Interreg CENTRAL EUROPE

Co-funded by the European Union

PoLaRecCE

Action plan developed for roadside soil, degraded by traffic pollution

Best available practices and on-site techniques for environmental site assessment and soil recovery

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Executive summary

Within the framework of the project, PP4 WOODTECH, as a forestry-focused company, is primarily concerned with the revitalization of polluted areas next to roads and railways. An extremely large area is affected by the transport infrastructure throughout Central and Eastern Europe. Hungary has the lowest forest cover and area ratio covered by trees among the INTERREG-CE countries. Békés County has the fewest trees in all of Hungary (forest cover rate below 5% in the County).

Within the framework of the project, in cooperation with partners, with the help of a pilot site, we focus on creating new types of woody vegetation, typically phytoremediation forests (tree rows, small groves), in areas next to transport infrastructure (typically roads and railways), where transport pollution is measurable and significant. These are typically urban forest types, always mixed, planted using forestry methods, with cheap and durable technical solutions. The forests are specifically non-food oriented.

During the construction of the pilot site, we used tree species and cultivation methods that can most effectively reforest these linear infrastructures. In Hungary, tree rows next to roads and railways receive very little attention, even though they are necessary to reduce and absorb traffic pollution.

During the development of our methods, we developed a model where the produced wood can be utilized for energy purposes (firewood, wood chips) or for cellulose (fiber) purposes.

We interpret every tree planting as a community action. During the creation of the strategy, we aimed to ensure that the target groups using our methods (municipalities, road maintenance authorities, railway companies, local communities) can easily and cheaply adapt them and multiply the effects of the project.

These new types of tree rows also have significant, measurable and calculable CO_2 sequestration potential. The growth of trees is the only truly effective and cheap CO_2 absorption mechanism in the world today. We encouraged the members of our target groups to feel responsible for this.

With our strategy, we want to give local communities the skills that will make tree planting a simple routine for a wide range of social groups.

1 Introduction

1.1 Objectives

The objective of this document is to describe the strategy and action plan, including one or several alternative development pathways for the Békés pilot site, and to select the optimal procedure to be implemented in the pilot area. The Action plan also includes a financial model for the investment and a cost-benefit analysis for end-users.

The total built-up road network of the European Union (in terms of paved roads) is approximately 4,5 mln km, this is the most important distribution of transport infrastructure (thereof expressways and motorways are 75.000 km. TEN-T core network is 137.000 km.

The total length of railway lines in the EU exceeds 200,000 kilometres, Hungary is 8.800 km.

Roads and railways are typically linear infrastructures, where green belts must be maintained on both sides of the actually/effectively used surface. These belts are in a special maintenance environment:

- typically contaminated (in the case of roads: various dusts, gases, salt, de-icing fluids, oils; in the case of railways: brake dust, dust, oils, etc.);

- mixed soils, in many cases technosoils;

- trampling, compaction, periodically recurring disturbance, dumping of waste, etc.

These areas are typically overused with limited revitalization potential. There is also a social expectation that these critical infrastructures be at least partially greened. Grassing is typically not necessary, as the grass layer is typically overgrown by native+invasive weeds. However, planting shrubs and trees can bring about a quick and positive change in these degraded areas. Some bushes and trees also appear spontaneously, but this process can be slow, and considering safety rules, partially controlled plant breeding is preferable.

Within the framework of the PoLaRecCE project, we have developed a new type of tree-lined method for the safe, efficient and cheap establishment and maintenance of green belts along roads and railways. Instead of horticultural methods (large trees, expensive installation, limited number of trees), we establish tree-lined areas using forestry methods: planting small seedlings, no soil preparation, thick layer of mulch, individual protective netting against wild animals, reduced irrigation period only in the first two vegetation periods, a mix of fast and slow growing tree species.

We are also widely distributing the developed method among road and railway maintenance organizations. A large part of public roads is managed by local governments, so we have developed and demonstrated the method for them as well.

We believe that community tree planting, as an initiative with community-building power, can be an effective force in shaping society by re-greening public roads and railways.

1.2 Scope

The subject of the report is Békés pilot site located in south-eastern Hungary. The report includes the site description, containing information about its location in relation to the potential sources of pollution, both current and historical. Climatic conditions and their changes in the last decades. Based on earlier investigations, the current state of roadside and next-to-railways land degradations is analyzed as the starting point for the further strategy of development and possibility of adaptation for non-food tree production. The proposed land management directions are discussed including also possible alternatives for food production or non-food agriculture.

The development strategy involves also financial models of investment, and cost-benefit analysis related to the local market for the non-food agricultural product, originating from the new treelines. The report also includes technical guidelines for development and maintenance of the facility and risk assessment for the investment.

1.4 Intended Audience

Transport accounts for around a quarter of the EU's total carbon dioxide emissions, with road transport accounting for nearly 72% (about 18% of total emissions). To meet its climate goals, the EU is targeting a drastic 90% reduction in the transport sector by 2050, with stricter interim targets and zero-emission requirements for new vehicles. European rail transport is the most environmentally friendly transport sector in the EU. Although the sector accounts for a significant proportion of all passenger and freight kilometres, it only accounts for around 0,4% of total European transport carbon dioxide emissions (0,1% of total emissions).

By establishing tree lines in the land strips next to public roads and railways, the commitment to neutralizing the emitted CO_2 can be effectively reduced and effectively demonstrated. In the case of urban roads, this allows for even more intensive communication for local politics. Planting trees has a robust message, but supplementing/replacing existing tree rows and creating new ones also contributes quantifiably to the development of the environment and to the absorption and storage of CO_2.

1.5 Usage guidelines

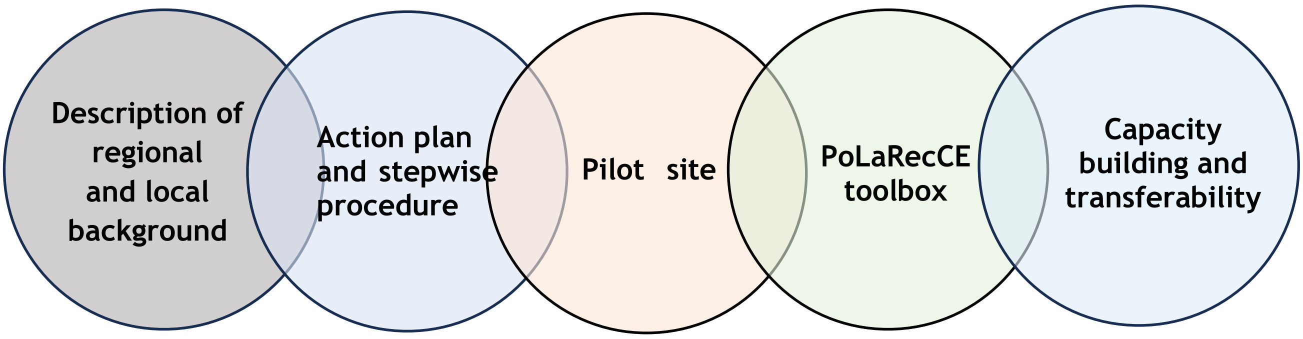
As a training material for end-users, this document has been written in an easy-to-understand language, supported by explanatory schemes, tables and figures. However, proper references are provided to allow those interested to further explore the topic. When preparing the paper, it was important to make it understandable, as the target group includes extremely diverse members (road and railway maintenance organisations, local and regional governments, farmers, students, teachers, local people etc.).

2 METHODOLOGY

The PoLaRecCE project involves different countries and project partners working together. During the demonstration actions, we aimed to work on the same methodology as much as possible, despite the different geographical, cultural and policy backgrounds, so that the results would be synergistic and comparable.

Building of the strategy and action plan for management of roadside soils, degraded by traffic pollutions consists of 5 elements.

1. Figure: Five-element PoLaRecCE strategy diagram



The background section constitutes the analytical part of the study, which identifies and monitors emerging problems and signs of change in both the internal and external environment, while describing the current situation at the regional and local levels. The primary step is to properly identify the drivers and assess the current situation by collecting background data. In the case of the Békés pilot site, this data refers to the revitalization of land strips next to roads and railways affected by road and railway maintenance.

The starting point of each action plan is a clear vision and strategy for the plan as the most interactive stage of the process is devoted to the development of goals, alternatives solutions in reaction to the identified challenges, problems and potentials. The expected outcomes of the plan and associated objectives and targets should be developed and assessed from the point of their coherence, achievability and responsibilities of actors. Different scenarios should be considered discussed and assessed. They should be confronted with existing local, regional and national policies. Finally, the stepwise procedure should be developed to ensure control, better planning and efficiency by carrying out activities in a specific sequence, often based on management functions: planning, organizing, leading and controlling.

The procedure was tested at a pilot site located in Békés county, Gyomaendrőd “Pólus-halma” area. The optimal solution was selected from several possible alternatives, considering local environmental conditions, climate change impacts, social circumstances, and the investment financing model, as well as a cost-benefit analysis for end users.

Capacity building involves developing the skills and competences of local and regional authorities, road and rail maintenance companies, landowners and managers. It improves institutional structures, management practices and operational strategies at different levels through training, mentoring, exchange of experiences and better access to technology and financing.

A key element of the strategy is transferability, which means the possibility of applying the developed solutions to other areas of Central Europe degraded by traffic pollution and roadside soil contamination.

3 BACKGROUND

3.1 Regional background

The development of roads and highways is the result of a long period of time. The Romans had already built roads in Europe, but the real large-scale and intensive development began with the industrial revolution. After that, the covered road network developed after World War I and World War II. The railway also dates back almost in parallel, in Hungary and East-Central Europe from the time of the Austro-Hungarian Monarchy (from the 1860s).

Simultaneously with the appearance of the collapsed roads and railways, the environment of these linear facilities also changed drastically. Forests were down, swamps were filled, mountain slopes were opened, embankments were built. Two new lanes appeared along the roads and railways, which nature spontaneously began to re-green. In many cases, this process was accompanied by human intervention: bushes and trees were planted to better integrate the raw technical content into nature.

In the political changes that took place in the 1990s, the quality of the surface of roads and railways was always more important in the eyes of society than the green belts next to the roads/railways. However, with climate change and the emergence of electric cars, the green aspect has become increasingly stronger. Roads and railways are critical infrastructure, and more attention is paid to these green belts.

The types of roads and railways have also expanded in recent decades, and today there are also separate bicycle path networks. The length of bicycle paths in Europe is several hundred thousand kilometers, of which 92,000 km is the international EUROVELO network. In the case of these roads, the condition and quality of the green lanes next to the roads is of paramount importance.

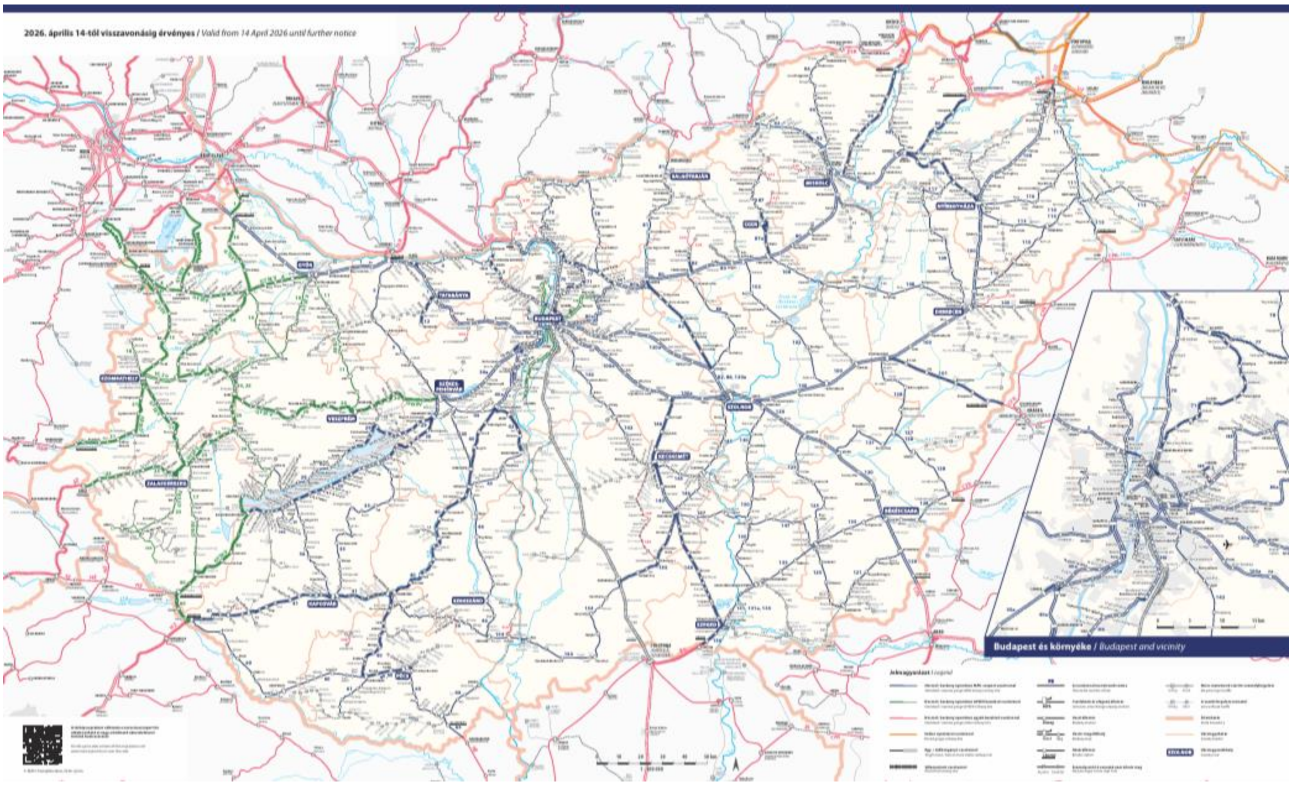
Basically, during the project, we focused on public roads (urban roads and road networks between settlements) and railways (in the case of railways, primarily on areas outside settlements).

The establishment of tree lines on these linear facilities is our dominant solution. We have developed a new type of tree row technology based on forestry solutions. We have built a pilot site and communication campaigns in connection with this.

In 1920, after World War I, Hungary received new borders. At that time, there were 27,866 km of public roads in the current area, 4% of which were paved roads. In 2025, there were 37,810 km of public roads nationwide that were maintained by the State Road Management Organization (all paved roads, motorways and national main roads). Local governments manage a much longer network of roads: they maintain 50,650 km of paved municipal roads and 138,870 km of unpaved (dirt) roads. The road network has increased more than 8x in 125 years.

The current length of the railway network is 6,980 km (8,800 km in 1990), making it one of the countries in Europe with a very high railway density in terms of both area and population.

2. Figure: Railway lines in Hungary (source: www.mavcsoport.hu)



3.2 Local background

The project focuses locally on the area of Békés County. The county has 1476 km of state road network and 2500 km of paved roads managed by local governments. The length of railway lines is 444 km.

Békés County is the county with the lowest forest cover in Hungary, with 5% forest cover (the EU average forest cover is 39%, Malta and Iceland are the countries with the least forest cover among the EU and associated states).

This low forest cover is also visible on the road and railway treelines in Békés County: they are incomplete in many places and are completely absent for kilometers. The soil conditions are typically good, and there are also good and excellent quality field soils in the county. The reasons for the lack of tree-rows here are typically the following:

- Traditionally there is little wood/trees locally, even in Ottoman-Turkish times the locals wrote letters to the Sandjac “Gyula” (regional military entity in Ottoman Empire) asking them to send wood because there is not enough for firewood or building. Before the major river regulations, a significant part of the region was swampy.
- It is expensive and few trees can be planted with horticultural solutions, and so far, tree-rows have been established almost only in this way since the 1990s (this was not the case before),
- Municipal road maintainers have few resources for such purposes, although they typically have the capacity to maintain green areas.
- Maintaining public roads is a robust cost for the state, and afforestation is typically not a priority due to scarce resources
- The issue of green lanes is also marginal when it comes to maintaining railways.
- We found no trace of any significant afforestation being established in the past decades as part of a community initiative next to roads/railways.

There is a city tree planting program throughout the country, but within this framework, a few hundred trees are planted, typically in public parks. Afforestation of roads and railways requires a professional, simple, cheap and effective solution, with the planting of several million trees. One of the EU's objectives is to plant 3 billion trees by 2030 (in addition to regular forestry reforestation). This is a very significant number, for Hungary alone this value means 68 million trees (this is equivalent to the creation of approximately 14,000 hectares of new forest, so 2,800 hectares would be needed annually).

The Hungarian paved road network is 95,000 km long, and of the 68 million trees planned to be planted, there would be room for about a third to a quarter of the public roads. The total length of the railways is 8,800 km, so the free potential here is accordingly much smaller.

We have examined several possible alternatives, as follows.

3.2.1 Planting busches

One way to utilize roadside areas is to plant grass + bushes, which typically occur spontaneously. In addition to roads and railways, dust pollution (which comes from the wear of the road and vehicle wheels, as well as from the soot of exhaust gases) is significant in these strips. Grassing (or spontaneous grassing) is an excellent and inexpensive method of connecting sloping surfaces. It does not affect the view, it only needs to be mowed when it becomes overgrown or the bush grows too much, but then every year.

There is currently a significant debate in Hungary about whether to eliminate the rows of bushes installed in the median strip of highways after the 1970s (to reduce the glare of oncoming cars). Instead, a colored, light-dampening, durable plastic mesh is being installed. All newly built highways and motorways are now built with this separation technique, without exception. The previous bush row solution had to be mowed 1-2 times a year, which required mobile traffic diversion and was increasingly expensive to maintain. The bushes were typically *Tamarix* and *Ligurnum* species or cultivars.

Grassland and bush planting bind a significant amount of CO_2 and thoroughly intertwine the soil with their roots. Many grass species also carry out significant accumulation activities to mobilize soil contaminants.

Grass from roadsides is typically unsuitable for forage. If it is mowed, it is treated with a mulching mower. If the mowed grass is collected, it can be used for energy or fiber industry purposes. In

Hungary, there is also bred energy grass for such purposes (Szarvasi-1 variety, Agropyron x elongatum, www.energiafu.hu).

A special grass-like solution is the planting of Miscanthus bushes, which can also be used for energy or fiber industry purposes. Miscanthus can also be invasive and is highly flammable when introduced and dry, easily ignited by a lit cigarette thrown from a vehicle, which is why it has not spread.

Industrial hemp is a tall fiber-plant that is also an excellent source of fiber, but its planting requires a police permit, and law enforcement does not like these plantations to be in the public eye.

Chinese bamboo is also a possible grass-type alternative, but due to its invasive and alien nature, it is not an optimal solution. Bamboo is an excellent raw material that can be used for many purposes, but it poses biological risks in Central Europe.

3.2.2 Classic afforestation

One possible way to cover the lanes next to roads/railways has been around for centuries: afforestation. This is an extremely widely used method, and there are also different solutions depending on the region. It has a tradition, some are created in poor quality, and some are quite artistic.

Tree rows and small groves also have a drastic effect on landscape architecture. Trees/tree rows/small groves next to roads/railways (hereinafter we will simply call them tree rows, as they are typically planted in strips on both sides of roads/railways) are fundamental landscape architecture elements. Their planning is for the long term. Professional mistakes can also be made during the installation of tree rows: attracting insects to the side of the roads, plants that do not tolerate dirt, drying out, plants that do not tolerate windbreaks, littering plants (e.g. with a large amount of fruit or loose foliage).

There is a significantly different approach in horticultural-type and forestry-type afforestation.

The garden is the oldest form of agriculture, the first active step after the gathering (hunting/fishing) way of life (grazing is more of a passive agricultural method, where only pens or moorings had to be used). Without tools or with simple hand tools, the area that a family or small community could cultivate was very limited: but this became the first garden. The garden is such an ancient method that it even appears in the Bible as a central location. Horticulture still has the characteristic of concentrating on small areas, although today complete machine systems are also available, and grape yards or fruit-plantations can be huge of course. Horticulture today produces high-quality plants, in an extraordinary variety. These plants represent high quality and a high price level, in addition to being typically produced in greenhouse or with a very carefully prepared seedling growing process, which is why they are very demanding and less tolerant of extreme conditions. For this reason, they are also less viable in harsh conditions (strong drying wind pressure, drought, contaminated soil, polluted air etc.).

Forestry is not as old a genre as horticulture, planned forest management and the planting of non-fruit-bearing tree species by human hands can be traced back to about 300-400 years in Central Europe: first forestry act in Hungary is 1769 by Maria Theresia, he looked at forestry mainly from the perspective of mining's needs, and for the first time prescribed the reforestation of cutted forests. Expertise has been accumulating in forestry for about 15-20 profession generations. The forest is a harsh environment: drought, snow pressure, strong wind, pests, extreme soils, etc. Forest nurseries grow hardy and inexpensive seedlings in large numbers mainly under extensive or semi-extensive conditions.

Therefore, it is better to plant seedlings in roadside tree rows from seedlings grown using forestry methods. The following aspects also support this opinion:

- In these areas, the often artificial, mixed soil (technosoil) that is formed during road construction and maintenance (e.g. due to embankments, cuts) poses an extraordinary challenge.
- Due to the winter salting or de-icing of roads, foreign materials (e.g. salt, crushed stone, fluids) are deposited on the pavement, which are difficult for plants to tolerate.
- Strong wind pressure, snow pressure, which occurs lengthwise or perpendicular to the road, both of which pose a specific load on tree rows. There are also openwork and multi-row tree rows, combined with bushes.

- Behind a tree row installed perpendicular to the prevailing wind direction, the wind deposits the snow in a large pile 10-15 meters away. Tree rows must also be sized for this special condition.
- Pollinating insects are attracted to certain tree species. However, this can be dangerous for drivers, because bees/wasps pose a danger when getting into the car. Beekeeping cannot be installed next to busy roads or railways. Tree species must be chosen so that this does not pose a problem.
- When planting trees, drying out is one of the biggest dangers in the first 2-3 years of the trees' life. This must be solved, for which there are many technical solutions: irrigation bags, drip irrigation, mulching, tanker irrigation, community irrigation in cities, etc.
- Tree species must be selected that do not require expensive maintenance later (e.g. no pruning or crown shaping, not susceptible to pests), since we plant many trees and there are no resources to treat them individually.
- Philosophically, these rows of trees are like a forest edge, and similar effects (in forestry we call this the edge effect) also affect these trees.

3.2.3 Phytoremediation forest - roadside forestry

In the framework of the project, we chose the second alternative. PP4 WOODTECH is a family company with a forestry tradition, since 1752. We have been through many community tree planting projects, and we believe that this works.

Tree rows (like all products and services in the world) change function every 10 years or so, their role, their impact, and people's attitudes towards them change. It is a general economic philosophy that everything changes every 10 years, since societies also change in approximately such cycles. Today, a tree row does not mean the same as it did during the Monarchy, nor does it mean the same as it did in the 1980s, nor even the same as it did at the turn of the millennium.

New types of tree rows need to be reinvented. There are aspects that did not even arise 10-20 years ago:

  - climate change,
  - invasive plants and new pests,

- new types of highways where trees/bushes are no longer needed in the median strip but plastic cordons,
- conscious landscape aesthetics that has developed extraordinarily in recent decades,
- energy transformation, the shift towards renewable energies in society,
- the importance of CO_2
- sequestration.

We have created a model plantation, which is a phytoremediation forest (grove), with which we demonstrate the construction of a new type of road/railway tree lines/groves developed by us in the project.

We performed payback calculations for these tree plantings, which also showed that these new types of tree rows could be economical for energy purposes.

As a phytoremediation afforestation, we have planned to plant the following species in the pilot plantation and in the tree rows (these tree species are also permitted for such purposes). We will mix fast-growing and medium-growing tree species to combine a quick effect and a long-term effect:

- Fraxinus (widely tolerant tree species, moderately fast growing, native)
- Ulmus (widely tolerant tree species, moderately fast growing, there are both native and non-native species)
- Acer (slower growth, good tolerance, its autumn foliage is very decorative, native)
- Corylus (semi-fast growing, good tolerance, native, bushy)
- Oak (just a very few pieces, slow growing trees, native)
- Robinia (very wide tolerance, fast growth, guest tree species)
- Willow (fast growth, good tolerance, short-lived, native)
- Poplar (fast growth, native and non-native species and cultivars)

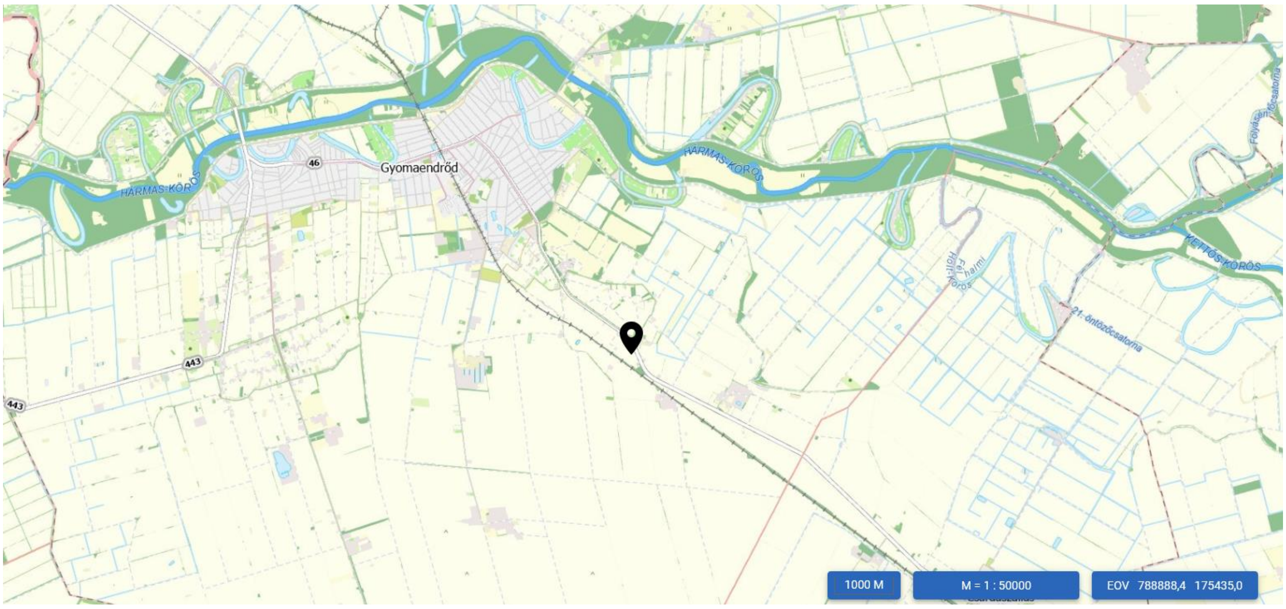
The pilot plantation and the planned community tree rows will be planted in a mixed manner, in all cases. This is important because this way the condition remains much fitter, and these tree rows are also much more decorative. Mixed tree rows are also preferred by other wildlife (small mammals, arthropods, marsupials, reptiles), and we can create much more stable micro-ecosystems on these extreme soils.

3.3 Area location and climatic conditions

The Békés pilot site is in SE part of Hungary, and its area reaches 2.700 m^2 (GPS coordinates: 46.902361, 20.85667). Altitude is 89 meters from see-level. The local name of the area is “Pólus-halma”, because to the north of the area there is a kurgan (barrow), the core of which was around the bus stop, but during the construction of the main road this mound was partially demolished. The name "Pólus" is the name of an old local family, whose farmstead was next to the mound for several generations from the second half of the 19th century. The name of the bus stop is currently being modified, as we also conducted historical landscape research within the framework of the project, and it turned out that its current name is not correct.

The pilot site is situated in an area of continental climate with hot, dry summers and cold winters. It is the warmest and sunniest part of Hungary, experiencing high temperatures in July and significant temperature variations throughout the year. The region faces various climatic challenges, especially drought seasons, which are the result of the ongoing climate change. The area of investment is owned by the PP4 WOODTECH and it was under agricultural cultivation from early middle age. It represents a classic overused agricultural area. Due to being very good quality, it was extensively used for food production. During 1950-1990, socialist agricultural production centers were established in the nearby surroundings (north of the bus stop). Extreme amounts of pesticides and fertilizers were used until mid of ’80s. Near to the pilot site a medium-traffic asphalt road as well as high-traffic international railway path (since 1870). Different types of crops were harvested from the Békés area, however due to seasonal drought and overuse the harvested crops were of poor quality. The soil-type is super chernozjom soil, it comes from the floods of the ancient-Körös river. The planned vegetation is phytoremediation forest (phytoremediation = active soil cleaning via trees, operating of accumulation process by trees).

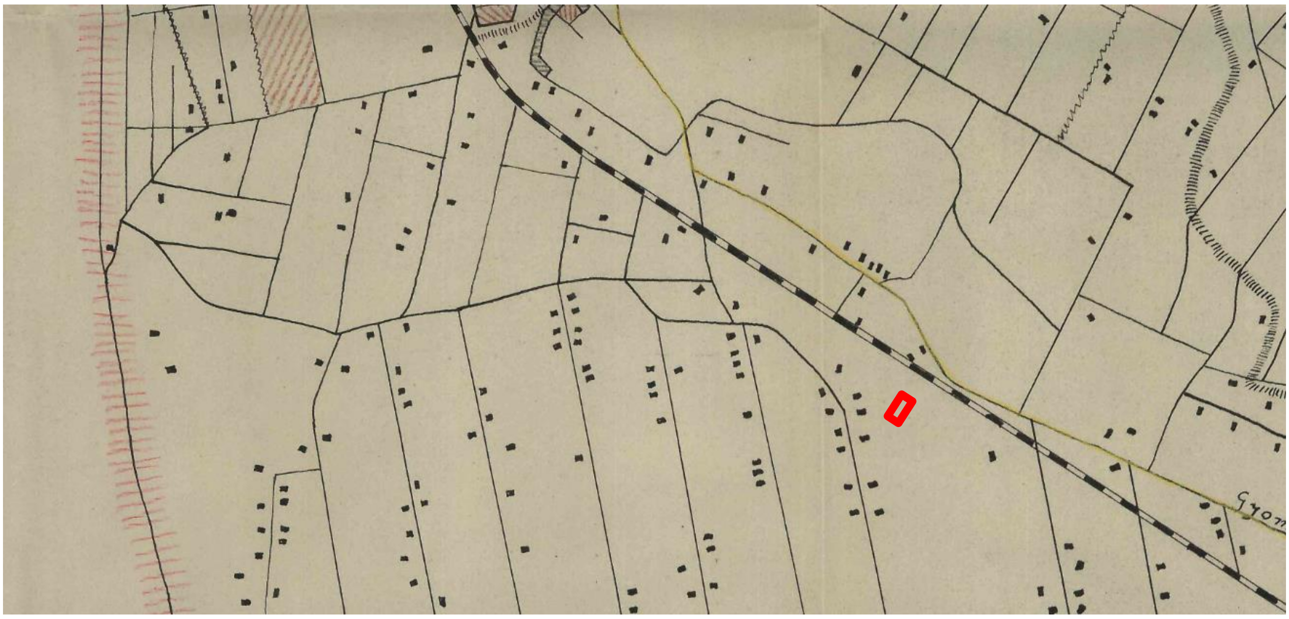
3. Figure: The area at the local map (in 2021)



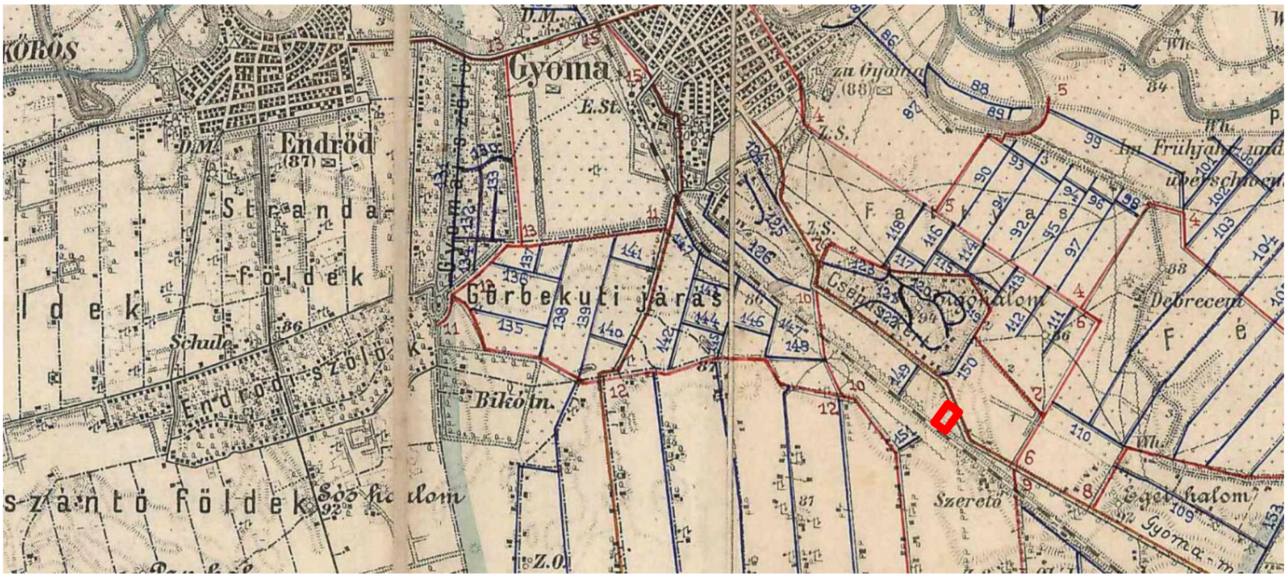
4. Figure: Orthophoto at year 2023

5. *Figure: Orthophoto from year 2005*

6. *Figure: After II. WW, in year 1945, tilling area*

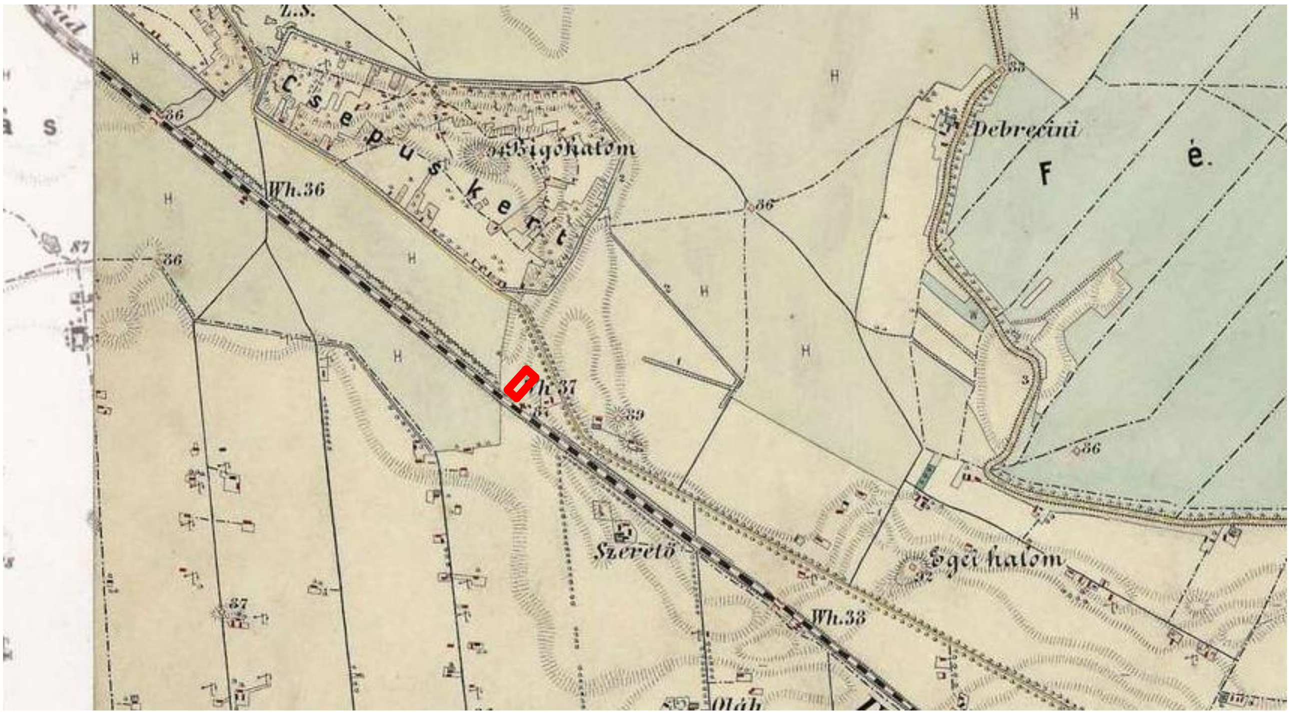


7. *Figure: Year 1909, in Austro-Hungarian Monarchy, agricultural area*

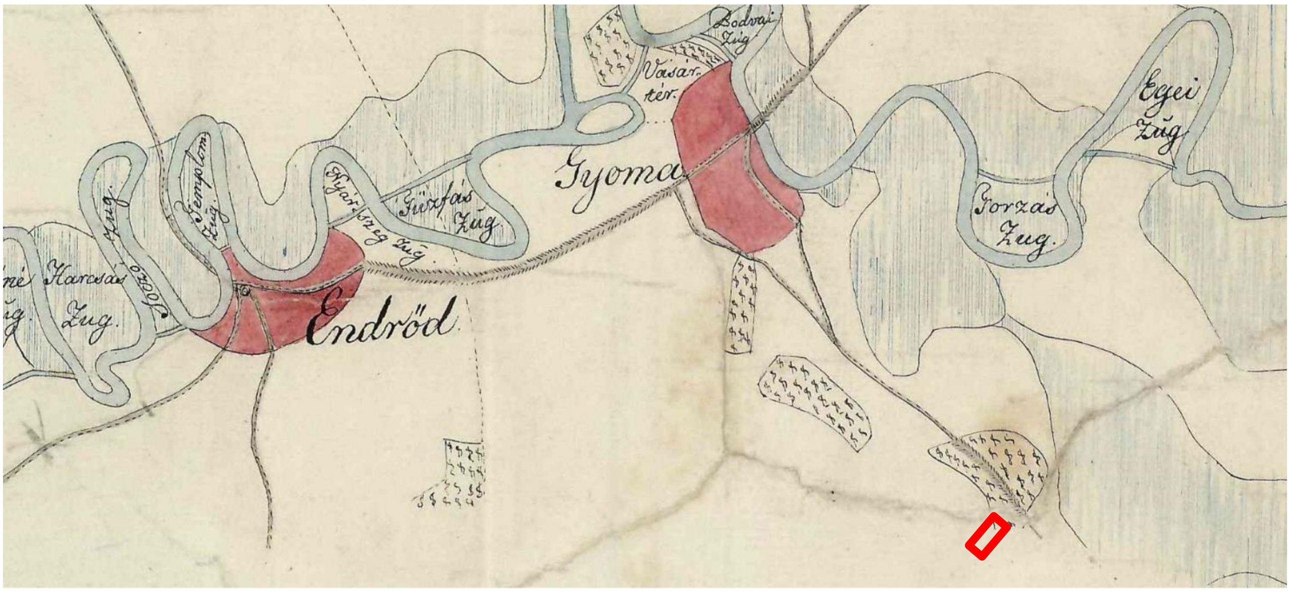


8. *Figure: In year of 1883, plow area*

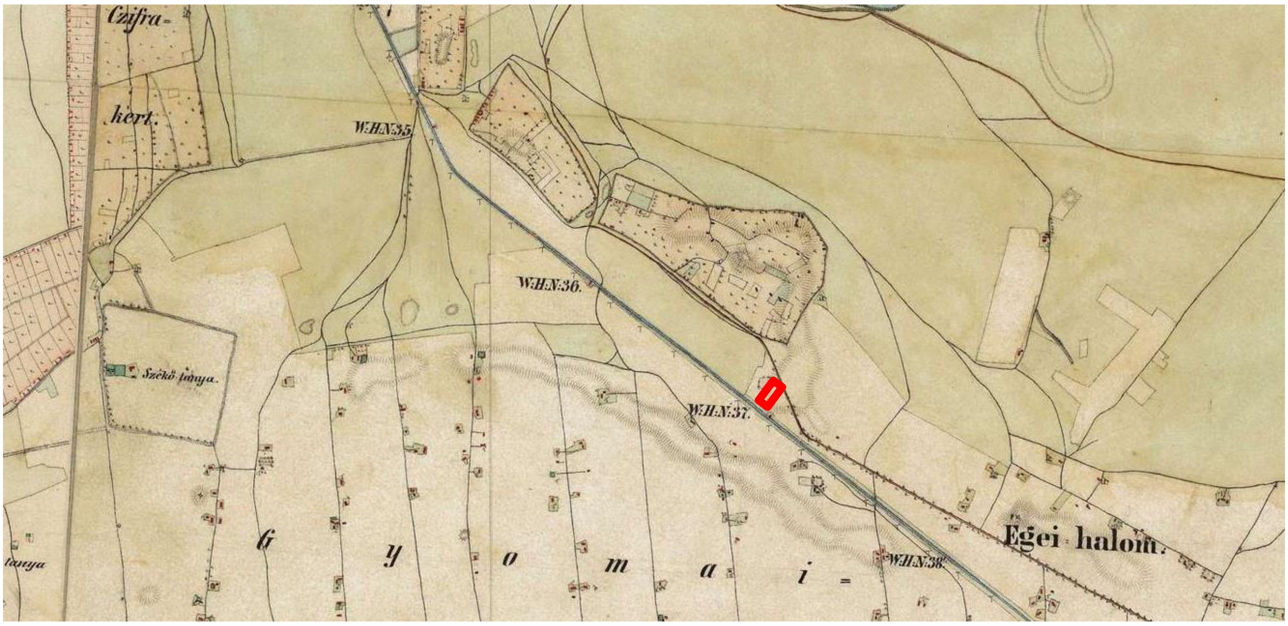
9. Figure: 3rd military mapping in Habsburg Empire – Kingdom of Hungary in 1869-1887, agricultural area, partly wet conditions



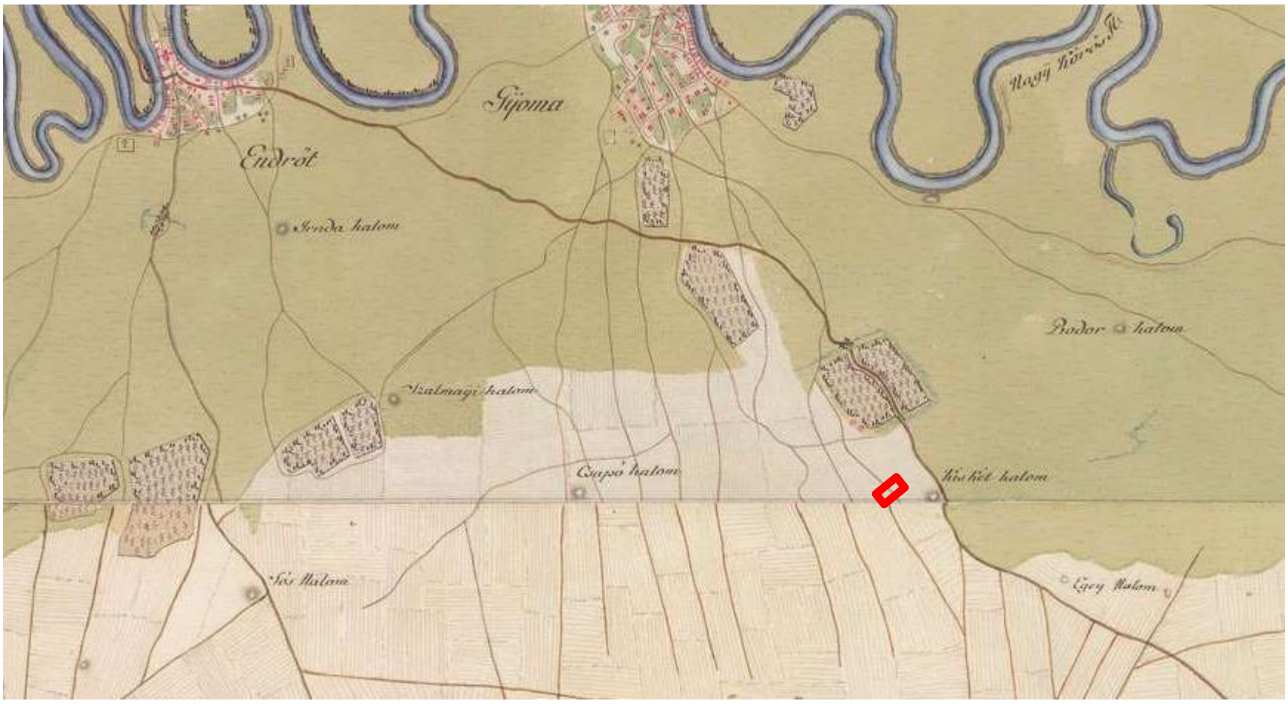
10. Figure: Year 1836, agricultural area, partly wet meadow (vineyards before the phylloxera epidemic are also visible)



11. Figure: 2nd military mapping in Habsburg Empire – Kingdom of Hungary in 1819-1869, tilling area (plow)



12. Figure: 1st military mapping in Habsburg Empire – Kingdom of Hungary in 1782-1785, tilling area



Previously, the pilot area was used for classical agricultural cultivation, approximately since the Middle Ages, since a significant part of the area is at a higher altitude and the ancient “Ős-Körös” river did not flood it. There were several Kurgans nearby, some of which are still visible today. There is also an old Kurgan, the “Pólus-halma”, at the corner of the area. There is also a bus stop here, whose name was previously incorrect. PP4 WOODTECH initiated the correction of the name of the bus stop in the spring of 2026, to "Bus stop: Pólus-halma", which was changed by the local government and the national bus company, and it now operates under this name. The Pólus-halma is also an archaeological site; the pilot plantation was established outside the site's boundaries.

3.4 Initial state of land degradation and soil quality

As indicated in the previous report, the pilot site investigated has been affected by long-term poor agricultural practices (e.g., nutrient depletion, over-fertilization, pesticide contamination) and by discharges from a nearby main road and railway line. In general, the concentrations of most investigated metals and metalloids are below the Hungarian national threshold values (except for Ni-concentration), and do not pose a significant risk for non-food agricultural use. Poor agricultural practices, and road-railway connection responsible for elevated Nickel concentrations in the central and eastern parts of the pilot site. Across the entire site, Barium concentrations exceeded the threshold value (250 mg/kg), which is likely a result of sewage sludge application. The concentrations of pollutants should not adversely affect tree species, and their potential accumulation in wood biomass used for energy purposes is not expected to pose an ecological risk.

This land is a highly valued agricultural soil in local/national terms. It is an agricultural soil with excellent fertility, where the micro-relief is very diverse (we can see this on old maps, part of the area was waterlogged for a long time, due to the floods of the ancient Körös River, but in the northern half there was a Kurgan, which has been dry for thousands of years). Because of long-term poor agricultural practices, these soils are significantly depleted in carbon. Conversely, their quality, as assessed by the Visual Soil Assessment (VSA), is rated as good. This apparent discrepancy is primarily due to a mismatch between soil organic carbon stocks and physical properties. Indeed, these soils do not exhibit any major physical limitations, as indicated by both bulk density measurements and the visual assessment of key physical characteristics such as texture and porosity. As a result, root growth is not restricted, and there is no evidence of water stagnation (e.g., no mottling or ponding observed). The VSA methodology is based on the visual assessment of key indicators of soil status and crop performance. The good physical condition of these soils clearly supports plant growth, particularly for tree species. However, good soil management practices will be necessary to prevent further degradation.

Nutrient analyses conducted at the pilot site revealed low N_{min} values, below 40 kg N ha^{-1}. Therefore, the total amount of nitrogen required should be applied. For grasslands with legumes, the recommended rate is 0–40 kg N ha^{-1} per year, while for grasslands without legumes, 40–80 kg N ha^{-1} should be applied annually. Slight exceedances of Nmin in some individual spots can be disregarded. Phosphorus contents are low; therefore, fertilization is recommended at a rate of 26–46 mg P kg^{-1}. In contrast, potassium (K) contents are high, so only small amounts—or none at all—of K fertilizers should be applied.

The pilot area, in addition to being an agriculturally overused area, is directly connected to the railway network and is also directly connected to a busy road. This is why we chose this area as a pilot area. The pilot area serves demonstration purposes and has excellent road accessibility (bus stop also).

4 ACTION PLAN

Afforestation of roads and railways is a solution for both revitalizing contaminated soils and mitigating the effects of climate change. During the project, we identified a social need, developed a technical solution to meet it, and developed a demonstration action plan to widely disseminate our results.

The plantation established for the purpose of this project has already been visited by the representatives of the local government and the vice-president of the county government, experts of local road authority and railway experts. The local and county governments, road authorities and railway companies agree with the development goals, and they will help with the demonstration tasks. The project objectives are also in line with the ones described in the Gyomaendrőd City Development Plan document (green economic objectives).

The formation of phytoremediation plantations can be transformed into a community movement. A significant part of urban society has never planted a tree in its lifetime, or if it has such experience, it often involves very inconvenient and complicated processes.

When establishing new types of phytoremediation plantations, a practical approach is applied that does not require special forestry or horticultural knowledge. An affordable, forest-grown seedlings can be planted in rows or in a defined grid, using simple tools (wedge digger, hand hole drill), a unique protective net, mulching, and simple low-period irrigation solutions. Road- or railway-workers, students, kinder, residents and other interested parties can also learn these techniques easily and safely.

Phytoremediation plantations bring also an additional benefit to community life (fresh air, landscape aesthetics, shade effect, etc.). With the tree planting experience, we can raise the awareness of the local community about these “unnoticeable” improvements.

The issue of forests/trees is always in the interest of communities. The EU takes the relationship between forests/trees and society extremely seriously, and this is also reflected in the regulations. The EUTR (EU Timber Regulation) has been in place for years, also due to the special relationship between trees/forests and society. There is a huge political debate about the new EUDR (EU Deforestation Regulation), which will bring extraordinary administrative and regulatory innovations and burdens to the EU/global trade in trees/timber.

4.1 Recognizing the problem (PoLaRecCE - EU-policy)

In Central Europe (CE), the sustainable management of roadside soils, degraded by traffic pollution, poses significant administrative and social challenges. Contaminated soils are typically removed from production and become wasteland, representing a substantial loss of the soil's biological potential. There is a lack of common and harmonized guidelines that could be applied across countries and administrative levels. The procedures developed within the project enable effective soil condition assessment based on innovative, predominantly field-based measurement techniques and methodologies. This makes it possible to evaluate the suitability of degraded soils for direct non-food agricultural production or to determine the need for reclamation measures aimed at restoring their biological activity and productivity.

The assumptions of the PoLaRecCE project are fully aligned with the European Union's policy on reducing environmental pollution and restoring the functional value of degraded areas. The main objective of the Soil Monitoring Law (Directive (EU) 2025/2360), as well as the PoLaRecCE strategy, is to reduce soil pollution to levels that are no longer considered harmful to human health and the environment. The practical implementation of the project strategy will contribute to the gradual improvement of soil conditions in the Békés County region and may be adopted in other regions touched with roadside soil, degraded by traffic pollution practice of Central Europe and the entire EU territory. This project represents one of the first comprehensive attempts to improve the quality of roadside soils to achieve healthy soil by 2050, given that soils host more than 25% of global biodiversity and constitute the second-largest carbon pool on the planet. Healthy soils, which capture and store carbon, also contribute to achieving the Union's climate objectives. The project also represents an important step toward enhancing biodiversity, ecosystem functions and services, ecological integrity, and connectivity, in line with the Convention on Biological Diversity.

Finally, the PoLaRecCE project strategy aims to develop innovative tools and approaches that support land management practices to better adapt degraded soils to the environmental, social, and economic needs of local communities. The guidelines developed within the project emphasize the need to assess soil condition before restoring its productive role to propose appropriate land management directions.

4.2 Effective environmental site assessment procedure (Ecological Services)

As a member of the PoLaRecCE project, PP4 WOODTECH applies the same approach to ecosystem services as the other project partners. Accordingly, there are many similarities in the aspects, but the values have been rethought.

Effective environmental site assessment procedure is a fundamental element in the development of strategies for the recovery of roadside soils (degraded by traffic pollutions) for purposes other than food production.

The starting point is:

1. Characterization of the site based on existing/current soil and climatic conditions. This characterization includes the following elements:

- Geographical location of the site (geographic coordinates, province, municipality, land use). Graphical representation is based on GIS tools.
- Climatic conditions (based on multi-year data) considering parameters such as length of the growing season, average annual air temperatures, average temperatures during the growing season, amount of precipitation during the growing season, length of the frost-free period).
- Current soil conditions (soil type and subtype, fertility class) include the determination of the degree of soil degradation based on national and EU legal acts (e.g. Directive (EU)

2025/2360) Determining the sources and causes of soil degradation based on historical data.

Environmental assessment of the site and its immediate surroundings, including the state of habitats and valuable existing fauna and flora species. Determining whether there are any protected areas nearby according to Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora; Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds.

2. Analysis of potential directions of land development and use within the framework of current environmental conditions and local land development and agricultural plans within individual municipalities, road- and railway authorities

Local land development plans should consider assumptions at the regional level. A Regional Climate and Energy Action Plan has been established for Békés County region in year 2020.

One of the goals of the European Union's climate and energy policy until 2030 is to increase the share of energy from renewable sources to at least 32% of gross final energy consumption. Energy plantations are part of this goal.

3. Ecosystem services

Soils are considered as important and strategic natural capital. Soil ecosystem services can bring provisions in nutrition, materials and energy, can bring also mediation of wastes, toxic elements. In addition, non-degraded areas can provide cultural services (physical, spiritual and symbolic interactions with soil biota or landscape). Quantity and quality of soil ecosystem services depend on proper management. On degraded areas soil cannot be capable to fulfill all its services, especially food production.

The determination of the potential of ecosystem services results from the implementation of the following stages:

- Initial State – Analysis of applicable legislation and strategic plans at the local and regional levels. Identification of existing obstacles and assessment of factors encouraging the development of degraded soils.
- Advanced stage – creation of recommendations and tools at the municipal level to support the management of degraded soils.
- Assessment of soil ecosystem services in each project.

Based on the above aspects and considerations, we have prepared the following table and its values, specifically for the properties of the phytoremediation pilot site.

1. Table: Example of table for assessment of soil ecosystem services, especially covered with phytoremediation forests

Ecosystem Services	*Service Importance Level of energy plantations*				
	Pivotal	*Important*	*Necessary*	*Not necessary*	*Irrelevant*
Provisioning services					
- *food*					*x*
- *water*	*x*				
- *genetical sources and medicines*		*x*			
- *wood*	*x*				
Regulating services					
- *clima and air*	*x*				
- *water and soil protection*	*x*				
- *pollination*	*x*				
Cultural services					
- *recreation and tourism*	*x*				
- *cultural values*	*x*				
Supporting services					
- *soil formation*	*x*				
- *nutrient cycling*	*x*				
- *photosynthesis*	*x*				

4.3 Considered solutions for the recovery of roadside soil degraded by traffic pollution

The selected land management direction for the Békés pilot site is the phytoremediation forest. We recommend establishing plantations for energy and fiber purposes with the following parameters:

- planting areas under 5,000 m2 (because at this point it is not yet legally considered a forest);
- maximum of 3 parallel rows, because such plantations are not considered forests;
- planting in close cooperation with the road or railway authority, because technical safety comes first (it is important to plant trees that do not spread lint, dangerous seeds or thorns);
- in addition to filtering air, dust, and noise, protecting the slopes next to roads/railways is also an important task, it must be salt-tolerant, extreme heat islands can form next to roads and railways, which the tree rows must also tolerate.

“Phytoremediation forest” is the name used in the project for this new type of wooded area, but in fact it is a tree-lined plantation, where the goal is specifically to create tree vegetation along roads and railways, on contaminated soils.

During the planning of the Békés experiment, we set up several alternatives. We chose the phytoremediation forest purposes, because the region has had very little available wood for centuries, and the forest cover is the lowest in Hungary.

Additional alternatives at the Békés pilot site:

- Energy plantation was an interesting option, but besides roads and railways, the main interest is the aesthetic appearance and durable green cover. Therefore, and due to the limited technical accessibility, this variation was discarded.
- One possible alternative was bamboo. However, this is a Far Eastern species, which is invasive, and several EU directives do not recommend its planting. It is very water-intensive, therefore not optimal.

- Miscanthus was also considered, but there is no infrastructure in the area to utilize the final product (chips). There were such plantations before, but they were not successful in the region. Miscanthus may be successful when mixed with trees, as it is non-invasive and provides a basic aesthetic appearance. Wood chips and miscanthus can be harvested together and make a good quality fuel when mixed.
- Energy grass breeding is taking place in the neighboring settlement of Szarvas. They are also experimenting with irrigation methods here. We were there for an on-site meeting. The end product is hay that can be used for energy purposes, but it can only be used in a boiler after baling. During baling, either plastic string or wire is put into the boiler room. Neither solution is optimal, so we rejected this one too.
- We did not want a classic forest because it's payback is slow, it causes numerous legal restrictions in the legal forest area, and the farmers did not like this solution.
- These areas are unsuitable for food production in several respects (pollution, technically difficult to access areas, small areas). We rejected another solutions for-food from the outset.

Based on the above considerations, we established a model phytoremediation forest with a quick cutting cycle for energy and fiber purposes, mixed with native and foreign species, specifically with seedling species. Thus, the cost of renovation after harvest is minimal, and the forest can withstand numerous rotations. The plantation provides an optimal solution for achieving the goals set out in the project from a nature conservation and environmental perspective.

Timber production is not a priority in the phytoremediation forests. However, we have selected tree species that include fast-growing, medium-growing and slow-growing species. For this reason, it is inevitable that there will be no timber that cannot or should not be harvested within a 5–10-year period. Timber production from these tree lines is typically not a priority for road and railway maintainers, but there are periods when it becomes important, and in an unstable period, substantial timber can be supplied to meet social firewood needs from such regionally significant tree line systems, without this endangering the survival of the tree lines.

4.4 Initiation and activation of local administration, road- and railway authorities

The target groups were defined within the project framework, related to this point:

- urban road management organizations (typically departments of local governments),
- regional road management authorities,
- regional track maintenance offices of national railway companies (there are two in Hungary).

The owners of the affected areas are typically the state or local government. The management of the areas is carried out by the road and railway authorities, while in the case of urban municipalities this is done by a separate local road department.

The activation of target groups, as well as active collaboration with local administrations, constituted a core horizontal activity of the PoLaRecCE project and was pursued through a combination of early engagement, targeted dissemination, and field-based cooperation.

The project objectives, governance structures, communication approaches, and the Interreg Central Europe framework were discussed with all relevant stakeholder groups. This established the basis for long-term cooperation focused on remediation and non-food land use. International meetings and events should be used to disseminate the project strategy among professional stakeholders, companies, and institutional representatives from the concerned sectors to increase its visibility and support networking activities relevant to soil restoration and land management.

Technical exchange visits to pilot sites where solutions have already been implemented, combined with meetings involving local authorities and stakeholder organizations, are an effective tool for knowledge transfer. Also, the field visits to see already existing solutions in different regions of CE are part of the PoLaRecCE activities. On-site discussions can facilitate the exchange of practical knowledge on soil diagnostics, pollution sources, and remediation options, while supporting the identification of site-specific challenges and opportunities for non-food land use. Educational and awareness-raising activities may serve as an important complementary pathway for long-term stakeholder engagement. Dissemination activities targeting high school students and the broader educational community are also part of this strategy.

Overall, the activation of local administrations and landowners should be achieved through consistent engagement, alignment with policy frameworks, and the combination of scientific expertise with practical, field-based interaction. These actions will strengthen cooperation between research institutions and local stakeholders and support informed decision-making for the revitalization of degraded and contaminated lands.

4.5 Influence of national legislative for implementation of „Action plan"

The strategy developed for roadside soils degraded traffic pollution and implemented at the Békés pilot site.

The Action Plan directly influences the creation of phytoremediation forests. The Békés County Development Plan includes green areas that can be established as part of community tree planting, for local energy and fiber wood production purposes, basically for community purposes. The project supports these synergies and common thinking on the subject
It is particularly important for road and railway authorities that green vegetation along roads is aesthetic and safe. The methods we developed in the project meet this requirement.

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5 PILOT SITE AND ECONOMIC DEVELOPMENT

5.1 Renewable backgrounds

In Hungary, the renewable energy mix has undergone drastic development in the last 10 years. Solar energy today accounts for about 20% of electricity production (solar energy is also used for heating). Classic wood burning still accounts for 30% in Hungary, which is a very high proportion. However, the price of firewood is low, as the price of piped residential natural gas is the lowest in Europe, which is why families typically use wood burning as a second solution, or only in very cold periods (supplementary heating), when they do not feel that gas burning is sufficient. As a result, the price of firewood is permanently low, and the demand is also permanent. When the price of natural gas creeps up (due to political uncertainty or drastic changes in the world market), the price of firewood will be high again. The market price of firewood fluctuates every 5-7 years, the last time the price was very high in 2022, now it is much more moderate, but the demand for it is stable.

The planting of these new types of tree rows is basically the phytoremediation of contaminated soils, and not the production of timber. However, trees grow in all conditions and produce timber (this is a special feature of the forests).

The new types of tree rows can also be planted with a spacing where cleaning (thinning) will be necessary at the age of 4-5 years, because the trees will become too dense. We have selected tree species that regrow after harvesting (coppice mode) and can grow again without requiring any treatment for this.

5.2 Financial model for investment

Within the framework of the project, different pilot area types will be tested. The Békés pilot site ("Pólus-halma" area) is managed by PP4 WOODTECH and the Dél-Alföld pilot site ("Szérüskert" area) is managed by PP8 Gyomai Gazdakör, in both cases we test and demonstrate woody vegetation. The WOODTECH pilot site concerns the revitalization of roads and railways and urban soils (in many cases technosoils) with trees, while the Gyomai Gazdakör pilot site (utilized and revitalized with energy plantations) is about degraded agricultural soils. These are two completely different biological-technical situations, with completely different properties. There are no universal solutions for the two areas, which is why we separated these two large areas when planning the project.

There is one common feature in the management of the two different pilot area types: we worked together with PP OIKON on the financial model of woody vegetations, and financially these two variants are almost completely identical. In the case of energy plantations, since 90%+ of the land users are private farmers, it was a high priority that each such plantation be competitive, generate a meaningful product and cash flow.

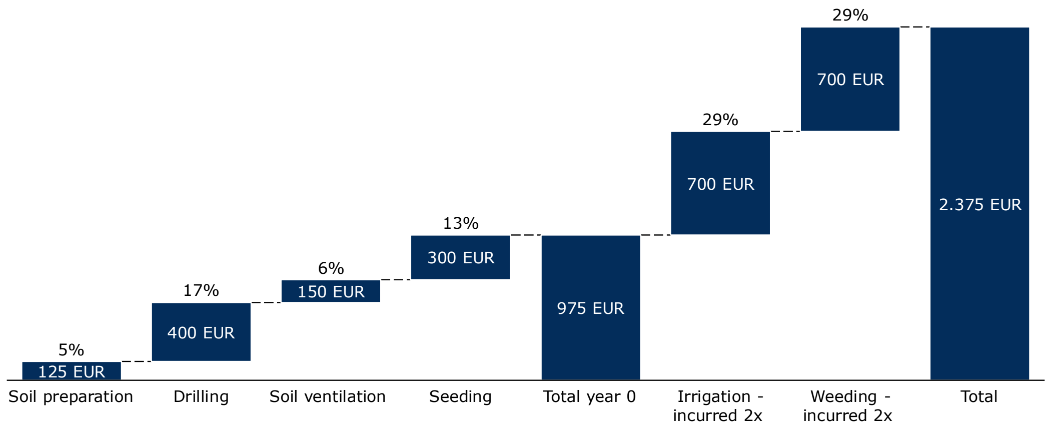
However, the phytoremediation forest model will be operated by 99%+ state road management organizations, state railways or local governments, where economic return is less or not at all a consideration. Nevertheless, we have shown that this model can be just as sustainable and economical as in the case of energy plantations.

Following the pre-feasibility assessment outlined in a previous document, wood biomass (mainly firewood) has been identified as a strategic solution for revitalising degraded land affected by soil overutilisation and pollution. The pilot targets a 2.700 sqm plot of land, which would demonstrate the feasibility of wood biomass for road- and railway maintenance organisations, and create additional green space for municipal residents. In this section we are presenting the financial model detailing the financial costs and benefits of the selected investment.

The total initial investment amounts to for a similar plantation is EUR 2.375. This represents the establishment phase capital expenditure required to prepare the degraded site and establish commercial wood biomass production. The investment breakdown comprises six principal cost categories, detailed in the table above, reflecting the specific requirements of establishing forestry operations on historically overutilized agricultural land. The modest investment scale makes this pilot accessible for farmer replication whilst demonstrating commercial viability.

13. Figure: Project investment costs (year 0-)

Cost category	EUR	Period
Soil preparation	125	Year 0
Drilling	400	Year 0
Soil ventilation	150	Year 0
Seeding	300	Year 0
Irrigation	350	Years 1-2
Weeding	350	Years 1-2
TOTAL	**2.375**	**Years 0-2**



Soil Preparation (EUR 125)

Soil preparation accounts for 5% of total investment and addresses the compacted soil resulting from decades of intensive agricultural use. The allocation covers several critical activities designed to create optimal conditions for tree establishment. The equipment used includes subsoilers or rippers that penetrate 30-40 cm depth without inverting soil horizons, preserving soil structure whilst alleviating compaction. Given the site's history of overutilisation, this preparation phase proves essential to ensuring adequate growing conditions for the selected tree species.

Hole drilling by robot (EUR 400)

Drilling represents 17% of investment and covers the creation of planting holes for seedlings. The allocation reflects mechanised drilling operations using tractor-mounted augers, which prove more cost-effective than manual excavation at pilot scale.

The drilling operation includes site marking to ensure proper spacing between trees, accounting for the mixed-species planting plan. Robinia, Ulmus, and Fraxinus require 2 m x 2 m spacing (2.500 trees/ha), whilst Populus uses wider 3 m x 3 m spacing (1.100 trees/ha).

Soil ventilation (EUR 150)

Initial soil ventilation accounts for 6% of investment and represents an innovative approach to addressing soil degradation without conventional deep ploughing. The technology employs compressed air injection at depth to create fracture networks that restore soil porosity and improve drainage. This method avoids the soil structure disruption associated with mechanical tillage, preserving beneficial soil biology whilst addressing compaction.

The allocation covers equipment mobilisation, operator time, and compressed air generation for treatment of the entire 2.700 m^2 area. This technology proves particularly valuable for the pilot's demonstration objectives, as it showcases modern soil management approaches applicable to degraded agricultural lands across the municipality.

Planting (EUR 300)

Planting represents 13% of investment and covers procurement of quality seedling material. The allocation includes purchase of bare-root seedlings of Robinia pseudoacacia, Ulmus minor, Fraxinus angustifolia, and Populus alba, selected for their adaptation to local conditions and fuelwood quality. The species mix (two-thirds Robinia/Ulmus/Fraxinus, one-third Populus) balances yield potential with species diversification, reducing biological risk whilst optimising revenue generation.

Seedling quality proves critical to establishment success and long-term productivity. The budget prioritises certified material from reputable nurseries, ensuring disease-free stock with well-developed root systems. One-year-old seedlings (height 60-80 cm) represent optimal balance between establishment success and cost. The allocation includes contingency stock (10% oversupply) to replace any mortality during the establishment phase, ensuring target planting density is achieved.

Irrigation (EUR 700 – invested over 2-year period 350 EUR each year)

Irrigation accounts for 29% of total investment, reflecting the critical importance of water availability during the establishment phase. The allocation covers two growing seasons (Years 1-2) of supplemental irrigation to ensure seedling survival and promote vigorous growth. Young trees prove particularly vulnerable to water stress, and adequate moisture proves essential for root development and canopy establishment.

The budget encompasses both infrastructure and operational costs. Basic irrigation equipment includes water storage tanks, distribution pipes, and manual or low-cost automated delivery systems suited to the pilot scale. Operational costs cover water supply, system maintenance, and labour for monitoring soil moisture and adjusting irrigation schedules. The allocation assumes supplemental irrigation during dry periods rather than continuous watering, reflecting the species' drought tolerance once established. From Year 3 onwards, trees rely on natural rainfall, eliminating ongoing irrigation costs.

Weeding (EUR 700 – invested over 2-year period 350 EUR each year)

Weeding represents 29% of investment and addresses competition from herbaceous vegetation during the critical establishment phase. Young trees compete poorly with aggressive weeds for light, water, and nutrients. Without adequate weed control, establishment failure rates increase substantially, and growth rates decline, delaying the first harvest and reducing long-term productivity.

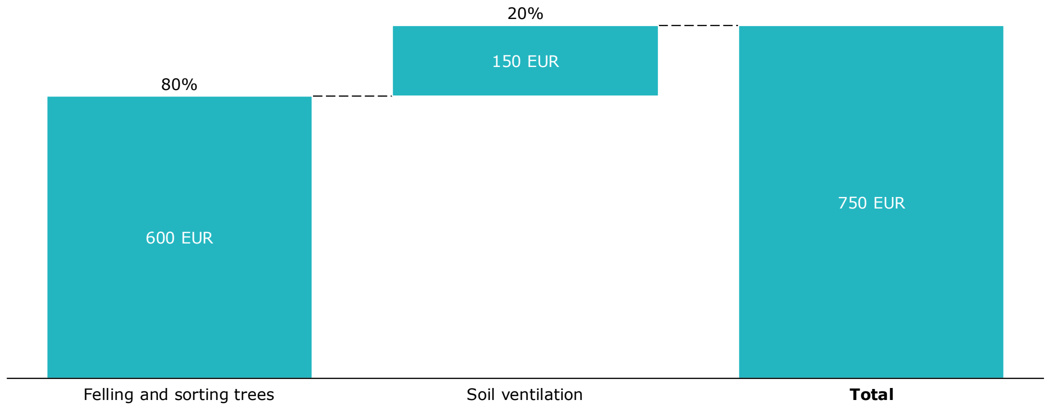
The allocation covers two years of intensive weed management using manual or mechanical methods. Manual weeding around individual trees prevents damage to seedlings whilst removing competing vegetation in the critical root zone (1 m radius). Between-row weeding uses mechanical cultivation or mulching to suppress weed germination. The labour-intensive nature of this operation explains the substantial allocation, with approximately 4-6 interventions required annually during the establishment phase.

From Year 3 onwards, tree canopy closure significantly reduces weed pressure, and the root systems prove sufficiently developed to outcompete herbaceous vegetation. This transition eliminates ongoing weeding requirements, substantially reducing maintenance costs. The front-loading of weeding costs during establishment reflects biological reality: investing in early vegetation control proves far more cost-effective than attempting to remediate establishment problems later.

The investment structure reflects the perennial nature of forestry operations, where substantial upfront capital establishes productive capacity that generates returns over extended periods. The municipality's access to PoLaRecCE funding eliminates financial barriers for the pilot whilst demonstrating commitment to innovative land use solutions. The modest EUR 2.375 investment makes farmer replication economically feasible, particularly when scaled to larger areas where per-hectare costs decline through economies of scale.

14. Figure: Operational costs (every 5th year)

Cost category	EUR
Felling and sorting trees (labour)	600
Soil ventilation	150
TOTAL	**750**



Following the establishment phase, the plantation transitions to a five-year harvest cycle. Trees are felled and sorted in Year 5, Year 10, Year 15, and continue every five years thereafter. The operational cost structure reflects the periodic nature of forestry operations, with costs incurred only during harvest years.

Felling and sorting trees, harvesting (EUR 600 base)

Felling and sorting constitute 80% of operational costs and represent the primary recurring expense. The allocation covers semi-mechanised harvesting operations suited to the pilot scale. Harvesting teams use chainsaws for felling, followed by delimbing, crosscutting to standard lengths (typically 1 m for firewood), and sorting by diameter class and species.

Labour requirements vary with yield, creating natural cost scaling. The base EUR 600 assumes 25 m^3 harvest volume (Year 5 level), with labour productivity of approximately 3-4 m^3 per person-day for manual operations. As yields increase to 30 m^3 (Year 10) and stabilise at 35 m^3 (Year 15+), labour costs scale proportionally. The model accounts for this through inflation indexing, which approximates the volume-driven cost increases whilst avoiding complexity.

The allocation includes on-site stacking of sorted material, facilitating collection by buyers or municipal transport. For farmers considering replication, this cost component proves highly flexible: own labour can substitute for hired workers, substantially reducing cash outlays. This flexibility enhances economic viability for smaller operators whilst maintaining commercial feasibility at scale.

Soil ventilation (EUR 150 base)

Soil ventilation accounts for 20% of operational costs and represents the second component of the harvest cycle. Following each cutting cycle, the site receives soil ventilation treatment to restore porosity and prepare for regeneration. The regrowth of trees from stumps after harvest drives the economic model, eliminating replanting costs and accelerating subsequent rotations.

Soil ventilation between rotations serves multiple functions. It alleviates any compaction caused by harvest operations (equipment traffic, log extraction), improves water infiltration to support new development, and creates favourable conditions for root expansion from the established stump system. The mature root network present after the first rotation significantly enhances subsequent growth rates.

The operational cost structure demonstrates the economic efficiency of forestry compared to conventional agriculture. Costs occur only every five years, eliminating annual input requirements (fertiliser, pesticides, fuel for tillage). This periodic structure suits absentee landowners unable to provide continuous management whilst generating positive cash flow.

2. Table: Revenue projections

Parameter	Robinia/Ulmus/Fraxinus (m^3)	Populus (m^3)
Year 5	16,67	8,33
Year 10	20,00	10,00
Year 15+	23,33	11,67
Base Price (Year 1)	EUR 80/m^3	EUR 40/m^3
Annual Price Escalation	5%	5%
Total Revenue Year 5	**2.127,14**	
Total Revenue Year 15	**4.850,83**	
Total Revenue Year 30	**10.084,53**	

The plantation generates revenue through firewood sales on a five-year rotation cycle. Revenue projections account for biological yield increases as trees mature, species-specific pricing differentials, and conservative price growth assumptions reflecting long-term market dynamics. The revenue structure demonstrates strong growth over the 30-year planning horizon, driven by yield stabilisation and sustained price appreciation.

Yield projections reflect the biological development pattern of forestry agriculture. The first rotation (Year 5) generates 25 m^3 total yield (16,67 m^3 Robinia/Ulmus/Fraxinus, 8,33 m^3 Populus), representing establishment phase productivity. This initial harvest validates the species selection and site suitability while still providing revenue.

The second rotation (Year 10) demonstrates the productivity gains from regrowth from the established stumps. Yields increase to 30 m^3 (20,00 m^3 Robinia/Ulmus/Fraxinus, 10,00 m^3 Populus), representing 20% growth. This improvement reflects the mature root system's capacity to support vigorous new growth.

From Year 15 onwards, yields stabilise at 35 m^3 (23,33 m^3 Robinia/Ulmus/Fraxinus, 11,67 m^3 Populus), representing full biological potential under the five-year rotation regime. This plateau reflects the equilibrium between stump vitality, new growth, and rotation length. The consistent 35 m^3 yield from Year 15 onwards simplifies long-term revenue forecasting and demonstrates sustainable productivity without degradation.

Pricing Structure

Firewood pricing reflects species quality differentials and market positioning. Robinia, Ulmus, and Fraxinus command EUR 80/m³ wholesale, reflecting high calorific value, low moisture content, and excellent burning characteristics. These hardwood species produce long-lasting heat with minimal smoke and ash, making them premium products for residential heating. Populus, whilst faster growing, yields EUR 40/m³ due to lower density. The species mix (two-thirds premium, one-third economy) generates weighted average pricing of EUR 66,67/m³.

These wholesale prices assume sales to distributors such as DALERD Délalföldi Erdészeti Zrt or direct sales to bulk consumers. The pricing structure incorporates 5% annual growth, reflecting long-term firewood market dynamics. Hungarian consumer firewood prices increased 9% annually from 2000-2024, but the model deliberately adopts conservative 5% growth. This is done account for increased biomass production capacity, potential substitution by other renewables, market saturation, and the fact that the model does not sell directly to consumers, rather it uses the distributor system hence the same price cannot be given.

3. Table: Financial assumptions

Assumption	Value
Inflation Rate (Costs)	3% per annum
Price growth rate	5% per annum
Discount Rate	6% per annum
Corporate Income Tax Rate	10%
Project Timeline	30 years
Harvest cycle	5 years

The financial model employs a conservative assumption framework appropriate for a municipal pilot intended to demonstrate commercial viability to private farmers. Each parameter reflects careful consideration of local conditions, national policy objectives, and biological constraints inherent to forestry systems.

Discount Rate (6%)

The 6% discount rate exceeds typical municipal project rates (3-4%) to reflect three specific risk factors. First, the periodic cash flow structure creates timing risk compared to annual revenue systems. Second, the farmer replication objective introduces implementation risk beyond the pilot itself. Third, biological yield variability creates revenue uncertainty even under competent management. The 6% rate approximates the Weighted Average Cost of Capital (WACC) for small-scale agricultural enterprises in Hungary, ensuring the model generates returns sufficient to attract private farmer participation.

Inflation Rate (3%)

The 3% inflation assumption aligns with European Central Bank medium-term price stability targets. Hungary experienced elevated inflation (2022: 14,6%, 2023: 17,0%) following energy price shocks, but these peaks represent temporary deviations from long-term trends. The 3% rate drives operational cost escalation through labour wage indexing and input price increases.

Price Growth Rate (5%)

The 5% firewood price growth assumption represents deliberately conservative modelling despite stronger historical performance. Hungarian consumer firewood prices increased 9% annually from 2000-2024, but the model reduces this to 5% to account for expanded biomass plantation capacity, potential renewable technology substitution, market maturation, and international competition. Furthermore, the 9% increase reflected the consumer price inflation, which we cannot fully take into account in this model, as we do not envisage direct consumer sales, rather we chose to sell wholesale and through distributors, both require a reduction in price growth. The 5% rate exceeds inflation (3%), generating 2% real price appreciation reflecting biomass's role in energy transition strategies.

Corporate Tax Rate (9% or 10%)

The 10% corporate tax rate reflects Hungarian taxation on business activities and small-scale agricultural enterprises (basic level is 9%, but it is some modifying aspects in corporate taxation). The model applies tax to EBITDA rather than net income, creating conservative tax burden estimates whilst avoiding complexity around depreciation schedules and capital allowances.

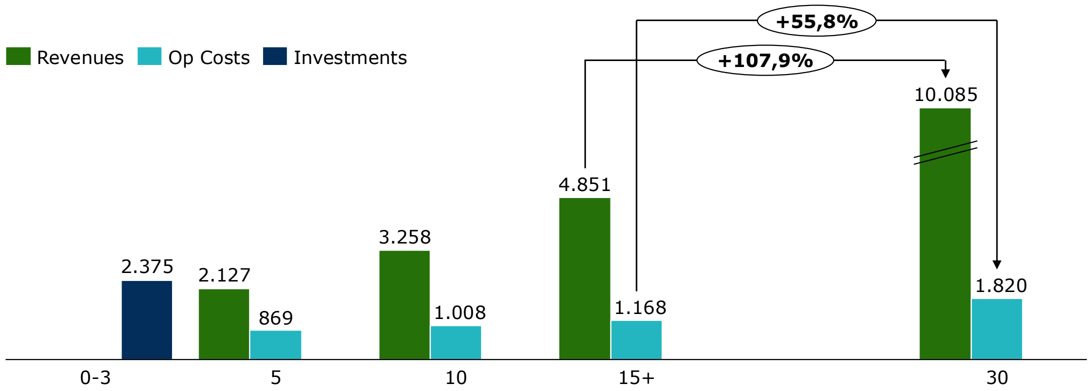
Project timeline (30 years)

The 30-year planning horizon captures six complete harvest cycles, demonstrating long-term sustainability and productivity trends. This duration aligns with municipal capital planning timeframes and exceeds typical farmer investment horizons, providing comprehensive assessment of biological and economic performance. Thirty years also matches realistic tree longevity under five-year rotations, after which we expect the plantation will no longer be productive.

Harvest Cycle (5 years)

The five-year harvest cycle represents optimal balance between biological growth, economic return, and management simplicity for the selected species. Five-year rotations suit Robinia, Ulmus, Fraxinus, and Populus growth characteristics: stems reach 8-12 cm diameter, suitable for firewood processing, whilst maintaining vigorous regrowth capacity.

15. Figure: Assumption summary



The chart above projects the relevant project investment assumptions in the first 3 years, as well as first three harvest cycles. Furthermore, it showcases the projected growth in prices and costs due to inflation between the year 15 and year 30.

Revenue assumptions demonstrate strong growth trajectory over the planning horizon. Year 5 gross revenue of EUR 2.127 reflects the combination of initial 25 m³ yield and five years of 5% annual price growth. This is done as the prices are influenced by external factors not related to our project, we need to consider that our revenue is "on-the-spot" revenue realised after harvest based on market prices at that time.

Year 10 gross revenue increases to EUR 3.258, driven by higher yield (30 m³) and continued price appreciation.

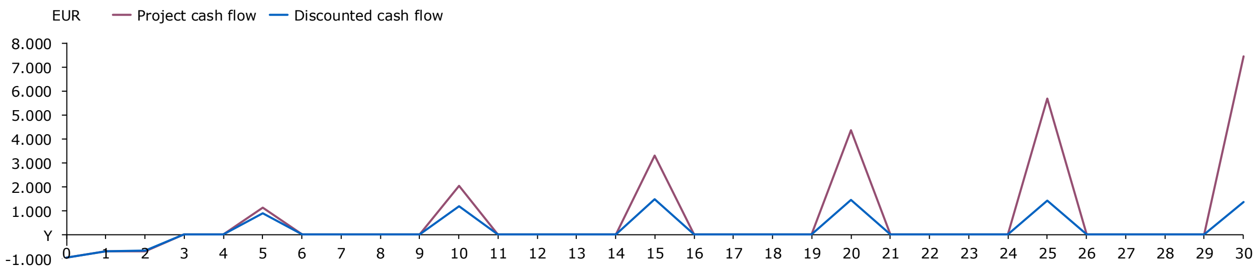
From Year 15 onwards, revenues accelerate as both yields stabilise at maximum biological potential (35 m³) and prices continue compounding. This progression demonstrates the long-term value creation potential of forestry systems, where biological productivity stabilises whilst market prices continue rising.

The operational costs are incurred only at harvest cycles, as outside of harvests and the initial investment period the plantation is self-sufficient and does not require maintenance. This makes it perfectly suited for supplemental business in the ongoing agricultural operation, or for someone who is not able to fully dedicate their time to agriculture. Similarly to revenue, operational costs are subject to annual growth of 3%, which again occurs outside of the project and is modelled as such. The harvests costs are larger than baseline estimates as we take into account the time spent between the harvests.

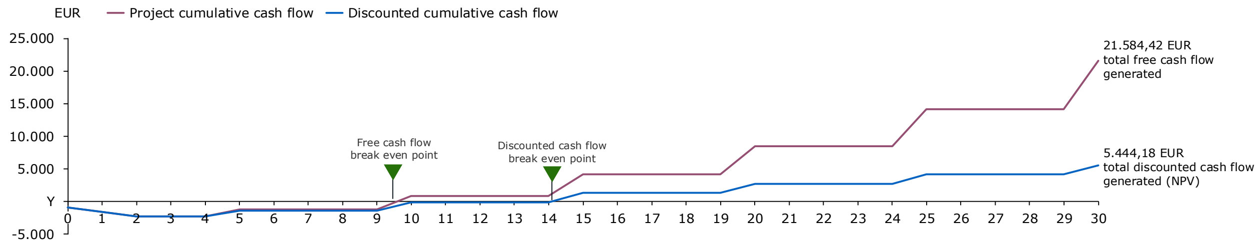
Investment costs on the other hand occur in the initial three years of operations, as it is explained in the investment portion of this chapter. They are accounted at the beginning and there is no recognised need for subsequent investments after the initial period.

Financial model results and interpretation

16. Figure: Projected project cash flow (free and discounted)



17. Figure: Projected project cumulative cash flow (free and discounted)



Metric	EUR
Net Present Value (NPV)	4.071,51
Internal Rate of Return (undiscounted)	14,01%
Internal Rate of Return (discounted)	7,80%
Money Multiple	2,11
Payback Period (undiscounted)	10 years (2nd harvest)
Payback Period (discounted)	15 years (3rd harvest)
Total Cumulative Cash Flow (30 years)	**21.584,42**
Total Discounted Cumulative Cash Flow (30 years)	**4.999,59**

The table above, and the two charts, summarise the key financial performance metrics derived from the 15-year financial model.

Year 0-5: Establishment Phase

The project begins with negative cash flow as establishment costs accumulate. By Year 2, cumulative cash outflow reaches EUR 2.375. The plantation then enters dormancy until Year 5, when the first harvest generates EUR 1.132 net revenue. This initial return recovers 48% of total investment, reducing cumulative deficit to EUR 1.243.

Year 6-15: Growth Phase

The Year 10 harvest yields EUR 2.025, pushing cumulative cash flow positive at EUR 782. This marks the undiscounted payback point. Year 15 contributes EUR 3.314, reflecting both yield maturation and 5% compounded price growth. By Year 15, cumulative cash flow reaches EUR 4.096, generating return multiple of 1,72× on the EUR 2.375 investment.

Year 16-30: Maturity Phase

Yields stabilise at 35 m^3 but revenues continue growing through price appreciation. Year 20 delivers EUR 4.353, Year 25 generates EUR 5.698, and Year 30 produces EUR 7.438. By project end, cumulative cash flow totals EUR 21.584, achieving 9,10× return on investment without discounting.

The undiscounted NPV of EUR 19.209 demonstrates strong absolute returns. Discounting at 6% reduces this to EUR 4.072, still representing 171% return on the EUR 2.375 investment. The discounted IRR of 7,80% exceeds the discount rate, confirming positive economic value.

The 15-year discounted payback period aligns with typical forestry investment horizons. For municipal planning, the 10-year undiscounted payback provides a clearer milestone. However, what needs to be noted is the fact that the harvest cycles means that for 5 years the plantation is dormant. For this reason we should also note that the discounted payback period is in 3rd harvest, where the plantation reaches biological maturity, after which it is generating pure return. On the other hand the undiscounted payback is in 2nd harvest, even before the biological maturity is reached.

These metrics confirm financial viability under conservative assumptions. The model withstands price growth reductions to 3% (from 5%) whilst maintaining positive NPV, though payback extends beyond Year 20. This sensitivity indicates robust fundamentals despite periodic cash flow structure.

5.3 Cost-benefit analysis

The financial analysis demonstrates strong economic returns with NPV of EUR 4.072 and IRR of 7,80% (undiscounted IRR 14,01%). However, the true value proposition extends considerably beyond monetary metrics. The investment delivers environmental, social, and strategic benefits that strengthen the investment case and position the project as a catalyst for broader municipal development.

Green Space Creation and Urban Amenity

Unlike agricultural landscapes that dominate Gyomaendrőd, the plantation creates accessible green space without land use conflict. Mature trees provide shade, noise absorption, providing an ideal area for a municipal park or outdoor sports area. This arrangement addresses a frequent planning tension: municipalities need green infrastructure but face budget constraints for non-revenue land uses. The biomass plantation resolves this by generating income whilst delivering ecosystem services. Residents gain recreational space without additional municipal expenditure, a compelling model for peri-urban areas were agricultural zoning limits park development.

Soil Restoration and Agricultural Sustainability

The pilot site exemplifies soil overutilisation from decades of industrial farming. Continuous cropping with heavy machinery compacted the soil, reducing water infiltration and root penetration. The plantation reverses this degradation through three mechanisms: deep-rooted tree species break up compaction layers, organic matter from leaf litter rebuilds soil structure, and periodic soil ventilation restores porosity.

For farmers, this presents a soil rehabilitation strategy that generates revenue during the recovery period. Rather than leaving degraded plots lay dormant, sacrificing income for multiple years, farmers can plant biomass species that actively improve soil whilst producing marketable output. After 15-20 years, plots can return to food crop rotation with restored fertility, having generated EUR 10.000-15.000 in net revenue during the restoration phase. This economic buffer removes a key constraint to adopting restorative practices: farmers need income during soil rest periods.

The soil restoration benefits extend beyond individual plots. Municipality-wide adoption could rehabilitate hundreds of hectares of degraded agricultural land, rebuilding the productive asset base for future generations.

Emigration Resilience and Absentee Land Management

Gyomaendrőd experiences significant emigration to Budapest and abroad, leaving land parcels unused as owners lack time or capacity for cultivation. Traditional crops demand regular attention: planting, pest management, irrigation, harvest, all requiring physical presence or hired labour. This makes conventional farming unviable for absentee owners, resulting in abandoned plots that degrade further through weed invasion and erosion.

Biomass plantations require labour only at planting (Year 0) and harvest (every five years). Between these events, minimal intervention suffices. For emigrants maintaining property, this enables productive land use without continuous management. Furthermore, the project enables full absentee land management through the use of hired labour, which is needed only twice per decade, making the economics manageable even with coordination costs of EUR 200-300 per intervention for contractor engagement. This model transforms stranded assets into income-generating holdings.

At municipal scale, enabling productive use of absentee-owned land preserves the agricultural land base and maintains tax revenues from productive use. Properties abandoned to weed growth generate no economic activity and require municipal intervention to prevent fire hazards or pest management. Biomass plantations convert these liabilities into assets, stabilising the rural economy despite demographic pressures.

Energy Security and Import Substitution

Gyomaendrőd currently imports firewood and biomass from external suppliers, incurring logistics costs that inflate local heating expenses. Long-haul transport from forested regions adds 15-25% to wholesale prices, a burden particularly acute for lower-income households dependent on wood fuel. Local production eliminates transport premiums, with firewood available at EUR 66,67/m³ base price (Year 0), rising to EUR 85/m³ by Year 5 and EUR 132/m³ by Year 30. These prices remain below delivered import costs throughout the planning horizon, generating 10-15% savings for bulk buyers.

The municipality can also use output for social programmes: distributing firewood to vulnerable households as winter fuel assistance. Allocating 5-10 m³ annually (14-29% of Year 5 yield, 6-12% of Year 30 yield) addresses energy poverty whilst converting cash welfare expenditure into internal circulation. This social use creates multiplier effects: rather than exporting EUR 500-1.000 annually to distant suppliers for welfare firewood, the municipality pays local contractors for harvesting whilst retaining wood for distribution. The harvesting income employs local labour, creating secondary economic activity.

Scaling the pilot across multiple farmers strengthens these effects. With 100 hectares under biomass (achievable with 10-15 participating farmers replicating the model), annual output would reach 14.000 m³ at maturity (400 ha × 35 m³/ha ÷ 5-year cycle). This supply cushion stabilises local prices and reduces vulnerability to supply chain disruptions or price volatility in external markets. The 5 year cycle can be offset by staged implementation of the reforestation projects, ensuring that some plots mature each year, enabling steady supply of firewood for the municipality.

Innovation Demonstration and Technology Transfer

The pilot incorporates soil ventilation technology, an emerging practice in central European forestry. Rather than deep ploughing (which further damages compacted soil), ventilation uses targeted aeration to restore porosity without mechanical disturbance. This technique remains uncommon in Hungarian agriculture, where traditional tillage dominates despite mounting evidence of soil structure damage.

By testing this approach in a municipal setting, the project creates a demonstration site for local farmers. Visitors can observe soil improvement outcomes, compare establishment costs against conventional methods (subsoiling: EUR 200-250/ha vs ventilation: EUR 150-180/ha plus superior results), and assess applicability to their own holdings. This reduces adoption barriers for innovations that lack local track records.

The demonstration value extends beyond technique to mindset: showing farmers that degraded land retains economic potential. Many landowners view compacted plots as permanently damaged, suitable only for low value uses (grazing, hay). The pilot challenges this assumption, demonstrating that appropriate interventions restore productivity for commercial forestry. This psychological shift proves as valuable as technical knowledge, rebuilding confidence that drives investment in land improvement.

Climate Mitigation and Carbon Sequestration

Though not quantified in the financial model, the plantation sequesters atmospheric carbon in biomass and soil. Over 30 years, 210 m^3 harvested across six rotations (35 m^3 × 6) represents approximately 150-180 tonnes CO_2 equivalent stored and released through combustion, with additional permanent sequestration in roots and soil organic matter estimated at 30-50 tonnes CO_2e. This contribution aligns with Hungary's 2030 climate commitments (40% greenhouse gas reduction vs 1990, 21% renewable energy share) without requiring carbon credit monetisation.

The substitution benefits deserve emphasis: local firewood displaces fossil heating fuels (natural gas, heating oil) or long-distance wood imports. Each cubic metre of local firewood avoids 0,6-0,8 tonnes CO_2e from fossil fuel combustion or 0,1-0,2 tonnes CO_2e from transport emissions.

Scaling to 100 hectares (40 pilot-equivalent units) generates 7.200-9.200 tonnes CO_2e benefit, equivalent to removing 1.500-2.000 passenger vehicles from roads annually. This positions Gyomaendrőd as a contributor to national climate goals whilst generating local economic activity, demonstrating the feasibility of aligning environmental and economic objectives.

Financial Conclusions

The cost-benefit analysis confirms that financial returns, whilst strongly positive (NPV EUR 4.072, IRR 7,80%, 15-year payback discounted), constitute only part of the value proposition. Green space provision converts degraded land to community amenity. Soil restoration rebuilds productive capacity for future agricultural use. Emigration resilience enables absentee owners to maintain productive holdings. Energy security reduces import dependence and stabilises local prices. Technology demonstration accelerates innovation adoption. Climate mitigation contributes to national environmental goals.

These co-benefits collectively generate social returns exceeding direct financial metrics. For Gyomaendrőd municipality, this justifies public investment even under conservative financial scenarios. For private farmers, the financial model alone suffices (2,11× money multiple, 7,80% IRR), with co-benefits providing additional rationale. The pilot's dual function as proof-of-concept and operational revenue source positions it as a scalable solution to interrelated challenges: soil degradation, demographic change, and energy transition.

We have made a mainly similar calculation for tree rows as the one made by the GYOMAI GAZDAKÖR for the revitalization of degraded agricultural areas. This is because the tree species and methods vary, but the wood that can be extracted is ultimately almost the same for both places. Forestry (including urban forestry) is fundamentally a primary production activity, with a modest but stable source of income, and well-planned return conditions.

5.4 Site specific actions for “Békés” pilot site

The best solution for revitalizing polluted soils along roads and railways is planting tree rows. We also examined other options (grassing, bamboo, miscanthus, industrial hemp), but we decided on afforestation because it has a real potential in the Greater Central European Region (which also covers the INTERREG-CE region). The raw materials (seedlings, mulch) and the necessary expertise are available for this.

When creating, maintaining and dismantling the tree row, we recommend following the technical steps described in this document. Each country has its own unique regulatory environment for the creation and maintenance of tree rows, and several EU rules also apply to them. These regulations can be ensured by the local eco-government, road and railway maintenance organizations.

With thorough preparation (good seedlings, mulching, irrigation, wildlife protection), these forest trees will start growing quickly and the tree row will remain productive for a long time. Maintaining tree rows has been possible for centuries, and each tree species is naturally viable for different periods of time. That is why we mix them, because there are trees that are viable for a short time (e.g. willows, which typically dry out after 20-30 years), and there are those that live for a longer time (e.g. ash or maple, which can be viable for several hundred years). New trees can be planted later to replace extinct pioneer species (willow, poplar), and if a part of the stand is harvested every 5 years, then the roots of each tree will remain alive for a longer time anyway due to renewal.

One of the basic ideas of the project was to develop a new system that does not require special expertise, special machines and materials, or special conditions.

Communities can safely install, maintain and harvest (only thinning) new types of tree rows with their own machines and expertise. As part of the project, we are also planning training for employees of local governments, road maintenance and railway maintenance organizations.

5.4.1 Initial site assessment and selection

In Hungary, no permit is required for the installation of tree rows and tree plantations under 5000 m^2. In the case of areas above this limit, a simple notification to the government office is required. The selection of tree species and the planting network require planning.

These tree-rows are broken wherever there is a connecting road, ditch or any terrain obstacle. For this reason, these tree rows practically do not reach this spatial dimension anywhere (continuously 5000 m^2). Strips next to public roads and railways are typically considered construction areas, and trees can be planted freely on them. Prior permission is typically not an obstacle, since no one's interests are violated by a new tree row.

The pilot site area was a former agricultural area, between the main traffic route no. 47 Gyomaendrőd and the double-track main railway line between Budapest and Lőkösháza. The northern side of the area is an archaeological site, as there was also a kurgan there. There are no archaeological restrictions on the southern side of the area where the model plantation was established.

The area has undergone thorough soil testing. Our planting strategy was developed considering this.

5.4.2 Implementation procedure (rehabilitation and plantation establishment)

When planting trees, we do not perform special, full-area soil preparation. It would be possible to use strip soil milling, but there are often very diverse micro-surface changes along roads/railways, so this is typically not a viable route. Here, a unique tree planting must be planned, technically like a large-scale fruit tree plantation or a large-scale poplar plantation.

We use a hole-drilling machine (hand tool or tractor) for planting, but in the case of small-rooted trees, a manual planting tool (wedge spade, planting tree) is also suitable.

The seedlings to be planted can be bare-rooted or covered-rooted (ground-balled). The spacing between plants is 3 meters as standard, but it can be rarer on request.

A special solution can be acorn planting, in nests. This can create a very resistant oak stand, which is a slow-growing tree species, but direct acorn planting can be a safe solution for establishing a tree row. Oak tree rows must be mixed with fast-growing tree species to achieve a spectacular and rapid effect. In this project, we did not examine the economic effects of tree rows that can be established with oak acorn planting.

A special soil preparation method is soil aeration. During this, 12 bars of compressed air is forced into the soil at a depth of approx. 80 cm. Thanks to the design of the spike, the air drastically increases the macroporosity of the soil at a depth of approx. 1.2-1.5 meters, cuts off the roots and ensures that winter precipitation can penetrate the lower layers of the soil. The process was first tested by PP4 WOODTECH in forestry conditions in a large area. The results obtained were of great value, since after the treatment the growth of the trees doubled in the summer, which means that the condition of the trees improved drastically. The treatment has an effect for about 4-5 years, after which the soil can be aerated again. The procedure is often successfully used in our country for horticultural crops (typically in vineyards and orchards), but it also works excellently with forest tree species.

The trees receive a unique protection, which is a biodegradable or subsequently collectable plastic net (120-150 cm high against wild animals). The net is held by a 180 cm long bamboo pole, which is drilled into the ground to a depth of 40 cm, and the net is attached to it with a quick-release fastener.

After planting, the mulch (wood chips) is spread around the trees in a 50 cm radius and 10 cm thick (Figure 17). This blocks the spread of weeds for two years and keeps the soil under the mulch moist all summer long. This is especially important during dry seasons when there is not enough summer rainfall.

18. *Figure: Photograph showing soil ventilation at the pilot site*

19. *Figure: Robot drilling holes at the pilot site*

20. Figure: Mulching performed

5.4.3 Maintenance and annual care

Trees can be watered by bag irrigation, drip irrigation, or from a tanker truck. Community irrigation is also possible if it is in a residential area (with a little organizing work, a temporary watering community can be organized from residents, where everyone waters the trees on different weekends. This solution is an excellent task-sharing method and is very effective.

Tree care consists of phytosanitary monitoring, such as pruning and replacing infected seedlings. Trees require special attention during the growth phase, but this is more of a passive observation than an active intervention.

Below you will find some basic insights into the fertilization requirements of the selected experimental site.

NITROGEN-tests

4. Table: Austrian guidelines for Nitrogen

Austrian guidelines for considered fertilization in agriculture and greenland:			
TABLE 9: CLASSIFICATION OF NITROGEN MINERALIZATION POTENTIAL BASED ON ANAEROBIC MINERALIZATION, MINERALIZATION POTENTIAL ACCORDING TO EUF NORG, AND HUMUS CONTENT			
Classification of Mineralization Potential	**Anaerobic N-Mineralization (mg N / 1000 g fine soil per week)**	**Mineralization Potential according to EUF Norg (mg / 100 g fine soil)**	**Classification according to Humus Content (%)**
low	< 35	< 1.5	< 2
medium	35 – 75	1.5 – 2.5	2 – 4.5
high	> 75	> 2.5	> 4.5

5. Table: Pilot site values for Nitrogen

	Nmin (kg/ha)
HUNGARY	
FIELD 1: Woodtech	
GYO 1	43,68
GYO 2	30,58
GYO 3	18,92
GYO 4	14,76

6. Table: Guideline for fertilization with Nitrogen in kg N/ha at medium yiedl expectation (in German)

		kg N/ha
Getreide	Weizen, Durum	110 - 130
	Roggen	80 - 100
	Dinkel	80 - 100
	Winterfuttergerste	100 - 120
	Winterbraugerste	70 - 90
	Triticale	90 - 110
	Sommerfuttergerste	80 - 100
	Sommerbraugerste	50 - 70
	Hafer	70 - 90
Hackfrüchte	Mais (CCM, Körnermais)	120 - 140
	Silomais	140 - 160
	Zuckerrübe	110 - 140
	Futterrübe	120 - 140
	Speisekartoffel, Industriekartoffel	130 - 150
	Früh- und Pflanzkartoffel	90 - 110
	Körnerhirse/-sorghum	120 - 140

The measurements showed that the N content in the soil is low. Based on the Austrian and Hungarian recommendations, a N supply of 0-40 kg is recommended. In forestry, fertilizers are usually not applied (except for seedling production). In the case of a plantation, fertilization is possible, but in this case not in the entire area, only next to each planted tree. It can be applied directly under the mulch, at the same time as planting (by spoon dosing, proportionally redistributing the required amount calculated for the area).

In the pilot site area, the N value in the upper 20 cm level was above 43 kg/ha. This is at a minimum level, but the measured N in the following layers was low. Ploughing was not performed at the pilot site. At the final stage (during the installation) N supplementation was not applied. It is planned to carry out another soil ventilation treatment when the plantation is 2-3 years old, then liquid N fertilizer will be distributed into the deep soil layers using air at a pressure of 12 bar.

PHOSPHOR and POTASSIUM tests

7. Table: Austrian guidelines for P and K levels

Austrian guidelines for considered fertilization in agriculture and greenland:						
Assessment of Phosphor content:						
		Agriculture	**Greenland**			
	Nutrient supply		mg P/1000 g			
Content class						
A	very low	< 26	< 26			
B	low	26 - 46	26 - 46			
C	adequate	47 - 111	47 - 68			
D	high	112 - 174	69 - 174			
E	very high	> 174	> 174			
Assessment of Potassium content:						
		Agriculture			**Greenland**	
		Clay content (%)			mg K/1000 g	
	Nutrient supply	light	medium	heavy		
Content class		< 15	15 - 25	> 25		
A	very low	< 50	> 66	> 83	< 26	
B	low	50 - 87	66 - 112	83 - 137	26 - 46	
C	adequate	88 - 178	113 - 212	138 - 245	47 - 68	
D	high	179 - 291	213 - 332	246 - 374	69 - 174	
E	very high	> 291	> 332	> 374	> 174	

8. Table: Pilot site values for P and K

	Phosphor (mg/kg)	Potassium (mg/kg)
HUNGARY		
FIELD 1: Woodtech		
6_GYO1	41,62	201,60
7_GYO2	30,58	140,96
8_GYO3	24,63	151,51
9_GYO4	24,61	186,51

9. Table: Guideline for fertilization with Phosphor and Potassium at content class C (in German)

Tabelle 41: Richtwerte für die Düngung mit Phosphor und Kalium bei Gehaltsklasse C (Angaben in kg/ P_2O_5 bzw. K_2O/ha und Jahr)

	Kultur	P_2O_5	K_2O
Getreide (Weizen, Durum - Weizen, Roggen, Wintergerste, Dinkel, Triticale, Hafer, Sommergerste)		55	80
Hackfrüchte	Mais (CCM, Körnermais)	85	200
	Silomais	90	225
	Zuckerrübe	85	320
	Futterrübe	85	320
	Speise- und Industriekartoffel	65	200
	Früh- und Pflanzkartoffel	60	180
	Körnerhirse/-sorghum	85	210
	Silohirse/-sorghum	95	375
Öl- und Eiweißpflanzen	Körnererbse	65	100
	Ackerbohne	65	120
	Sojabohne	65	90
	Körnerraps	75	200
	Sonnenblume	65	200
	Ölkürbis	50	180
Zwischenfruchtfutterbau	mit und ohne Leguminosen	25	80
Sonderkulturen	Mohn	55	100
	Kümmel	60	80

10. Table: Correction factor to be considered for the content classes (in German)

Tabelle 42: Korrekturfaktoren für den Wert aus Tabelle 41 in Abhängigkeit von der Gehaltsklasse für Ackerkulturen

	P_2O_5		K_2O			
Gehalts-klasse	Spezifikation	Korrekturfaktor			Spezifikation	Korrekturfaktor
A		1,5				1,5
B		1,25				1,25
C1		1				1
C2	90 - 111 mg/1000 g P	0,5	Getreide, Stärke-indusrtrie-kartoffel	Ton < 15 %	148 - 178 mg/1000 g K	0,5
				Ton 15 - 25 %	177 - 212 mg/1000 g K	
				Ton > 25 %	205 - 245 mg/1000 g K	
			übrige Kulturen	Ton < 15 %	148 - 178 mg/1000 g K	0,75
				Ton 15 - 25 %	177 - 212 mg/1000 g K	
				Ton > 25 %	205 - 245 mg/1000 g K	
D1	Unterschreitung des Mindestgehalts gem. Tabelle 11, > 15 % Ton*	0,5				0,5
D2		0	Getreide			0
E		0				0

*… P-Gabe als Unterfußdüngung

The P and K content is medium or high in the pilot site area (at surface). In the analysis prepared by the KEFAG and BAY ZOLTÁN laboratories (measurements were also done for each soil horizon), the results showed that the P content is high in the upper 20 cm layer, however it reaches a bit lower levels in the deeper parts. Soil ventilation changes the state of the soil colloid, allowing water-soluble substances to penetrate deeper layers. The high content of P, found in the upper layer, helps seedlings to grow quickly.

11. Table: Measurement results from the KEFAG laboratory

KEFAG Kiskunsági Erdészeti és Faipari Zrt.
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Cégjegyzékszám: 03-10-100107

3 / 4. pages

Municipality: Gyomaendrőd
Block:
Lot #.: 0286/11
Subcompartment:
Soil profile: 2.

Soil Test Results

Lab report # 2024/058

Sample ID	Depth	Soil pH		Acidity		Carbonate content	Phenolphtalein alkalinity	Salt content	Arany's plasticity index	Kuron's hygroscopy	5h capillarity	Organic matter
		pH(H_2O)	pH(KCl)	Hydrolitic (y1)	Exchangeable (y2)	in $CaCO_3$	in Na_2CO_3	(water soluble)	K_A	hy		
	[cm range]	[-]		[cmol/kg]		[m/m %]	[m/m %]	[m/m %]	[m/m %]	[m/m %]	[cm/5 h]	[m/m %]
592	0-30	8,0	6,9			0,4	0,000	0,16	54	3,80		2,49
593	30-60	8,2	7,2			3,7	0,000	0,08	56	4,71		1,46
594	60-110	8,9	7,8			21,2	0,043	0,05	53	3,16		0,00
595	110-160	9,4	8,1			19,5	0,069	0,11	62	3,41		0,00
596	160-	9,3	8,0			17,0	0,083	0,19	64	3,61		0,00
Uncertainity:		± 0,1	± 0,1	± 5 rel. %	± 5 rel. %	± 7,5 rel. %	± 7,5 rel. %	± 7,5 rel. %	± 3	± 5 rel. %	± 5 rel. %	± 7,5 rel. %

Sample ID	Depth	Stone (>2,0 mm)	Mechanical particle size analysis				Bulk density	Phosphorus pentoxide (AL)	Potassium oxide (AL)	Nitrite+nitrate-nitrogen (KCl)
			Coarse sand (2,0 - 0,2 mm)	Fine sand (0,2 - 0,02 mm)	Silt (0,02 - 0,002 mm)	Clay (<0,002 mm)	(undisturbed)	AL-P	AL-K	$NO_3 + NO_2$ - N
	[cm range]	[m/m %]	[m/m %]				[m/m %]	[mg/kg]	[mg/kg]	[mg/kg]
592	0-30							226,9	349,5	14,6
593	30-60							58,5	270,2	6,1
594	60-110							11,8	147,9	7,1
595	110-160							16,7	111,7	4,4
596	160-							30,9	115,4	4,4
Uncertainity:		± 5 rel. %	± 5 rel. %	± 5 rel. %	± 5 rel. %	± 5 rel. %	± 5 rel. %	± 5 rel. %	± 5 rel. %	± 10 rel. %

Equipment Used: balance(Ohaus AR5120), analitikal balance(Sartorius AC2110), pH meter (VWR pH1100L), conductometer (WTW Cond 3110), calcimeter (Lab-Intern 84-11), shaker (Heidolph Reax20), drying oven(Memmert UN110), spectrohotometer (Shimadzu UV-1800), flame photometer (MOM Flamom-B)

Note: The examination results are related to air-dry soil. The results only pertain to the soil sample(s). The laboratory does not take responsibility for the accuracy of the sample origins. Without the permission of the testing laboratory, the report may only be reproduced in its full extent. The sample submitted to the laboratory will be retained for thirty days from the date of the examination report's issuance. Any comments or objections regarding the examination should be made within thirty days. The examinations are not accredited.

This report contains 4 numbered pages.

Dated.: Kecskemét, 2024.10.22.

Plc. of Seal

KEFAG Kiskunsági Erdészeti és Faipari Zártkörűen Működő Részvénytársaság

Maleczné Barányi, Anita
head of laboratory

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12. Table: Measurement results from the BAY ZOLTÁN laboratory (Hungary) – line 0286/11 is the pilot-site data

Bay Zoltán Kutatóközpont

B2					0,351
C					0,504
A1	0106/6	$NO_2^- + NO_3^-$ - N (KCl)	MSZ 20135:1999 5.4.5. section	mg/kg d.m.	59,6
A2					7,45
B1					1,99
B2					5,56
C					18,7
A1	0286/11				7,58
A2					4,5
B1					6,06
B2					1,84
C					1,55
A1	0106/6	P_2O_5 (AL)	MSZ 20135:1999 5.1. section	mg/kg d.m.	762
A2					26,4
B1					<20
B2					54,6
C					242
A1	0286/11				33,8
A2					57,4
B1					23,7
B2					<20
C					<20
A1	0106/6	K_2O (AL)	MSZ 20135:1999 5.1. section	mg/kg d.m.	1430
A2					766
B1					355
B2					402
C					284
A1	0286/11				375
A2					317
B1					248

Bay Zoltán Alkalmazott Kutatási Közhasznú Nonprofit Kft.
Biotechnológiai Divízió
Cím: H-6726 Szeged, Derkovits fasor 2.
Adószám: 23497980-2-43
Levelezési cím: H-6726 Szeged, Derkovits fasor 2.
Telefon: +36/62-432-248
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E-mail: bayzoltan@bayzoltan.hu

Siker a tudomány hullámhosszán

5.4.4 Harvesting and monitoring

These tree rows are not primarily established for timber production. However, there are uses that do not compromise the original purpose (reducing soil pollution, protecting roads and railways).

In tree rows planted with the right design, it is possible to harvest commercial quantities of wood every 4-5 years. It is common practice to provide social firewood to the poor from the tree rows. However, the resulting wood can also be sold commercially, wood chips can be produced and used as a cellulose raw material.

By the end of the 4th or 5th summer, the trees will be of harvestable size. Under favorable conditions, they will reach a trunk diameter of 10-12 cm, which is suitable to produce firewood or wood chips without splitting (no splitter is needed, since the diameter of the logs is small). There is a significant market demand for both. It can be sold within a short supply chain. Harvesting is carried out by a chainsaw or a woodchipper.

The timber is mainly harvested with a chainsaw. Road/railway maintenance organizations also have such machines and specialists.

The technical work system is designed so that operators can carry out all work operations themselves, relying on their existing machines. However, in certain situations, it may be necessary to subcontract work, e.g. the production of wood chips can also be carried out by a subcontractor.

According to one working method, after harvesting, the wood is cut into 2–3-meter pieces and loaded onto a trailer. Further processing is basically not planned. Another working method is complete wood chipping.

The plantation consists of a good part of seedling tree species. The harvested individuals do not need to be replanted in the 5th year; they simply sprout again from the existing root system. The new generation will grow more intensively than the first. It does not require special care; the sprouting trees grow in large numbers and quickly. It can be harvested again in another 4-5-year cycle.

The number of production cycles can be 5-10, when the trunks start to rot, then it is no longer necessary to sprout again. These tree rows are designed for the long term; we utilize intermediately cultivated tree species. When the entire tree row reaches its biological maximum age (typically 60-80 years due to moderately slow-growing tree species), then the whole can be harvested, but another solution is to harvest only the trees in a deteriorating state and replace the empty spaces with new seedlings.

The structure of degraded soils (macroporosity, carbon content) improves drastically with the cultivation of woody vegetation. The microclimate also changes: the humidity will be higher next to and around them, the soil will dry out more slowly due to the shadow effect, the tree line stores precipitation for a long time and distributes it to the surrounding environment. These diverse tree lines also have a significant protective effect on roads/railways.

5.5 Risk assessment for “Békés” pilot site

We have prepared a full risk assessment for the phytoremediation forest with the involvement of an insurance professional. This is a tree-covered vegetation, the risks of which are very similar to the risks of the energy plantation implemented by the PP8 Gyomai Gazdakör. Therefore, the risks detailed in this chapter and their management solutions are largely the same as those discussed for energy plantations.

During the establishment and maintenance of tree rows, special attention should be paid to some hazards:

- Biological hazards for individual tree species (e.g. invasiveness, spread of pathogens).
- Technical hazards due to roads or other damage caused by large-growing trees.
- Work safety hazards during planting, maintenance and logging/shredding.

- Chemical hazards during establishment and maintenance (farmers near roads/railways may use chemicals during crop protection spraying that can be fatal to the tree line), and during the burning of trees.
- General business hazards for road/railway operators.

Biological hazards

Biological hazards can be reduced by following generally accepted schemes and relevant legislation when planning tree rows. The Hungarian Chamber of Agriculture provides forestry advice free also for road/railway operators. In diverse stands, fast-growing and slow-growing tree species are planted in a mixture, which significantly improves the resistance of plantation to harsh conditions.

Technical hazards

When establishing tree-rows next to the traffic routes, care must be taken to ensure sufficient distances (tree height/edge width). Trees that fall onto neighboring plots, roads, railways, or ditches (e.g. after a storm) must be removed. The chances of this happening are low because the trees are young and do not grow large due to the 5-year cycle. However, later, when trees grow large enough, especially in the abandoned plantations, the risk of falling is high (e.g. due to dynamic weather conditions). Nevertheless, the local fire department has sufficient practice and technical equipment to resolve such problems.

Work safety hazards

During planting, maintenance and logging/shredding, various occupational safety problems may arise. Operators have their own occupational safety documents (risk assessment, regulations, etc.). During logging, the small-sized trees are harvested (diameter 10-12 cm, height 4-6 meters), and such work can be done by operator’s workers without special qualifications. If necessary, a short technical course can be organized to explain the basic techniques.

During community tree planting, motorized machinery is usually not used. The trees are planted with simple hand tools (shovel, hoe, rake, bucket). During such event, a verbal briefing about the dangers and safety before planting is generally sufficient.

Chemical hazards

The chemicals will not be applied during planting and maintenance procedures. However, some plant health interventions may require chemicals and, in such cases, the applicable legislation on general plant protection products must be implemented. Chamber advisors may provide support in planning and carrying out plant protection tasks.

While logging, the chain oil is used, generally bio-certified, biodegradable version is recommended.

During combustion of wood materials, CO_2 and many other elements are released into the air. The quality of the emitted smoke, soot and ash depends also on the quality of the incinerator. Soot and ash can be reused in plantations; both are excellent micronutrient fertilizers.

Business hazards

This report includes financial analysis of the planned actions (planting and maintaining of plantations) and description of major business opportunities and risks (chapter no. 5). It was concluded that with careful planning (proper selection of tree species, planting scheme, irrigation, maintenance), the risk of failure can be significantly reduced. Wood has been part of the global business for thousands of years, and the product, timber, will be even more important in the coming years and decades than it is today. Long-term business estimates clearly state that wood (in any form) will continue to be an important part of world trade in the future.

Road/railway operators are 99%+ state or municipal operators. Therefore, the impact of these business-related risks is highly limited.

5.6 Ecosystem services for “Békés” pilot site

Soil ecosystem services can bring provisions in nutrition, materials and energy, can bring also mediation of wastes, toxic elements. Site assessment is a first step prior determination of the potential of ecosystem services. The value of individual soil services should be determined for each project.

The basic types of ecosystem services are set out in EU regulations. Based on these, we have classified the characteristics of phytoremediation forest.

This assessment is based on the criteria detailed in the previous part of the study. The assessment of ecosystem services (both in terms of nature and financial basis) is a relatively young approach but already has a large literature. The assessment contributes to the systematic analysis and comparison of the ecological benefits and products provided by a project or a plantation/forest.

13. Table: Assessment of soil ecosystem services for Békés pilot site

Ecosystem Services	***Service Importance Level of energy plantations***				
	Pivotal	***Important***	***Necessary***	***Not necessary***	***Irrelevant***
Provisioning services					
- food					**x**
- water	**x**				
- genetical sources and medicines		**x**			
- wood	**x**				
Regulating services					
- clima and air	**x**				
- water and soil protection	**x**				
- pollination		**x**			
Cultural services					
- recreation and tourism		**x**			
- cultural values		**x**			
Supporting services					
- soil formation	**x**				
- nutrient cycling	**x**				
- photosynthesis	**x**				

6 DURABILITY, UPSCALING AND DISSEMINATION PLAN

6.1 Durability model in practice

6.1.1 Durability models in practice

PP4 WOODTECH has developed a more-pillar sustainability model for durability of project results. Within this framework, it aims to achieve a lasting impact with the project. These pillars work closely together and reinforce each other.

Pillar 1

We give field lectures to road/railway maintenance organizations with practical demonstrations. A good permanent location for this would be the Békés experimental site, where we have established a model phytoremediation forest. We give field lectures to small groups, introducing them to tree species, planting methods, soil cultivation methods, wildlife protection, the effects of mulching, and optional irrigation systems. We also give demonstrations to settlement associations (e.g. county governments).

Pillar 2

Valuable energy and/or fibre raw material can be obtained from tree rows like phytoremediation forests. Typically, this is only needed by urban road managers, but in Hungary, the state road manager and the state railway also contribute to the social firewood program of local governments. Planned logging can be carried out in areas next to public roads and railways, but only with sufficient information, because the public is very sensitive to logging. The harvested wood reaches families in need through the social firewood program.

Pillar 3

Tree planting, as a skill, is fundamentally lacking in the younger generations. Based on our own experience, we see that young people in small towns have approx. Half of the urban youth, about 10%, have experience planting trees. We hold soil protection and tree planting sessions in kindergartens and primary schools. During this, we perform a simple soil analysis in the kindergarten or school yard (soil drilling, pH value, colors, macroforms). We talk about the trees in the yard and their history. We plant 15-20 trees together with the children and teachers. We organize community tree planting campaigns together with the PP8 Gyomai Gazdakör organization.

6.1.2 Financing

Medium- and slow-growing tree species (oak, corylus, farxinus, ulmus, acer) can grow over the long term (in the case of oak, 80-100 years is possible even under roadside conditions), while fast-growing tree species can operate over the same period due to their ability to sprout.

During the project's maintenance period, approximately 50+ years, the plantation has no maintenance costs. Trees sprout, and harvesting is possible every 4-5-6 years. The cost of harvesting is divided between the farmer association and the municipality, and in exchange for social firewood, the municipality partially covers the cost of logging or has its own workers carry it out.

The road/railway organizations and the municipalities have all the necessary equipment (saws, tractor, trailer, loader) to maintain the plantation.

6.1.3 Promotion and Replication

PP4 WOODTECH has established a pilot project within the framework of PoLaRecCE: it has established a community-based phytoremediation forest that closely fits the concept of new types of European public energy communities. Here, energy is not purchased on a community basis, but the production of the energy carrier is carried out, which is an inverse solution, but offers extremely exciting prospects.

When the trees are spectacular, we plan demonstrations on the phytoremediation forest created within the framework of the project, where other road authorities, local governments and local citizens will also participate, and we try to support the establishment of new plots.

Transportation Science Association have so far indicated their serious interest in the project and phytoremediation forest-model, its establishment and maintenance mechanism, and its financial model. These model forests could operate anywhere in Central and Eastern Europe and could provide good examples for community-planned energy- and tree-planting initiatives.

6.1.4 Sustainability and Durability Mechanisms

During the design of the project and the model forest, our basic idea was that the forest should be able to produce a product that does not require any special investment, especially external investment that is not available in Gyomaendrőd or elsewhere. Therefore, we designed the technical implementation, maintenance and extraction in such a way that it can be operated safely with the help of existing infrastructure and tools, and with skills that road/railway experts can also learn. This means that we only planned technical tasks that road/railway experts can perform with their own machinery (tractor, trailer, chainsaw, hand tools). The product is typically unsplit firewood or fiber wood cut into meters that can be sold on the open market.

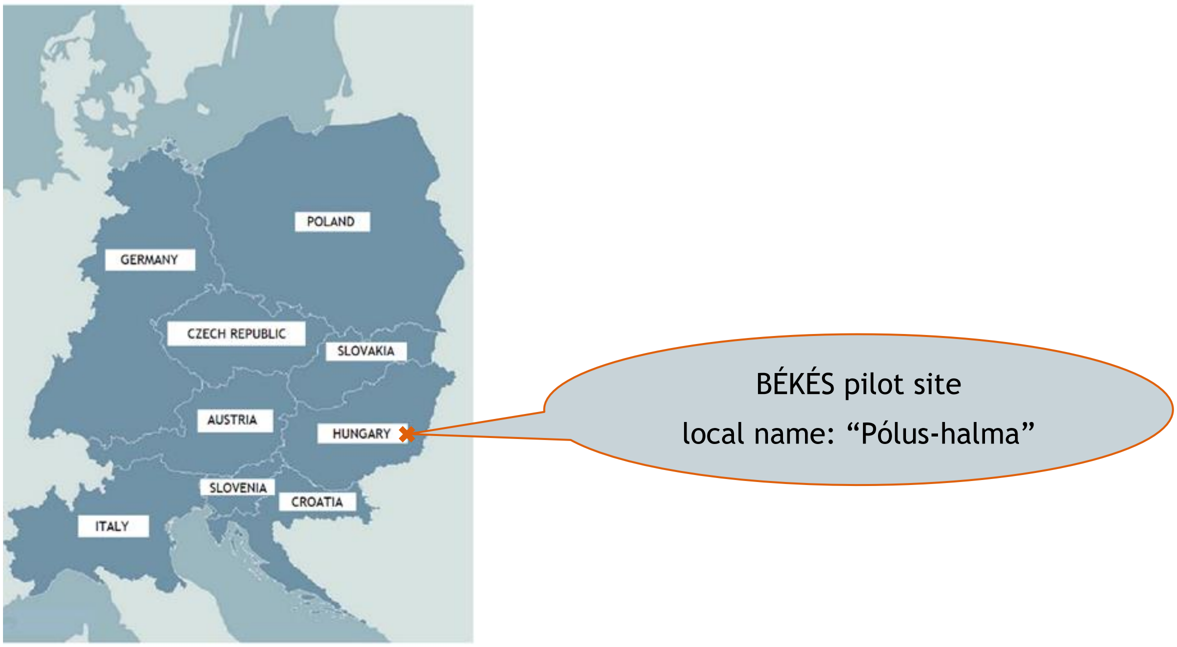
The fiber industry will be booming in the next decade, with significant fiber industry investments expected to come to Central and Eastern Europe, which is why the demand for fiber wood will also increase. Cellulose is a high-tech material, its uses are almost unlimited, cellulose will be the new plastic raw material when petroleum-based plastics become very expensive, and cellulose comes from a renewable source. It is important to prepare farmers for when grain production is already facing difficulties due to climate change and soil degradation, and new ways must be found. The production of raw materials for the fiber industry could be an excellent opportunity in the future, but farmers need to be educated about this. This is also what the project aims to do.

6.2 Comprehensive upscaling plan

In addition to the involvement and activation of road/railway experts, the involvement of younger generations was also achieved through early, targeted dissemination, field cooperation and alignment with EU policy frameworks in all activities. These measures strengthened the cooperation between road/railway experts and local stakeholders, supporting informed and sustainable decision-making on the revitalization of roadside areas in Hungary and other regions of Central Europe, where these problems are also known.

We believe that we can help scale up the project with dissemination and demonstration programs and events.

21. Figure: Integrated upscaling concept – planning area of Interreg CE



Scaling up the project results is a priority task, as the PoLaRecCE project is essentially a demonstration project.

During the project planning, we defined the target groups and the tools planned to reach the target groups.

14. Table: Planned means to reach the target groups

Target group	Tools for reach of target groups
local administration	Organizing meetings, seminaries, workshops Individual meetings with individuals or small groups
regional administration	Individual meetings with individuals or small groups
citizens	Organizing meetings, seminaries, workshops Publication in local papers or specialist magazines
students	Organizing meetings, seminaries, workshops Lessons or courses in schools
youth from secondary and primary schools	Organizing meetings, seminaries, workshops

We can scale up the project results with the planned tools. A significant part of the professional content for the communication channels is already available (these are practically the results and outputs created within the project). We will shape communication products from these professional materials and build the scale-up from them.

In final phase of work, we will prepare all necessary measures to reach the target groups as widely as possible with the planned tools. We will also work closely with the consortium partners on this topic.

6.3 Dissemination and demonstration plan

Based on the scale-up contents, the dissemination events and results implemented and planned activities so far are summarized in the table below. A significant part of the implemented and planned dissemination and demonstration activities (events, programs) are organized jointly with other consortium project partners and in many cases with external partners or strategic partners.

The table below presents the activities organized by or in collaboration with PP4WOODTECH, PP8 Gyomai Gazdakör and the Lead Partner.

15. Table: Dissemination and demonstration activities (implemented and planned)

Date of the event	**Description**	**Responsible project partner (PP)**
May 2025	Community tree planting campaign with young children at the Zsilip Utcai Kindergarten in Sopron (80 participants)	PP4+PP8
May 2025	Reception of the Mongolian delegation in Gyomaendrőd, from Csojbalszan City: adapting Robinia plantation opportunities to Eastern Mongolia	PP4+PP8
May 2025	Alternatives to Reduce Soil Degradation – conference by Hungarian Academy of Sciences – oral presentation by Dr. Sandor Horvath: Soil ventilation – a new way to revitalization	PP4
September 2025	The solutions developed for the PoLaRecCE pilot sites were presented at the EUROSOIL 2025 Congress in Seville, Spain, as a poster on soil degradation, contamination, remediation strategies, and the adaptation of degraded land for non-food agricultural purposes.	LP and PP2
October 2025	The solutions developed for the PoLaRecCE pilot sites were also presented to the Commission on Soils of Urban, Industrial, Traffic, Mining and Military Areas during the 13th SUITMA Conference in Pisa, Italy.	LP and PP2

Date of the event	Description	Responsible project partner (PP)
Jan 2026	Joint professional meeting with the ClimaPannonia project, we presented the project's results so far, the diversification opportunities inherent in community tree planting, and discussed agroforestry solutions for berries and forest trees	PP4
April 2026	Community tree planting campaign with young children at the Jókai Úti Kindergarten in Gyomendrőd (45 participants)	PP4+PP8
April 2026	Community tree planting campaign with young children at the Jókai Úti Kindergarten in Gyomendrőd (45 participants)	PP8+PP4
May 2026	International Conference on Alternatives to Reduce Soil Degradation - ARSD2026 - presentation by Dr. Sandor Horvath	PP4
May 2026	Community tree planting campaign with children at the Kis Bálint Primary School in Gyomendrőd (50 participants)	PP4+PP8
May 2026	Community tree planting campaign with children at the Kis Bálint Primary School in Gyomendrőd (50 participants)	PP8+PP4
May 2026	Community tree planting along Road Highway 46 in cooperation with the Road Authority	PP4
May 2026	First tree planting tests together with the Békés County Road Management Organization, we planted 50 trees in one hour next to country road number 47, we are continuously monitoring success and vitality	PP4 + PP8 + road experts
June 2026	The developed methodology for site assessment of areas polluted by urban and industrial deposition will be presented at the scientific conference *The Biennial Castle Meeting - New Trends in Rock, Paleo- and Environmental Magnetism*, held in Collonges-la-Rouge, Corrèze, France.	LP
June - July 2026	The developed methodology for site assessment of areas polluted by urban and industrial deposition of PTEs will be published in a high-ranking environmental science journal.	All project partners
September 2026	Connecting Europe Days 2026 Bruxelles - presentation about the new technology of roadside forestry, participants: European road and railway experts	PP4
September - October 2026	Case studies on the application of soil magnetometry in areas degraded by urban and industrial deposition of PTEs will be published.	LP

Date of the event	Description	Responsible project partner (PP)
October 2026	Community tree planting campaign with young children at the Kossuth Úti Kindergarten in Gyomendrőd (50 participants)	PP8+PP4
October 2026	Community tree planting campaign with children at the Hősök Úti Primary School in Gyomendrőd (50 participants)	PP8+PP4
October 2026	Community tree planting along Szolnok-Békéscsaba Railway Section in cooperation with the Hungarian Railway Company	PP4
October 2026	Transportation Science Association and Hungarian Road and Railway Authority organize a yearly conference for all road-railway experts about innovation for road/railway construction and maintenance – presentation about the project and new technology of roadside forestry	PP4
October 2026	SME-focused field presentation in collaboration with the Chamber of Agriculture for farmers planning agroforestry	PP4 + PP8
November 2026	The final toolbox/handbook, providing a set of procedures for quick, inexpensive, and effective environmental site assessment, as well as criteria for selecting the best available solutions for development and management strategies (with a special focus on non-food farming, including analysis of ecological and environmental benefits), will be published	All project partners
December 2026 - 2027	The handbook will be disseminated among local and regional administrations in Poland and other Central European countries.	All project partners
December 2026 - 2027	The final solutions and results of the project will be disseminated via social media in all participating countries.	All project partners
From 2024-	professional posts in topic of soil protection and forestry plantations - LinkedIn profile together by WOODTECH CAMPUS	PP4+PP8

7 POLICY TOOLS AND INSTRUMENTS

The consortium is working together on this chapter, the questionnaire, the database, the toolbox, and the handbook are the result of joint work. We also developed the pilot site concept together, the implementation of which was the responsibility of the individual project partners.

Within the framework of the PoLaRecCE project, the consortium developed a package of policy tools and instruments to ensure the widest possible demonstration of the project's results.

The following policy tools were developed:

- Development and sending **questionnaires** to local governments in Central Europe (we basically found that the local government level is where we can obtain relevant information on local soil pollution and overuse).
- Building of a **database** from the responses received from local governments, on a digital basis, with descriptive data and map display.
- **Toolbox** contains procedural solutions, presenting a simple soil quality monitoring solution and providing a simple communication solution for decision-makers and stakeholders.
- We are preparing a **handbook** about the strategic studies, action plans, practical information and practices completed within the project.
- We have developed a system of **pilot areas** in Poland, Italy, Slovenia and Hungary, where we demonstrate different utilization solutions in approximately the same areas (mischanthus plantation, peony plantation, mulberry plantation, energy plantation, phytoremediation forest plantation).

The **questionnaires** were developed by the consortium through extensive consultation. We developed simple answer options for 18 questions, covering the topic of contaminated and overused soil. The questions asked were:

- contamination from urban and industrial dust deposition
- leakage of oil and petroleum products
- leakage of waste waters or sewage sludge deposition (biological contamination)
- volatile organic compounds (e.g. PAHs)

- cyanides (e.g. from coking industry)
- dumping of waste materials from coal mining
- dumping of waste materials from ore mining
- dumping of ashes from power industry
- dumping of non-degradable trash or plastics (municipal waste)
- former quarries and areas after exploitation of natural resources
- flooding areas
- military areas
- heavily acidified soils
- saline or highly alkaline soils (e.g. from chemical, cement or ceramic industry)
- long-term poor agricultural farming practices (depletion of soil organic carbon and soil nutrients, over-fertilization, contamination by pesticides)
- wind or water erosion
- soil sealing or compaction
- others (give additional information)

The response options accordingly:

- Degree of importance of the Problem (0-3)
- If possible, please estimate the area affected by each type of land degradation (in % or km^2)
- Additional information or comments

During the completion of the questionnaires, we spoke to several Hungarian local governments in person, telephone inquiries were also made, and most responses were received by e-mail.

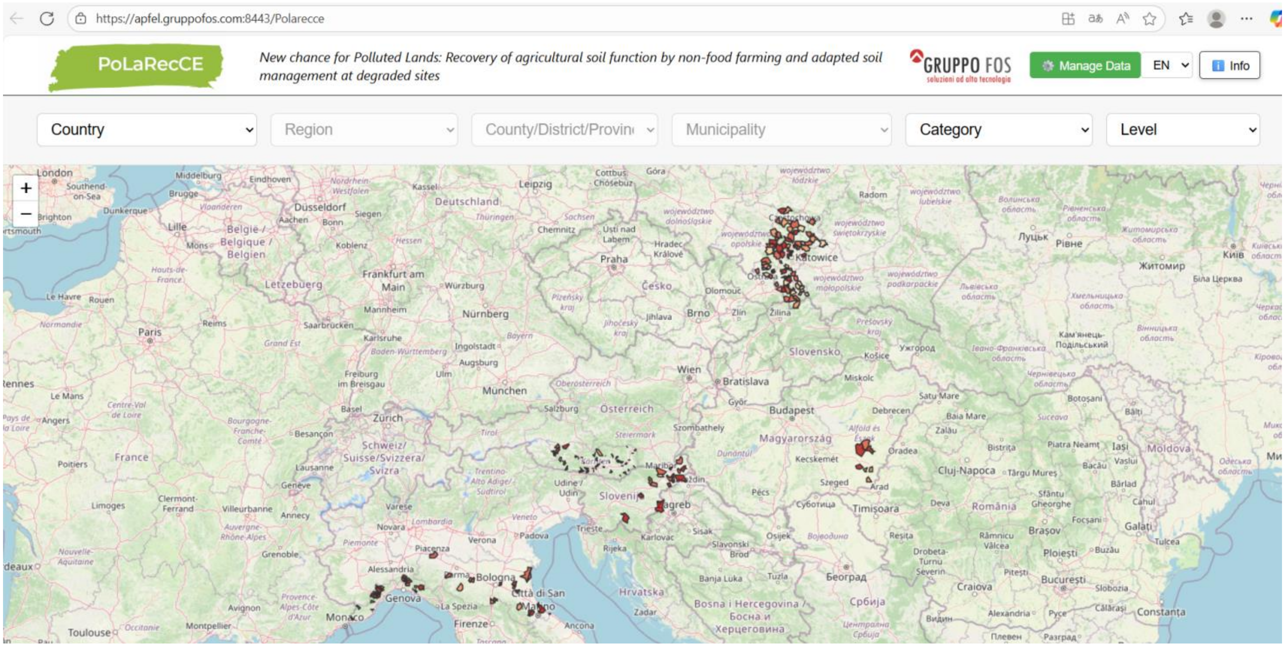
The responses came mainly from the local governments of Békés County, but in the fall of 2026, we will also contact additional Hungarian local governments to obtain as many responses as possible. The questionnaire was organized by the PP8 Gyomai Farmers' Association, and the answers were recorded in the database (and translated) by PP4 WOODTECH.

The analysis of the responses revealed that small (rural, small town) local governments typically have little information about their own area, and there is a significant lack of information on the topic. Everyone has heard that soil protection is an important topic, and that there are significant pollution and overuse throughout Europe, but practical solutions related to this, or specific small-scale action plans, are hardly known.

A common Central European **database** was created from the responses sent to and received from local authorities. The technical provider of the database is PP FOS, and its professional manager is the Polish lead partner. The database is an online, open access program consisting of maps and descriptive data, which can be freely expanded with data from additional municipalities during the project period and beyond.

The basic goal of the database is to present the patterns of soil pollution and overuse in each programme region and to serve as a single data source for further professional and policy materials.

22. Figure: Database of answers by local governments



Each programme country has its own soil protection action plan and there are national-scale soil pollution monitoring systems, but this is a bottom-up initiative that excellently complements, refines and brings knowledge related to the topic to the local level.

Based on the results of the database, significant motives are already apparent: In Békés County, pollution from industrial or mining sources is negligible, but agricultural overuse is significant, and we have also seen that local governments have very limited knowledge of the quality and problems of the soils in their own areas.

We developed a **toolbox** during the management of the program. In Hungarian local governments, this issue is basically assigned to environmental experts, but for them this topic is very marginal. There is also a significant lack of knowledge and information among local governments regarding their own soils. For this reason, the number of questionnaires sent out was also very low (out of 75 questionnaires, barely 8 were returned in the first round, which is a result of around 10-11%).

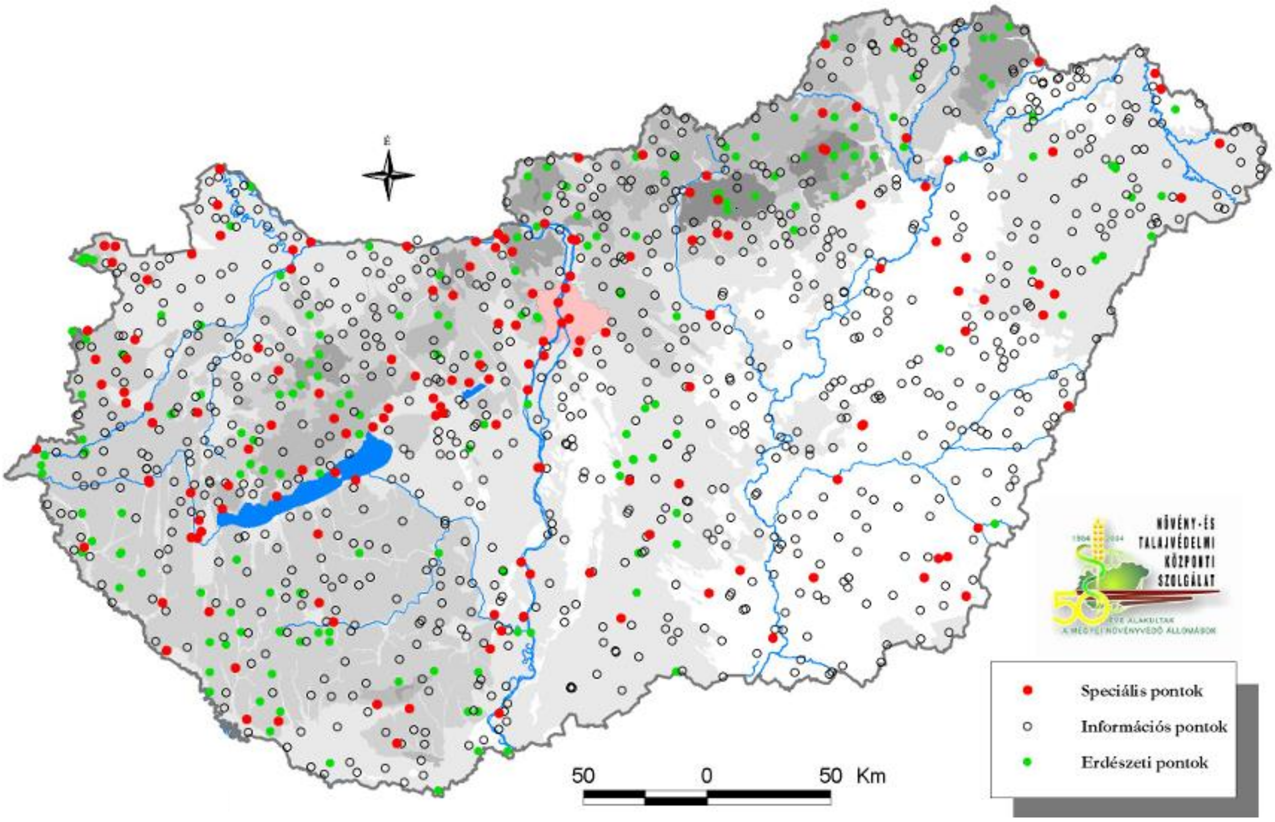
The national soil monitoring data are not known to local governments, they do not receive such information directly from a central organization. The soil protection authority is a government agency. Its operation typically coordinates humus rescues found in construction areas, they have an official task in the licensing of pesticides, they authorize the application of sewage sludge, and they monitor the use of organic and synthetic fertilizers applied by farmers.

There is a "Soil Protection Information and Monitoring System" in Hungary. The aim of the system is to objectively assess the quality of agricultural soil, to learn about continuous changes and their trends. Knowledge of changes in the processes taking place in soils provides an opportunity for effective and efficient state control, to promote and strengthen favourable changes, to prevent unfavourable changes, or to keep them within certain limits.

The system was developed by a committee consisting of experts from the Soil Science and Agrochemistry Research Institute of the Hungarian Academy of Sciences, the ministry responsible for agriculture, and the soil protection authority. The state survey and the first soil tests took place in 1992.

Soil sampling is carried out at 1,235 points annually within the framework of TIM. A fundamental requirement when selecting sampling points was representativeness, i.e. that the measurement point adequately characterizes the soil conditions of the natural geographical unit, thus creating an opportunity to characterize the soil condition.

23. Figure: Hungarian Soil Protection Information and Monitoring System since 1992



The national core measuring network represents the soil condition of the country's agricultural areas with 864 points. The forestry measuring points characterize the soils under forest ecosystems with 183 points. The special measuring points serve to characterize endangered or already polluted areas at 188 points.

Types of special points:

- Degraded areas. Mainly in agricultural areas, erosion caused by wind and water, acidification, salt accumulation, salinization, compaction, soil structure deterioration, biological degradation, soil pollution.
- Hydrogeological protection areas of drinking water bases.
- Watersheds of major lakes and reservoirs.
- Heavily polluted industrial areas.

- Agricultural areas with sewage sludge, wastewater, liquid manure.
- Heavily polluted agglomeration areas, recreational areas.
- Surroundings of waste and hazardous waste dumps.
- Degraded surfaces (surfaces damaged by surface mining, industry, infrastructure, reclaimed waste heaps, etc.).
- Areas affected by traffic, the vicinity of motorways.
- Nature conservation areas.
- Environmentally sensitive areas (e.g. buffer zones of protected areas)

To record the baseline state, very extensive investigations were carried out in the first year. Some of the parameters to be examined were determined only once, in the first year. Depending on the temporal variability of individual soil properties, the investigations are repeated annually, every 3 or 6 years.

Within the framework of the TIM program, on-site investigations and sampling are carried out by soil protection inspectors of the Plant and Soil Protection Directorates of the county Government Offices. Laboratory examination of soil samples is the responsibility of the 3 regional soil protection laboratories of the NÉBIH. Soil biological tests are carried out in the Soil Biological Laboratory of the National Institute of Soil Science and Technology, where all laboratories are accredited. The coordination of TIM's field and laboratory work and the organization of the test results into a database are carried out by the Directorate of Plant, Soil and Agri-Environmental Protection of the National Institute of Soil Science and Technology.

Together with the data obtained from the soil protection monitoring system, we are planning an information campaign within the framework of the project in the fall of 2026, where we will inform local governments about the importance of soil protection, the Hungarian and international changes and practical solutions experienced in recent decades.

Handbook as a tool developed during the PoLaReCE project is a primary document intended for the local and regional officials including decision makers responsible for soil management practices. It will contain a full description of the tools designed during implementation of the PoLaReCE project (questionnaires, database and toolbox). Furthermore, it will provide criteria for selecting the best possible revitalization procedure as well as detailed instructions on how to perform the cost-benefit analysis for selected investment options. Pilot sites selected for the purpose of handling different soil degradation types will provide a robust example to stakeholders on how to effectively process and manage lands affected by various pollution sources.

We established an energy tree plantation in the "Dél-Alföld" pilot area, specifically for the revitalization of degraded agricultural soils.

We have established an energy tree plantation in the Southern Great Plain pilot area, specifically for the revitalization of degraded agricultural soils. In this manual, we summarize the establishment and maintenance practices of this area, demonstrating that tree planting and the maintenance of non-food agroforestry systems are an easy-to-learn, quick and effective solution for any farmer to combat soil degradation.

Within the framework of the project, we have established five active **pilot areas**, in Poland, Italy, Slovenia and Hungary. The explicit aim of the demonstration areas is to develop new types of land use alternatives for the target groups. One of the Hungarian non-food pilot areas is an energy plantation (typically with fast-growing tree species, but there are also medium-growing tree species, mixed, mulched and irrigated), the other is a phytoremediation forest (where fast, medium-growing and slow-growing tree species are planted in a mixed manner, for the purpose of accumulation and carbon dioxide absorption, to demonstrate the revitalization of contaminated and compacted/mixed soils along roads and railways).