LIFE Environment and Resource Efficiency project

"Nutrient recycling circular economy model for large cities – water treatment sludge and ashes to biomass to bio-energy "

Project Acronym: NutriBiomass4LIFE
Project Number: LIFE17 ENV/LT/000310

Biomass ashes recycling in NutriBiomass4LIFE circular economy model

WEB page Report prepared by

NutriBiomass4LIFE project team of UAB "Pageldynių plantacija"

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Preface

The purpose of this document is to provide insights on biomass ashes recycling in biomass plantations activity during implementation of the project NutriBiomass4LIFE. Over 4 years of implementation of the project 2169 t of biomass ashes were recycled in NutriBiomass4LIFE biomass plantations.

For the implementation of the NutriBiomass4LIFE project, a subsidy is awarded from the EU LIFE program, the EU's funding instrument for environment and climate action. The funding of the project also come from the Swedish Energy Agency and Ministry of Environment of the Republic of Lithuania.

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III. About the NutriBiomass4LIFE Project

The Nutribiomass4LIFE project was launched on 1 July 2018 and will be running until the end of September 2023. Within the framework of this project, 6 beneficiaries from Lithuania and Sweden aim to create and demonstrate the first of its kind on the EU level full scale self-sustainable closed loop circular economy model for large cities' nutrient rich waste - municipal wastewater treatment sludge and biomass ashes – recycling into renewable energy for city's needs via environment friendly biomass plantation phytoremediation filter. The circular economy model is based upon Vilnius city, the capital of Lithuania (550 thousand population).

The specific objectives of the project included:

- promoting resource efficiency through reuse of nutrients (less usage of mineral fertilizer) and decrease in transportation distances and flows;
- promoting waste management pyramid priorities via changing path from landfilling and incineration of nutrient rich waste towards reuse in biomass growth improvement;
- mitigation of food chain contamination risks via changing path of nutrient rich waste from uncontrolled usage in food crop growing towards 100% legally compliant and monitored non-food biomass yield improvement;
- creating new best practices for dried MWTS digestate usage for non-food biomass;
- developing new business models to make biomass growing / forestry on marginal and less suitable to agriculture soils economically attractive via substantial biomass yield improvement;
- promoting soil organic content improvement via bio-solids applications;
- promoting renewable energy production;
- promoting afforestation of less suitable for agriculture / marginal lands;
- contributing significantly to climate change impact reduction by sequestrating significant volume of CO2 in the whole circular economy model value chain, promoting renewable energy production, soil carbon content improvement;
- promoting of EU and national legislation and policies and contributing to their development by promoting safe and environment friendly reuse of nutrients from wastes.

The Coordinating beneficiary:

1. UAB "Pageldynių plantacija" (Lithuania)

Associated beneficiaries:

2. Forest and Landowners Association of Lithuania (Lithuania)
3. Lithuanian Research Centre for Agriculture and Forestry (Lithuania)
4. UAB "Kirtimu katiline" (Lithuania)
5. UAB "Vilniaus vandenys" (Lithuania)
6. Swedish University of Agricultural Sciences (Sweden)

For more information, please visit the project's website: www.nutribiomass.eu.

IV. List of Abbreviations and Partner Acronyms

NutriBiomass4LIFE	EU LIFE project "Nutrient recycling circular economy model for large cities – water treatment sludge and ashes to biomass to bio-energy ", No. LIFE17 ENV/LT/000310
AGROLAB	Lithuanian Research Centre for Agriculture and Forestry
CCE	Calcium carbon equivalence
CE	Circular economy
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
EU	European Union
FTE	Full time employed
g	gram, 1 kg = 1000 g
kg	kilogram, 1 t = 1000 kg
ha	hectare, 1 ha = 1000 square meteres
km	kilometre, 1 km = 1000 m
KK	UAB "Karlų katilinė"
LMSA	Forest and landowner's association of Lithuania
µ	microgram, 1 mg = 1,000 µg
mg	milligram, 1 g = 1000 mg
MWTS	Municipal waste-water treatment sludge digestate
PP	UAB "Pageldyniu plantacija"
PE	UAB "Kirtimu katiline"
r. or reg.	administrative district
sen.	regional units of administrative district
t	metric ton, 1 t = 1000 kg
VV	UAB "Vilniaus vandenys"

Introduction

Purpose and Aim

The purpose of this document is to reveal the results of biomass ashes recycling in biomass plantations (B3) during implementation of the project NutriBiomass4LIFE.

Structure

The document is divided into four main chapters:

- Chapter 1 “Role of biomass ashes in circular economy” defines rationale for using biomass ashes in circular economy.
- Chapter 2 “Biomass ashes supply” discloses volume of biomass ashes supplied during NutriBiomass4LIFE project for recycling in biomass plantations.
- Chapter 3 “Quality of biomass ashes” discusses nutrient and contaminant content of biomass ashes used during NutriBiomass4LIFE project for recycling in biomass plantations.
- Chapter 4 “Biomass ashes recycling locations” discloses land plots in which biomass ashes were used for recycling in biomass plantations during NutriBiomass4LIFE project.
- Chapter 5 “Nutrient recycling” discloses volumes of nutrients recycled from biomass ashes in biomass plantations during NutriBiomass4LIFE project and discusses rationale for usage of biomass ashes.
- Chapter 6 “Heavy metal and other contaminant inputs” discloses volumes of heavy metals recycled from biomass ashes in biomass plantations during NutriBiomass4LIFE project and associated risks.
- Chapter 7 “Economics of biomass ashes recycling” discloses costs of biomass ashes recycling in biomass plantations.
- Chapter 8 “Carbon footprint” discloses CO2 footprint of biomass ashes recycling in biomass plantations during NutriBiomass4LIFE project.
- Chapter 9 “Policy” discusses policy and national legislation issues related to biomass ashes recycling.
- Chapter 10 “Continuation” discusses NutriBiomass4LIFE post project possibilities.

1 Role of biomass ashes in circular economy

Biomass is the key renewable resource of the world's renewable energy. With the target to shift towards net zero carbon emissions, biomass role in renewable energy will remain strong worldwide and in the EU.

The amount of ash produced by combustion of wood chips or wood pellets typically ranges from 1,4 to 2,1% of the input of fuel. In households, heated individually with biomass, biomass ashes are reused locally to fertilize soil in local gardens. Industrial and municipal biomass boilers must deal with large quantities of biomass ashes which are left after combustion of significant quantities of biomass like a waste or like sub-product for further reuse.

In Lithuania biomass ashes are mainly residues from combustion of wood. Fine particle size fly ashes are separated from the flue gases by using electrostatic separators or fabric filters, and coarser bottom ashes are collected from the bottom of the combustion chamber. In smaller and older facilities, some of the ash is collected by means of cyclones. The amount and characteristics of different ash fractions strongly depend on the combustion technology used. Flue gas treatment technology, fuel properties and process parameters also have a significant effect on the ash quality. Fly ash is the main ash fraction from fluidised bed combustion. The share of fly ash is typically 70–90% and correspondingly the share of bottom ash (also called as bed sand) 10–30%. Bottom ash is the main ash fraction (60–90%) from grate boilers, and the rest (10–40%) is collected as fly ash. Sometimes bottom ashes from grates are collected as wet. Fly and bottom ashes are mainly collected separately.

Reusing potential of biomass ashes in circular economy is defined by chemical characteristics and economic conditions. The most important chemical characteristics, important for biomass ashes usage in agriculture and forestry are as follows:

- Calcium (Ca) – 15-20%
- Potassium (K) – 2-5%
- Phosphorus (P) – appr. 1%
- Sulphur (S)
- Other micronutrients (Mn, Fe, Cu ir Zn)

Besides macro and micro-nutrients, which are the key reason for reusing biomass ashes in agriculture/forestry, biomass ashes due to high volume of silica (Si) and calcium (Ca) can be used in construction of infrastructure (roads, etc.), but with loosing all nutrient pools.

Besides nutrients, reusage of biomass ashes in agriculture/forestry have negative implications due to negative externalities: accumulation of heavy metals and radioactive substances in biomass ashes.

The risk of high concentration of heavy metals in biomass ashes is low if woody biomass for energy is composed of virgin wood, coming in the form of harvesting residues, sawmilling residues, abandoned agricultural land cleaning from woody vegetation, biomass plantations. Heavy metal concentrations in biomass ashes may increase due to incineration of secondary wood from construction, furniture and other industries, affected by chemicals, which illegally may be mixed into raw wood biomass. Nevertheless, this risk is decreasing due to improved waste management practices.

One more risk associated with reusage of biomass ashes in agriculture/forestry is a radioactive contamination. Radioactive contamination risks are related to woody biomass supply for incineration form the regions contaminated with radioactive contaminants for Chernobyl nuclear power plant (Ukraine) disaster which happened in 1986. After incineration of biomass, concentration of heavy metals and radioactive substances in biomass ashes increases hundreds of times comparing to those found in woody biomass. Till 2021, large portion of biomass for energy (30 to 40% of total central heating market) was supplied from Byelorussia, of which some regions in the south were the most severely contaminated by radioactive substances after Chernobyl nuclear power plant disaster. Since 2022 supplies of biomass for energy from Byelorussia stopped therefore radioactive contamination risks decreased substantially.

2 Biomass ashes supply

During implementation of the Nutribiomass4LIFE project (action B3) total 1771,26 t. of biomass ashes was supplied by UAB “Kirtimų katilinė” (PE) biomass boiler located in Vilnius city, to be used for fertilization in Nutribiomass4LIFE biomass plantations.

Table 2-1. Biomass ashes supply by PE

Dates of supply	Number of truks	Biomass ashes supplied, t
total	**84**	**1771,26**

Additionally, 398 t of biomass ashes were supplied by UAB “Karlų katilinė” (KK) biomass boiler located in Visaginas, to be used for fertilization in Nutribiomass4LIFE biomass plantations.

Table 2-2. Biomass ashes supply by “Karlų katilinė“

Dates of supply	Number of truks	Biomass ashes supplied, t
TOTAL	**18**	**398,34**

3 Quality of biomass ashes

Biomass ashes quality is characterised by positive impact from nutrients and other soil improvement elements and by negative impacts which comes from potential contaminants.

Positive impact from reusage of biomass ashes in soil is coming from Calcium (Ca), Potassium (K), Phosphorus (P), and various micronutrients. Negative impact on usage of biomass ashes on soil is coming from heavy metals, aromatics and radioactive substances.

Total 11 biomass ashes quality analysis were conducted for biomass ashes of PE and KK quality assessment.

3.1 Nutrient content

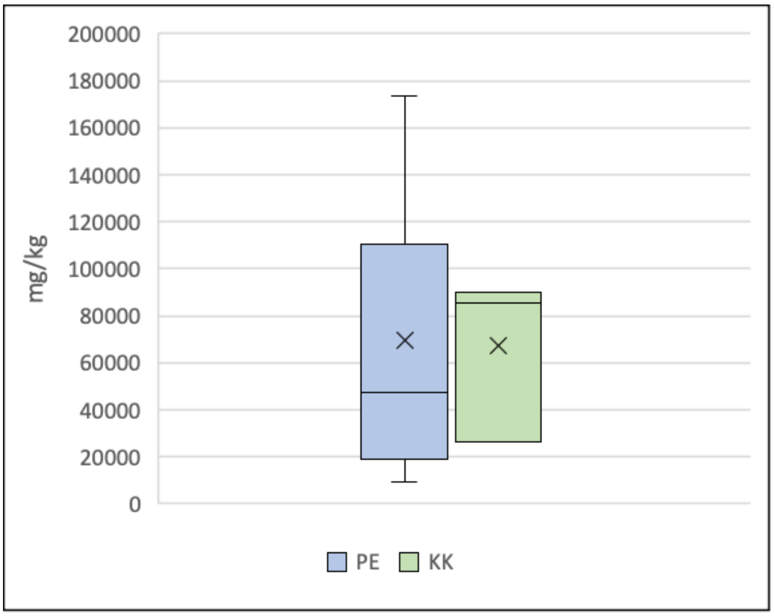
The key mean macro and micro-nutrient concentrations in reused biomass ashes are presented in the Table 3-1.

Table 3-1. Mean values of nutrient content in biomass ashes

Nutirent values	units	PE	KK
pH		12,5	12,7
Total organic carbon	%	1,5	3,7
Total phosphorus (P)	mg/kg	10012	9040
Magnesium (Mg)	mg/kg	8843	7090
Potassium (K)	mg/kg	21497	20571
Calcium (Ca)	mg/kg	69533	67211
Total nitrogen (N)	mg/kg	905	
Ammonia nitrogen (N-NH4)	mg/kg	2,0	
Nitrate nitrogen (N-NO3)	mg/kg	21,4	
Manganese (Mn)	mg/kg	2866	
Total chlorine (Cl)	mg/kg	576	
Total sulphur (S)	mg/kg	2151	

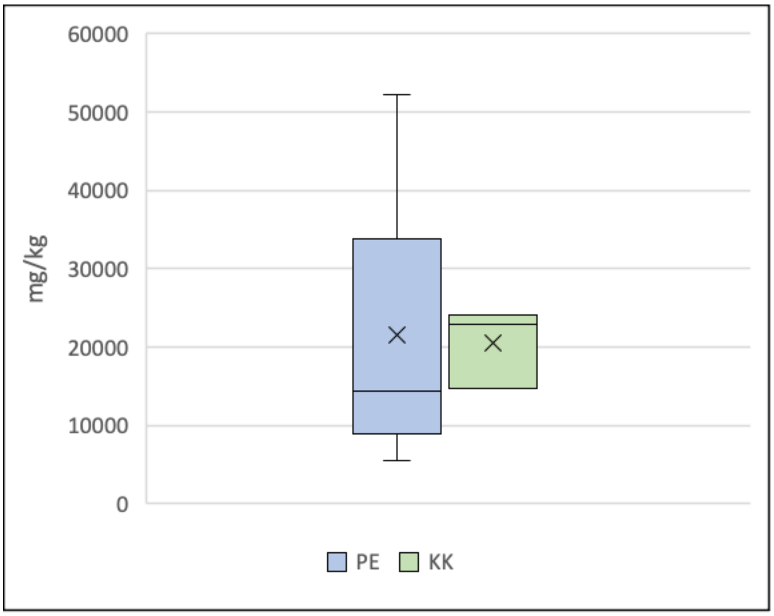
The key positive element in biomass ashes, which is used as soil improver is Calcium (Ca). Calcium is used to decrease soil acidity to improve overall soil nutrient balance – for soil liming purposes. Mean calcium (Ca) concentrations in reused biomass ashes were 69533 mg/kg (PE) and 67211 mg/kg (KK), although it ranged from max 173750 mg/kg to min 9530 mg/kg. Such a high variation in calcium (Ca) concentrations is dependant on analysis methods used, which changed over time, therefore for comparative analysis the same analysis methods have to be used.

Picture 3-1. Calcium (Ca) concentrations in reused biomass ashes, mg/kg



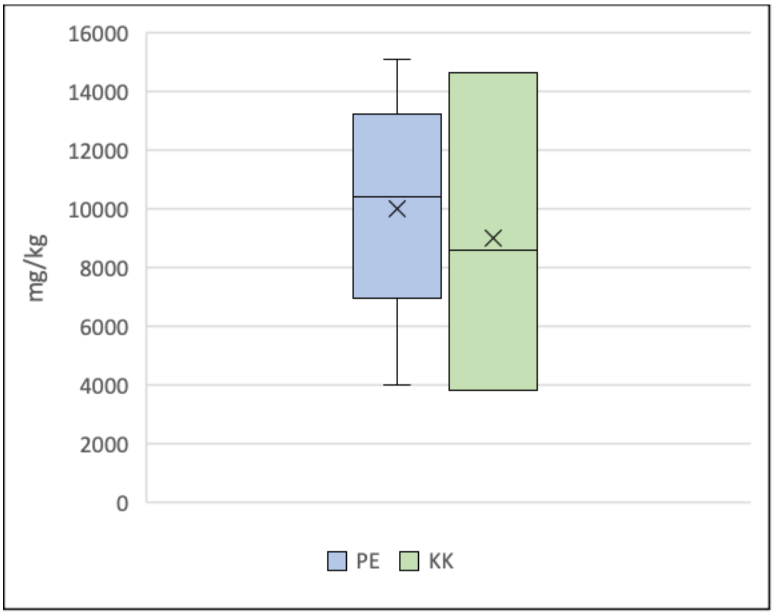
Biomass ashes as a nutrient source are also important due to potassium (K) concentrations. Mean potassium (K) concentrations in reused biomass ashes were 21497 mg/kg (PE) and 20571 mg/kg (KK), and ranged from max 52281 mg/kg to min 5580 mg/kg. Application of biomass ashes as potassium (K) rich fertilizer is useful for fast growing tree species, in particular on soils with high organic matter, as on such soils plants face potassium (K) deficiency which is essential for trees to prepare for winter frosts.

Picture 3-2. Potassium (K) concentrations in reused biomass ashes, mg/kg



Biomass ashes also had valuable total phosphorus (P) concentrations, where mean phosphorus (P) concentrations in reused biomass ashes were 10012 mg/kg (PE) and 9040 mg/kg (KK), where it ranged from max 15101 mg/kg to min 5878 mg/kg. Application of biomass ashes as phosphorus (P) rich fertilizer has one big limitation - despite pretty high total phosphorus (P) concentration in biomass ashes, not all total phosphorus is composed of plant available phosphorus (P2O5). During incineration of woody biomass under very high temperatures, part of phosphorus (P) is bind into insoluble compounds and will become plant available only over many years. That is why biomass ashes usage as a fertilizer in agriculture, where plants immediately need plant available phosphorus (P2O5) is not the best recycling solution, while in forestry (tree farming) it makes big sense as trees will absorb phosphorus (P) over many years.

Picture 3-3. Total phosphorus (P) concentrations in reused biomass ashes, mg/kg



More detailed analysis on biomass ashes quality used in NitriBiomass4LIFE project are presented in the report of Agrolab.

3.2 Contaminants

Despite abundant nutrients, application of biomass ashes in agriculture/forestry contains certain risks related to heavy metal, aromatic and radioactive contaminants.

According to national regulation, concentrations of heavy metal and aromatic, shall not exceed certain limit values before them applying in agriculture or forestry.

Table 3-2. Mean concentrations of contaminant elements in biomass ashes

Contaminant concentrations	units	Limiting concentrations for biomass ashes usage in agriculture	PE	KK
Boron (B)	mg/kg	250	55	51
Chrome (Cr)	mg/kg	30	28	17
Cuprum (Cu)	mg/kg	200	87	57
Nickel (Ni)	mg/kg	30	9	8
Zink (Zn)	mg/kg	1500	445	287
Vanadium (V)	mg/kg	150	11	9
Cadmium (Cd)	mg/kg	5	2,4	1,3
Lead (Pb)	mg/kg	50	9,0	4,8
Arsenic (As)	mg/kg	3	1,2	1,5
Mercury (Hg)	mg/kg	0,2	0,037	0,030
Benz(a)pyrene	µg/kg	0,5	<0,44	<0,50

As discussed earlier, if virgin wood is supplied without mixing with contaminated secondary wood, there is no risk of exceeding limiting concentration values of heavy metals and aromatics.

Contamination of biomass ashes with radioactive substances is measured via concentration of ^{137}Cs radionuclide activity in biomass ashes. According to national legislation, it is not allowed to use biomass ashes, derived via incineration of biomass imported from third countries affected by Chernobyl nuclear power plant disaster, in agriculture/forestry if concentration of ^{137}Cs radionuclide activity in biomass ashes is greater than 1,00 Bq/g (e.g in Sweden this limiting contamination value is 10,00 Bq/g). While reusing biomass ashes for NutriBiomass4LIFE project several radioactive contamination analyses have been conducted and results show that radioactive contamination of biomass ashes was under the controlled limits.

Table 3-3. Analysis values of concentration of ^{137}Cs radionuclide activity in biomass ashes

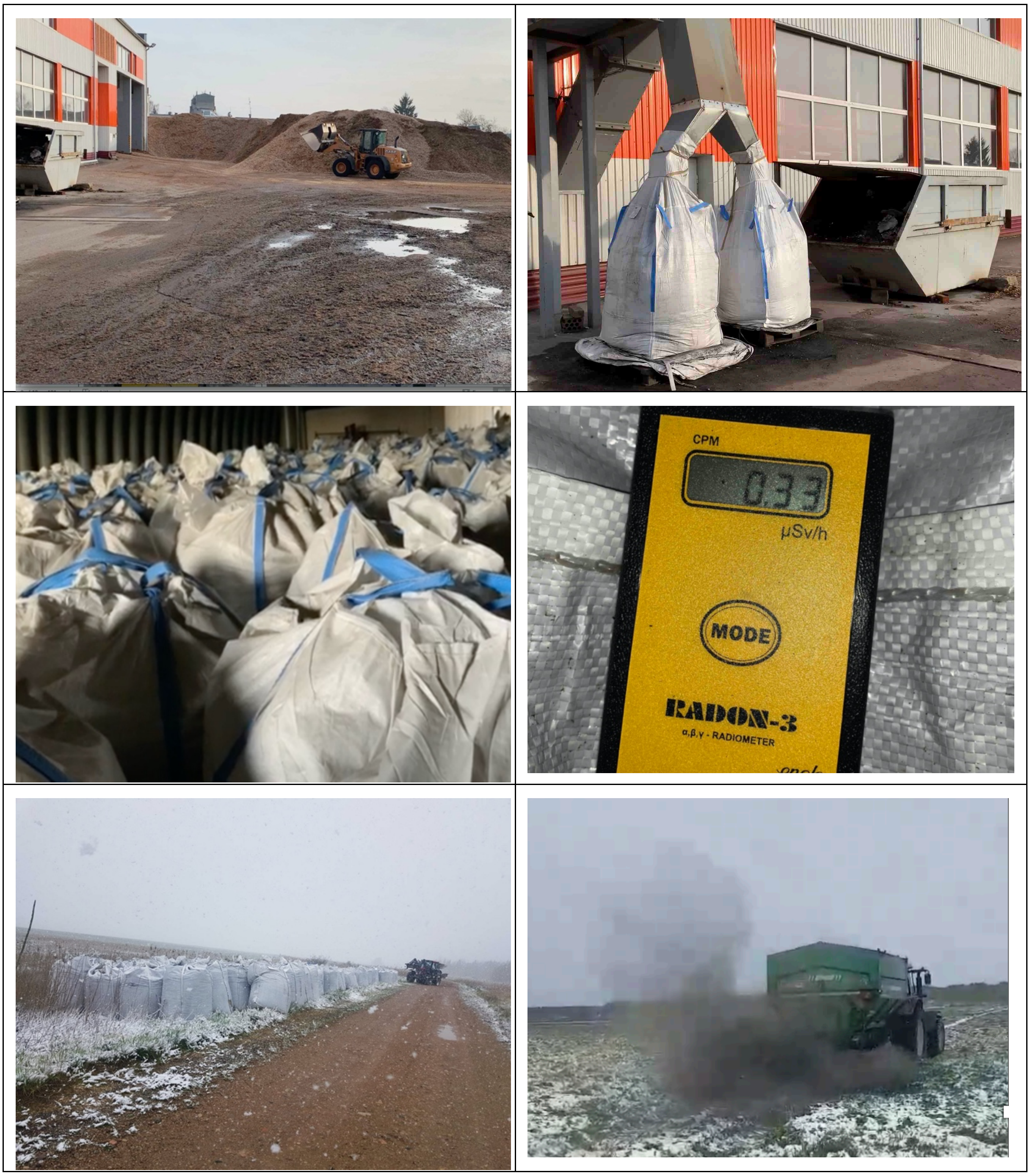
	limit value, Bq/g	PE	PE	PE	PE	KK	KK
		2019-07-08	2019-07-08	2021-10-27	2022-02-19	2021-10-27	2022-03-17
		G-2019-571	G-2019-572	G-2021-1052	G-2022-171	G-2021-1051	G-2022-228
Concentration of ^{137}Cs radionuclide activity	**<1,00**	0,074	0,710	0,080	0,280	0,560	0,140

4 Biomass ashes recycling technology and locations

Biomass ashes (bottom ashes and fly ashes) from biomass boilers can be supplied either packed in big-bags (each of up 1 ton) or supplied unpack in the containers. Biomass ashes can be either dry or wet. When biomass ashes are packed into big bags, they can be transported by ordinary trailers, when biomass ashes are collected into containers – they can be transported with specialised machinery, which transports such containers.

Dry biomass ashes, after production at PE, have been packed into big bags. Later big bags are stored in warehouse before transportation to the fields.

Picture 4-1. Biomass ashes packing in big-bags at PE



During the project biomass ashes as soil amendment were used in several locations with established woody-biomass crops and overall 208 ha area soil was improved using biomass ashes. Land plots in Trakai district were fertilized with biomass ashes exclusively, while land plots in Anykščai district were fertilized jointly with biomass ashes and MWTS.

Table 4-1. Biomass ashes used for soil amendment and fertilization

Address	Land plot No.	Total area, ha	Fertiliza-tion area, ha	Max fertiliza-tion rate t/ha	2019 t	2020 t	2021 t	2022 t	Total t
Total		260,30	208,08		597,32	554,80	573,90	443,58	2169,6

5 Nutrient recycling

Table 5-1 provides information on nutrients recycled after reusing of 2169,26 tons of biomass ashes in biomass plantations by specific land plots. Among nutrients, the largest volumes were reused of calcium (Ca) – 149,9 t, potassium (K) – 46,27 t, phosphorus (P) - 21,3 t and magnesium (Mg) – 18,49 t.

Table 5-1. Total nutrient recycling volumes from biomass ashes, t

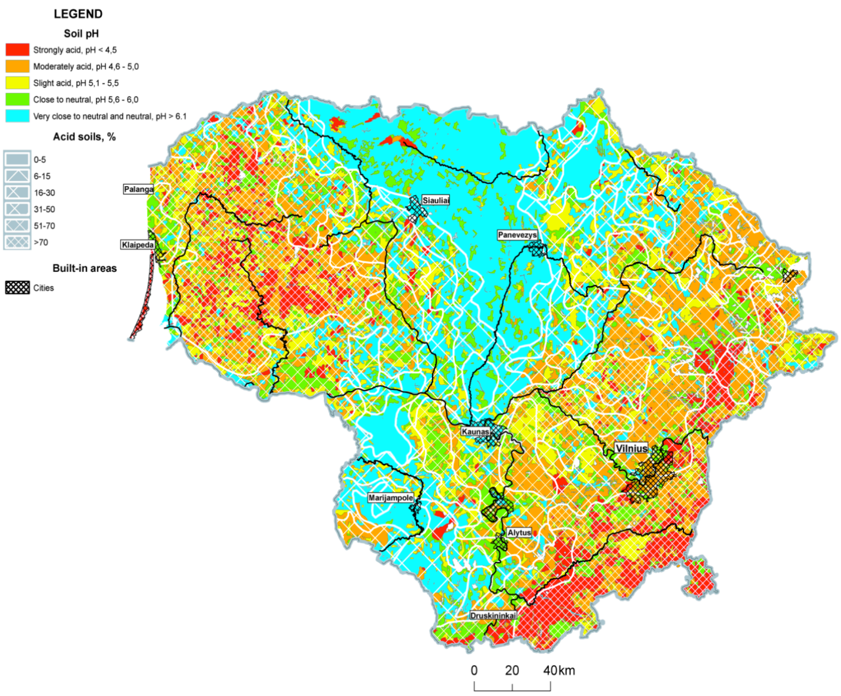
Land plot Unique No.	P, t	Mg, t	K, t	Ca, t	N, t	N-NH4, t	N-NO3, t	Mn, t	Cl, t	S, t
Total, t	21,33	18,49	46,27	149,93	1,96	0,00	0,05	6,22	1,25	4,67

Table 5-2. Nutrient recycling volumes from biomass ashes, kg/ha/year (4 year period)

Land plot Unique No.	P, kg/ha/year	Mg, kg/ha/year	K, kg/ha /year	Ca, kg/ha year	N, kg/ha /year	N-NH4, kg/ha/year	N-NO3, kg/ha/year	Mn, kg/ha /year	Cl, kg/ha/year	S, kg/ha/year
Total, t/ha/year	26	22	56	180	2,4	0,01	0,06	7,5	1,5	5,6

The ideal pH of soil for poplar cultivation should be between 5.8 to 8.5. In Lithuania the majority of poplars are being established in the areas with severe. natural constrains, i.e. on the soils less suitable for conventional agricultural activities. These areas also can be characterised as having higher acidity soils.

Picture 5-1. National map of soil acidity (pH)



NutriBiomas4LIFE poplars were established in South Eastern part of Lithuania – the area in which soils with highest acidity prevail in Lithuania, therefore measures to decrease soil acidity are very much welcomed to ensure productive growth of established biomass plantations. Overall pH in soils, especially in Eastern and Western parts of Lithuania, has the tendency to decrease – each year soils are getting more acid.

The soil acidity levels can be improved to targeted ones by applying lime fertilizers, which contain calcium carbonate (CaCO3).

Table 5-3. The recommended rate of lime fertilizer (CaCO3 t/ha) to increase soil pH by 0.1

	Soil acidity (pH)					
Soil texture	**<4,5**	**4,6-5,0**	**5,1-5,5**	**5,6-6,0**	**6,1-6,5**	**6,6-7,0**
Sand	0,58	0,54	0,84	1,29	1,42	2,01
Sandy loam	0,55	0,62	0,79	1,20	1,80	2,62
Light loam	0,69	0,73	0,92	1,33	2,60	7,01
Medium loam	0,71	0,76	1,00	1,61	2,67	7,60
Heavy loam	0,73	0,80	1,05	1,80	2,90	9,20
Clay	0,73	0,80	1,40	1,80	2,91	12,50

While calculating application rates of different liming material, calcium content in various materials have to be taken into accounts and calcium carbon equivalence (CCE) has to be established. The percentage of calcium (Ca) in calcium carbonate (CaCO3) is 40%, while mean calcium (Ca) content in biomass ashes used in NutriBiomass4LIFE project is about 7% only. This means that CCE of biomass ashes NutriBiomass4LIFE reused is equal to 17,5%, i.e. to achieve the same effect of soil acidification reduction as calcium carbonate (CaCO3), 5,7 times more (in terms of tons) of biomass ashes have to be applied.

Based on the data in Table 5-3 and taking into account the characteristics of the soil, the application rate of liming fertilizer is calculated for various plants or for the entire crop rotation. Therefore, it is necessary to know the optimal pH value and the initial pH value of the soil. To get the rate of fertilizing material to neutralize the acidity of the soil to the optimum pH, the resulting difference in pH values is multiplied by the rate of calcium carbonate (CaCO3) required to increase the pH by 0.1 and to divide by calcium carbon equivalence (CCE) of a particular liming fertilizer. For example, if the pH of loam should be on average 5.8 (pH 5.6-6.0) for poplars, but it was pH 5.4, the acidity of the soil should be reduced increasing pH by 0.4. in Table 5-3 we find: when the pH of the soil is 5.0-5.5, it is necessary to increase the pH by 0.1 1 t/ha of CaCO3, and when the pH is 5.6-6.0 - 1.6 t. The total rate of CaCO3 will be 5.8 t/ha (1x1 t/ha +3x1.6 t/ha) and correspondingly the rate of total rate of NutriBiomass4LIFE quality biomass ashes will be 33 t/ha ((1x1 t/ha +3x1.6 t/ha)/17.5%).

In addition, it is estimated, that every year 1 ha of soil loses (washes out) 193 - 251 kg/ha of calcium (Ca), i.e. soil becomes acidified by 0.1-0.2 pH, which means that 0.5-1 ton of calcium carbonate (CaCO3) or 2.8-5.7 ton of NutriBiomass4LIFE quality biomass ashes must be added for maintenance of stable soil acidity level each year.

Current national legislation allows very restricted rates of biomass ashes to be reused in agriculture/forestry, which can neither change acidity level to targeted, nor ensure maintenance stable acidity level. This can be observed from soil analysis of NutriBiomass4LIFE project. In Trakai district, where soil (Histosols) was treated solely with biomass ashes, median pH over 4 years decreased from 6.4 to 6 pH. On the other hand, in Anykščiai district where soil (various mineral soils) were treated with biomass ashes combined with MWTS, median pH over 4 years remained stable at 5.9 pH level. This shows that combination of biomass ashes and MWTS is more desirable not only from the point of providing more comprehensive mix of nutrients (which differs in MWTS and biomass ashes). Such a combinations gives also better effect on soil acidity regulation as MWTS (which is also alkaline) is allowed to be used at much higher rates than biomass ashes.

Biomass ashes can be valued as potassium (K) rich fertilizer, which is much demanded by fast growing tree species. With average application of 3,5 t/ha of biomass ashes, appr. 60 kg/ha/year of potassium (K) were be added to the soil.

Biomass ashes can be viewed as total phosphorus (P) rich fertilizer, as mean total phosphorus (P) concentration in NutriBiomass4LIFE quality biomass ashes was about 1 %. The problem here is that, the part of total phosphorus (P) in biomass ashes is in the form of plant unavailable forms (insoluble compounds), thus as phosphorus (P) fertilizer biomass ashes are not highly relevant as fertilizer for one year rotation agricultural crops, which require all plant available phosphorus in one year.

As short rotation trees may uptake nutrients in many years, biomass ashes may be well accepted as long-lasting phosphorus fertilizer. In this case to avoid leaching of phosphorus into water, it may be reasonable to analyze and fertilization rate limit to define based not at total phosphorus (P) concentration but a plant available phosphorus (P2O5) concentration.

Biomass ashes have very limited amount of nitrogen therefore we cannot see short term effect on poplar growth while reusing biomass ashes as fertilizer. Biomass ashes can be used like long lasting fertilizer and soil improvers.

6 Heavy metal and other contaminant inputs

While reusing biomass ashes in NutriBiomass4LIFE plantations, the total highest amounts of heavy metal inputs included zinc (Zn) – 787 kg, copper (Cu) – 178 kg and boron (B) – 177 kg. Above mentioned heavy metals are also considered as micronutrients, therefore they do not impose high risk to plants.

Table 6-1. Total heavy metal inputs from biomass ashes

Land plot Unique No.	B, kg	Cr, kg	Cu, kg	Ni, kg	Zn, kg	V, kg	Cd, kg	Pb, kg	As, kg	Hg, kg
Total, kg	**117,23**	**56,58**	**177,70**	**19,64**	**787,4**	**23,29**	**4,75**	**17,80**	**2,69**	**0,059**

From the point of heavy metal inputs from biomass ashes into the soil as per mg/kg, the amount added to the soil is insignificant per all heavy metals analysed. In addition, part of added heavy metals is being again absorbed by fast-growing trees into biomass, therefore no significant increase in heavy metal concentrations in soil is observed.

Share of total input of heavy metals in the highest allowed heavy metal concentration in soil does not exceed 1% in all heavy metal cases, and was highest in zinc (Zn), cadmium (Cd) and copper (Cu).

Table 6-2. Heavy metal inputs from biomass ashes, mg/kg soil

Land plot Unique No.	B, mg/kg	Cr, mg/kg	Cu, mg/kg	Ni, mg/kg	Zn, mg/kg	V, mg/kg	Cd, mg/kg	Pb, mg/kg	As, mg/kg	Hg, mg/kg
Total, mg/kg	**0,250**	**0,121**	**0,380**	**0,042**	**1,682**	**0,050**	**0,010**	**0,038**	**0,006**	**0,0001**
Highest allowed concen-tration in soil, mg/kg		**50**	**50**	**50**	**160**		**1**	**50**		**0,6**
Share of total input / allowed concentration in soil		**0,24%**	**0,76%**	**0,08%**	**1,05%**		**1,01%**	**0,08%**		**0,02%**

Note: Density of top 0-20 layer of soil: sandy loam (1,40 g/cm3) and organic (0,80 g/cm3)

7 Economics of biomass ashes recycling

The economics of biomass ashes reusing in biomass plantations defined by several key inputs:

- Soil analysis costs
- Transportation costs
- Spreading (field) costs
- Biomass yield improvement

National legislation on biomass ashes application in agriculture/forestry was drafted on sludge directive basis, thus requires costly comprehensive analysis of soil nutrients and heavy metals of each 5 ha of fertilized area. Taking into account limited rates use of biomass ashes and soil sampling and analysis costs – it is estimated that only soil analysis costs about **8,4 eur/t** of biomass ashes applied in biomass plantations (calculated as heavy metal and nutrient analysis in soil – 97 eur/5ha sample plus sample collection 50 eur/5ha divided by 17,5 t of biomass ashes applied to 5 ha sample)

Transportation costs of biomass ashes are dependent, whether biomass ashes are supplied packed in big bags or container. If biomass ashes are supplied packed in big-bags, transportation volume is about 21 t/truck (NutriBiomass4LIFE case) and the average price per truck is about 200 eur/truck or 9,5 eur/t. Additionally we have to add big-bag costs – 5 eur/t. Thus total transportation costs of biomass ashes packet in big bag costs are **14,5 eur/ha**. Transportation costs of unpacked biomass ashes in 12 t containers is also 200 eur /truck or **16,6 eur/t.**

Costs of biomass ashes spreading in the biomass field are composed of unloading, spreading and disking (insertion into soil) costs. It is assumed, that 48 t /day of biomass ashes can be reused for fertilization with one set of machinery (two tractors). Spreading costs are composed of 7,67 l diesel /t of biomass ashes consumption @ 1,5 eur/l, plus 300 eur / day / two tractor drivers wages and 200 eur /day tractor ((ease/maintenance) costs. Total biomass ashes spreading in biomass field costs are **22 eur/t biomass ashes.**

Overall costs for recycling of biomass ashes in biomass fields total about 45 eur /t biomass ashes, including soil analysis costs.

Biomass yield improvement while using biomass ashes ash as fertilizer is quite limited in short term and positive impact cannot be observed. Fertilization and soil improvement with biomass ashes has long term positive effect, therefore it is difficult to assess positive impact on yields which could compensate or reduce costs associated with biomass ashes recycling in biomass plantations.

8 Carbon footprint

Carbon footprint of biomass ashes recycling in CE model consists of several key elements:

- Transportation of biomass ashes from biomass boiler to biomass ashes recycling locations
- Application of biomass ashes in biomass plantations and supervision
- Replacement effect of nutrients (negative emissions)
- Biomass yield improvement (negative emissions)

8.1 Transportation carbon footprint

Carbon footprint of biomass ashes transportation form biomass boilers to biomass fields for recycling is based on the following assumptions:

- Long-haul trailer CO_2 emissions – 57g per t km
- Average weight of truck – 21,27 t
- Distance from biomass boilers (PE and KK) to biomass fields

It is estimated that carbon footprint from biomass ashes transportation form biomass boilers to biomass fields for recycling in biomass plantations during NutriBiomass4LIFE project implementation **equalled to 9,2 tCO_2.**

Table 8-1. Nutribiomass4LIFE carbon footprint from transportation of biomass ashes

items		No. of trucks	CO_2 footprint, t CO_2
Long-haul trailer CO_2 emission factor, g CO_2 /t km	57		
Transportation distances	km		
from PE to Trakai r.	38	52	2,4
from PE to Anykščiai r.	107	32	4,2
from KK to Trakai r.	190	1	0,2
from KK to Anykščiai r.	117	17	2,4
			9,2

The key factor in reducing CO_2 emissions from transportation is biomass ashes is reducing distance to biomass fields from biomass boilers, therefore nutrient recycling from biomass ashes in biomass fields is a local business approach, which allows to benefit municipal district heating and local farmers.

8.2 Application of biomass ashes in biomass plantations carbon footprint

Carbon footprint of application (fertilization) of biomass ashes in biomass plantations for recycling depends on the diesel fuel consumed by agricultural machinery and is based on the following assumptions:

- Average 3,5 t/ha biomass ashes applied
- 6 ha /day of biomass plantations fertilized with one set of machinery

- 48 t /day of biomass ashes used for fertilization with one set of machinery
- Diesel fuel consumption is 14 l/h per one set of machinery

Carbon footprint of biomass ashes recycling supervision was calculated based on car fuel consumption, while travelling to biomass ashes recycling sites.

It is estimated that carbon footprint of application (fertilization) of biomass ashes in biomass plantations for recycling during NutriBiomass4LIFE project implementation **equalled to 45 tCO2.**

Table 8-2. Nutribiomass4LIFE carbon footprint from application of biomass ashes in biomass plantations

	diesel l/t ash	ash, t	CO2 footprint, t CO2
1l diesel CO2 emission factor, kg CO2 /l	2,68		
Loading-unloading of trucks and disking	5,33	2169,60	31,0
Spreading of biomass ashes	2,33	2169,60	13,6
Visiting biomass ashes recycling locations with petrol cars (8 l gasoline / 100 km)	2,3 kgCO2/l	2000 km	0,4
total	**7,67**	**2169,60**	**45,0**

Agricultural operations have significant carbon footprint due to high diesel consumption. This carbon footprint can be reduced by switching to renewable fuels.

8.3 Nutrient replacement effect

Biomass ashes contain nutrients, from application of which in biomass plantation, negative CO2 footprint can be recorded from nutrient replacement activities. The major replaced nutrients which have the largest effect on negative CO2 footprint are calcium (Ca), potassium (K) and phosphorus (P).

Table 8-3. Nutribiomass4LIFE carbon footprint from nutrient replacement using biomass ashes

Replacement of nutrients	Fertilizer production footprint t CO2 eq/t nutrient	tons reused	CO2 emission avoiding by replacement, t CO2
Total phosphorus (P) ref P2O5	0,56	21,33	-11,9
Total potassium (K) ref K2O	0,43	46,27	-19,9
Total calcium (Ca) ref CaCO3	0,10	149,93	-14,7
Total nitrogen (N) ref Urea	3,6	1,96	-7,1
total			**-53,6**

Total negative CO2 footprint from nutrient replacement from NutriBiomass4LIFE biomass ashes recycling in biomass plantation activity implementation **equalled to minus 53,6 tCO2.**

8.4 Biomass yield improvement

Biomass yield improvement while applying biomass ashes could give negative carbon footprint value for application of biomass ashes. Nevertheless, biomass ashes have a very slow effect on biomass yield improvement therefore no negative CO2 footprint effect from biomass ashes on biomass plantation yield improvement is considered.

8.5 Carbon footprint balance

Calculated CO_2 footprint balance from NutriBiomass4LIFE biomass ashes recycling in biomass plantation activity implementation **equalled to 0,6 tCO2** and was composed of:

- CO2 footprint from biomass ashes transportation form biomass boilers to biomass fields for recycling in biomass plantations, which equalled to 9,2 tCO2
- CO2 footprint from application (fertilization) of biomass ashes in biomass plantations, which equalled to 45,0 tCO2.
- negative CO2 footprint from nutrient replacement from biomass ashes recycling in biomass plantation activity implementation, which equalled to minus 53,6 tCO2

9 Policy

Return of biomass ashes to the soil is the most sustainable utilization of biomass ashes as minerals in biomass ashes that were extracted by trees from the soil are returned to the soil. In this case the quality of biomass ashes have to be controlled to avoid possible contamination of soil.

Biomass ashes application in soil as fertilizer and/or soil improver is not regulated on the EU level, and the main regulation is passed to the national level. According to the NEW EU Fertiliser Regulation 2019, the countries may apply less strict limits for applications of biomass ashes in top soils, but may not export the biomass ashes to other countries as CE marked product for applications in top soils. After processing and stabilization, biomass ashes may fulfil the criteria to be used as component for inorganic macronutrient fertilizers, liming materials or inorganic soil improvers under the EU Fertilizing Products Regulation.

Different countries have various regulation frameworks for application of biomass ashes to soil. Biomass ashes application in agriculture and forestry is a common practice in Northern European countries where biomass as a renewable energy source has significant share in total energy production, consequently leading to higher volumes of biomass ashes available.

In Lithuania, application of biomass ashes on soil is regulated by special regulation approved by the minister of environment in 2011 – "Regulation on management and application of biomass ashes". This regulation was developed based on Sludge directive, therefore some requirements for application of biomass ashes in agriculture and forestry are costly and excessive. The regulation on biomass ashes application almost has not been changed since adoption and require certain improvement.

National regulation sets very stringent quality requirements for biomass ashes application in CE. There is questionable distinction in quality requirements while applying biomass ashes in forestry and agriculture: the quality (concentrations of heavy metals) requirements of biomass ashes are less stringent when applying on food crops (agriculture), comparing to non-food (forest) application. Many of limiting requirements for heavy metal concentrations in biomass ashes for application in agriculture and forestry in Lithuania are almost ten times more stringent than those defined by EU regulation on fertilizing products (2019/1009), regulation frameworks in Sweden and other EU countries.

Table 9-1. The highest limiting values of contaminants in biomass ashes for different applications (mg/kg)

Name of element	Lithuania	Lithuania	Sweden	EU regulation of fertilizing products			
mg/kg	Agriculture and land reclamation	Forestry	Forestry	Liming material	Organic soil improvers	Inorganic soil improvers	Organo-mineral fertilizers
Boron (B)	250	200	800				
Chromium (Cr)	30[1]	20[1]	100[1]	2[2]	2[2]	2[2]	2[2]
Cuprum (Cu)	200	100	400	300	300	300	300
Nickel (Ni)	30	20	70	90	50	50	50
Zink (Zn)	1500	1000	min. 500 max7000	800	800	800	800
Vanadium (V)	150	150	70				
Cadmium (Cd)	5	3	30	2	2	2	3
Lead (Pb)	50	40	300	120	120	120	120
Arsenic (As)	3	3	30	40	40	40	40
Mercury (Hg)	0,2	0,2	3	1	1	1	1

[1] t highest limit of total Chromium (Cr) concentration (mg/kg)
[2] highest limit of hexavalentchromium (CrVI) concentration (mg/kg)

There are also questionable quality distinction comparing biomass ashes and municipal solid waste incineration ashes while applying them in civil engineering – for the application of biomass ashes in road construction the highest allowed heavy metal concentrations in municipal solid waste incineration ashes are many times higher as they are based on leaching concentrations while those set for biomass ashes are based on total concentrations.

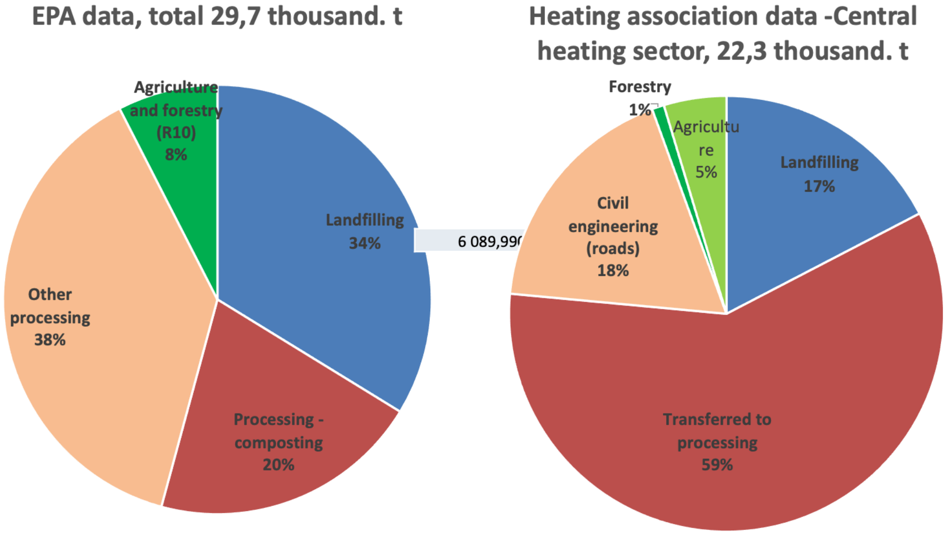
Limits for application rates (t/ha) of biomass ashes defined in national regulation lack scientific background as defined in Chapter 5 "Nutrient recycling" and make liming capabilities pf biomass ashes very limited, especially when it is allowed to apply biomass ashes at very limited rates only once in three years. It would be reasonable to set biomass ashes application limits based on two factors: phosphorus inputs (40 kg/ha/year) and liming needs based on pH of soil and liming capabilities of biomass ashes based on calcium carbon equivalence (CCE) of biomass ashes.

There are other excessive and questionable requirements which make application of biomass ashes in agriculture and forestry less attractive and economically inefficient for land-owners.

10 Continuation

In 2021 in Lithuania municipal and industrial boilers produced 29,7 thousand t of biomass ashes (Lithuanian environmental protection agency data) - 22,3 thousand t of which were produced in central heating sector (Lithuanian heating association data). From 2024 this volume of biomass ashes will be increased by 30% (9 thousand t) which will be supplied by new Vilnius biomass co-generation power plant.

Picture 10-1. Uses of biomass ashes in Lithuania in 2021



Biomass plantations established and mobilized during and after NutriBiomass4LIFE project have a potential to use up to 2-3 thousand t of biomass ashes each year. In case national regulation would be adjusted and biomass ashes would be allowed to use each year – biomass ashes application potential may increase 3 times -- to 6-9 thousand t/year.

Although due to low nitrogen content there is no fast benefit on biomass plantation yield improvement while using biomass ashes, nevertheless it may have long term effect on stabilizing pH of soil while growing trees.

We will continue biomass ashes recycling activities to provide these services to biomass boilers. First of all, we are considering continuing working with PE boiler in Vilnius to recycle up to 1 thousand to biomass ashes in NutriBiomass4LIFE plantations. We discussed possibility to recycle biomass ashes from the new Vilnius biomass co-generation power plant, but quality of ashes and logistics have to be considered after cogeneration plant will be operational.

11 Conclusions

Over 4 years of implementation of the project 2169 t of biomass ashes were recycled in NutriBiomass4LIFE biomass plantations, i.e. NutriBiomass4LIFE project target (1500 t) was implemented by 145%.

The key lessons we learned from biomass ashes recycling during implementation of NutriBiomass4LIFE project:

- **Return of biomass ashes to the soil is the most sustainable utilization of biomass ashes as minerals in biomass ashes which were extracted by trees from the soil are returned back to the soil.**
- The quality of biomass ashes produced in Lithuania is sufficient to ensure biomass ashes usage in circular way – have rich concentrations of calcium (Ca), potassium (K) and phosphorus (P), and low concentrations of contaminants.

- Soils in Lithuania, especially in ANC regions, have a tendency to acidify over time, therefore biomass ashes can be valuable source for stabilizing of pH of soils planted with trees, where other soil liming options are not considered.
- Biomass ashes have slow effect on biomass yield improvement due to very low nitrogen concentrations, therefore the best effect can be achieved while mixing biomass ashes and municipal waste-water treatment sludge for application in biomass plantations as both types of nutrient rich waste can complement each other.
- Lithuania has old and excessively stringent regulation on biomass ashes application on land, that limits possibilities for biomass ashes recycling. It would be reasonable to adjust it based on latest EU regulation on fertilizing products and scientific knowledge.
- There is good potential to continue and expand biomass ashes recycling activities at NutriBiomass4LIFE plantations.