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 plantations establishment for Nutribiomass4LIFE circular economy demonstration model report

WEB Report prepared by

UAB "Pageldynių plantacija"

September 2023

Preface

The purpose of this document is to provide insights on biomass plantations establishment for circular economy demonstration model action (B1) during implementation of the project NutriBiomass4LIFE. During implementation of the NutriBiomass4LIFE project total 902 ha of poplar plantations were established for the development of circular economy model to ensure recycling of dry sewage sludge digestate of Vilnius city. During the project implementation period, due to superior poplar CO_2 sequestration capacities 902 ha of newly planted poplar plantations already generated negative 19963 tCO_2 footprint. Additionally, older 1516 ha of older biomass plantations included in NutriBiomass4LIFE CE model generated negative 81407 tCO_2 footprint.

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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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 CO_2 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.

III. 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
AGB	Above ground biomass
ANC	areas facing significant natural constraints
BGB	Bellow ground biomass
CE	Circular economy
CO_2	Carbon dioxide
C_{org}	Organic carbon
CRCF	Carbon Removal Certification Framework
dmt	Dry matter ton (t)
DMWTSD	Dried granulated municipal waste-water treatment sludge digestate
EU	European Union
FSC	Forest Stewardship Council®
g	gram, 1 kg = 1000 g
kg	kilogram, 1 t = 1000 kg
ha	hectare, 1 ha = 1000 square meters
K	Potassium, total
km	kilometre, 1 km = 1000 m
l	liter, 1000 l = 1 cub. m
LAND 20-2005	"Rules of waste-water treatment sludge usage in fertilization and land reclamation LAND 20-2005" issued by the Minister of environment of the Republic of Lithuania
LVL	laminated veneer lumber
MAI	Mean annual increment
MWTS	municipal waste-water treatment sludge
N	Nitrogen, total
NPV	Net present value
P	Phosphorus, total
PP	UAB "Pageldyniu plantacija"
r. or reg.	administrative district
sen.	regional units of administrative district
SLU	Swedish university of agricultural sciences
SOC	Soil organic carbon
SRC	Short rotation coppice
t	metric ton, 1 t = 1000 kg
VV	UAB "Vilniaus vandenys", Vilnius city municipal water supply and sewage water treatment company

Introduction

1.1 Purpose and Aim

The purpose of this document is to reveal the results of biomass plantation establishment for CE model (B2) during implementation of the project NutriBiomass4LIFE.

1.2 Structure

The document is divided into four main chapters:

- Chapter 1 “Multipurpose biomass plantations” describes multiple roles of poplar plantations.
- Chapter 2 “Biomass plantation establishment” discloses locations, previous land uses, soil types and poplar clones used in newly established poplar plantations.
- Chapter 3 “Poplar plantation establishment and management technology” discusses during the project used poplar plantation establishment and management technologies.
- Chapter 4 “Economics of poplar plantation establishment” discloses costs, revenue sources and financial results costs of poplar plantation establishment.
- Chapter 5 “Carbon footprint” discloses CO_2 footprint of poplar plantation establishment during NutriBiomass4LIFE project.
- Chapter 6 “Policy” discusses policy and national legislation issues related to poplar plantation establishment.
- Chapter 7 “Continuation” discusses poplar plantation establishment replication and transfer plans.
- Chapter “Conclusions” provides key finding from poplar plantation establishment action of Nutribiomass4LIFE project.

1 Multipurpose biomass plantations

During implementation of NutriBiomass4LIFE project about 1,5 million poplar trees were planted on 901,7 ha of agricultural land to create circular economy model for dry sewage sludge digestate recycling in biomass plantations.

Established poplar plantations on agricultural land deliver multiple purposes:

- New poplar plantations serve as a key final 'infrastructure" for dry sewage sludge digestate final management – they will serve to provide 1/3 of total VV sewage sludge recycling needs.
- Establishing poplar plantations – planting of trees on agricultural land - is the most powerful carbon removal tool among agricultural activities – they can remove and permanently store over 250-300 tCO_2/ha.
- Poplar plantations established on marginal lands help to diversify and increase farmers' revenues.
- Established poplar plantations allow to decrease resource pressure on natural forests as serve as a significant roundwood supply source for industry and for local district heating and power production – the targeted biomass volume – 600 cub m/ha per one 20-year rotation.
- Although considered monoculture, establishment of poplar plantations contribute towards biodiversity increase, especially comparing to croplands; poplar plantations grown in Lithuania have much more biodiversity than grasslands as poplar plantations have constant grass cover and serve as a shelter for insects, birds, wild animals and cattle during hot summers.
- Established poplar plantations contribute towards soil erosion mitigation.
- Established poplar plantations contribute towards decrease of temperature during hot summers, especially on micro level.
- Established poplar plantations contribute towards cleaner waters as absorb excessive nutrients from agricultural activities.
- Established poplar plantations contribute towards cleaner air as absorb contaminants and heavy particles from air.

Aligning with EU policies (cascading use of wood, climate mitigation) it is worth to consider changes in strategy regarding rotation of biomass plantations. Initially, we were considering growing poplar plantations for 10–12-year rotation. The changing policies and changing markets are motivating to search for new biomass plantations growth models, which are more beneficial both for land-owners and the society.

We think that longer rotations (20 years) of biomass plantations can deliver more diverse benefits over short rotations. 20-year rotation poplar plantations can provide substantially higher value carbon removal services – removing appr. 250 tCO_2/ha (20-year rotation) over 90 tCO_2/ha (10 year rotation).

Additionally, switching to 20-year rotation allows to deliver poplar biomass (roundwood) not only to energy sector but to industry, so reducing pressure on natural forests. We approached several big wood industry players, which tested poplar wood in their production processes and will be glad to use it in future as raw material from NutriBiomass4LIFE plantations will be available.

Potential buyers for poplar roundwood will be:

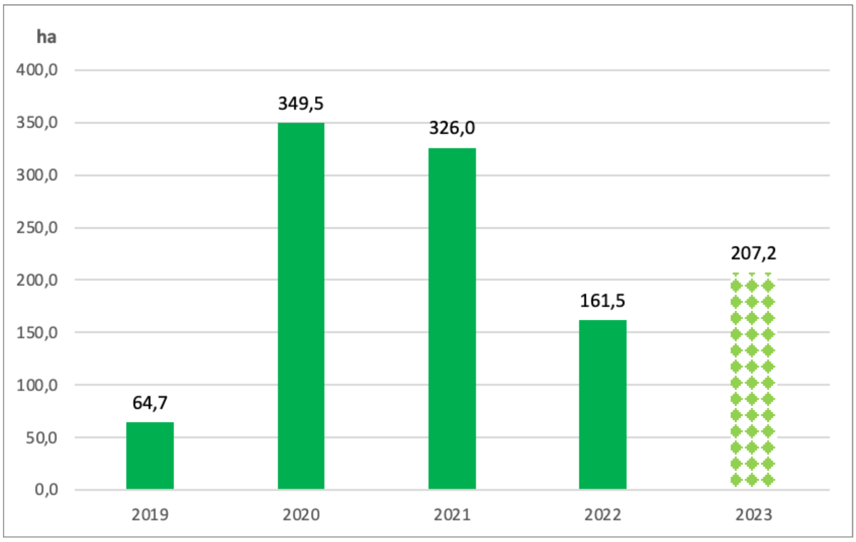
- IKEA plant at Kazlu Ruda, which produces particleboard for furniture industry;
- New Homanit panel mill near Vilnius, which starts MDF and HDF production for furniture and construction industries at the beginning of 2024;
- Sodra Morrum pulp mill (South of Sweden), which produces textile fiber – poplars are perfect material for textile fiber production;
- VMG group – bended plywood furniture production mill near Klaipeda and new LVL mill in Akmene. The company expresses interest to use poplars for bended plywood furniture production, while poplar veneer usage for LVL production has to be tested.
- Plywood producer – Likmere mill in Ukmerge – currently veneer from poplars is not produced at Likmere mill, as there is huge demand for birch plywood but in future this may change when raw material will be available at sufficient quantities.

2 Biomass plantation establishment

During 2019-2022, 901,7 ha of poplar plantations were established on newly mobilized agricultural land to be included in NutriBiomass4LIFE CE model. 901,7 ha of NutriBiomass4LIFE poplar plantations were established on 197 new land plots with combined 1228 ha area, meaning that the average poplar established land area was 4,58 ha. The largest land plot for poplar plantation establishment was 92,41 ha on which 79,7 ha of poplars were established in Moletai region. The efficient poplar establishment area totaled 73,4% of overall land plot area. This poplar not used land area was utilized to set aside for environmental purposes while certifying poplar plantations for sustainable forest management (FSC) – to maintain original land purpose and biodiversity, which prevailed before establishment of poplar plantations.

In the Picture 2-1. annual NutriBiomass4LIFE poplar planted areas is presented for 2019-2022. Additionally, in 2023, 207 ha of new poplar plantations were established as a project replication and transfer action and more widely presented in the chapter “Continuation”.

Picture 2-1 NutriBiomass4LIFE biomass plantation establishment area, ha

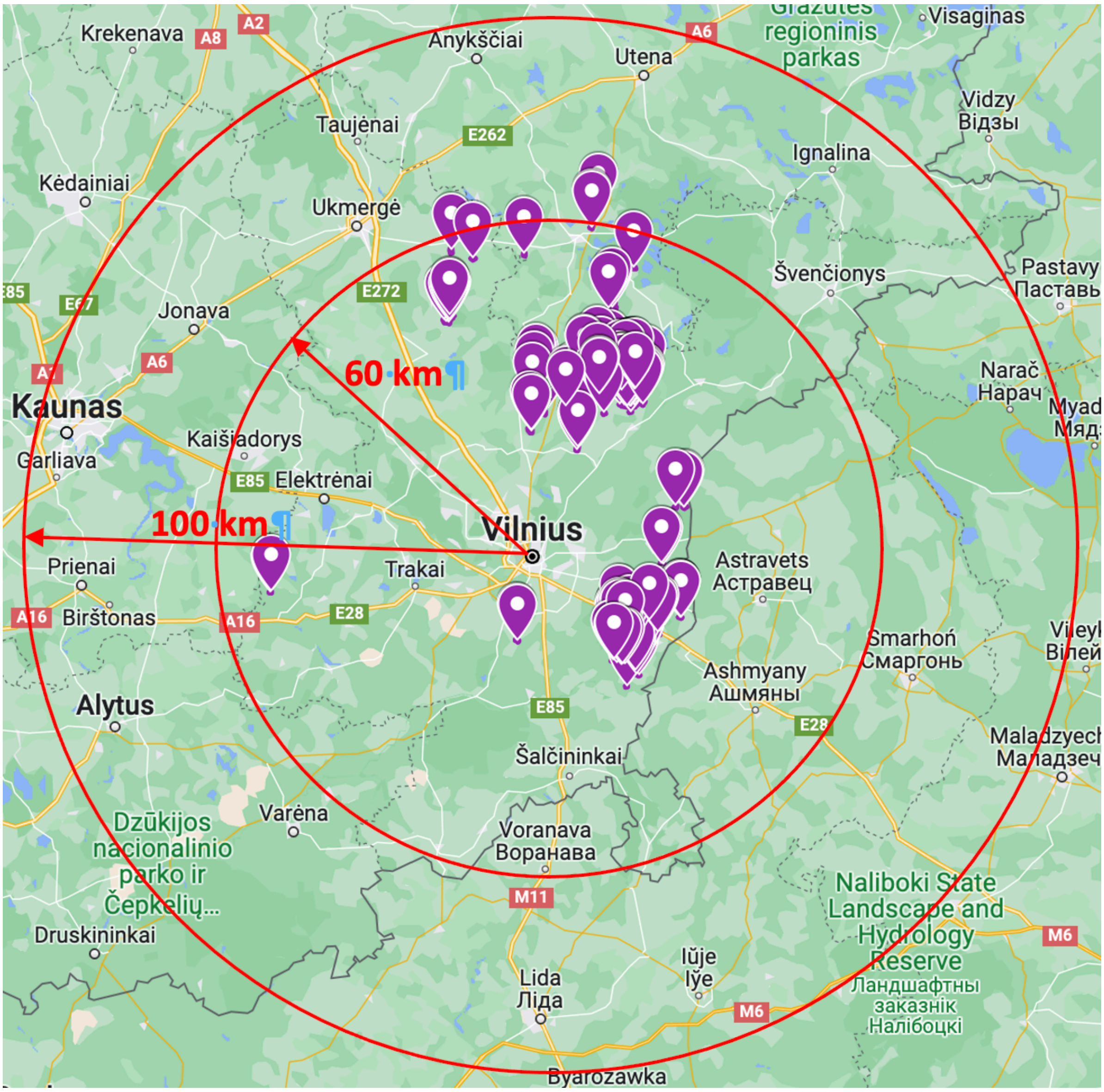


All the NutriBiomass4LIFE lands for biomass plantation establishment were successfully mobilized within 60 km radius from Vilnius city. The average distance (radius) of all established Nutribiomass4LIFE plantations is 37 km from Vilnius.

2.1 Locations of biomass plantations

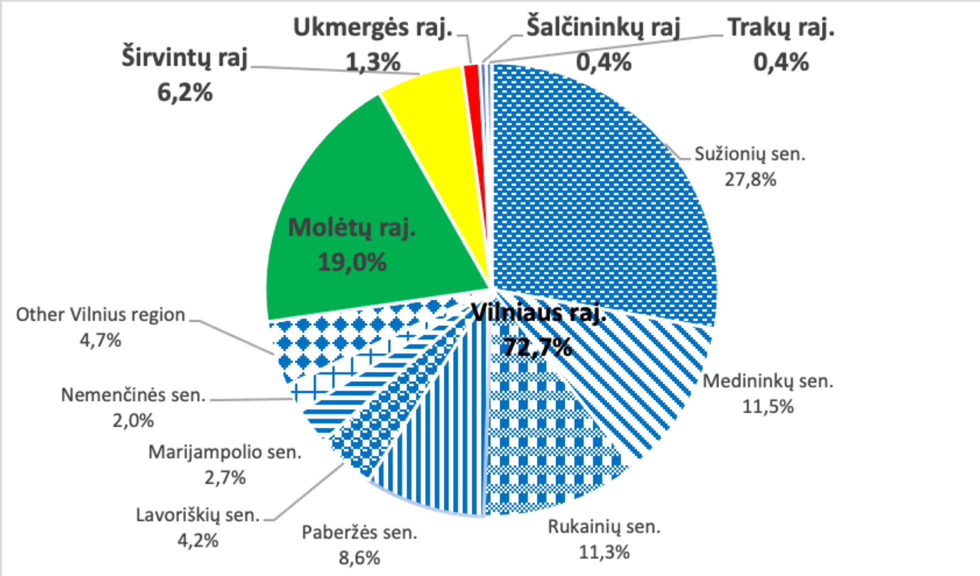
As it can be seen from Picture 2-2, NutriBiomass4LIFE plantations were established in certain clusters – at a close proximity from each other, which provides efficiency in terms of management and nutrient recycling. Nutribiomass4LIFE plantations were mainly established in the North of Vilnius and the South-East of Vilnius directions, where soils, more suitable for poplar growth, are located (South and Western direction of Vilnius are mainly dominated by dry sandy soils).

Picture 2-2. Locations of NutriBiomass4LIFE plantations, established in 2019-2022



The majority of Nutribiomass4LIFE poplar plantations were established in Vilnius district (72,7%), Molėtai district (19%) and Širvintai district (6,2%). In Vilnius district the leading administrative units for the establishment were Sužionių sen. (28%), Medininkų sen. (12%) , Rukainių sen. (11%) and Paberžės sen. (9%).

Picture 2-3. Nutibiomass4LIFE biomass plantation establishment by districts

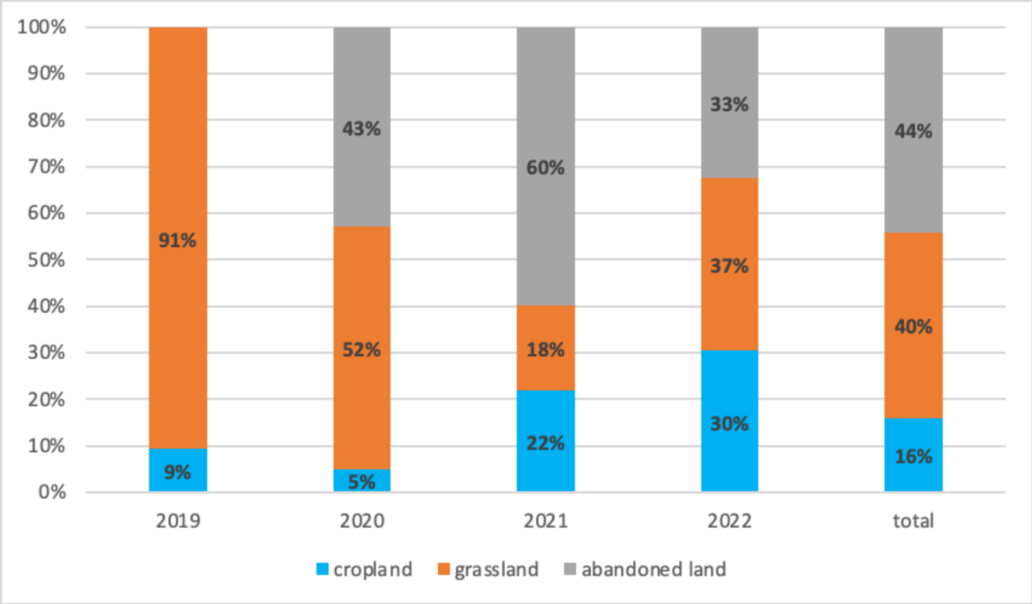


2.2 Previous use of land of established biomass plantations

NutriBiomass4LIFE biomass plantations were established in the EU defined areas facing significant natural constraints (significant ANC), where traditional agricultural activities have been limited due to low fertility of land and other natural constraints.

Over the project period (2019-2022) the majority of mobilized agricultural lands can be characterized as abandoned agricultural lands (44%) and grasslands (40%). Croplands, planted with NutriBiomass4LIFE poplar plantations, contributed only to 16% of total land area mobilized.

Picture 2-4. Nutibiomass4LIFE biomass plantation establishment by previous land use (%)



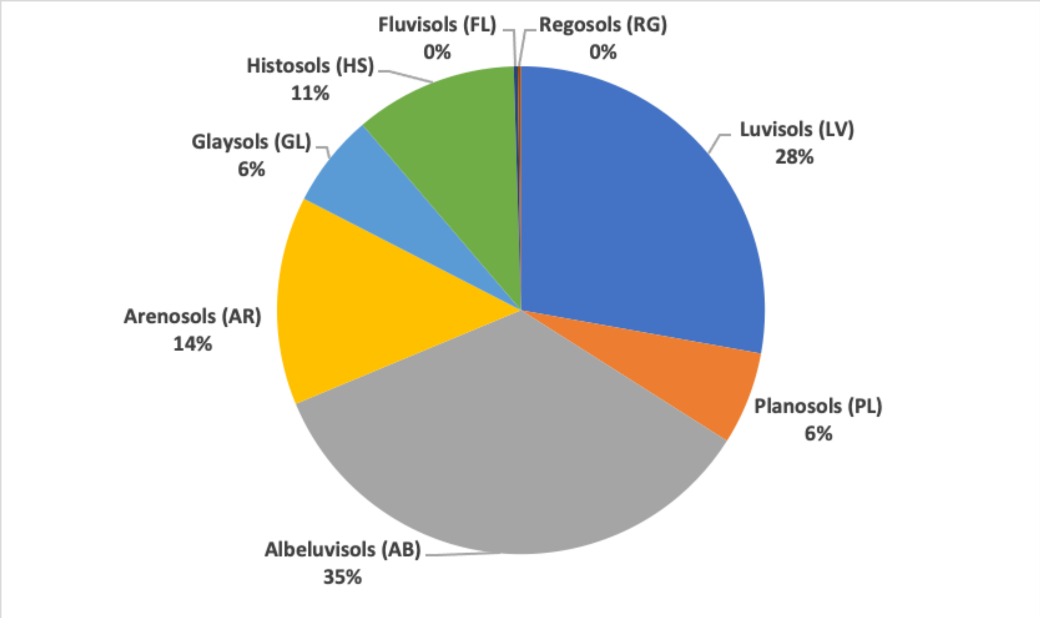
2.3 Soil types of established biomass plantations

Soil types of NutriBiomass4LIFE established poplar plantations are very much diverse – especially on larger sites we have different soil types present.

The prevailing soil types of established NutriBiomass4LIFE poplar plantation included Albeluvisols (AB) – 35 %, and Luvisols (LV) – 28%. Luvisols (LV) are the most fertile soil type in the ANC areas and are followed by Albeluvisols (AB).

Poplar establishment on organic (Histosols (HS)) are risky due to high nutrient imbalance and increased autumn frost risks. Dry sandy soils (Arenosols (AS)) also became riskier for poplar establishment and growth, because increasing repetition of big droughts during vegetation season significantly influenced poplar growth, especially in the early stages while developing root systems. In the portfolio of NutrioBiomass4LIFE established poplar plantation, Arenosols (AS) total 14% and Histosols total 11%.

Picture 2-5. NutriBiomass4LIFE biomass plantations establishment by soil type



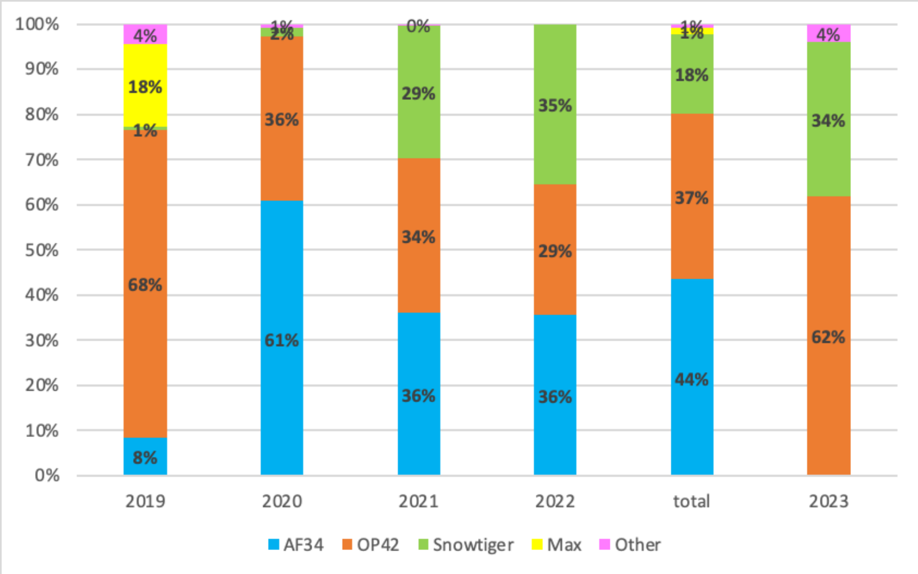
2.4 Biomass plantations by poplar clones

Sufficient supply of Lithuanian climate adapted poplar clones was one of the limiting factors , especially at the beginning of NutriBiomass4LIFE project. Several selected commercial varieties (clones) of poplars were planted in Lithuania during implementation of the project:

- Italian AF34 clones had the highest share of 44% among total poplars established during NutriBiomass4LIFE, as AF clones are the most widely used poplar clones in Europe. Initial shortage of other Lithuanian climate adapted poplar clones contributed to the high share of AF34 clone, but later during implementation of the project the usage share of AF34 clone decreased
- OP42 clone had the second highest share of 38% among total poplars established during NutriBiomass4LIFE as OP42 is the most widely used poplar clone in the Baltic Sea region. Its share grew in NutriBiomass4LIFE portfolio, with wider availability over project implementation.
- Snowtiger clonal mix had the third share of 18% among total poplars established during NutriBiomass4LIFE. Share of Snowtigers increased during last two years of the project as supply with these novel Nordic climate adapted poplar clones increased.
- Other clones constituted up to 2 % of total – these were German, Belgium and Swedish forest research institute clones.

Post project poplar supplies (2023) are already dominated by OP42 and Snowtiger mix as these clones are most adapted to Lithuanian climate conditions.

Picture 2-6. NutriBiomass4LIFE biomass plantations establishment by poplar clones



2.4.1 Italian AF34 poplar clones

Italian AF clones are the most widespread in Europe. AF clones, predominantly *Populus deltoides × P. nigra* hybrids, are very productive in warmer climates because they have a much longer vegetation season, which can last until mid-October. Their vegetation starts when the climate and soil warm up, so in Lithuania, due to the cold spring, their vegetation can start very late - sometimes even in the beginning of May.

For the NutriBiomass4LIFE project AF34 (which is a close relative of the AF7 clone) was selected. AF34 is a *P. deltoides* (♀) × *P. nigra* (♂) hybrid (*P. Canadensis*) bred by the Italian Alasia family 20 years ago. AF34 is mainly grown in Southern Europe, and due to its straightness is grown for a longer rotation (15 years) for the plywood industry. In Lithuania, it was selected for its fast growth and relatively good resistance to cold during wintertime. The bark of AF34 is completely resistant to severe frosts, but due to its long vegetation, one-two-year-old trees can be severely damaged by early autumn frosts. In later years of growth, the risk of frost is low. All AF seedlings are grown in Italy from where they are imported.

Picture 2-7. Four-year-old AF34 clones, (planted in 2020, Molėtai reg., PR25)

One more risk, which is associated with AF34 clone and emerged during implementation of NutriBiomass4LIFE project, is susceptibility to bacterial infection (canker) after pruning or damage of stem. This risk emerged after two years after pruning of some AF34 plantations with the purpose to grow higher quality wood. This risk has to be observed and assessed over longer term. Therefore, pruning of AF34 clones is postponed.

2.4.2 OP42 clones

The OP42 clone was bred by Oxford Paper Company, Pennsylvania (US) more than 100 years ago by crossing *Populus maximowiczii* (♀) × *P. trichocarpa* (♂) elite trees.

Today it is the most widely used poplar clone in the Baltic Sea region, while in the US this clone is quite rare because many new, more productive clones have been bred later. OP42 clones were bred for longer rotation, cellulose production. Because of its branching, it is less suitable for veneer production.

OP42 clones are characterized by a later and longer vegetation season (comparing to Snowtigers), which can cause younger trees to freeze and become crooked in the fall. After 4-5 years, when the trees reach a height of 8-10 meters, the probability of frosts is low.

It is a reliable, time-tested poplar clone, suitable for Lithuania, but due to early autumn frost damage, planting in lowlands and peaty soils should be avoided. Since the OP42 clones are old, they are not licensed.

Picture 2-8. Four-year-old OP42 clones, (planted in 2020, Vilnius reg., PR20.1)

2.4.3 Snowtiger clones

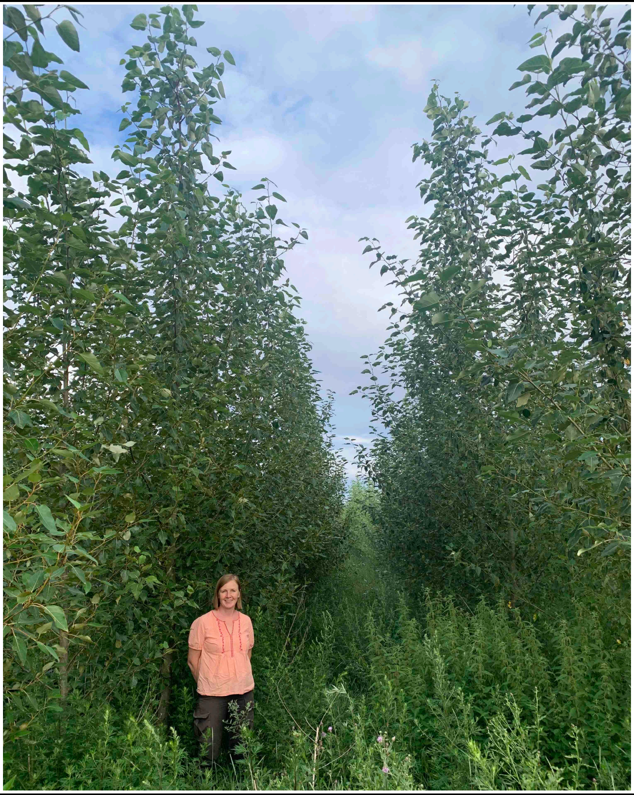
Snowtiger clones are among the most productive in Lithuanian conditions, suitable for all types of soil. The Snowtiger poplar clonal trials were established in Lithuania in 2014 under EUROSTARS E! 8443 project "High productive and climate adapted poplar clones for the energy and forestry sector in Baltic Sea Region".

SnowTiger poplar clonal mixture consists of planting material bred specifically for Northern European climates by crossing North American *Populus P. trichocarpa* (♀) × *P. trichocarpa* (♂) elite trees. The planting material is suitable for the breeding of plantation of highly productive woody biomass used in the energy, pulp and plywood production sectors and for environmental purposes.

The SnowTiger clonal mixture consists of four main clones ST2, ST3, ST4 and ST6. There are also ST10, ST22, ST34 and ST108 clones, but their production volumes are quite limited. All Snowtiger poplar clones are male (♂).

Compared to very popular OP42, Snowtiger clones are straighter, with thin branches, more suitable for plywood production, and more resistant to frost and drought.

Picture 2-9. Four-year-old Snowtiger clones, (planted in 2020, Vilnius reg., PR20.1)



2.4.4 Other clones

During implementation of the project, several other clones were planted for testing purposes. These clones included German, Belgium and Swedish poplar clones.

The German MAX clones (MAX1, MAX2 and MAX3) are *Populus maximowiczii × P. nigra* hybrids, bred exclusively for cultivation in short rotation (up to 5 years) for biomass energy. The German MAX clones are not suitable for growing for longer rotation roundwood due to their crookedness, extensive branching and often broken tops.

The German Matrix (Matrix 24 and Matrix 49) *Populus maximowiczii × P. tricho*carpa hybrids are newer clones compared to the MAX clones and are suitable for growing in a longer rotation for roundwood. Matrix clones are characterized by a longer rotation, so Matrix clones are not suitable for Lithuanian conditions due to the risk of early autumn frosts.

The new German clones FastWood1 and FastWood2 (*Populus maximowiczii × P. trichocarpa* hybrids) have a shorter growing season than the Matrix clones, but are also vulnerable to early autumn frosts.

Various Belgian clones have been tested in Lithuania: Oudenberg and Vestern (*Populus deltoides × P. nigra* hybrids) and new Denker, Skado, Bakan, Balebek (*Populus maximowiczii × P. trichocarpa* hybrids) are risky in Lithuanian conditions due to long vegetation and the risk of early frosts.

The Swedish Forest Research Institute offers a collection of Ekebo poplar clonal mix, the majority of which is clone OP42. Two non-OP42 clones are selected from this collection: SvSFPo6 and SvSFPo4. SvSFPo6 is a *Populus maximowiczii × P. trichocarpa* hybrid, a close relative of OP42. SvSFPo4 is a

Populus *balsamifera × P. trichocarpa* hybrid. SvSFPo6 and SvSFPo4 are suitable for cultivation in Lithuanian conditions and the first tests showed that their productivity is close to OP42.

3 Poplar plantation establishment and management technology

The technology of poplar plantation establishment and management includes:

- Soil preparation
- Planting
- Weed control
- Pruning
- Thinning

3.1 Soil preparation

Soil preparation plays a very important role as root development of poplars requires loose soil and good soil aeration conditions for optimal poplar growth. If there is a compacted pad formed in the soil, it should be broken up with a deep grinder.

Since the poplar seedlings are planted deep enough (60 cm deep), the soil should be plowed accordingly - 35-40 cm deep. Deep plowing is also necessary, because poplar plantations are often established on agricultural soil that have not been actively used for agriculture for a long time, where the soil has been undisturbed and compacted for a long time, and the aeration in the soil is poor.

Such deep plowing is quite expensive and slow - only an average 3 ha can be plowed. The soil can be plowed both in the fall and in the spring before planting of poplars. If soil is plowed in spring, just before poplar establishment, such plowing has initial pre-emerging weed protection, because herbicides are not used for weed control while establishing poplars. In case of plowing of not-used for agriculture land in autumn, disking of weeds before plowing may be needed.

After plowing, before planting the soil is cultivated to flatten the soil.

Picture 3-1. Soil preparation – plowing and cultivation

3.2 Planting

Poplars are planted in spring and may be established till end of June. Planting of poles is possible in late autumn as well, but as vegetation of poplars is long, seedlings for planting may be ready only in November. Planting of poplars in November-December is very problematic due to wet soils.

Planting of long poles is done with special machine, planting long poles 60 cm deep.

2 ha / day of plantations are established using long poles, at 1600 plants /ha density.

Picture 3-2. Planting long poplar poles

3.3 Weed control

Weed control (competing vegetation) is very important to ensure the vitality and rapid growth of planted poplar plantations in the first year, especially during droughts. In the second year, weed control is not compulsory, after poplars reached 1.5-2 m. height in the first year, but is recommended.

Herbicides are not used for weed control in NutriBiomass4LIFE plantations, therefor weed control of planted poplars is carried out in a mechanical way - disking between planted poplar rows. In the first year, if pop

lars are planted early (March-April) and especially if the soil for planting was prepared from the fall, it is recommended to carry out weed control by disking twice a year (e.g. at the end of May and mid-July). It is estimated, weed control by disking can be performed at an area of 6 ha per day.

Picture 3-3. Mechanical weed control – disking

3.4 Pruning

Pruning is necessary if poplars are established by long poles and are grown for higher quality roundwood in longer rotation. Poplars, established with long poles, usually start vegetation from a few buds, so the goal of pruning is to limit the growth of competing shoots, concentrating all the energy of the plant on the leading shoot. Such pruning should be done in the second year when the leading shoot reaches 1-1.5 years. (it is important that deer would not reach the upper bud) and if there is no high risk of browsing by moose. If the risk of moose browsing is high, pruning can be done in the third year.

Pruning of long poles is done in the following way:

- A diagonal cut cuts off the top of a long pole (usually dead) above the leading shoot so that the leading shoot can easily overgrow it to form a straight tree.
- Competing branches below the leading shoot are cut leaving 1/3 of their length (when pruning is carried out in the second year). If competing branches grow from the same bud as the leading shoot, they are removed right next to the tree stem, leaving only the leading shoot.
- When pruning is carried out in the third or fourth year, when trees reached a height of 6 meters or more, competing branches up to 2.5 meters high can be removed right next to the stem.

Picture 3-4. AF34 clone after pruning in the third year (planted in 2020, Molėtai reg., PR25)

The second pruning to form stems for veneer logs is carried out in the seventh-ninth year, that is, after thinning, by removing branches near the stem at a height of up to 8 meters.

3.5 Fertilization

Poplar plantations, which are usually established on low productivity, nutrient deficient soils, can be fertilized with nutrient rich waste – sewage sludge digestate and biomass ashes, to increase biomass yields. Nutrient rich waste – sewage sludge digestate and biomass ashes – can be used for fertilization because poplars can act as phytoremediation crops, which absorb heavy metals and nutrients in more efficient way than agricultural crops. Usage of nutrient rich waste for fertilization usually does not invoke additional costs to landowners. It is estimated that fertilization with sewage sludge may increase biomass yield by 12-20%.

In Lithuania it is allowed to use 11 dmt/ha of sewage sludge and 1-3 t/ha of biomass ashes once in three year for fertilization of biomass plantations.

Picture 3-5. Fertilization of poplar plantations with sewage sludge

3.6 Thinning

NutriBiomass4LIFE plantations, established at 1600 plants/ha density will have to be thinned at 6-9th year of growth.

If plantations are grown for a 20-year rotation to produce high value veneer logs, it is reasonable to have no more than 600 trees in the plantation during the final felling.

Thinning is done by harvesting each the second row of poplars with light excavator ant mounted tree shear to it, which collects and loads harvested trees near remaining rows of poplars. This allows to collect and forward harvested biomass with light forestry trailers. Light machinery is preferably to be used for harvesting and thinning in order to avoid poplar root damage and soil compaction.

Picture 3-6. Thinning at age of 7 years (AF7 clone), Vilnius region.

Poplar biomass harvested during thinning can be used for energy chip production or as roundwood in wood panel production.

Picture 3-7. Poplar thinning biomass

3.7 Sustainable plantation management

In 2023, all NutriBiomass44LIFE plantations were certified for sustainable forest management under Forest Stewardship Council® (FSC®) certification requirements.

From August 3, 2023 all NutriBiomass4LIFE poplar and hybrid aspen plantations are certified under the Scope of group Sertifikuoti miškai VšĮ FSC® Forest Management and Chain of Custody Certificate NC-FM/COC-066941.

NutriBiomass4LIFE poplar and hybrid aspen plantations are sustainably managed, which includes various sustainable forest management provisions, like setting aside at least 10% of certified area for nature conservation purposes, no use of pesticides and chemical fertilizers, etc.

4 Economics of poplar plantation establishment

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

- Land costs
- Soil preparation costs
- Planting costs
- Weed control costs
- Pruning costs
- Thinning costs
- Final harvesting costs
- Biomass sales revenues
- Revenues from CO_2 removal revenues

In this chapter actual current costs are presented which due to high inflation are higher than those planned 5 years ago before implementation of the project and during implementation of the project.

4.1 Land costs

While calculating economics of poplar plantation establishment, land costs have to be taken into account as land availability is one of the key success factors for plantation establishment and the most significant cost item.

Despite investment into poplar plantation establishment are significantly higher comparing to annual conventional agricultural cultivation costs, land costs are even much higher. Land costs may differ, depending on the ownership and possession of the land. In Lithuania, the following land costs may be considered while planning investment in poplar plantation establishment:

- If plantation is established by existing landowner, landowner has to consider alternative usage revenues – lease of the land, other agricultural use (if appropriate) or sale of the land.
- If plantation is established on leased land – land costs may range from 150 eur/ha in ARNC area. Considering long term lease requirement– contracts are usually indexed for inflation. Long term land lease option for plantation establishment is economically more beneficial than investment into land acquisition.
- If investment is made into land for poplar plantation establishment, typically low productivity land in ANC area costs 4000 eur/ha.

4.2 Soil preparation costs

Soil preparation costs include:

- Weed disking before plowing (if required) costs
- Plowing costs
- Cultivation after plowing costs

It is assumed that weed disking before plowing can be performed at 6 ha/day area. Disking before plowing costs are composed of 12 l diesel /h tractor fuel consumption (diesel price @ 1,5 eur/l), plus 150 eur / day / tractor driver wage, 200 eur /day tractor ((lease/maintenance) costs and 20% overhead costs. Total costs for disking before plowing are **100 eur/ha**. Overhead costs include driving to land plot costs, supervision and other overhead costs. If land plots are smaller, then disking costs will be higher, as smaller area will be disked per day. Disking before plowing costs are not included in basic scenario costs calculations as in most cases land preparation is done before planting in spring, therefore disking before plowing is not required.

It is assumed that deep plowing (35-40 cm deep) can be performed at 3 ha/day area. Plowing costs are composed of 12 l diesel /h tractor fuel consumption (diesel price @ 1,5 eur/l), plus 150 eur / day / tractor driver wage, 200 eur /day tractor ((lease/maintenance) costs and 20% overhead costs. Total costs for deep plowing are **190 eur/ha**.

It is assumed that cultivation after plowing can be performed at 6 ha/day area. Cultivation after plowing costs are composed of 12 l diesel /h tractor fuel consumption (diesel price @ 1,5 eur/l), plus 150 eur / day / tractor driver wage, 200 eur /day tractor ((lease/maintenance) costs and 20% overhead costs. Total costs for cultivation after plowing are **100 eur/ha**.

Total soil preparation costs (not including disking before plowing) for poplar planting are **300 eur/ha**.

4.3 Planting costs

Planting costs are composed of seedling costs and actual planting costs.

For poplar plantation establishment in Lithuania, it is recommended to use OP42 and Snowtiger poplar clones. At the beginning the growth of OP42 and Snowtiger clones is slower than AF34 but taking longer rotation (20 years) OP42 and Snowtiger are less risky and biomass yield is compatible to AF34.

It is recommended to plant two-year-old OP42 and Snowtiger long poles with 5-10 cm one year-old shoot on top with one or two fresh buds. Such long poles are more vital and drought resistant, but their production is more expensive, as two-year-old poles have to be cleaned from small branches during pole for seedling preparation. Therefore, costs of such poles are 1,1 eur/unit. Taking into account, that planting density of poplars is 1600 plants/ha, **total plant costs are 1760 eur/ha.**

It is assumed that long pole planting with special machine can be performed at 2 ha/day area. Planting costs are composed of 11 l diesel /h tractor fuel consumption (diesel price @ 1,5 eur/l), plus 150 eur / day / tractor driver wage, 200 eur /day tractor ((lease/maintenance) costs, plus two planting workers each @ 120 eur/day and 20% overhead costs. Total costs for planting are **440 eur/ha**.

Total poplar plantation establishment/planting (including seedling and planting) costs are **2200 eur/ha.**

4.4 Weed control costs

Herbicides are not used for weed control in NutriBiomass4LIFE plantations. Weed control of planted poplars is carried out in a mechanical way - disking between planted poplar rows. In the first year, it is recommended to carry out weed control at least one time, while the second time is optional.

It is assumed that weed control (disking) can be performed at 6 ha/day area. Weed control (disking) costs are composed of 12 l diesel /h tractor fuel consumption (diesel price @ 1,5 eur/l), plus 150 eur /

day / tractor driver wage, 200 eur /day tractor ((lease/maintenance) costs and 20% overhead costs. Total one-time costs for weed control (disking) are **100 eur/ha**.

Overall first year poplar plantations establishment (land preparation, seedlings, planting, weed control) costs total 2700 eur /ha.

4.5 Pruning costs

Pruning costs very much depend on the timing (how old are plantations) of pruning:

- When pruning is done at the end of first year of growth or beginning of the second year – pruning costs appr 150 eur/ha – pruning of all 1600 trees/ha.
- When pruning is done at third year of growth or beginning of the fourth year – pruning costs appr 250 eur/ha – but pruning is done only on each the second line, or 800 trees/ha.
- When pruning is done after thinning at year seven to ten – pruning costs appr 600 eur/ha – and pruning is done on 700-800 trees/ha.

4.6 Thinning costs

Thinning costs consist of poplar harvesting and forwarding to the road-side costs. In winter 2022/2023 poplar thinning was performed by the contractor at a price **16 eur/cub m**, which included both harvesting and transportation to the roadside services.

It is calculated that thinning-harvesting can be performed with light excavator ant mounted tree shear at 70 cub m/day harvesting output. Poplar thinning-harvesting costs are composed of 10 l diesel /h of light excavator fuel consumption (diesel price @ 1,5 eur/l), plus 150 eur / day / light excavator driver wage, 200 eur /day light excavator ((lease/maintenance) costs and 20% overhead costs. Total thinning-harvesting costs are **7,7 eur/cub m**.

It is calculated that biomass transportation to the roadside costs are based at 65 cub m/day transportation to the roadside volume. Poplar transportation to the roadside costs are composed of 7 l diesel /h tractor consumption (diesel price @ 1,5 eur/l), plus 150 eur / day / tractor driver wage, 200 eur /day tractor ((lease/maintenance) costs and 20% overhead costs. Total transportation of biomass to road -side costs are **8,3 eur/cub m**.

Total thinning (including forwarding to the roadside) costs are **16 eur/cub m**.

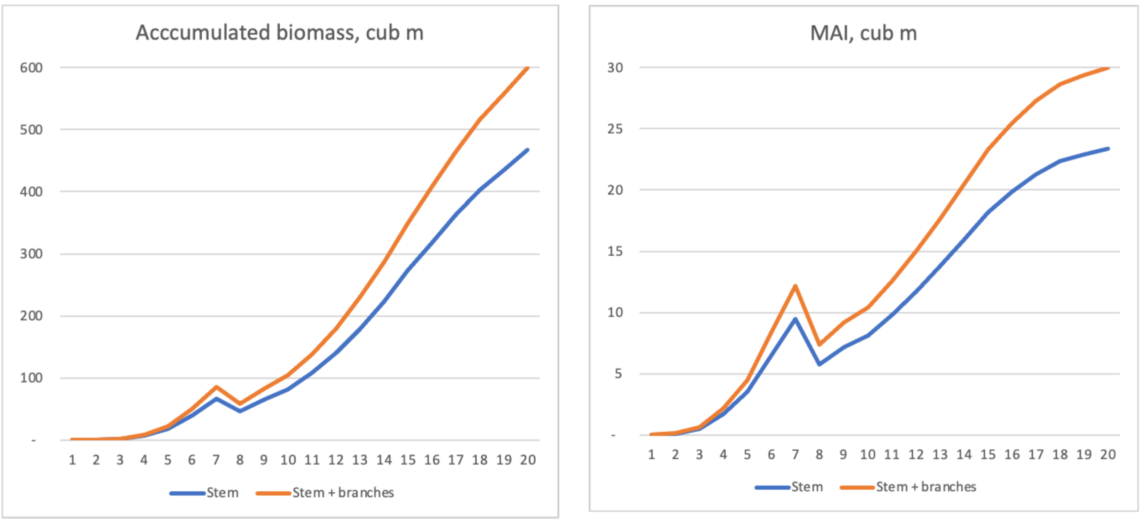
4.7 Final harvesting costs

Final harvesting costs of poplars are lower than of thinning and are compatible to forest clean cutting as traditional forest harvesting machines are used. Final forest clean cutting and transportation to the roadside cost appr. **12 eur/cub m**, taking into account that poplars are more uniform and typically with lower transportation distances to the roadside, it is assumed that final poplar harvesting costs will be **10 eur/cub m.**

4.8 Revenues from biomass sales

Biomass yield is based on the poplar yield model developed by SLU, for 20-year-old poplars (OP42 clone), planted in Southern Sweden. This model assumes poplar yield unfertilized. According to initial Lithuanian data (4-year-old) under Lithuanian conditions poplars grow faster, but we lack long term data for the model. It is assumed that unfertilized poplar biomass will reach 31 cub m MAI in 20 year and will accumulate 650 cub. m. in 20 years (including 50 cub m thinning harvesting).

Picture 4-1. Poplar yield (unfertilized) curve



The prices of wood experienced significant fluctuations over recent years. Business model of poplars are based on current wood prices and expected mix of output:

- 60 % of roundwood will be sold as veneer logs
- 40% roundwood will be sold as pulpwood and sawlogs
- Branches and tops will consist 28,2% of roundwood and will be sold as energy wood

4.9 Revenues from CO_2 removal

Poplar plantations are the most efficient and powerful carbon removal tool in agriculture, when calculating carbon removals. Poplar growing on agricultural land as CO_2 removal activities may come to assist businesses to achieve their carbon neutrality goals, especially related to their scope three emissions, which contribute to 25% of total global CO_2 emissions.

Today exist several global possibilities to benefit from carbon removal activities and issue of carbon credits, associated with afforestation, including establishment of longer-term rotation poplar plantations. The most globally recognized and reliable carbon removal certification schemes include VERRA, Gold Standard, American Carbon Registry, Climate Action Reserve and Cercarbono.

In 2023 EU Commission came with Carbon Removal Certification Framework (CRCF) proposal, which targets to regulate carbon removal activities on the EU level and potentially open possibilities to businesses/farmers/forest owners to cash out from carbon removal activities. Although CRCF include carbon farming activities, still it is not yet clear whether when and how it will be engaged and how tree growers could benefit that.

Nevertheless, today poplar plantation growers may benefit from global carbon removal practices by joining VERRA or Gold Standard certification schemes under the following conditions:

- Poplars are newly established and grown for rotations not shorter than 20 years.

- At least two rotations of poplars have to be grown – meaning that total tree growth duration on agricultural land should be not shorter than 40 years.
- 10% of generated carbon credits are transferred to intermediary, which develops certified carbon credit project and covers all costs for project development and carbon credit validation – meaning landowner, which establishes poplars, does not need to incur any upfront project development and other carbon issue costs.
- Poplar plantations over the first 13 years can generate to landowner 210 carbon credits (after buffer and intermediaries commissions) without counting SOC increase.
- The price for carbon removal is assumed at 30 eur/t CO_2 and later is expected to increase.

It is estimated that the Net present value (discounted @9,5%) of CO_2 removals due to poplar plantation establishment (not fertilized) is **2901 Eur/ha**, therefore Carbon Credits can be a sound financial incentive to promote establishment of poplars. Revenues from carbon removal (carbon credits) can generate return to compensate establishment costs, but will not generate return on land investment, which can be compensated from wood sales at final felling (at the end of 20 year rotation).

Table 4-1. Calculation of NPV of revenues from CO_2 removals from establishment of poplar plantations

	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10	year 11	year 12	year 13
Accumulated CO_2 removals, not fertilized, tCO_2/ha	0	0	1,6	8,8	24,5	48,9	80,1	116,3	155,4	196,0	224,1	252,0	262,0
Accumulated deducted buffer (10%) and intermediar commissions (10%)	0,0	0,0	-0,3	-1,8	-4,9	-9,8	-16,0	-23,3	-31,1	-39,2	-44,8	-50,4	-52,4
Accumulated land owner's CO_2 removals (Carbon Credits), tCO_2/ha	0	0	1,3	7	19,6	39,1	64,1	93	124,3	156,8	179,3	201,6	209,6
Annual CO_2 removals (Carbon Credits), tCO_2/ha	0	0	1,3	5,7	12,6	19,5	25	28,9	31,3	32,5	22,5	22,3	8
Annual revenues from CO_2 removals, EUR/ha	**0**	**0**	**39**	**171**	**378**	**585**	**750**	**867**	**939**	**975**	**675**	**669**	**240**
NPV, EUR/ha (@ 9,5%)	2 901												

4.10 Financial result of biomass plantations establishment activity

Proposed poplar plantation establishment for CE model has a long economic horizon (20-year rotation). The absolute majority of investment (land and poplar plantations establishment) typically are incurred at the beginning of the cycle, while major revenues from biomass sales can be expected at the end of the cycle - after 20 years only. Additional revenues can be expected from carbon removal – sales of carbon credits, which in 13 years can compensate poplar plantations establishment costs.

Overall costs for establishment of poplar plantation is about 2700 eur/ha. Much higher investment are related to the land itself, e.g. in Lithuania's case – 4000 eur/ha. Financial calculations show that poplar plantation establishment business case can generate about **9,3% of internal rate of return (IRR)** considering land investment as well. Additional revenues from CO_2 removal (sale of carbon credits) can improve profitability of poplar growing business case to achieve **12,3 % internal rate of return (IRR).**

Financial calculations show that investment into poplar plantation establishment and carbon removal can generate sound return to investors. Despite high IRR, such an investment is not highly attractive by farmers as poplar establishment cannot ensure stable annual revenues and the major revenues still are expected in 20 years. Nevertheless, poplar plantation establishment investment may be very attractive investment opportunity for long term institutional investment as this offer green and carbon removal investment. Such an investment is also may be interesting to landowners (especially younger ones who inherited land), who live in cities and agriculture is not their major activity, but who are interested in making climate beneficial investment. Such an investment is in particular interesting for landowners who already own land and doe not use it or get insignificant revenues from land lease. But the limiting factor for such investors may be significant investment of 2700 eur/ha in poplar plantation establishment as banks in Lithuania still do not provide long term funding for carbon removal activities, such as establishment of trees.

5 Carbon footprint

Carbon footprint of biomass plantation establishment consists of several key inputs:

- Land preparation
- Planting
- Weed control
- Transportation and supervision
- Biomass yield (negative emissions)
- Soil organic carbon improvement (negative emissions)

5.1 Carbon footprint from land preparation

Carbon footprint from land preparation (plowing and cultivation) depends on the diesel fuel consumed by agricultural machinery and is based on the following assumptions:

- Plowing (35-40 cm deep) was performed at average 3 ha/day area.
- Cultivation after plowing was performed at average 6 ha/day area.
- Diesel fuel consumption was 12-14 l/h per one machine (tractor).

It is estimated that carbon footprint of land preparation for establishment of biomass plantations during NutriBiomass4LIFE project implementation **equaled to 123,8 tCO_2.**

Table 5-1. Nutribiomass4LIFE carbon footprint from land preparation activities

	diesel l/h	ha	diesel, l	CO_2 footprint, t CO_2
1l diesel CO_2 emission factor, kg CO_2 /l	2,68			
Plowing, total	**34,5**	**901,7**	**31130**	**83,4**
2018	37,5	16,0	600	1,6
2019	37,5	226,9	8509	22,8
2020	36,0	235,0	8468	22,7
2021	32,0	262,3	8394	22,5
2022	31,9	161,5	5158	13,8
Cultivation, total	**17,2**	**876,0**	**15075**	**40,4**
2019	18,7	102	1908	5,1
2020	18,2	377	6867	18,4
2021	15,9	264	4201	11,3
2022	15,8	133	2099	5,6
total land preparation			**46204**	**123,8**

5.2 Carbon footprint from planting

Carbon footprint from poplar plantation planting depends on the diesel fuel consumed by agricultural machinery and is based on the following assumptions:

- planting was performed at average 2 ha/day area.
- Diesel fuel consumption was 11-12 l/h per one machine (tractor).

It is estimated that carbon footprint from poplar plantation planting during NutriBiomass4LIFE project implementation **equaled to 111,7 tCO_2.**

Table 5-2. Nutribiomass4LIFE carbon footprint from poplar plantation planting

	diesel l/h	ha	diesel, l	CO_2 footprint, t CO_2
1l diesel CO_2 emission factor, kg CO_2 /l	2,68			
2019	48,0	64,7	3105	8,3
2020	49,4	349,5	17275	46,3
2021	43,5	326,0	14194	38,0
2022	43,9	161,5	7093	19,0
Planting, total	**46,2**	**901,7**	**41667**	**111,7**

5.3 Carbon footprint from weed control

Carbon footprint from poplar plantation weed control depends on the diesel fuel consumed by agricultural machinery and is based on the following assumptions:

- Weed control in the first year was performed at average 6 ha/day area.
- Diesel fuel consumption was 12 l/h per one machine (tractor).

It is estimated that carbon footprint from poplar plantation weed control during NutriBiomass4LIFE project implementation **equaled to 38,7 tCO_2.**

Table 5-3. Nutribiomass4LIFE carbon footprint from poplar plantation weed control

	diesel l/h	ha	diesel, l	CO_2 footprint, t CO_2
1l diesel CO_2 emission factor, kg CO_2 /l	2,68			
2019	16,0	64,7	1035	2,8
2020	16,0	349,5	5592	15,0
2021	16,0	326,0	5216	14,0
2022	16,0	161,5	2584	6,9
Weed control, total	**16,0**	**901,7**	**14427**	**38,7**

5.4 Carbon footprint from transportation and supervision

Carbon footprint from tractor driver travelling to poplar establishment sites and poplar plantation establishment supervision was calculated based on car fuel consumption, while travelling to poplar plantation establishment sites.

It is estimated that carbon footprint from travelling to poplar establishment sites and poplar plantation establishment supervision during NutriBiomass4LIFE project implementation **equaled to 11,4 tCO_2.**

Table 5-4. Nutribiomass4LIFE carbon footprint from travelling and supervision of poplar plantation establishment

	fuel CO_2 footprint, kg CO_2/l	fuel consumption, l/100km	travel distance, km	CO_2 footprint, t CO_2
Tractor driver travelling with petrol cars	2,3	8	32165	5,9
Tractor driver travelling with diesel cars	2,7	15	12306	5,0
Manager visiting land plots with petrol car	2,3	8	2568	0,5
total			**47039**	**11,4**

5.5 CO_2 sequestration in poplar, established during NutriBiomass4LIFE project, biomass

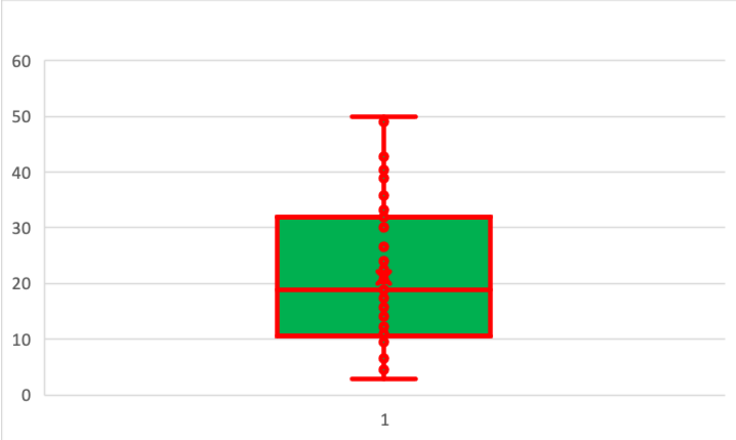
Poplar established on agricultural land and grown for a longer rotation are probably the most efficient CO_2 removal and storage tool in terms of CO_2 removal per ha value. Poplar plantations remove and store the majority of CO_2 in poplar biomass, the yield of which accelerates over the time. As NutriBiomass4LIFE project period covers only initial CO_2 removal and storage in poplar biomass values, it is estimated that during NutriBiomass4LIFE project implementation period only 8% of CO_2 removal and storage in poplar biomass potential was executed.

Biomass yield has a strong negative carbon footprint value, as it is associated with CO_2 removal and storage in biomass increment (sequestration). As presented in the Table 6-5 bellow CO_2 removal is dependent on the following factors:

- Type of biomass crops involved – poplars yield patterns during NutriBiomass4LIFE project. We used biomass yield curves developed by Swedish university of agricultural sciences (SLU)
- Year of establishment – according to the growth curve, older plantations have respectively much higher annual yield increment, therefore, yield increase due to fertilization is also much higher than comparing to young plantations.
- Survival rate – tree survival rate has a direct impact over plantations biomasses yield and CO_2 removal capacities. Survival rates of established NutriBiomass4LIFE plantations is high, though some replanting is taking place because of significant droughts over recent years – it is estimated that about – 7% of pants are being replanted.
- Overall biomass yield – in September-October 2023, four-year-old poplar plantations were measured for biomass yield accumulation. Based on the measurement results and SLU yield model, two and tree year old poplar plantations yields was calculated.
- Dry biomass and CO_2 coefficients – based on coefficients developed during project's C2 action fresh biomass is converted to dry biomass and 0,48 coefficient applied to convert dry biomass to carbon (C); later 3,67 coefficient is applied to convert C to CO_2.

In October 2023 four-year-old NutriBiomass4LIFE poplar plantations have been measured to assess CO_2 removal and storage data in newly established poplar plantations. It was estimated, that newly stablished four-year-old NutriBiomass4LIFE poplar plantations accumulated average stem wood of 21 cub m/ha. Variation in stem wood biomass yield of different sampling plots was significant, and ranged from 4,4 cub. m/ha to 49 cub. m/ha per sample plot at the age of four years (Picture 6-1).

Picture 5-1. Four-year-old NutriBiomass4LIFE poplar stem wood accumulation, cub. m /ha



Based on four-year-old biomass yield and VERRA's Verified Carbon Standard methodology calculations, it is estimated that average accumulated CO_2 removal in four-year-old poplar plantations totaled 24,14 tCO2/ha.

Estimations of carbon footprint from biomass yield accumulation at newly established poplar plantations during implementation of the project NutriBiomass4LIFE, are presented in the Table 6.5 bellow and equaled to **minus 14657 tCO_2.**

Table 5-5. Nutribiomass4LIFE carbon footprint from biomass yield of newly established poplar plantations

NutriBiomass4LIFE poplar establishment	ha	2019	2020	2021	2022	2023	total
CO_2 removals by age t CO_2/ha		-0,33	-2,03	-9,51	-24,14	-43,15	
Poplars established in 2019	64,7	-21	-110	-484	-946	-1230	**-2791**
Poplars established in year 2020	349,5		-114	-596	-2615	-5113	**-8437**
Poplars established in year 2021	326,0			-106	-556	-2439	**-3101**
Poplars established in year 2022	161,5				-53	-275	**-328**
Total CO_2 footprint, tCO_2	**901,7**	**-21**	**-224**	**-1186**	**-4169**	**-9056**	**-14657**

5.6 Soil organic carbon improvement of NutriBiomass4LIFE established plantations

Establishing of poplars, which are being grown at longer term rotations will contribute to soil organic carbon increase due to adding organic carbon to soil through extensive leaf litter, dead wood and root development.

SOC annual change, (t C ha^{-1} year) are calculated according to the following formula:

$$SOC_a = (SOC_{ref} - SOC_{conc.in} \times TS \times SG)/Y, \quad (1)$$

Where:

SOC_a – Annual organic carbon change in soil, t C ha^{-1} year;

SOC_{ref} – Reference carbon stock in soil for the climate and soil combination, 71 t C ha^{-1}; (IPCC 2006, book 4, table 2.3)

$SOC_{conc.in}$ – Initial soil organic carbon concentration, %;

TS – soil density, g cm^{-3} for different types of soils in Lithuania (s – 1,35, ps – 1,40, p-p$_1$ – 1,45,

p_2-m – 1,55, pv – 1,10, d – 0,65–0,95)

SG – humus rich topsoil layer, cm (for mineral soils – 30 cm)

Y – rotation length (20 years)

SOC changes at newly established NutriBiomass4LIFE poplar plantations are calculated only for the mineral soils and separately for croplands and grasslands/abandoned lands. Soil analysis shows, croplands, which were planted with poplars have significantly lower initial SOC concentrations ($SOC_{conc.in}$) comparing to grasslands/abandoned lands – 1,16% vs. 1,34%, therefore croplands have a greater potential to accumulate organic carbon in soil due to land use change to reach reference level of 71 tC/ha (IPCC 2006, book 4, table 2.3).

Negative CO_2 footprint from SOC increase due to land use change during Nutribiomass4LIFE project implementation period is calculated as presented in the Table 6.6 bellow and equals to **minus 5480 tCO_2.**

Table 5-6. Nutribiomass4LIFE carbon footprint from calculated SOC increase due to shift in land use

		established 2019	established 2020	established 2021	established 2022	TOTAL
Initial SOC accumulations on cropland mineral soils, tC/ha	1,16					
Annual SOC accumulations on cropland mineral soils, tC/ha/year	1,11					
Total poplar plantations established on cropland mineral soils, ha		6,00	17,20	71,24	49,21	**143,65**
SOC accumulations on croplands, mineral soils, tC		27	57	158	55	**297**
Initial SOC accumulations on grassland/abandoned mineral soils, tC/ha	1,34					
Annual SOC accumulations on grasslands/abandoned mineral soils, tC/ha/year	0,74					
Total poplar plantations established on grasslands/abandoned, mineral soils, ha		20	312	251	98	**681**
SOC accumulations on grasslands/abandoned, mineral soils, tC		59	692	372	72	**1196**
Total SOC accumulations, tC		86	749	531	127	**1493**
Total CO_2 footprint, tCO_2		**-316**	**-2751**	**-1947**	**-466**	**-5480**

5.7 CO_2 sequestration in older biomass plantations, included in NutriBiomass4LIFE project

Total 1616 ha of older biomass plantations are included in Nutribiomass4LIFE model to ensure 9000 dmt of DMWTSD recycling in biomass plantations each year (at 11 dmt/ha fertilization rate once in three years). These older biomass plantations sequestrate significant volumes of CO_2 in biomass (AGB and BGB), as fast-growing tree CO_2 sequestration capacities increase substantially reaching 8-15 years, comparing to their initial growth.

The older biomass plantations have lower CO_2 sequestration potential over the whole life cycle comparing to the newly established NutriBiomass4LIFE poplar plantations, as older plantations were established with climate riskier and less productive clones and their survival rate is lower. Nevertheless, due to approaching the most productive age, their CO_2 sequestration capacities are getting more significant.

Estimations of carbon footprint from biomass yield at older biomass plantations included in NutriBiomass4lIFE CE model are presented in the table 6-7 bellow and equaled to **minus 70362 tCO_2.** This carbon footprint from biomass yield at older biomass plantations included in NutriBiomass4lIFE CE model does not include carbon footprint from biomass yield improvement in older biomass plantations due to fertilization with dry sewage sludge digestate, that is presented as a separate carbon footprint item in a separate chapter.

Table 5-7. Nutribiomass4LIFE carbon footprint from biomass yield in older biomass plantations

Biomass crops	Planting year	Plantation area, ha	Survival	annual increment, fresh t					
				2019	2020	2021	2022	2023	total
Poplars,	2014	8,37	71%	78	77	83	89	113	**362**
Poplars	2015	393,82	71%	3040	3659	3621	3920	3541	**14741**
Poplars	2016	209,36	80%	1051	1804	2171	2148	2326	**8448**
Hybrid aspen	2011	30,10	78%	237	239	318	349	402	**1308**
Hybrid aspen	2012	256,95	90%	2115	2330	2350	3129	3442	**11251**
Hybrid aspen	2013	156,28	80%	950	1140	1257	1267	1688	**5352**
Hybrid aspen	2014	239,42	70%	878	1282	1539	1695	1709	**6225**
Hybrid aspen	2015	219,92	65%	321	748	1094	1312	1446	**4600**
Willows	2014	51,15	90%	117	196	274	275	348	**1093**
Willows	2015	81,07	90%	186	310	434	437	551	**1732**
Total increment, fresh t		**1642,44**		**8972**	**11785**	**13139**	**14622**	**15566**	**55112**
Total biomass annual increment, fresh t		**1642,44**		**13835**	**18172**	**20260**	**22548**	**24003**	**84983**
Total biomass annual increment, dry t		**1642,44**		**6502**	**8541**	**9522**	**10597**	**11281**	**39942**
Total CO_2 removed, tCO_2		**1642,44**		**-11454**	**-15046**	**-16774**	**-18668**	**-19873**	**-70362**

5.8 Soil organic carbon improvement of older biomass plantations included in CE model

Older biomass plantations, included in NutriBiomass4LIFE CE model contribute with negative CO_2 footprint from SOC increase due to land use change – establishment of biomass crops of agricultural land, which is calculated according to formula (1).

Total 1616 ha of older biomass plantation are included in Nutribiomass4LIFE model to ensure 9000 dmt of DMWTSD recycling in biomass plantations each year. Out of these 1616 ha older plantations, 501 ha were established on organic and mineral-organic soils. SOC changes at older NutriBiomass4LIFE poplar plantations are calculated only for the mineral soils. Soil analysis shows, that mineral soils of older biomass plantations included in Nutribiomass4LIFE CE model had average 1,37% organic carbon concentration ($SOC_{conc.in}$). This is by 10% higher compared to average initial soil organic carbon concentrations before establishment of newly NutriBiomass4LIFE established poplar plantations on grassland and abandoned lands, revealing that biomass plantations tend to accumulate SOC over time.

Negative CO_2 footprint from SOC increase due to land use change in older biomass plantations included in Nutribiomass4LIFE CE model is calculated as presented in the Table 5-8 bellow and equals to **minus 13716 tCO_2.**

Table 5-8. Nutribiomass4LIFE carbon footprint from calculated SOC increase due to shift in land use change in older biomass plantations included in Nutribiomass4LIFE CE model

		2019	2020	2021	2022	2023	TOTAL
Initial SOC accumulations in older biomass plantations, mineral soils, tC/ha	1,37						
Annual SOC accumulations on older biomass plantations, mineral soils, tC/ha/year	0,67						
Total older biomass plantations included in NutriBiomass4LIFE model, ha	1616						
Older biomass plantations included in NutriBiomass4LIFE model, established on organic soils, ha	307						
Older biomass plantations included in NutriBiomass4LIFE model, established on mineral-organic soils, ha	194						
Older biomass plantations established on mineral soils, ha		1115	1115	1115	1115	1115	**1115**
SOC accumulations on grasslands/abandoned, mineral soils, tC		747	747	747	747	747	**3737**
Total CO_2 footprint, tCO_2		**-2743**	**-2743**	**-2743**	**-2743**	**-2743**	**-13716**

5.9 CO_2 emissions due to harvesting older biomass plantations, included in NutriBiomass4LIFE project

According to existing methodologies, CO_2 removed and stored in tree biomass is released when trees are harvested. The same methodology is applied for biomass plantation harvesting for renewable energy production during NutriBiomass4LIFE project implementation. As all biomass crops included in NutriBiomass4LIFE regrow after harvesting, only CO_2 emissions form harvested AGB is included in the calculations of CO_2 emissions.

In total 4332 cub. m (solid) of biomass were harvested during 2022/2023 season to supply district heating system of Vilnius city. 4332 cub. m of poplar wood harvested corresponds **to 2671 tCO_2 emissions** form harvested AGB.

Table 5-9. Nutribiomass4LIFE carbon footprint from biomass for energy harvesting

Address	Land plot Unique No.	Plantation area, ha	Harvesting rate, %	No. of trucks	AGB harvested, cub m	CO_2 footprint, t
TOTAL		**128,94**		**138**	**4332,0**	**2671**

5.10 Carbon footprint balance

Calculated CO_2 footprint balance from NutriBiomass4LIFE CE model biomass plantation establishment action implementation **equaled to minus 19963 tCO_2** and was composed of:

- CO_2 footprint from land preparation for establishment of NutriBiomass4LIFE poplar plantations, which equaled to **123,8 tCO_2**.
- CO_2 footprint from planting of NutriBiomass4LIFE poplar plantations, which equaled to **111,7 tCO_2**.
- CO_2 footprint from weed control of newly established NutriBiomass4LIFE poplar plantations, which equaled to **38,7 tCO_2.**
- CO_2 footprint from travelling to poplar establishment sites and poplar plantation establishment supervision, which equaled to **11,4 tCO_2**.

- Negative CO_2 footprint from AGB and BGB biomass yield accumulation at newly established NutriBiomass4LIFE poplar plantations, which equaled to **minus 14657 tCO_2**
- Negative CO_2 footprint from SOC increase at newly established NutriBiomass4LIFE poplar plantations, which equaled to **minus 5480 tCO_2.**

Additionally calculated CO_2 footprint balance from older biomass plantation, which are included in NutriBiomass4LIFE CE model, to reveal full extent of NutriBiomass4LIFE CE model carbon footprint, **equaled to minus 81407 tCO_2** and was composed of:

- Negative CO_2 footprint from AGB and BGB biomass yield accumulation at older biomass plantations included in NutriBiomass4LIFE CE model, which equaled to **minus 70362 tCO2**.
- Negative CO_2 footprint from SOC increase at older biomass plantations included in NutriBiomass4LIFE CE model, which equaled to **minus 13716 tCO_2**
- CO_2 footprint from release of CO_2 from harvested biomass at older NutriBiomass4LIFE poplar plantations for renewable energy production, which equaled to **2671 tCO_2**.

6 Policy

Under the European Green Deal, a number of various commitments and specific targets are being proposed and implemented. Tree planting is widely regarded as one of the solutions to climate change. The European Union has made a pledge to plant additional three billion trees by 2030 which foresees that new trees should be planted not only in forests but also in rural and urban areas.

Poplars established on agricultural land as perennial short rotation agricultural crop and grown for longer rotation (e.g. up to 20 years) are probably the best tool for biodiversity increase, soil health and carbon removal in agriculture. Unfortunately, the measures and tools implemented by these policies leave this perfect tool in "a grey zone", as from the point of public administration of agriculture this crop is seen more like forestry measure, while from forestry side it is not considered a forest. This problem is reflected in the EU policies, which are in great favor of forestry promotion and agroforestry promotion in agriculture, while tree growing on agricultural land as an exclusive activity (short rotation coppice or short rotation forestry) is left without a clear definition and direction.

6.1 Coherence with EU policies

A roadmap to implement 3 billion tree planting is supported by EU's Biodiversity Strategy and other key strategies and initiatives under the European Green Deal at implementation level, in particular such as the Certification Framework for Carbon Removals and the Soil Mission.

Planting of poplars on agricultural land provides the synergistic benefits of improved land use efficiency and income diversification, enhanced biodiversity, soil conservation and carbon sequestration.

6.1.1 EU biodiversity and soil policies

Under the European Green Deal, the EU's Biodiversity Strategy tackles the protection and restoration of nature by making a number of various commitments, among them biodiversity-friendly afforestation, reforestation and tree planting.

Poplars, planted on agricultural land are considered agricultural crops, therefore biodiversity and other policy baseline, first of all, should be compared with agricultural activities. Besides that, studies show that biodiversity in poplar stands are much grater than in pure coniferous forests.

Poplar plantations, compared to most of agricultural practices, in particular crop growing, are considered a useful strategy for the following objectives related to ecosystem services and biodiversity:

- Improving overall biodiversity.
- Contributing towards preserving biodiversity at forests – trees grown on agricultural land can provide significant volume of additional biomaterial, which is needed by different bioeconomy sectors: from traditional renewable energy and wood processing sector to advanced biofuels and bio-chemicals and so reducing pressure on traditional forests, especial forests with high biodiversity.
- Creating buffer zones (e.g. riparian buffers), when poplar plantations are established surrounded by agricultural landscape.
- Establishing biological corridors to enhance landscape connectivity and landscape - level biodiversity.
- Transformation from conventional to organic agriculture, leading to a decreased need for pesticides and fertilisers as NutriBiomass4LIFE poplar establishment is implemented without pesticides and mineral fertilizers. This is especially useful as poplars planted at lower density are favourable to pollinators.
- Reclamation and rehabilitation of degraded or abandoned agricultural land.
- Improving support for ecosystem services and regulating aspects such as nutrient cycling, soil formation, water regulation, erosion control, etc.
- Adapting to climate change, in particular, by creating micro-climates which regulate extreme temperatures and become a shelter during heatwaves for wild animals, birds, insects and cattle.
- Mitigating climate change through increased carbon sequestration.

Picture 6-1. Animal biodiversity at NutriBiomass4LIFE poplar plantations (Vilnius distr.)

The EU Soil Strategy for 2030, adopted in 2021 as part of the European Green Deal, provides the framework towards protecting and restoring soils and ensuring that they are used sustainably. In particular, the attention is paid to soil health and its improvement.

Due to falling leaves and the continuous renewal of fine roots, poplars inject organic matter into the soil, feeding the flora and fauna there and increasing biological activity to make it a living and fertile soil. In addition, their root system improves the soil structure. Porosity increases, allowing better infiltration, the storage of water and further promotion of biological activity. Finally, poplars create a temperate microclimate favourable to the development of microbial populations, microfungi and microfauna (e.g. lumbrics, etc.). This all leads towards significant nature-based improvement of soils, especially degraded after intensive agricultural usage.

Given extensive root system, poplars contribute to recycling of the excessive macro nutrients other mineral elements from the soil, which accumulated in the soils due to extensive fertilization over long period.

6.1.2 EU climate policies

Poplars grown on agricultural land are probably the most efficient carbon removal tool in agriculture in terms of carbon removal per ha of land. Establishment of longer rotation poplars on agricultural land can remove and permanently store 250-300 tCO_2/ha. Comparing to traditional forestry, established poplar plantations remove carbon 3-4 times faster than established traditional forest tree species. That is important when we have to take urgent steps towards removing CO_2.

On 21 November, 2023 European Parliament adopted Carbon Removal Certification framework. Carbon Removal Certification framework defined four different types of activities covered by the certification framework, that will be able to benefit from their contribution to meet EU climate targets: carbon removal, carbon farming sequestration, carbon farming emissions reduction and carbon storage in products.

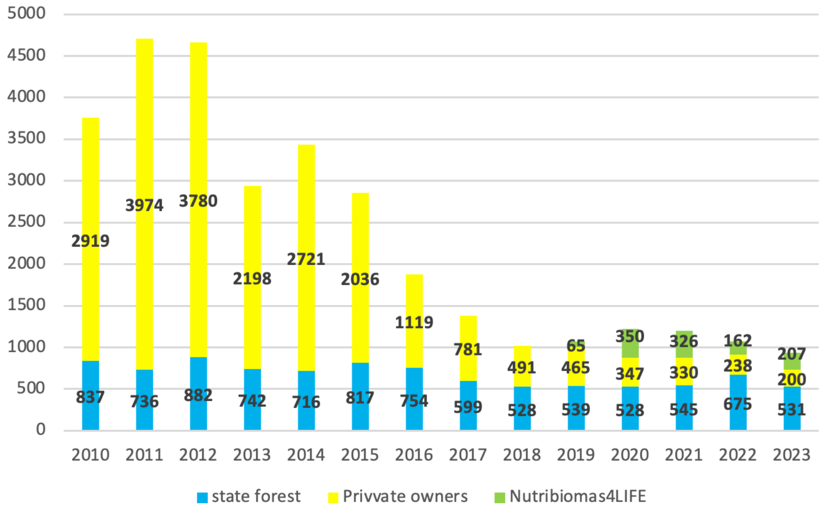
Establishment of poplars has clearly significant carbon removal footprint and complies with carbon farming initiative, but benefitting from Carbon Removal Certification framework will depend on developed carbon removal methodologies, which already posing certain questions: whether short rotation trees on agricultural land will be considered forestry or agricultural activity. From the forestry point, the problems may arise from definition of "monoculture forest" as there are intentions to exclude monoculture forest as definition due to lower biodiversity as a default of "monoculture" definition. From forestry point, poplars look like monoculture forestry as definition usually narrowly looks at the composition of number of tree species, not at a whole ecosystem mix. Nevertheless, poplar plantation with constant grass cover as an ecosystem has greater biodiversity than coniferous forests. Comparing to other cropping systems in agriculture, poplars as agricultural crops are probably the most diverse ecosystem, but policy instruments in agriculture usually address agroforestry solely.

6.2 Coherence with national policies

NutriBiomass4LIFE CE model is fully coherent with national policies which are mainly facilitated by the key EU policies. In Lithuania, special attention can be paid to climate policies as poplars, established during NutriBiomass4LIEF are becoming an important carbon removal tool in Lithuania.

Although the public policies toward planting of new trees and forest establishment vocally were in heavy support of tree planting and new forest establishment, unfortunately real policy measure taken have had absolutely an opposite effect. This can be seen when comparing Lithuania's afforestation measure development as presented in Picture 6-2, including poplar plantations established by NutriBiomass4LIFE project. As it can be seen from the picture bellow, from 2016 private forest establishment actions decreased substantially as national authorities took efforts to demotivate private owners' forest establishment efforts by decreasing forest establishment payments from Rural development program. Although in 2018 these payments for forest establishment were reinstated, the interest of private owners for forest establishment was killed by authorities which were responsible for forest establishment promotion.

Picture 6-2. Afforestation in Lithuania (ha)



NutriBiomass4LIFE brought a new lifeline for private owners to plant trees on agricultural land and that doubled private owners tree planting results in Lithuania. Taking into account low afforestation efforts from state forestry, NutriBiomass4LIFE established poplars totaled 25% of all Lithuania's afforestation efforts during the last four year period.

This remarkable NutriBiomass4LIFE efforts in Lithuania's afforestation efforts is important in terms of implementation of climate policies. Initial Lithuanian National energy and climate plan for 2021-2030 was targeting that private and state forest owners' efforts for afforestation could reach 15000 ha per year. At the end of 2013 Lithuanian National energy and climate plan for 2021-2030 was revised as afforestation measures failed completely, and the new target was set at 1000 ha per year level, which without NutriBiomass4LIFE efforts would not be achievable again.

Besides shift in policies regarding subsidies to landowners for establishment of forests on agricultural land, in Lithuania people moved out of afforestation of agricultural land because of extremely strict regulation regarding usage of forest land. In Lithuania it is not allowed to do anything on forest land: neither to build house, nor wind power mill or some other infrastructure. Besides that, owners of forest are skipped out of certain non-wood rights – they do not have right to hunt or sell hunting right, they cannot restrict others from mushroom, berry, or other good gathering from their properties, etc. Al the restrictions and insufficient property rights lead to the situation, that after forest is established on agricultural land, the land value loses its value by several times.

Poplar establishment do not receive any subsidies, but there is no requirement to change land purpose from agricultural land to forest land, which is now getting more valuable to landowners. In Lithuania there is no clear definition on maximum allowed age per rotation of such plantations. The limiting factor, which defines when the private land planted with poplars can be converted to agricultural land is the age of trees, which is defined in the Law on forests – over 20 years. Members of the NutriBiomass4LIFE consortium proposed to have a clearer definition of the age of short rotation plantations, which are grown on agricultural land. Currently in the new draft Law on forests, there is a a definition related to short rotation plantations (short rotation coppice), which will define the age of rotation of such plantations – up to 20 years.

7 Continuation

Replication and transfer of the NutriBiomass4LIFE actions of poplar plantation establishment will continue after the end of the project as we gained valuable experience in poplar planting and management, which we are sharing with other landowners and investors.

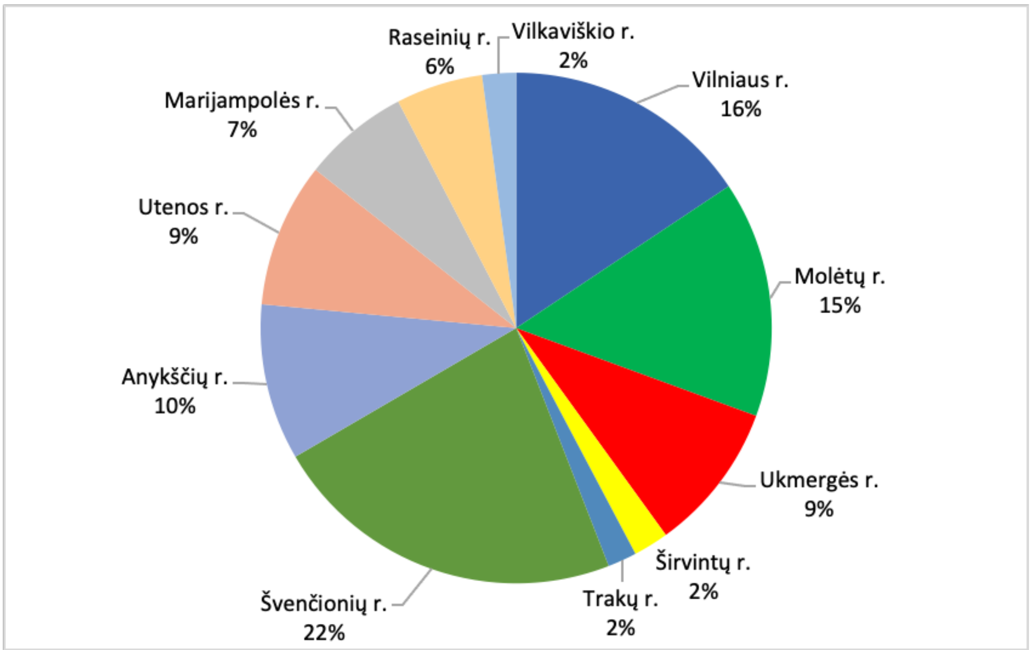
Rapid Carbon credit market development and possibilities to get revenues from carbon removals, as poplars are the most efficient crop for carbon removal in agriculture, will provide more incentives to invest into new tree planting, including poplars. Therefore, we see good prospects for continuation of this activity both in Lithuania and other markets.

7.1 Lithuanian market

We expect to continue new biomass plantation establishment in Lithuania and in the next three years we are targeting to establish 800 ha of new poplar plantations. We expect to expand our scope in Lithuania and consider establishing new poplar plantations all over Lithuania.

As it was presented in the Picture 2-1., in 2023, 207 ha of new poplar plantations were already established as a project replication and transfer action.

Picture 7-1. Poplar plantation establishment geography in Lithuania in 2023-2024 for Nutibiomass4LIFE continuation



7.2 Other markets

7.2.1 Sweden

We looked at Swedish poplar plantation establishment possibilities and see good potential there:

- Historically, in Southern Sweden some OP42 poplars were planted, so Swedes already know poplars.
- Scientists in Sweden try to develop alternatives to forest monoculture planting and poplars are on the testing list of alternative species.

- Forest ownership is well respected and favored in Sweden and poplars are viewed as alternative to widespread monoculture spruce forests.
- Some private forest owners have large properties, among which there are plots of not used land, which may be favored for poplar establishment.
- The key limiting factors for poplar establishment in Sweden were lack of poplar establishment and growing experience, lack of seedlings, and high damages by wild animals.

We consider the following business models for the entering Swedish market:

- Offering poplar planting and management experience and services to Swedish landowners.
- Leasing land in Sweden to establish new poplar plantations.
- Joint activities with Swedish forest owners – sharing costs and profits on long term agreement basis.
- Taking over initial poplar plantations establishment and management risk. The key risk associated with poplar growing is the first year – right poplar planation establishment and management. Additionally, in Sweden there is high risk of gaming (wild animal) damage as most of the forest are spruce forests, therefore wild animals are keen to taste other species than spruce. We will offer to take over a two-three year establishment and management risk – after that period owners could decide whether they would like to acquire established plantation or to lease land for 20 years.

We target entering Swedish market with poplar plantation establishment in 2025. We anticipate that initially the major business model will be - taking over initial risk. We will target to reach 100 ha of newly established plantations in 2026 in Sweden.

7.2.2 Latvia

Latvian market, which is close to Lithuania, has similar possibilities for poplar establishment as in Lithuania. We started discussion with large forest and landowners and, similar to Sweden, business model - taking over initial risk - may be appropriate for start of operations in Latvian market.

7.2.3 Ukraine

Ukrainian poplar plantation establishment opportunity looks attractive in case carbon credits for carbon removal will be availabl:

- We started discussion with Ukrainians authorities, municipalities, and local actors (farmers) regarding transfer of the NutriBiomass4LIFE model to Ukraine.
- We consider starting NutriBiomass4LIF CE model transfer from western part of Ukraine (Lviv, Rivne, Volyn regions), the area which is less agriculture intensive and more unused land available for poplar plantation establishment.
- We are analysing possibilities to secure land for poplar plantation establishment – current legislation allows to lease land from municipalities for up to 50-year term. We are looking towards possibilities to start the project from establishment of NutriBiomass4LIFE plantation in 2025/2026 and in several years to move towards stable 1000-3000 ha of biomass plantations establishment each year.

- We are looking for possibilities to secure hybrid poplar seedling supplies as from 1 million to 5 million of new trees will have to be planted annually to meet biomass plantation establishment targets.
- We are strongly looking at carbon markets developments and Carbon Removal Certification Framework implementation as transfer of NutriBiomass4LIFE model in Ukraine will lead towards removal of millions of tons of CO_2 and carbon markets may become a primary source of funding for the NutriBiomass4LIFE CE model transfer to Ukraine.

Conclusions

The key lessons we learned from biomass plantations establishment for circular economy demonstration model during implementation of NutriBiomass4LIFE project:

- During implementation of the project about 1,5 million poplar trees were planted on 901,7 ha of agricultural land (net established plantation area), on the agricultural lands mobilized within 60 km radius from Vilnius during the project implementation.
- New poplar plantations were established on abandoned agricultural lands (44%), grasslands (40%) and croplands (16%). The initial growth of poplars on croplands has been less favorable, as croplands due to intense plowing losing their water retention capacities. The share of abandoned agricultural lands has been increasing over the project implementation period.
- Sufficient and stable supply of Lithuanian climate adapted poplar clones was one of the limiting factors, especially at the beginning of the project as there was a significant shortage of suitable planting material. The major planted hybrid poplar clones during implementation included: AF34 (44% of total plants), OP42 (37%), SnowTiger (18%). Post project poplar supplies (2023) of poplar clones are already dominated by OP42 and Snowtiger mix as these clones proved to be most adapted to Lithuanian climate conditions.
- Management of established poplar plantations included mechanical weed control (herbicide have not been used during the project) and pruning. During implementation of the project the risk associated with AF34 clone emerged - susceptibility of AF34 clone to bacterial infection (canker) after pruning or damage of stem. This risk has to be observed and assessed over longer term, therefore, pruning of AF34 clones is postponed.
- In 2023, all NutriBiomass plantations were certified for sustainable forest management under Forest Stewardship Council® (FSC®) certification requirements under the Scope of group Sertifikuoti miškai VšĮ FSC® Forest Management and Chain of Custody Certificate NC-FM/COC-066941. NutriBiomass4LIFE biomass plantations are sustainably managed, which includes various sustainable forest management provisions, like setting aside at least 10% of certified area for nature conservation purposes, no use of pesticides and chemical fertilizers, etc.
- From business perspective we are targeting longer rotation – 20 year – poplar business model, which allows to utilize the highest poplar yield, carbon removal and the highest revenue from industrial roundwood sales potential.
- Since the end of establishing of NutriBiomass plantations (June 2022), inflation reached over 20%, thus total poplar plantations establishment (land preparation, seedlings, planting, weed control) costs increased to 2700 eur /ha.
- Poplars are the most efficient agricultural crop for CO_2 removal in agriculture. Carbon footprint balance from biomass plantation establishment action implementation was negative and

equaled to minus 19963 tCO_2. This is just 9% of total CO_2 sequestration potential, which will be achieved by 901,7 ha of poplar plantations established during project implementation over targeted 20-year rotation, i.e. 225 thousand tCO_2. Additionally, 81407 tCO_2 were removed by older biomass plantations included in the CE model during implementation of the project.

- Replication and transfer of poplar establishment actions has successfully started already in 2023, when 207 ha of new plantations were established. We will seek to establish 800 ha of new poplar plantations in Lithuania and to move to Swedish, Latvian and Ukrainian markets as well.
- Poplars established on agricultural land as perennial short rotation agricultural crop (SRC) and grown for longer rotation (e.g. up to 20 years) are probably the best tool for biodiversity increase, soil health and carbon removal in agriculture. Unfortunately, the measures and tools implemented by various EU policies leave this efficient tool in some kind of "a grey zone". From the point of public administration of agriculture such crops are seen more like forestry measure, while from forestry administration it is not considered a forestry instrument. This problem is reflected in the EU policies, which are in great favor of forestry promotion and agroforestry promotion in agriculture, while tree growing on agricultural land as an exclusive activity (short rotation coppice or short rotation forestry) is left without a clear role and direction.