger applications- 10 MW for bubbling fluidised bed systems and above 50 MW for circulating fluidised bed systems. That, alongside their comparatively longer start-up times puts fluidised bed combustion plants at a disadvantage compared to other available technology [48] [37].

Dedicated pellet boilers

In the Baltic States Lithuania hosts two pellet boiler production companies-Biokaitra and Kalvis.

Biokaitra

One of the boiler types produced by them are advertised as being able to handle straw pellets, but in reality, as was described by a retailer and a technician, the pellet burners quickly clog with ashes and are not suitable for long term usage of grass pellets [43].

Kalvis

The second pellet burner producing company is Kalvis and they employ moving grate, as well as rotating and stationary grate burners in their boiler design. All their burners are from Polish company PellasX [43].

PellasX

This Polish company is the producer of burners employed at a number of different pellet boiler production companies. The advantage of PellasX burners are the moving grates that make it possible to use paludiculture biomass pellets as fuel. PellasX produces a line with moving grate burners of different capacity; there are 4 models: 4-16 kW, 5-26kW, 8-35kW and 120-500kW. This covers client demographics from households to local energy producers.

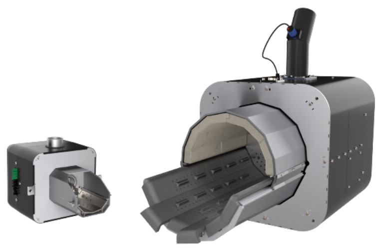

Photo 4: PellasX grate burners [49].

What became apparent in Poland, Lithuania and in Belarus, where graminoid pellets were produced and/or used, is that the increased amount of ash makes it only possible to use pellet burners with moving grates. After the experience of straw pellet combustion in Poland and grass pellet combustion in Belarus it also became apparent that biomass from pellets needs to be leached in order for boilers to be able to withstand using it at all, even if moving grate burners are employed. Pellets, made from paludiculture biomass, if the biomass is not leached naturally or manually and retains all chlorines and alkali metals will not be profitable, nor will they receive a widespread usage. PellasX burner temperature can be regulated by air correction, so in theory it can be set around 800°C, which would help mitigate the problem of paludiculture biomass low ash melting. That would still not resolve the problem of corrosion as prolonged combustion with this kind of biomass would lead to severe corrosion problems. As follows it is suggested to use leached paludiculture biomass and burn it in moving grate burners that can accommodate for increased amount of ash [43].

5. Specialised combustion technology

Further a closer look is taken on combustion technology designed especially for grass biomass combustion, its advantages and disadvantages compared to conventional combustion technology.

Baled biomass combustion

Advantage of it are in the fact that baled biomass can be directly combusted without shredding. Furnaces and boilers that would use baled biomass from agricultural production can be in a wide power range from 0.1 to 2 MW or more. These are the so called ”cigar” burners that ensure continuous combustion and smaller biomass boilers that need to be opened up and cleaned after every set of loaded bales burns through.

Possible disadvantages of cigar burner combustion system include: a) a need for a “smart” and sophisticated process control system; b) thermal cracks, thermal attacks on the metal combustion chamber, as experienced by this model boiler creator. It is recommended that the moisture content of bales shall not be greater than 25%.

Bale burners available on the market

In Poland there are manufacturers producing commercially available biomass boilers.

GRASO constructs both cigar burners and non-continues burners that need to be cleaned after every usage. Manufacturer claims 15-20 years’ durability of its models. That is however if the boiler is operated correctly and the flue gases are not let to cool down in the boiler, unused, causing corrosion.

Photo 5: Polish Graso non-continuous (left) and cigar (right) bale burners [57]

In Latvia self-grown reed canary grass has been already successfully used as fuel by farmers in these kind of bale biomass boilers. After loading 2 bales of RCG the boiler was said to burn for 1-2 days, with a large amount of heat going to the heat storage. The boiler has served for many years without any complaints from the technical point of view. However, farmers had to eventually stop using it for a number of reasons: the cleaning procedure took too much time, especially considered the boiler had to be cleaned after every operation so once a day or once every 2 days; the smoke from combustion was described as rancid and not pleasant to come in contact with; finally, a business decision to stop growing RCG rendered getting a hold of alternative grass fuel as more of a hassle. It is worth mentioning that changing the proportions between the boiler capacity, storage tank capacity and heating territory capacity would result in different amount of bale usage and ash cleaning times [43].

Straw combustion grate furnaces

There are specialised grate furnaces and indeed whole plants made with the thought of grass or straw biomass combustion. Leading in the sector of moving grates straw biomass furnaces is the Danish Linka Energy manufacturer that produces straw biomass boilers with 250 kW to 15 MW capacity.

Linka boiler used in Malchin, Germany

A promising concept for the energetic utilization biomass from rewetted peatlands was realised in Malchin (north eastern Germany) in 2014 by the company Agrotherm GmbH. A biomass boiler for graminoid fuels with 800 kW combustion capacity was installed and integrated into the existing district heating network of the city of Malchin. There are now talks of increasing capacity to approx. 1.2 MW. The biomass is produced near the town on an area of about 400 ha of rewetted peatlands during short term dry phases, baled and stored to ensure a continuous operation of the plant during the heating season. Each year, around 800-1,200 tons of fuel are produced and used in this plant, supplying more than 550 households with heating energy and replacing 290,000 to 380,000 l heating oil [54].

Linka boiler design limitation

Linka boilers allow not only grass biomass, but also wood chip combustion. Wood chips can be used both with the grasses and as sole fuel. There is however one important handicap to keep in mind: clogging of the flue gas-bag filter if the moisture content in biomass is above 21%. As was described by the users, the filter will clog anyway at one point because of usage, but if fuel with high amount of moisture is used a new filter will clog after just several days of usage. The filter is valued at two to three thousand € and cleaning a clogged one was described as inefficient [43].

This issue with moisture levels is going to deny any widespread usage of these kind of boilers in the Baltics as it is difficult to imagine that they would be fired with only biomass of recommended moisture, especially taking into account the amount of perspiration that Baltic countries experience in a year. However usage of different filtering technology needs to be investigated to determinate if it is a feasible option.

CHP in Emlichheim, Germany

Build by the German company BEKW (Bioenergiekraftwerk Emsland GmbH & Co. KG), is Based on Danish technology where comparable such plants are constructed for >30 years.

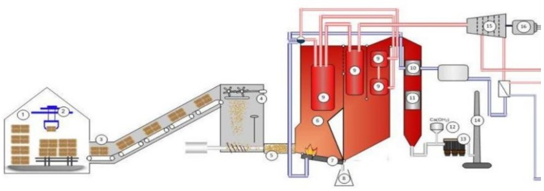

Figure 10: Schematic composition of Emlichheim plant:1-straw warehouse; 2-krane; 3-feeding conveyer; 4-bale shredder; 5-stocker feeder; 6-boiler; 7-grate; 8-slag container; 9-superheaters; 10-economiser; 11-air preheater; 12-Ca (OH2) injection; 13- filter; 14-chimney; 15-turbine; 16-generator. [59]

The plant is burning straw currently, but can be easily fuelled with paludiculture grass biomass, or wood chips. Again moisture plays an important role here, with max. water content of bales stated as no more than 22%. Unlike Linka boilers though BEKW can technically handle higher moisture contents in the biomass, but moisture content is optimised around 20% to facilitate economic operation.

The plant uses a vibrating grate in the design. Vibrating grate has been marked as cheaper option compared to a moving grate, that gives more control on primary air distribution while burning. The downsides include the fact that it is more complex and it cannot handle waste wood biomass (old furniture and such) as it is less rigid against corrosion, and with metal contamination corrosion may set in already after 6 months. The plant has a 49.5 MW capacity with 2 feed lines. Energy produced by the biomass goes into heated steam (110 Bar, 520°C 8.5 kg/sec) with 3 outlets: a turbine for electricity generation, steam for a local potatoes producer, steam for district heating. The plant consumes 75,000 ton of hay yearly. The project had cost 56 mil. € [43] [58] [59].

Other methods of energy extraction

Paludiculture biomass, instead of being combusted as is or transformed into pellets can be used as energy source in different ways. Other methods involve pretreatment steps such as fermentation with the end goal of production and combustion of ethanol, or thermal gasification with subsequent combustion of biogas.

Biogas production

Biogas is a biofuel produced by anaerobic fermentation, during which various types of biomass (substrate) are converted to CH_4 (methane) and CO_2 mainly in an oxygen-free environment by microorganisms. After cleaning the gas from impurities methane is obtained [9].

Under the current circumstances, the production of biogas from reeds as the main substrate is risky due to pre-treatment technologies and large investments.

Ethanol production

Grasses are lignocellulos crops, with cellulose being the primary substrate for ethanol production in this case.

Ethanol production from reed, RCG and other paludiculture grasses is comparatively less studied and less utilised then direct combustion. As such this paper does not focus on it.

Currently available areas for paludiculture implementation

In a feasibility study carried out within the EUKI project "Paludiculture in the Baltics" for all Baltic countries a set of sites had been identified where a rapid implementation of paludiculture pilots is promising. Currently there are 15 readily available sites for paludiculture implementation [9]. Future upscaling within the identified Baltic spatial scenario needs further prioritization and verification on the ground and investors as well as practitioners who want to replicate paludiculture experience gained in successful implemented paludiculture pilots.

6. Provision costs for paludiculture and comparison to existing biomass

Boiler installation prices

Prices for renovating existing boiler houses with additional equipment installation are given in the table 2 below.

Table 2: Boiler installation prices [60] [61]

Installed capacity, [MW]	Costs [€]	Costs [€/kW]	Notes
3.1	479 000	155	A moving grate furnace was installed together with an automatic cleaning device and an automatic command and control system. In addition, a fuel warehouse was built, consisting of a wood chip warehouse and a conveyor room. Costs include: technical project development; project author supervision; dismantling of existing equipment. Efficiency not less than 87%.
1.5	93 000	62	Underfeed stocker boiler fuelled by wood chips with an auger feed in the furnace, a fuel bunker with three hydraulically operated pushers and a hydro station. Boiler efficiency not less than 82%. Even though cheaper, underfed stockers are not suitable for fuel with high ash amount.
3	523 081	174	Costs include: construction of a new boiler house; wood chip warehouse construction; chimney construction; delivery and installation of all technological equipment. Boiler efficiency 87%.
5.3	2 042 862	385	Costs include: technical project development; construction of boiler house; delivery and installation of all technological equipment. Boiler efficiency 87%.
30 (15x2)	~6 000 000	200	Costs include: technical project development; reconstruction of boiler house; delivery and installation of all technological equipment.

As can be seen specific costs for the projects differ a lot with many things to consider, but it still gives a good overview on how much a grate biomass boiler installation could cost [60] [61].

Paludiculture associated equipment costs

Local boiler houses using fossil fuels could be transformed to boiler houses, which use biomass from paludiculture. [9].

It is important to understand exactly which pieces of equipment and modifications to existing equipment are needed in every specific case.

If paludi-biomass is to be pelleted, then investments into a pelleting station would be around 96,000 € if the equipment is not brand new. The price of constructing or refitting the premises is not taken into account [43].

If biomass is to be shredded for combustion the costs of a second-hand shredder, dependent on the performance and other factors, are around 8,000 €. An additional storage space construction can be around 186,000 € for a 2,000 m^2 storage house, VAT not included.

For increasing the efficiency of a boiler house an additional flue gas condenser may be installed with around 445 €/kw [62]. Baled biomass combustion station would cost 50 €/kw [63].

Linka grass biomass plant installation, based on two projects would cost 370 to 800 €/kW [9].

A bigger CHP plant that can combust both paludiculture and wood biomass, example being BEKW plant in Emlichheim would cost around 1,131 €/kW for the whole project.

If a boiler house is not equipped with sophisticated heating mains, then the price for construction of it would be around 275 €/m with prices in bigger towns going up to 382 €/m and in smaller towns decreasing to 216 €/m [60]

Regarding the connectivity to the transmission network the Baltic states the following is true for the installed total biofuel RES generating capacities on 31st December, 2014:

Lithuania had 97 MW of biofuel RES with all of biofuel power plants being connected to distribution network. Most of biofuel power plants belong to private industrial companies, so they are spread through the whole area of Lithuania. Latvia had 118 MW installed with 24 MW connected to transmission network. Estonia had 131 MW installed with 97 MW connected to transmission network. Estonia's largest CHPs being Lohkva CHP and Tallinna CHP with capacity of 25 MW each. The mentioned CHPs use wood chips, natural gas and peat as fuel. There is 102 MW of biomass fuelled, 17 MW of waste fuelled and 11 MW of biogas fuelled capacity known to be connected to the grid, as of 2014. [64].

Fuel and energy prices

Electricity costs for household consumers including all taxes and levies as of 2020: Estonia 123.6 €/MWh; Latvia 142.6 €/MWh; Lithuania 142.6 €/MWh [65].

District heating costs in Estonia from around 46 to around 55 €/MWh depending on the region and not including VAT; In Lithuania the prices are 35.9 to 90.3 €/MWh with an average being around 50 €/MWh, VAT including; in Latvia the prices are around 44.1 €/MWh to 56.02 €/MWh without VAT [66] [67] [68].

The economics of biomass power generation are critically dependent upon the availability of a secure, long term supply of an appropriate biomass feedstock at a competitive cost. Feedstock costs can represent 20%-50% of the total cost of electricity produced from grate firing plants and 29-55% of CHP [69]. With Latvian district heating price fuel costs currently being calculated as 16.5 € of every MWh [60].

Paludiculture biomass will have to compete with wood chip prices that now seem to range widely from around 26 €/ton up to 54 €/ton (10-20.1 €/MWh respectively for 45% moisture content wood chips). Natural gas prices are around 31-36 €/MWh. Price for peat pellets is 90 €/m^3 (about 45 €/MWh) without VAT [60] [9] [70] [43].

With that in mind Lihula heating plant has fuel costs per tonne of 13 € (3.25 €/MWh, provided that it is dried to <20% moisture) for hay and 19 € (7.36 €/MWh) for wood chips [9].

Prices for paludiculture biomass are considerably less studied than wood prices, adding that to the fact that practise of growing grass biomass on rewetted peatlands is rather new- there are quite a few uncertainties in the final price calculation for this type of fuel. In addition, the prices of important steps of paludiculture growth fluctuate constantly. For example, in 2018, compared to 2017, the largest price increase was for chipping (+49.32 %) and for spreading organic manure (+10.51 %). At the same time, prices decreased for drying (-25.62 %) and for cultivation with a working width above 6 m (-9.40 %). Price changes are explained by market demand changes and rapid weather change (extreme deviations from the normal weather conditions). These examples indicate that the calculation of prices for the installation of any paludiculture species, including has many characteristics that cannot be accurately predicted. Nevertheless, some approximate calculations have been made [9].

Cattail

In Latvia the costs of the established fields are relatively small.

Cattail fields require some maintenance (e.g., removing other plants such as reed; irrigation system, removal of a top layer vegetation before planting), their sowing must not be repeated, and therefore the further costs are related only to mowing, transport to storage facilities, shredding, and storage.

In newly established/sown fields harvest is only feasible after the 2nd vegetation period. Biomass in the 1st vegetation collapses easily as there are not enough stolon stabilizing the plant in the wet ground.

The 1 m^3 of chipped dry cattail biomass in the second year could cost approx. 12-14 € (28-33 €/MWh) and 7-9 € (16.7-21.5 €/MWh) in the following years, depending on mowing costs.

Reed canary grass

Cost for setting up a reed canary grass plantation and sown area is different for the first three years, with the highest costs in establishing the field and planting RCG. Whereas during the following years a notable rise in profit is expected.

The largest investments for the production of reed canary grass biomass are needed in the first two years. According to studies in Latvia, the average net profit of 10 t/ha reed canary grass reached 602 €, while in the third year 948 € in 2018, provided that it is utilised for combustion. The calculations did not take into account the subsidies, which means that the growth of reed canary grass could pay off even more quickly as it is eligible for CAP direct payments.

In most circumstances, introduction of RCG is advantageous for the low costs of establishing parts, minimal or no required use of herbicides or pesticides, and other low direct costs [9].

Reed

Although not grown specifically in a restored peat field it is also important to take into account wild plants as biomass. Harvesting wild reeds in winter, it is possible to cut 2.5 tons of reeds with a moisture content of 15-20% per hour. If used for thatching, common reed is transported in bundles with a density of 150 kg/m3 for transportation. It is assumed that winter mowing is performed with a motorised machine with a diesel consumption of 10 litres per hour.

Table 3: Wild reed harvesting prices [33] [71]

Stage	Costs without VAT	Notes
Mowing		
In water	450–500 €/ha	With amphibia+unloading on shore
	60 €/ha	Mowing with a shredder, without collection
	400 €/ha	Mowing with shredding and collection in a hopper (2 m^3)
On dry land	**60 €/ha**	Mowing without shredding
Transport	1 €/km + 25 €/h	Transport in a 20 m^3 truck

Ethanol from reeds
Studies on the total production costs of reed ethanol have shown that the extraction of the resource amounted to 2,387 €/ha, but the value of the obtained energy, based on 2010 energy prices, was 1,151 €/ha. With 2020 prices on ethanol in Spain being 1.42 €/l it would be on average 2,390 €/ha, prices in other large markets such as in France are 0.68 €/l, in Sweden 1.16 €/l [33] [72].

Obstacles and support

Main obstacles for a conversion towards wet peatland utilization are direct payments that currently are lostwhen a farmer decides to rewet drained agricultural land and starts cultivating wetland species that are not listed as agricultural crops. The only agricultural crop that may be considered as paludiculture crop that currently can receive direct payments is reed canary grass. Direct payments also may be received for an area where a single age species of short rotation coppice is sown and cultivated - aspen tree, willow or grey alder.
There are various support schemes for farmers. Estonian farmers who work on alluvial meadows rely on support schemes for management of these protected wet meadow vegetation. In 2018 there are annual support schemes for: Grass cutting with 85 €/ha, cattle breeding with 150 €/ha; in case of wooded meadow support is 450 €/ha and 250 €/ha accordingly, plus areal support similar to other agricultural land – 90.48 €/ha.
Costs for harvest and haymaking: For Estonian farmers working by Lihula plant they are 85 €/ha for mowing semi-natural vegetation + 27 €/ha compensation of lower income (Nature conservation payments) + common agricultural support 90.83 €/ha. Totalling 202.83 €/ha [9].

Conclusions

- To contribute to the achievement of the Paris Agreement goals the Baltic States will need to lower their GHG emissions, as starting from 2026 the GHG emissions from wetland management will be counted with others. It is essential for the Baltics, that poses great territories of drained and degraded peatland, to start restoring them.
- Paludiculture helps to restore peatlands while simultaneously diversifying the energy sector and creating jobs with an economically benefiting activity. Wet peatland management and paludiculture is auspicious in future for the Baltics with good availability of sites for rewetting and potential of energetic utilisation of paludiculture biomass. .
- There is a selected number of species that thrive well on rewetted peatland under the climatic and edaphic conditions in the Baltics. These species include common reed, cattail, reed canary grass and sedges. The aforementioned species are comparable to wood in energy characteristics, while having a higher ash content.
- There exists a sufficient number of boiler houses that can use biomass from paludiculture as fuel either co-combusting it with wood or combusting it pure. Using existing moving grate technology with leached paludiculture biomass provides the most cost effective solution. Minimal investments are needed.
- Current CAP does not provide any support for the management of organic soils in a climate-friendly way, excluding reed canary grass. Farmers need to be able to get more direct support from the government, especially considering the wood biomass fuel prices and paludiculture biomass manufacture price fluctuation.

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Abbreviations & Acronyms

CHP - Combined Heat and Power
DM - Dry Mass
EE - Estonia
EUKI - The European Climate Initiative
GHG - Greenhouse Gases
LT - Lithuania
LULUCF - Land Use, Land Use Change and Forestry
LV - Latvia
NPP - Net Primary Production
RCG - Reed Canary Grass
RES - Renewable Energy Systems
VAT - Value-Added Tax

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