# *COMPARATIVE LIFE CYCLE ASSESSMENT OF TREE PLANTING AND SEEDLING PRODUCTION IN THE LIFE TERRA PROJECT*

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## Overview

The LIFE Terra project aims to support climate change mitigation through the development and deployment of scalable afforestation practices across Europe. Central to its approach is the integration of technological innovation and sustainable material use in two critical stages of tree establishment: field planting and nursery-based seedling production. This study delivers a dual assessment of environmental and economic performance, evaluating two comparative cases: (1) traditional versus automated tree planting methods, and (2) conventional versus biochar-enhanced seedling substrates. The methodology combines Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) frameworks, both conducted in alignment with ISO 14040 and ISO 14044 standards. The purpose is to quantify and compare greenhouse gas (GHG) emissions and associated economic costs for each practice.

## Methods

Two LCAs were conducted to evaluate the environmental impact of the practices. The first LCA focused on tree planting activities, contrasting a conventional approach using a gasoline-powered auger and manual monitoring against the LIFE Terra method, which employs the LandLife Tree Seeding Robot (LLTSR) combined with UAV-based monitoring. The second LCA examined seedling production processes in greenhouses, comparing traditional peat-based substrates with a biochar-peat mixture. In both LCAs, the system boundaries are from raw material acquisition through the operational phase of planting or cultivation, to transportation of materials and personnel. The functional unit is defined as one tree planted or one seedling produced, facilitating a standardized comparison of environmental impacts.

In parallel, the LCC methodology estimated the total cost of each scenario based on three core components: Equipment Costs (EC), Operating Costs (OC), and Environmental External Costs (EnExC). All financial values were adjusted over a five-year analysis period.

## Results

The results of the LCA demonstrated a clear environmental benefit from the adoption of the LIFE Terra planting methodology. Specifically, GHG emissions per tree were reduced from 0.029 $kgCO_2eq$ under traditional methods to 0.021 $kgCO_2eq$ when using LLTSR and UAV monitoring—an overall reduction of approximately 27%. These savings came from more efficient energy usage and the reduced environmental impact of automated monitoring.

In the case of seedling production, the transition from a peat-only substrate to a biochar-peat mix resulted in a GHG reduction from 0.0616 $kgCO_2eq$/tree to 0.0529 $kgCO_2eq$/tree, amounting to a 16% improvement. The carbon sequestration capacity of biochar and the decreased dependence on peat, were the primary contributors to this reduction.

Economic analysis via LCC revealed that the LLTSR planting method incurred a cost of 1.68 €/tree, substantially lower than the 2.50–3.5 €/tree range associated with traditional planting (based on market contractor rates). Furthermore, under optimized operational conditions (e.g., 400 pits planted per day), the LLTSR cost could decrease to just 0.90 €/tree. For seedling production, costs were relatively similar between scenarios: 0.343 €/seedling using peat versus 0.360 €/seedling for the biochar mix. This marginal increase is offset by the environmental benefits and potential soil health improvements.

## Conclusions

The combined Life Cycle Assessment and Life Cycle Costing analyses presented in this study validate the environmental and economic advantages of innovative approaches promoted by the LIFE Terra project. The use of the LLTSR planting system not only lowers greenhouse gas emissions but also improves cost-efficiency, making it a promising solution for large-scale reforestation efforts. Similarly, the substitution of peat with biochar in seedling substrates supports emission reduction and soil regeneration, aligning with circular economy principles. Overall, the adoption of automation and sustainable materials in afforestation processes can deliver measurable climate benefits while maintaining or even improving economic performance


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