AGRICULTURAL UNIVERSITY OF ATHENS
DEPARTMENT OF AGRICULTURAL ECONOMY & DEVELOPMENT
DEPARTMENT OF ANIMAL PRODUCTION SCIENCE

MSc ENTREPRENEURSHIP & CONSULTING
IN RURAL DEVELOPMENT

Master Thesis

Importance of reusing wood from pruning and promotion of circular economy principles in agricultural sector in Tripolis, Greece

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Σημασία της επαναχρησιμοποίησης του ξύλου από το κλάδεμα
Και προώθηση των αρχών της κυκλικής οικονομίας στον αγροτικό τομέα
στην περιοχή της Τρίπολης

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MSc Entrepreneurship & Consulting in Rural Development
Department of Agricultural Economy & Development
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ABSTRACT

The purpose of this postgraduate study is to investigate the significance of reusing wood from pruning and promoting the principles of the circular economy within the agricultural sector, specifically focusing on Tripolis, Greece. The study aims to explore current practices related to the management of pruning residues, identify both environmental and economic benefits from these practices, and offer strategic recommendations for improvement. By integrating circular economy concepts into agricultural practices, this study seeks to enhance sustainability, resilience, and productivity in the rural economy. Moreover, it aims to contribute to the achievement of broader sustainable development goals (SDGs) by providing actionable insights that can benefit local farmers and stakeholders. Through detailed case studies, literature reviews, and interviews with local practitioners, this study will highlight the potential for adopting more sustainable practices in agricultural waste management, thereby improving resource efficiency and supporting long-term environmental and economic benefits for Tripolis, Greece

Scientific area: Circular Economy

Keywords: Circular economy, bioeconomy, agricultural waste, pruning wood reuse, sustainable agriculture, resource efficiency

Σημασία της επαναχρησιμοποίησης του ξύλου από το κλάδεμα και προώθηση των αρχών της κυκλικής οικονομίας στον αγροτικό τομέα στην περιοχή της Τρίπολης

ΔΠΜΣ Επιχειρηματικότητα & Συμβουλευτική στην Αγροτική Ανάπτυξη
Τμήμα Αγροτικής Οικονομίας & Ανάπτυξης
Τμήμα Επιστήμης Ζωικής Παραγωγής

ΠΕΡΙΛΗΨΗ

Σκοπός της παρούσας μεταπτυχιακής μελέτης είναι η διερεύνηση της σημασίας της επαναχρησιμοποίησης του ξύλου από το κλάδεμα και η προώθηση των αρχών της κυκλικής οικονομίας στον αγροτικό τομέα, με έμφαση στην περιοχή της Τρίπολης στην Ελλάδα. Η μελέτη στοχεύει να διερευνήσει τις τρέχουσες πρακτικές που σχετίζονται με τη διαχείριση των υπολειμμάτων κλαδέματος, να εντοπίσει τόσο περιβαλλοντικά όσο και οικονομικά οφέλη από αυτές τις πρακτικές και να προσφέρει στρατηγικές συστάσεις για βελτίωση. Με την ενσωμάτωση των εννοιών της κυκλικής οικονομίας στις γεωργικές πρακτικές, αυτή η μελέτη επιδιώκει να ενισχύσει τη βιωσιμότητα, την ανθεκτικότητα και την παραγωγικότητα στην αγροτική οικονομία. Επιπλέον, στοχεύει να συμβάλει στην επίτευξη ευρύτερων στόχων βιώσιμης ανάπτυξης (SDGs) παρέχοντας αξιόπιστες γνώσεις που μπορούν να ωφελήσουν τους τοπικούς αγρότες και τα ενδιαφερόμενα μέρη. Μέσα από λεπτομερείς περιπτωσιολογικές μελέτες, ανασκόπηση βιβλιογραφίας και συνεντεύξεις με τοπικούς επαγγελματίες, αυτή η μελέτη θα αναδείξει τη δυνατότητα υιοθέτησης πιο βιώσιμων πρακτικών στη διαχείριση των γεωργικών απορριμμάτων, βελτιώνοντας έτσι την αποδοτικότητα των πόρων και υποστηρίζοντας μακροπρόθεσμα περιβαλλοντικά και οικονομικά οφέλη για την περιοχή της Τρίπολης

Επιστημονική περιοχή: Κυκλική Οικονομία

Λέξεις κλειδιά: Κυκλική οικονομία, αγροτικά απόβλητα, επαναχρησιμοποίηση ξύλου κλαδέματος, βιώσιμη γεωργία, αποδοτικότητα πόρων

Content

1. Introduction **5**
1.1 Background and Scope of the Study 5
1.2 Circular Economy Principles in Agriculture 6
1.3 Reusing Pruning Residues: Wood and Leaves in a Sustainable Context 7
2. Literature Review and Theoretical Framework **8**
2.1 Defining Circular Economy and its Principles in Agriculture 8
2.2 Concepts and Practices of Sustainable Agriculture 9
2.3 The Role of Sustainable Development Goals (SDGs) in Agriculture 13
2.4. Integrating Circular Economy into Agricultural Practices 15
2.5. Best Practices for Circular Agriculture Strategies 16
3. Research Methodology **19**
4. Case Study: Tripolis Agricultural Sector **21**
4.1. Overview of Agricultural Practices in Tripolis 21
4.2 Current Approaches to Circular economy practices 21
4.3. Thematic Insights from Interviews 24
4.4. Local Practices and Analysis - Insights from an Agricultural Livestock Cooperative 28
4.5. Analysis of Crop Distribution and Potential for Wood Waste Reusein the Tegea area 31
Nut Orchards and Pome Fruits: Major Contributors to Biomass 33
Stone Fruits: A Robust Source of Renewable Biomass 34
Vineyards: A Consistent Source of Pruning Residues 34
Other Tree Crops: A Modest but Meaningful Contribution 35
Total Biomass Potential and Strategic Implications 35
4.6. Analysis in Arcadia 35
5. Quantitative and Economic Analysis of Circular Agricultural Practices **40**
5.1. Market Opportunities: Biochar, Compost, and Biomass Fuel in Arcadia 40
5.1.1. Biochar Use in Arcadia: A Strategy for Sustainable Agriculture 40
5.1.2. Compost: Versatility and Market Demand 42
5.1.3. Biomass Gasification: Processes and Applications 43
5.2. Financial Incentives and Funding for Circular Agriculture 48
5.3. Social and Community Engagement in Circular Agriculture in Tripolis 57
6. Conclusions and Recommendations **60**
7. References - Appendices **62**
7.1. References 62
7.2. Diagrams 68
7.4. Tables 69
7.5. Survey Discussion Guide 69

1. Introduction

1.1 Background and Scope of the Study

The agricultural sector holds substantial economic and social significance, particularly in developing areas where it serves as a cornerstone for rural economies, employment, and income generation. In areas like Tripolis agriculture remains the lifeblood of local communities, where traditional farming practices have been honed over centuries. However, this sector faces ongoing sustainability challenges, including resource depletion, environmental degradation, and the disposal of agricultural residues, such as wood waste from pruning, which are often left unmanaged or improperly disposed of, contributing to broader ecological issues (Geissdoerfer, Savaget, Bocken, & Hultink, 2017).

The agricultural sector in Greece holds a dual role as both an economic driver and a cornerstone of environmental stewardship. Accounting for approximately 4% of the national GDP and employing over 10% of the workforce, agriculture is a vital contributor to the country's economic stability (Hellenic Statistical Authority, 2023). It also forms the backbone of rural livelihoods, particularly in regions like the Peloponnese, where traditional farming practices are interwoven with local culture and history.

Economically, Greece's agriculture is characterized by the production of high-quality products such as olive oil, wine, and fresh fruits, many of which are significant exports. These exports contribute to the nation's balance of trade and enhance its global reputation for premium agricultural goods. For instance, Greek olive oil and wine are recognized worldwide for their quality, with exports growing steadily in recent years (Hellenic Ministry of Rural Development and Food, 2023).

Environmentally, the sector plays a crucial role in maintaining biodiversity and mitigating climate change. Traditional farming systems, such as those seen in olive groves and vineyards, promote diverse ecosystems, supporting pollinators and other wildlife. Additionally, the adoption of sustainable practices, including organic farming, integrated pest management, and circular economy principles, has the potential to reduce greenhouse gas emissions and conserve natural resources (European Commission, 2021). However, the sector also faces environmental challenges. Soil degradation, water scarcity, and the overuse of chemical inputs pose significant risks to long-term sustainability. The importance of agriculture extends beyond economics and ecology; it is a social and cultural pillar of rural Greece. Local festivals celebrating harvests, traditional methods of farming, and family-owned enterprises underscore the deep connection between agriculture and Greek heritage. This multifaceted role of agriculture makes it a sector of strategic importance, requiring targeted policies and investments to ensure its sustainable growth.

The circular economy has emerged as a sustainable alternative to the linear economic model, which relies on a resource-intensive "take, make, dispose" approach that burdens ecosystems. In contrast, a circular economy is structured to reduce waste and extend resource life cycles by promoting reuse, repair, and recycling within closed-loop systems (Ellen MacArthur Foundation, 2013). This paradigm shift has the potential to safeguard finite resources, mitigate pollution, and strengthen economic resilience (Korhonen et al., 2018).

A circular economy model seeks to maintain the utility of resources by extending their life cycles and minimizing waste. This approach is particularly relevant to agriculture, where resource efficiency, waste reduction, and closed-loop systems could transform waste into valuable assets (Ellen MacArthur Foundation, 2013). In practice, circular agriculture involves recycling organic waste into the soil, converting crop residues into bioenergy, and enhancing resource use efficiency through integrated farm management (Meybeck & Gitz, 2017). These strategies reduce agriculture's environmental impact, conserve resources, and bolster economic resilience.

1.2 Circular Economy Principles in Agriculture

The circular economy (CE) represents a transformative framework designed to replace the traditional "take-make-dispose" linear model. It emphasizes waste minimization, resource efficiency, and regenerative practices to create a sustainable economic system. Unlike the linear model, CE focuses on designing out waste and pollution, keeping products and materials in use, and regenerating natural systems (Ellen MacArthur Foundation, 2013). These principles align closely with global sustainability goals, such as the United Nations Sustainable Development Goals (SDGs), particularly those addressing climate action, responsible consumption, and biodiversity preservation.

In the context of agriculture, CE provides a pathway to sustainable resource management by prioritizing the reuse, repair, and recycling of organic and inorganic materials. The agrifood sector, being a significant consumer of resources and producer of organic waste, offers immense potential for adopting CE principles. For example, organic waste from pruning residues, crop by-products, and livestock manure can be reintegrated into farming systems through composting, biochar production, or renewable energy initiatives.

By embedding CE principles in agriculture, farmers can reduce input costs, mitigate environmental degradation, and increase resilience to climate change. These practices promote closed-loop systems where organic matter and nutrients are cycled back into the soil, supporting long-term soil fertility and ecosystem health.

1.3 Reusing Pruning Residues: Wood and Leaves in a Sustainable Context

The sustainable management of pruning residues represents a vital application of circular economy principles in agriculture. Pruning, a common horticultural practice aimed at maintaining plant health and productivity, generates considerable organic waste in the form of wood and leaves. Traditionally, these residues have been burned, contributing to air pollution and greenhouse gas emissions, or discarded, creating an underutilized resource. Within the circular economy framework, these materials can be repurposed into valuable products, offering both environmental and economic benefits (Blanco-Canqui & Lal, 2009).

Repurposing pruning residues provides several environmental advantages. For instance, using pruned wood and leaves as mulch improves soil organic matter, reduces erosion, and enhances water retention, leading to healthier soils and better crop productivity. Composting these residues transforms them into nutrient-rich organic matter that can replace synthetic fertilizers, thereby minimizing the environmental footprint of agricultural operations (Steiner et al., 2007; Ghisellini et al., 2016). Additionally, these practices sequester carbon in soils, contribute to climate change mitigation, and promote biodiversity by creating a supportive habitat for soil microorganisms.

Economically, the reuse of pruning residues reduces waste management costs and opens up new revenue streams. Farmers can save on fertilizer expenses by using compost made from pruned materials and may generate additional income by selling excess compost or biomass. Furthermore, utilizing pruning residues for renewable energy production, such as biomass fuel, supports local energy needs and reduces reliance on fossil fuels, aligning with regional energy sustainability goals (Scarlat et al., 2015).

The reuse of pruning residues also aligns with global sustainability frameworks, including the United Nations' Sustainable Development Goals. Practices such as mulching and composting support SDG 12 by optimizing resource efficiency, SDG 13 by reducing greenhouse gas emissions, and SDG 15 by improving soil health and fostering biodiversity (UNDP, 2015). For regions like Tripolis, where agriculture plays a significant economic role, integrating circular practices into pruning residue management could enhance soil fertility, lower environmental impacts, and bolster the economic resilience of local farmers (Pereira et al., 2016).

The adoption of circular principles in managing pruning residues underscores the potential for modern agriculture to balance environmental stewardship with economic viability. By integrating these practices into local farming systems, Tripolis can serve as a model for sustainable agriculture in Mediterranean regions, demonstrating how traditional methods can be innovatively adapted to align with global sustainability goals.

2. Literature Review and Theoretical Framework

2.1 Defining Circular Economy and its Principles in Agriculture

The circular economy (CE) offers a transformative framework for addressing key challenges in agriculture, including declining soil fertility, water scarcity, and greenhouse gas emissions. By rethinking traditional linear approaches, which rely on extracting, using, and discarding resources, the CE model promotes a closed-loop system where waste is repurposed into valuable inputs. Applying these principles to agriculture optimizes resource use, minimizes waste, and enhances the overall sustainability of production systems.

One of the core practices in agricultural circularity is composting. Organic waste, such as crop residues and animal manure, can be processed into nutrient-rich compost, providing an environmentally friendly alternative to synthetic fertilizers. This practice not only improves soil health by increasing organic matter but also reduces the environmental impact of chemical fertilizer use. Another innovative technique is the production of biochar, a carbon-rich material derived from pruning residues and woody biomass. Biochar enhances soil structure, increases water retention, and sequesters carbon, offering both agricultural and climate mitigation benefits.

Mulching is another effective application of CE principles in agriculture. Repurposing crop residues and prunings as mulch protects the soil from erosion, conserves moisture, and suppresses weed growth. This practice is particularly vital in regions like Arcadia, where water scarcity and soil degradation are persistent issues. Renewable energy production also plays a significant role in agricultural circularity. By converting agricultural waste into biogas or biomass energy, farmers can meet local energy needs sustainably, reducing dependence on fossil fuels and lowering carbon emissions.

These examples demonstrate how CE principles can transform waste into a valuable resource, aligning agricultural practices with environmental sustainability. For instance, in Mediterranean regions like Arcadia, pruning residues are often burned, contributing to air pollution and greenhouse gas emissions. By instead utilizing these residues to produce biochar or biomass energy, farmers not only mitigate environmental harm but also contribute to local economic resilience and climate change mitigation efforts (Blanco-Canqui & Lal, 2009; Ellen MacArthur Foundation, 2013). Through such practices, the circular economy becomes a practical and impactful approach to fostering sustainable agricultural systems.

2.2 Concepts and Practices of Sustainable Agriculture

Sustainable agriculture emphasizes farming practices that safeguard environmental health, biodiversity, and soil quality while maintaining economic viability and ensuring food security. This approach seeks to balance agricultural productivity with environmental stewardship, ensuring that resources remain available for future generations and agricultural systems can adapt to changing conditions (Pretty, 2008).

One fundamental practice in sustainable agriculture is **crop rotation and diverse cropping**, which helps disrupt pest and disease cycles while improving soil fertility. By rotating crops and incorporating a variety of plant species, farmers can reduce reliance on chemical inputs and maintain healthier soil ecosystems (Altieri, 1999). Another key method is **conservation tillage**, which minimizes soil disturbance, thereby reducing erosion and improving soil water retention. These benefits contribute to enhanced crop yields over time while protecting soil structure (Lal, 2004).

Integrated Pest Management (IPM) represents a strategic approach to pest control, combining biological, cultural, and chemical methods to manage pests effectively while minimizing harm to the environment. This approach aligns with the principles of sustainability by reducing pesticide dependency and promoting natural pest regulation systems. Similarly, **organic farming** practices rely on natural inputs and processes, avoiding synthetic fertilizers and pesticides. This approach contributes to ecosystem health by fostering biodiversity, improving soil quality, and reducing agricultural pollution (Reganold & Wachter, 2016).

These practices collectively illustrate the potential of sustainable agriculture to address the dual challenges of food production and environmental conservation, offering a pathway to more resilient and eco-friendly farming systems.

The integration of Circular Economy (CE) strategies into sustainable agriculture offers a transformative approach to addressing environmental and economic challenges within farming systems. By rethinking waste, optimizing resource use, and supporting ecosystem health, CE strategies align agriculture with principles of sustainability and circularity, fostering resilience and long-term productivity.

One essential CE strategy is **waste-to-resource practices**, which transform agricultural residues such as pruning by-products and crop waste into valuable outputs like compost, bioenergy, and animal feed. These practices embody CE principles by diverting waste from disposal pathways and reintegrating it into the agricultural cycle. This approach not only reduces environmental burdens but also enhances soil health by increasing organic matter and fertility. Moreover, bioenergy derived from residues can provide farms with renewable energy sources, reducing dependency on fossil fuels and contributing to climate action goals (Blanco-Canqui & Lal, 2009).

In the European Union, programs like **AgroCycle** are at the forefront of implementing CE strategies in agriculture. By analyzing the agri-food value chain and identifying opportunities to reuse crop and livestock by-products, AgroCycle demonstrates the potential of closed-loop systems to improve resource efficiency and sustainability. This initiative exemplifies how CE practices can be applied at scale, enhancing the economic and environmental viability of agriculture across diverse contexts (AgroCycle, 2017).

Another pillar of CE in agriculture is **resource efficiency**, which emphasizes the optimized use of water, nutrients, and energy throughout farming operations. Precision agriculture and smart irrigation technologies are pivotal tools in achieving these goals. By tailoring water and nutrient applications to specific crop needs, these technologies reduce input waste, lower production costs, and mitigate the environmental impact of farming practices. This efficient management ensures that resources are conserved while maximizing agricultural productivity, aligning closely with CE objectives (Ghisellini et al., 2016).

A critical outcome of CE-aligned practices is the promotion of **healthy soils and biodiversity**, which are fundamental to sustainable agriculture. Practices such as compost application and organic farming replenish soil organic matter, enhance soil structure, and boost microbial activity. These improvements not only increase soil fertility but also support biodiversity, creating resilient ecosystems capable of sustaining agricultural productivity over the long term. The regenerative aspect of these practices helps reverse the negative impacts of conventional farming, ensuring that ecosystems remain robust and self-sustaining (Pretty, 2008).

Incorporating CE principles into agriculture provides a clear pathway to a sustainable future, where waste is minimized, resources are used efficiently, and natural systems are actively regenerated. These practices, exemplified by initiatives like AgroCycle and supported by advancements in precision technologies, showcase the potential for agriculture to transition toward a more sustainable and circular model, fostering environmental health and economic resilience.

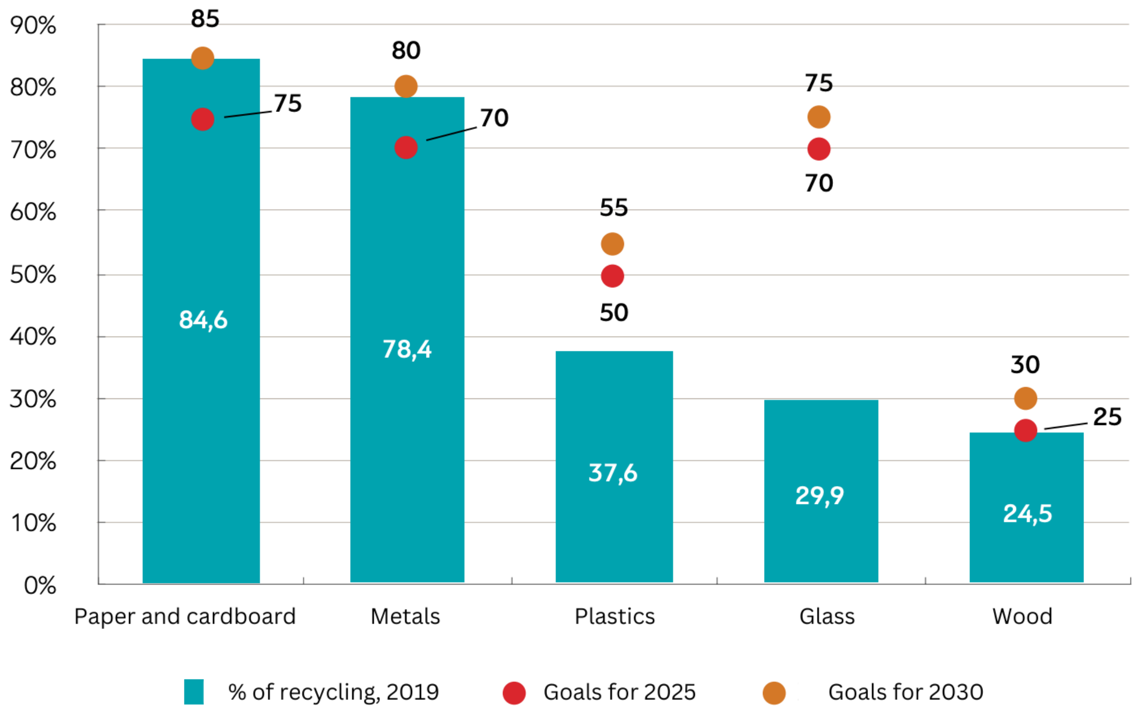

Diagram 1. Packaging waste recycling and national targets for 2025 and 2030 (YPEN, National waste management plan)

National and European Packaging Waste Management Goals

The advancements in Greece's national planning for recycling paper and cardboard packaging bring the country closer to meeting its circular economy objectives. However, challenges persist, particularly with recycling rates for plastic, glass, and wooden packaging, which lag behind both national targets for 2025 and 2030 and the European averages (YPEN, National Waste Management Plan). For example, Greece's recycling rates for plastics remain below European levels, which highlights the need for enhanced recycling infrastructure and more comprehensive waste management strategies.

The implementation of the European own resources mechanism to enhance plastic recycling is expected to encourage Greece to improve its recycling efforts, as the country's national contribution for non-recycled plastic packaging stood at €111.2 million in 2019 (Economic and Industrial Research Foundation, 2022). This financial mechanism demonstrates the economic cost of failing to meet recycling targets and highlights the importance of policy-driven incentives to increase recycling rates and reduce the environmental footprint of plastic packaging waste.

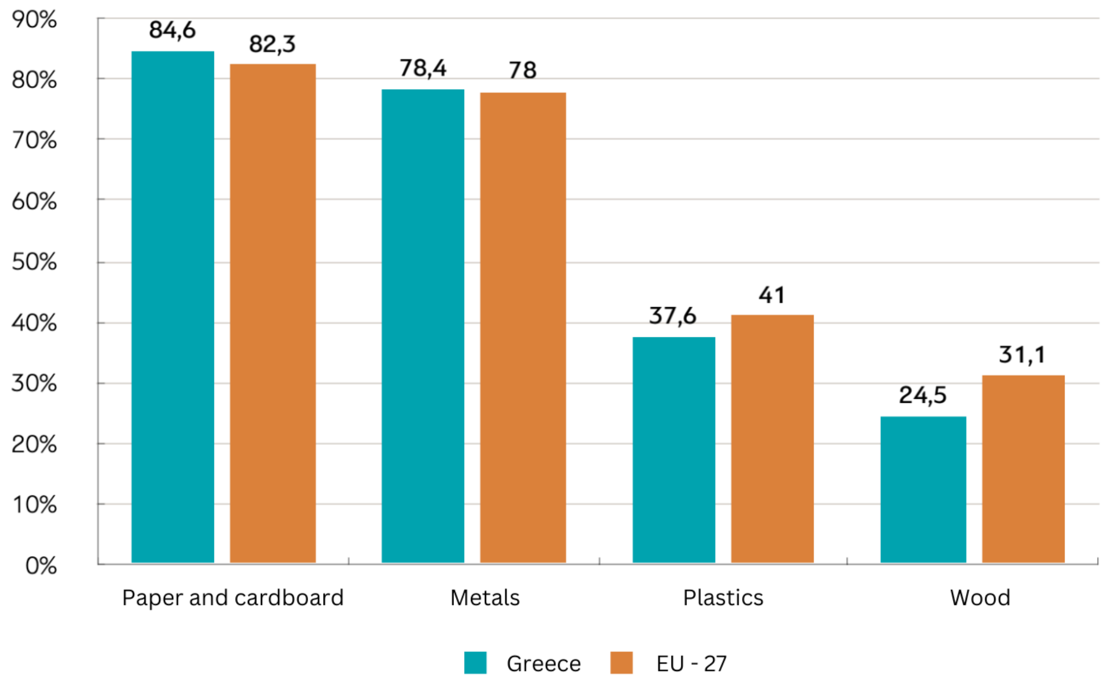

Diagram 2. Packaging recycling, Greece and EU-27 (%) (Eurostat)

In Greece, there are currently 18 composting facilities that produce soil improvers with concurrent energy production, boasting an installed capacity of 14.07MWe. Additionally, some private sector initiatives, such as the Plastics of Crete company, work to recycle agricultural film, covering up to 90% of film waste in Crete. However, these operations cover only a fraction of agro-livestock waste produced in Greece, and a considerable amount remains unutilized, often burned at the application site. This practice not only prevents material circularity but also releases toxic pollutants into the environment (European Commission, 2022).

The European Circular Economy Action Plan (CEAP), launched in 2015 and further expanded in 2020, represents the EU's commitment to reducing the environmental impact of production and promoting green economic growth through waste management, innovation, and resource efficiency. The new CEAP aims to minimize environmental footprints, reduce raw material consumption, and foster green job creation, particularly in waste management and sustainable product design sectors. Specific goals include the adoption of CE practices within value-intensive industries such as electronics, batteries, vehicles, packaging, plastics, and agriculture (European Commission, 2022).

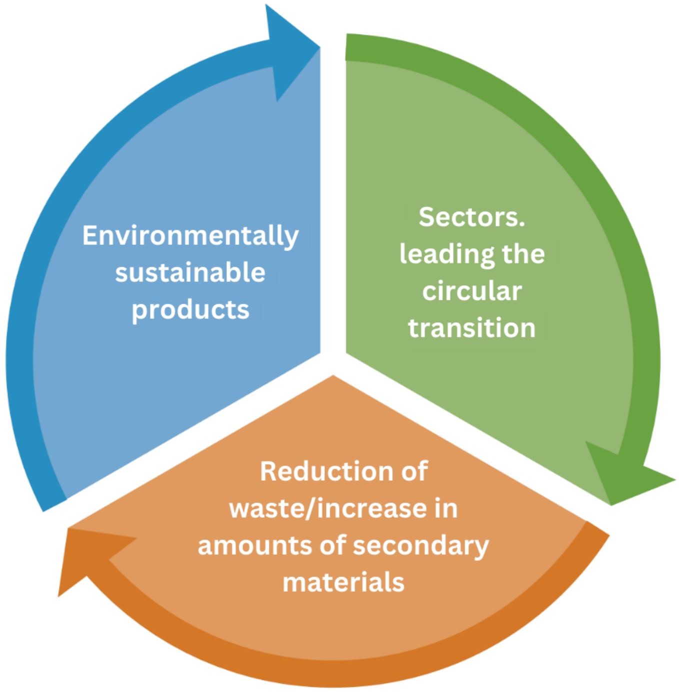

Diagram 3. Objectives of the European plan for the circular economy (COM (2020) 98 - The new Circular Economy Action Plan – For a cleaner and more competitive Europe.

In order to achieve the above, it is envisaged to establish a special framework for the manufacture, distribution and use of environmentally sustainable products. This builds on past European policies, such as the implementation of the European Ecolabel, the implementation of the Green Public Procurement scheme and the eco-design of energy-related products (European Commission, 2022). In addition, the plan includes actions to empower consumers in the media from the provision of more and more complete information related to the lifetime of the products, their repairability as well as their overall environmental footprint, which is estimated with a specific methodology.

The plan also aims to highlight the material-intensive sectors involving value chains of basic products that should lead the way in adopting circular economy applications. These industries include electronics, batteries, vehicles, packaging, plastics, textiles, construction, food, water and nutrients.

2.3 The Role of Sustainable Development Goals (SDGs) in Agriculture

Integrating Circular Economy (CE) strategies within agriculture aligns seamlessly with the United Nations Sustainable Development Goals (SDGs), offering a structured framework to address global challenges related to sustainability, food security, and economic resilience. By promoting practices such as the reuse of pruning wood, agriculture can significantly contribute to achieving these goals while fostering long-term environmental, social, and economic benefits.

Promoting Sustainable Food Production (SDG 2: Zero Hunger)
Sustainable food production systems that enhance ecosystem resilience are critical to achieving SDG Target 2.4. Reusing pruning wood as compost or mulch directly supports this goal by improving soil fertility and structure. These practices increase crop yields while reducing reliance on chemical fertilizers, fostering agricultural sustainability and resilience. The economic benefits—such as lower input costs for farmers—play a crucial role in strengthening food security, particularly in rural communities reliant on local production (Blanco-Canqui & Lal, 2009).

Advancing Renewable Energy in Agriculture (SDG 7: Affordable and Clean Energy)
Transforming pruning residues into renewable energy sources supports Target 7.2, which emphasizes increasing the share of renewable energy in the global energy mix by 2030. Localized energy solutions reduce reliance on conventional energy sources, lowering operational costs and environmental impacts. Additionally, minimizing transportation emissions further supports the environmental benefits of sustainable agricultural practices (Scarlat et al., 2015).

Boosting Economic Productivity and Employment (SDG 8: Decent Work and Economic Growth)
Circular economy (CE) practices create new economic opportunities by adding value to agricultural waste, diversifying income streams, and fostering local entrepreneurship. The use of pruning residues for soil enrichment and other applications generates jobs, particularly in rural areas with limited employment opportunities. These initiatives align with Target 8.2 by enhancing economic resilience through innovation and diversification (Food and Agriculture Organization, 2018).

Reducing Agricultural Waste (SDG 12: Responsible Consumption and Production)
Target 12.5 emphasizes reducing waste generation through recycling and reuse. Transforming pruning residues into compost avoids their disposal in landfills, where they would otherwise contribute to greenhouse gas emissions. By reintegrating these materials into agricultural cycles, a closed-loop system is created that conserves resources and aligns with the CE's sustainability objectives (Ghisellini et al., 2016).

Climate Action through Agriculture (SDG 13: Climate Action)
Circular practices leveraging pruning wood contribute to Target 13.1 by reducing greenhouse gas emissions and enhancing carbon sequestration. Composting captures carbon in organic matter, improves soil structure, and retains water, helping local ecosystems adapt to climate change. These approaches reduce agriculture's carbon footprint while bolstering its long-term resilience (Lal, 2004).

Combating Land Degradation and Supporting Biodiversity (SDG 15: Life on Land) Pruning wood applications, such as mulch or compost, support Target 15.3 by combating soil erosion, retaining moisture, and restoring degraded lands. These practices improve soil health and promote biodiversity by fostering habitats for microorganisms essential to ecosystem regeneration. Enhancing the vitality of terrestrial ecosystems is a vital contribution of agriculture to preserving land and biodiversity (Blanco-Canqui & Lal, 2009).

Building Partnerships for Sustainability (SDG 17: Partnerships for the Goals) Achieving sustainability requires multi-stakeholder partnerships, as emphasized in Target 17.16. Circular approaches in agriculture promote collaboration among farmers, researchers, policymakers, and businesses. Such partnerships facilitate innovation, policy development, and scaling of sustainable practices. By uniting resources and expertise, these efforts drive transformative change in agricultural systems (Pretty, 2008).

By integrating circular economy strategies, agriculture aligns with the Sustainable Development Goals, fostering a resilient and sustainable future. These practices—rooted in waste-to-resource approaches, resource efficiency, and ecosystem regeneration—highlight agriculture's potential to significantly contribute to global sustainability objectives.

2.4. Integrating Circular Economy into Agricultural Practices

The integration of circular economy (CE) principles into agriculture marks a critical evolution in the sector's approach to resource utilization, waste management, and environmental stewardship. This transformation builds on both historical agricultural wisdom and modern technological advancements, enabling sustainable agricultural systems that balance productivity with ecological resilience. The CE model emphasizes the cyclical use of resources, minimizing waste and enhancing the environmental and economic sustainability of farming practices.

Historically, agricultural systems have embodied principles of circularity through their reliance on natural cycles and resource optimization. Crop rotation was a fundamental practice that allowed farmers to maintain soil fertility and disrupt pest and disease cycles by alternating crops with varying nutrient requirements. This method reduced soil depletion and fostered long-term agricultural productivity, avoiding the monoculture practices that often lead to ecological imbalances (Altieri, 1999). Similarly, intercropping—growing multiple crops in the same field—improved resource efficiency by enhancing nutrient uptake and reducing pest infestations. Intercropping also supported biodiversity within the agroecosystem, increasing resilience to environmental stresses and promoting sustainable land use (Francis, 1986).

Traditional farming systems relied heavily on manual and animal labor, fostering a close relationship between farmers and their environment. This approach enabled careful monitoring of crop health and soil conditions, ensuring adaptive and sustainable management practices. While labor-intensive, these methods allowed for more personalized and ecologically sensitive agricultural systems (Mazoyer & Roudart, 2006).

In waste management, traditional agricultural practices demonstrated a strong alignment with circular principles by employing closed-loop systems that effectively recycled organic and inorganic materials. Composting was a common method for converting crop residues and animal manure into nutrient-rich organic matter, improving soil fertility and promoting microbial activity. This practice exemplified the circular economy by reintegrating agricultural waste into the ecosystem (Blanco-Canqui & Lal, 2009). Green manuring, which involved planting cover crops such as legumes, enriched the soil with organic matter and nitrogen, reducing the need for synthetic fertilizers. This practice not only supported soil fertility but also contributed to weed suppression and soil structure protection (Lal, 2004). Additionally, the use of animal manure as fertilizer improved soil structure and enhanced biodiversity, fostering a productive and ecologically balanced farming environment (Pretty, 2008).

Building on these historical foundations, modern agricultural systems have adopted and refined these practices, incorporating advanced CE strategies to enhance efficiency and sustainability. Innovations such as precision farming, renewable energy integration, and biotechnology complement traditional methods by improving resource use and reducing environmental impacts. For example, precision agriculture allows for optimized water and nutrient management, while renewable energy sources like solar power and bioenergy reduce reliance on fossil fuels. These advancements have expanded the scope of circular practices, enabling farmers to balance economic viability with environmental conservation.

By integrating CE principles, agriculture can achieve a resilient, resource-efficient system capable of meeting the demands of a growing population while addressing environmental challenges. This synthesis of historical knowledge and modern innovation highlights the potential of CE to redefine agriculture as a sustainable and regenerative industry, aligning with global goals for food security and ecological sustainability. Through these efforts, the sector can play a pivotal role in promoting environmental resilience and advancing sustainable development.

2.5. Best Practices for Circular Agriculture Strategies

Circular agriculture practices around the world highlight the transformative potential of applying circular economy (CE) principles to enhance sustainability and resource efficiency in farming systems. These strategies focus on reducing waste, optimizing resource use, and integrating innovative solutions to create resilient agricultural systems.

China: Technological Innovation in Waste Management

China's implementation of circular agriculture projects has showcased the potential of combining traditional farming methods with modern technology. The nation has focused on converting agricultural residues, such as crop stalks and animal manure, into biogas and organic fertilizers through anaerobic digestion. These technologies have been deployed in rural pilot programs, significantly reducing the environmental footprint of farming. Additionally, wastewater from agriculture is treated and reused for irrigation, closing the water-use loop and addressing water scarcity issues. Such projects not only minimize waste but also enhance soil fertility, reduce dependency on synthetic inputs, and contribute to rural energy supply (Geng et al., 2013). China's efforts illustrate the potential of CE strategies to transform agricultural systems at a large scale while addressing sustainability challenges.

Australia: Conservation Agriculture for Soil Health

Australia has emphasized conservation agriculture to combat soil erosion and water scarcity. Key practices include crop residue recycling, no-till farming, and the use of cover crops to protect and enrich soil. Farmers often leave crop residues in the fields to decompose naturally, replenishing soil organic matter and nutrients. Additionally, no-till farming minimizes soil disruption, which reduces erosion and enhances soil water retention. These methods not only improve farm profitability by increasing yields but also promote ecological stability by reducing greenhouse gas emissions and chemical inputs (Llewellyn et al., 2012). The integration of these strategies demonstrates how CE principles can simultaneously address environmental and economic challenges.

Andalusia, Spain: Biochar and Olive Farming

In Andalusia, Spain, olive farmers have adopted circular economy (CE) practices that focus on transforming agricultural residues, such as pruning wood, into valuable resources. One notable example is the production of biochar, a carbon-rich material used as a soil amendment. Through cooperative efforts, farmers share the costs of specialized equipment, making the process more accessible and efficient. This practice has significantly improved soil structure, enhanced water retention, and reduced the reliance on chemical fertilizers. Additionally, the area utilizes biomass heating systems powered by agricultural residues, which contribute to local energy self-sufficiency. By aligning with CE principles, these initiatives close material loops and create added value from agricultural waste, offering a scalable model for sustainable practices in other Mediterranean areas (Gómez, 2021).

Puglia, Italy: Biomass Fuel and Composting

In Puglia, Italy, grape and almond farmers have embraced innovative biomass fuel production from pruning residues. This biomass is used as a renewable energy source, reducing reliance on fossil fuels and lowering carbon emissions. In addition, composting programs in the area convert agricultural by-products into organic fertilizers, enriching soil quality and reducing the need for synthetic inputs. These practices have not only decreased costs for farmers but also contributed to environmental sustainability by addressing soil degradation and promoting biodiversity (Ferrari & Conti, 2019). Puglia's model demonstrates the practical application of CE principles to balance agricultural productivity with ecological stewardship.

Alentejo, Portugal: Composting and Drought Resilience

The Alentejo area in Portugal highlights the role of CE strategies in addressing climate challenges such as drought. Farmers there have established composting programs to process agricultural residues, creating nutrient-rich organic matter for their fields. This compost enhances soil structure, increases water retention, and improves crop resilience to drought conditions. Policies supporting cooperative composting facilities have enabled farmers to reduce costs while promoting sustainable land management practices. Alentejo's efforts exemplify how targeted policies can amplify the benefits of CE strategies, fostering resilience in semi-arid farming systems (Carvalho et al., 2020).

Göttingen, Germany: Bioenergy Villages

The Göttingen area in Germany provides a comprehensive example of circular agriculture through its bioenergy villages. These communities use locally sourced biomass, including crop residues and animal waste, to fuel biogas plants that generate electricity and heat. This system has reduced reliance on fossil fuels, lowered CO_2 emissions, and provided energy independence for rural areas. The bioenergy village model fosters community collaboration by involving local farmers, municipalities, and businesses in shared sustainability goals. Initiated in Jühnde in 2005, the program has expanded to other villages, demonstrating how rural communities can adopt CE principles to achieve economic revitalization and environmental benefits (Göttinger Land, 2022).

These global examples underscore the potential of CE strategies to transform agricultural practices. Whether through the technological advancements in China, conservation-focused methods in Australia, or biomass and composting initiatives in Europe, each territory highlights a unique application of CE principles. By focusing on waste management, resource efficiency, and community collaboration, these strategies provide a blueprint for sustainable agriculture that balances economic growth with environmental preservation.

3. Research Methodology

Data Collection and Analysis Techniques

This study combines various data collection methods, including surveys, interviews, and analysis of local agricultural datasets, to provide a comprehensive view of agricultural practices and the circular economy potential in Tegea area in Tripolis. The multi-method approach was selected to achieve a robust understanding of land utilization, crop types, farmer perspectives, and current practices for pruning residue management.

1. **Survey and Interview Data**:

   Surveys and interviews with local farmers were conducted to gather firsthand insights into current agricultural practices, attitudes toward waste reuse, and perceived challenges and opportunities for adopting circular economy practices. By engaging directly with farmers, the study can integrate qualitative insights that reflect local expertise and challenges, offering a nuanced perspective on the area's readiness for sustainable practices.

   - **Rationale**: Surveys and interviews provide qualitative data, essential for understanding the social context and farmer attitudes, which quantitative data alone cannot capture. These methods enrich the study by bringing forward local knowledge, challenges, and potential pathways that may not be evident through secondary data.

2. **ΟΠΕΚΕΠΕ Dataset Analysis**:

   The ΟΠΕΚΕΠΕ dataset provides quantitative data on land use, crop types, and the number of farmers across Tegea, offering a structured foundation for understanding land utilization patterns and potential biomass generation from prunings. The dataset includes the following key columns, each of which provides valuable data for our analysis:

   - **Year (2023)**: The dataset is specific to the 2023 cultivation period, ensuring the data reflects current trends and conditions in the agricultural sector.
   - **Location Specifications**: Detailed location data at the Regional Unit, Municipality, Local District, and number farmers allows for a focused analysis of agricultural practices across different areas in Tegea.
   - **Cultivation Code and Type**: Categorizing data by crop and land type (e.g., cereals, nut trees, vineyards, grazing land) provides a detailed view of agricultural diversity in the local landscape.
   - **Area in Hectares**: The area of land dedicated to each crop type is summed to calculate the overall percentage distribution for each cultivation type, offering insights into dominant crops.

- **Number of Farmers (AFM)**: Identifying the number of unique farmers per crop type provides an understanding of the scale of individual agricultural operations in Tegea and serves as an indicator of potential pruning residue generation per crop type.

3. **Hellenic Statistical Authority (ELSTAT)**: ELSTAT regularly publishes detailed data on agricultural production at national and regional levels, including crop yields, land use, and economic impacts. Their publications provide critical benchmarks for assessing Tripolis's agricultural performance and identifying growth opportunities (ELSTAT, 2023).

4. **Hellenic Ministry of Rural Development and Food**: The Ministry publishes extensive reports on agricultural practices, policy initiatives, and production data across Greece.

4. Case Study: Tripolis Agricultural Sector

4.1. Overview of Agricultural Practices in Tripolis

The agricultural sector in Tripolis, Greece, stands to benefit significantly from circular economy practices. Local advancements in waste management—such as on-site composting and reuse of pruned wood—could enhance productivity while fostering economic sustainability. This study aims to investigate the significance of pruned wood waste in Tripolis, evaluate current practices, and provide recommendations to embed circular economy principles into regional agro-environmental management. The next section delves into the theoretical foundation of the circular economy, followed by a literature review and discussion of relevant combined heat-power and district heating projects suitable for integration in Tripolis. This examination will include specific recommendations, barriers, and emerging opportunities for sustainable agriculture and circular economy practices.

The Municipality of Tripolis, located in the central Peloponnese, is a predominantly rural area where agriculture plays a critical role in the local economy. With a population of 47,467 as per the 2011 census, and spanning an area of 1,481 square kilometers, the municipality consists of eight distinct municipal units. These include Tripoli itself, a hub of administrative and economic activity, and several surrounding rural areas where agricultural activity predominates. Key crops such as cereals, olive trees, vineyards, and vegetables form the backbone of the local agricultural economy, reflecting both traditional practices and modern developments (Municipality of Tripolis, 2023).

The agricultural landscape of Arcadia is characterized by its diverse crop production, including cereals, apple trees, walnut trees, almond trees, peach and nectarine trees, and vegetables. This diversity highlights significant opportunities for implementing circular economy (CE) practices, particularly in managing pruning residues and other agricultural by-products. Integrating the data on crop cultivation and tree production from local and national statistical sources provides a detailed understanding of the territory's agricultural capacity and the potential for sustainable practices.

4.2 Current Approaches to Circular economy practices

The Municipality of Tripolis has demonstrated significant advancements in waste management and circular economy practices, positioning itself as a leader in sustainable agricultural and environmental management. A cornerstone of this effort is the Waste Management Unit in Palaiochouni, established as part of the Integrated Waste Management System of the Peloponnese Region. Operational since 2021, this facility represents one of Greece's most advanced infrastructures for waste processing. It handles up to 105,000 tons of mixed municipal solid waste annually, serving multiple regional units, including Arcadia, Argolida, and Corinthia. The facility incorporates state-of-the-art technology for waste sorting, recycling, and the production of compost-like outputs. Additionally, it captures biogas for energy production, embodying circular economy principles by converting waste into valuable resources (TERNA Energy, 2023; FPress, 2023).

This initiative is part of a broader regional strategy involving three Waste Treatment Units (WTUs) and Landfills for Residual Waste (LRWs) located in Arcadia, Messinia, and Laconia, complemented by two Waste Transfer Stations (WTSs) in Corinthia and Argolida. These systems collectively enhance resource utilization, mitigate environmental impacts, and promote sustainable waste management across the Peloponnese (Economistas, 2023). These efforts demonstrate the region's commitment to creating a sustainable model that reduces landfill dependency and integrates circular economy principles into waste management processes.

Complementing these waste management systems, the Municipality of Tripolis is advancing bioeconomy and circular economy goals through the Bioeconomy 360° Hub. This initiative, part of Greece’s National Just Development Transition Program, focuses on fostering entrepreneurship, applied research, and skills development in regions like Megalopolis, Tripolis, Gortynia, and Oichalia. The Bioeconomy 360° Hub aims to create hundreds of jobs, attract investments, and support critical sectors, including agriculture, pharmacology, and alternative fuels. This integrated approach not only revitalizes rural areas but also aligns local development efforts with national and European sustainability strategies (E-OTA, 2023; Anagnostis, 2023).

The hub’s significance was underscored at the 10th Just Transition Platform Conference in Brussels, where its role in achieving economic revitalization through circular and bioeconomy practices was highlighted. Supported by the Just Transition Fund (JTF), the Bioeconomy 360° Hub exemplifies how targeted investments in sustainability can drive innovation, enhance economic resilience, and mitigate climate change impacts (Anagnostis, 2024).

4.3 Environmental Costs of Burning Wood from Farming Procedures

While Tripolis is making strides in sustainable waste management, traditional practices such as burning pruning residues remain prevalent in farming. This practice imposes significant environmental and economic costs, which undermine regional and global climate goals. Traditional practices such as burning pruning residues, while prevalent in the agricultural sector of Arcadia and the broader Peloponnese region, impose significant environmental and economic costs. Despite strides in sustainable waste management in areas like Tripolis, these practices continue to undermine both regional and global climate goals.

Burning pruning residues releases considerable quantities of carbon dioxide (CO_2), a greenhouse gas contributing to global warming. While wood is often considered carbon-neutral due to the CO_2 absorption during tree growth, this balance is disrupted when residues are burned rather than repurposed. Incomplete combustion exacerbates this issue, emitting methane (CH_4) and nitrous oxide (N_2O), both of which have substantially higher global warming potentials than CO_2. Methane, for instance, has a global warming potential 25 times greater than CO_2 over a 100-year period (IPCC, 2019). Globally, the open burning of agricultural residues contributes 0.4–1.2 billion tons of CO_2 annually, highlighting the significant role this practice plays in climate change (Scarlat et al., 2015). In Arcadia, which boasts extensive olive groves, vineyards, and orchards, this practice exacerbates local carbon emissions and disrupts efforts to achieve carbon neutrality.

The burning of wood also produces harmful particulate matter (PM2.5 and PM10) that significantly affects air quality and public health. Exposure to these particulates has been linked to respiratory and cardiovascular diseases, as well as premature deaths (WHO, 2021). Burning releases additional harmful pollutants, such as carbon monoxide (CO), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), which contribute to smog formation and have carcinogenic properties. In Greece, the seasonal burning of pruning residues can account for up to 30% of local air pollution during pruning months, severely impacting air quality in both rural and urban areas. This is particularly relevant in Arcadia, where agricultural practices heavily influence regional air quality, affecting populations in and around Tripolis (Papadopoulos et al., 2020).

Beyond atmospheric impacts, burning pruning residues significantly depletes soil health. Essential nutrients such as nitrogen, phosphorus, and potassium are lost in the process, reducing soil fertility and increasing reliance on synthetic fertilizers. This degradation undermines long-term agricultural productivity and elevates the risk of soil erosion and desertification, particularly in Mediterranean regions prone to these challenges (Lal, 2004). Burning also disrupts biodiversity by destroying habitats for microorganisms and insects crucial for nutrient cycling and soil aeration. This loss of biodiversity weakens the resilience of agricultural ecosystems, further compromising sustainable farming practices (Geissdoerfer et al., 2017).

The environmental costs of burning wood are compounded by the missed opportunities for sustainable practices. Pruning waste, which is often treated as a disposal challenge, holds substantial potential for repurposing. It can be converted into biochar, a carbon-rich soil amendment that enhances fertility and acts as a long-term carbon sink. Additionally, pruning residues can be composted to improve soil organic matter and reduce dependence on chemical fertilizers. Biomass energy production offers another alternative, providing renewable energy and reducing reliance on fossil fuels. These circular economy approaches not only mitigate the environmental impacts of burning but also create economic opportunities for local farmers (Ghisellini et al., 2016; Ellen MacArthur Foundation, 2013).

In Mediterranean agricultural landscapes, such as those in Arcadia, the implications of burning pruning residues are particularly severe. Olive groves, vineyards, and orchards dominate the region, and the combustion of their residues contributes significantly to seasonal air pollution. Studies indicate that up to 30% of seasonal air pollution during pruning months originates from these practices, exacerbating greenhouse gas emissions and air quality issues (Scarlat et al., 2015; Papadopoulos et al., 2020). Furthermore, Arcadia's susceptibility to soil erosion and desertification amplifies the environmental costs, emphasizing the urgent need for sustainable alternatives. By adopting circular economy practices to manage pruning residues, the region can mitigate these environmental challenges, enhance agricultural sustainability, and contribute to broader climate action objectives.

4.3. Thematic Insights from Interviews

4.3.1 A Pioneer in Circular Agricultural Practices (A)

A chemical engineer, has established a forward-thinking agricultural enterprise, alongside his brother . Founded in 2020, the family-operated business emphasizes sustainable production, packaging, and distribution of high-quality agricultural products. The vertical integration of their operations, from cultivation to sales, reflects their commitment to excellence and environmental stewardship. Notably, the enterprise has adopted renewable energy sources, such as solar energy, to reduce water and energy consumption across the production cycle, aligning with the principles of the circular economy (CE). This approach not only minimizes environmental impact but also improves resource efficiency, setting a benchmark for sustainable agriculture in the Municipality of Tripolis.

A's understanding of CE principles underscores his dedication to minimizing resource waste and maximizing sustainability. For instance, the nearby artificial Taka Lake serves as a prime example of CE in action, collecting rainwater for irrigation and reducing reliance on natural water sources. The lake also supports biodiversity, acting as a natural habitat, which enhances ecological balance. On their farm, A emphasizes efficient water management through weather stations, enabling predictive resource utilization. Additionally, he highlights the potential of using agricultural residues, such as pruning wood, for compost or bioenergy, thereby transforming waste into valuable resources.

While acknowledging the current gaps in local adoption, he advocates for greater awareness and investment in such sustainable practices.

Despite the promising potential of CE practices, A identifies significant challenges in their implementation. Limited knowledge and the aging demographic of farmers in the area pose obstacles to widespread adoption. With over 55% of farmers aged above 50 and only 75% identifying as professional farmers, resistance to change and technological investment remains high. Furthermore, small, fragmented landholdings exacerbate the difficulty of implementing advanced CE practices. However, A suggests that coordinated efforts among farmers, policymakers, and scientific institutions could overcome these barriers. Initiatives such as composting and biogas production could not only reduce waste but also generate additional income streams for local farmers, albeit modest compared to the effort required.

A strongly supports the integration of CE principles to enhance soil health, reduce dependency on chemical fertilizers, and lower greenhouse gas emissions. Composting pruning residues, for instance, improves soil structure and fertility while contributing to biodiversity. Additionally, the use of bioenergy from organic waste reduces reliance on fossil fuels, cutting carbon footprints. By fostering collaborations with scientific and governmental entities, A envisions a sustainable agricultural future for Tripolis, with CE practices at its core. His vision underscores the importance of education, infrastructure development, and financial incentives to drive this transformative shift in agricultural practices.

4.3.2. Stakeholder Perspectives: Insights from B

B provides a detailed perspective on the integration of circular economy (CE) principles within agriculture, emphasizing their potential to transform waste management and enhance sustainability. He defines CE in agriculture as a holistic system aimed at minimizing waste and improving sustainability across all stages of agricultural production and distribution. By utilizing agricultural residues, such as pruning waste and animal by-products, as resources, farmers can recycle nutrients and reduce dependency on chemical fertilizers. This approach not only fosters environmental conservation but also contributes to the economic viability of farming operations by lowering input costs.

In the Mantineia section, where B is based, composting and organic farming represent the primary applications of CE principles. Composting converts organic waste, including crop residues, into nutrient-rich soil improvement substances, improving soil health and reducing reliance on synthetic fertilizers. Organic farming practices further support this approach by promoting the use of natural inputs and eschewing harmful chemicals, thus aligning agricultural practices with environmental stewardship. While these practices are beneficial, they remain underutilized, often limited to isolated cases due to a lack of awareness among farmers. B highlights the untapped potential of scaling up these efforts, particularly through education and the promotion of ready-made organic fertilizers derived from plant and animal waste.

One of the key barriers to the widespread adoption of CE practices in the area is the insufficient knowledge among farmers about their benefits. B underscores the importance of addressing this knowledge gap to facilitate broader acceptance of techniques such as composting and bioenergy production. He identifies significant opportunities for cost savings, noting that using pruning residues for soil enrichment and self-produced fertilizers can reduce cultivation expenses. Despite the challenges, these practices present an economically viable path toward more sustainable agricultural systems, offering both environmental and financial benefits to farmers willing to embrace circular approaches.

4.3.3. Stakeholder Perspectives: Insights from C

C, a 29-year-old farmer managing a 100-stremma farm of trees and vegetables, provides a practical and forward-thinking perspective on integrating circular economy (CE) principles into agricultural practices. His approach demonstrates how combining traditional methods with innovative practices can lead to more sustainable and efficient farming systems.

C actively employs CE practices, such as shredding pruning residues to produce biomass pellets for fuel. This method not only reduces waste but also generates an additional energy source for farm operations. Additionally, he capitalizes on agricultural by-products by selling apple residues to juice producers. Looking ahead, he plans to further enhance value by processing apple by-products himself into dried or juiced forms, thereby diversifying his farm's income streams. His on-site packaging facility further supports a vertically integrated farming model that reduces external dependencies and adds value to his products.

He highlights the potential for CE strategies in Tegea, particularly the opportunity to develop greenhouses that utilize agricultural residues for heating, enabling year-round production at reduced costs. C also advocates for seasonal optimization of crops, such as alternating vegetable cultivation from July to October and tree farming from October to May, leveraging the area's natural conditions for continuous and complementary production cycles. These approaches align with CE principles by maximizing resource use while reducing waste.

Despite the benefits, C notes several challenges to adopting CE practices. High technology costs, bureaucratic hurdles, and limited knowledge within public authorities (e.g., ΟΠΕΚΕΠΕ and ΔΑΟΚ) are significant barriers. He stresses the need for state support, including subsidies for advanced equipment, and the importance of educating older farmers, who are more resistant to change, through demonstrable results.

In terms of environmental impacts, C emphasizes the benefits of green manuring and incorporating pruning residues into the soil. These practices not only reduce carbon emissions but also improve soil structure and biodiversity, creating a healthier and more resilient agroecosystem. He envisions a collaborative approach where producer cooperatives play a central role in managing agricultural waste and facilitating CE initiatives, supported by government incentives and educational programs.

C’s commitment to CE principles reflects his belief in their potential to benefit both the environment and the economy. His willingness to engage actively in the development and dissemination of these practices highlights the importance of farmer-driven innovation and collaboration in achieving sustainable agricultural transformation.

4.3.4. Stakeholder Perspectives: Insights from D

D, the production manager at P Winery, provides a perspective rooted in practical application and long-term sustainability. Her understanding of the circular economy (CE) in agriculture emphasizes its potential to reduce costs, enhance profitability, and minimize the reliance on natural resources. According to D, CE embodies the philosophy that "nothing goes to waste," a concept highly relevant to both economic viability and environmental stewardship.

The winery has already adopted CE practices, including incorporating pruning residues as soil improvement substances and using manure for fertilization. These methods not only enrich the soil but also reduce dependency on synthetic fertilizers, demonstrating the dual economic and ecological benefits of circular strategies. D notes that many local farmers have also adopted similar practices, emphasizing their growing prevalence and potential to become standard in the area. However, she highlights an associated challenge: the potential for pruning residues to transmit diseases, such as Eutypa dieback ("ίσκα"), necessitating specialized equipment for effective management.

D identifies a significant opportunity in CE for lowering cultivation costs. For example, reusing pruning residues eliminates the need for costly removal processes and labor associated with burning or discarding them. Furthermore, the natural decomposition of organic matter in the soil contributes to nutrient cycling, partially offsetting fertilization costs. She acknowledges a balanced carbon footprint, as shredding and incorporating pruning residues require machinery, but this is outweighed by the environmental benefits of avoiding open burning and improving soil structure.

On broader environmental impacts, D underlines the positive effects of these practices on soil health and biodiversity. The integration of organic matter into the soil enhances its structure and nutrient profile, while promoting a healthier ecosystem. However, she stresses the need for extensive, long-term Greek scientific research to fully understand these impacts. Studies should focus on disease transmission, fertilization efficacy, and the broader ecological benefits, providing a robust foundation for wider adoption of CE practices in agriculture.

To ensure successful implementation, D calls for better farmer education and knowledge dissemination. She advocates for scientific validation of CE practices through rigorous research and subsequent outreach to farmers via training programs. This approach, coupled with government support in policy and incentives, could accelerate the adoption of CE practices. D remains committed to integrating sustainable practices into the winery's operations and promoting CE principles, recognizing their critical role in preserving biodiversity and maintaining ecological balance in the area.

4.4. Local Practices and Analysis - Insights from an Agricultural Livestock Cooperative

AN Agricultural Livestock Cooperative has established itself as a vital entity in facilitating communication and support for farmers within the zone. This cooperative plays a central role in informing local agriculturalists about new policies and programs. Most farmers receive updates through interpersonal interactions, primarily during their visits to complete necessary declarations under the Integrated Administration and Control System (IACS/OSDE). Despite the absence of a formalized information dissemination system, the cooperative's direct engagement ensures that critical information reaches its members.

Recent discussions with the cooperative highlighted that a small but growing number of farmers in Arcadia are adopting innovative tools and practices, such as branch shredders. This shift is aligned with circular economy principles, emphasizing waste reduction and resource efficiency. These shredders allow farmers to repurpose pruning residues, which not only reduces the need for burning but also enhances soil organic matter through decomposition. This aligns with insights shared by local farmers during interviews. For instance, D, from P Winery, emphasized the dual benefits of cost savings and environmental enhancement achieved through the integration of pruning residues into the soil as organic improvement substances. However, as noted by C, there remains a risk of pathogen transmission, such as Eutypa lata, which necessitates further research and training.

The cooperative also identified potential advancements in biogas production, a growing interest among farmers in Arcadia. Currently, the nearest biogas plant is located in Corinth, underscoring the need for more localized facilities to make this practice accessible. Biogas systems represent a promising solution for managing organic waste, including animal manure and crop residues, while generating renewable energy. These systems align with the ecological scheme P1-31.4, described in Chapter 4, Article 24, of the national framework for sustainable agricultural practices (Hellenic Government Gazette, 2023). The scheme encourages the adoption of innovations such as composting, both of which are categorized as pioneering technologies eligible for state funding and financial incentives.

The Circular Economy initiative in agriculture, particularly as outlined in the **P1-31.4 framework**, provides a robust mechanism for promoting sustainable practices within the Municipality of Tripolis. This framework not only aligns with the broader goals of environmental sustainability but also directly addresses practical and economic challenges faced by local farmers. According to the Ministerial Decision No. 1384/190515/19-6-2023 (Government Gazette 3946/B/19-6-2023), the initiative introduces a series of targeted actions aimed at different agricultural sectors, including arable crops, vegetables, tree plantations, kiwi fruit, and vineyards.

The program facilitates the implementation of **circular economy practices** such as **on-site composting, material recycling, and the use of organic soil improvement substances like compost or digestate**. Farmers are encouraged to integrate practices like creating compost piles on their farms or transporting crop residues to licensed facilities for biogas or compost production. These actions are designed to transform agricultural waste into valuable resources, reducing the dependency on chemical fertilizers while enriching soil organic matter. The flexibility in using compost, whether generated on-site or sourced from certified providers, ensures that the approach can be adapted to the specific needs and capacities of each farming operation. (Circular of the Integrated Management System for Single Applications within the framework of the 2023-2027 National Public Procurement Plan, 2023)

Additionally, the **ECO-04.05 on-site composting model**, which allows farmers to treat crop residues with microbial composting agents directly in the field, offers a practical solution for those with limited access to off-site facilities. The emphasis on **soil health monitoring**, including mandatory organic carbon percentage analysis, ensures that the program's environmental impact is measurable and sustainable. This practice not only helps in improving soil fertility but also serves as an eco-friendly alternative to the conventional burning of pruning residues, a practice now restricted under evolving environmental regulations.

The framework also includes **financial incentives** for farmers, offering subsidies for adopting composting technologies and implementing circular practices. These incentives address a significant barrier identified during interviews with local farmers and the the co-op: the high cost of technological adoption and insufficient state support. By funding innovation and supporting the purchase of necessary equipment like shredders or composters, the program enables farmers to transition smoothly into more sustainable practices.

Farmers and cooperatives, such as the Co-op, have expressed the need for **structured awareness campaigns** and **training programs** to familiarize them with the program's requirements and benefits. As highlighted in the interviews, the cooperative plays a pivotal role in disseminating information about such schemes, relying heavily on personal interactions with farmers who visit their offices for subsidy declarations under the Integrated Administration and Control System (OSDE).

The success of the P1-31.4 initiative relies on creating a seamless link between governmental policy and ground-level execution. Encouraging farmers to embrace these changes requires not only financial support but also reliable access to technical advice and monitoring frameworks. The inclusion of well-defined reporting protocols, such as maintaining a digital environmental file and ensuring annual soil assessments, underlines the initiative's focus on accountability and long-term sustainability. With these measures in place, the program positions itself as a transformative approach to integrating circular economy practices into Greek agriculture. This structured implementation could serve as a model for other areas, blending environmental responsibility with practical economic incentives.

Moreover, the cooperative has observed a gradual integration of composting practices among farmers. Composting offers a viable method for transforming agricultural residues into nutrient-rich organic fertilizers. However, as emphasized in discussions with farmers like B, rigorous residue analysis is essential to prevent the spread of fungal diseases and pathogens. This underscores the need for institutional support in providing technical expertise and access to modern diagnostic tools.

The interviews with local farmers further corroborated the necessity of financial support and incentives to drive widespread adoption of circular practices. C highlighted the economic barriers posed by the high cost of modern machinery and the bureaucratic challenges associated with certifications. These issues were echoed by D Winery, where the responsible manager stressed that government subsidies are crucial to offset the initial investment required for sustainable equipment, such as shredders and biogas systems. Additionally, many farmers, particularly older ones, are hesitant to adopt new methods without tangible evidence of their benefits. Demonstration projects and pilot programs could serve as critical tools in bridging this gap by showcasing the long-term economic and environmental advantages of circular practices.

Policy frameworks play a pivotal role in fostering the adoption of these practices. The cooperative emphasized that the introduction of subsidies for equipment and targeted training programs would significantly enhance farmer participation. Such programs should focus on providing hands-on training and clear communication about the benefits of circular agriculture. Furthermore, creating partnerships between cooperatives, research institutions, and government agencies is essential for developing localized solutions that address the specific needs of the Arcadian agricultural sector.

In conclusion, the Co-op serves as a cornerstone for advancing sustainable agricultural practices in the area. By leveraging the cooperative's existing communication networks and integrating insights from local farmers, policymakers can design more effective strategies to promote circular economy principles. These efforts must prioritize financial incentives, technical support, and education to overcome existing barriers and unlock the full potential of circular agriculture in Arcadia. The integration of innovative practices such as composting, biogas production, and the use of shredders not only contributes to environmental sustainability but also enhances economic resilience within the local farming community.

4.5. Analysis of Crop Distribution and Potential for Wood Waste Reusein the Tegea area

The adoption of circular practices in agriculture addresses pressing environmental challenges while offering substantial economic benefits. Establishing facilities for biochar production and composting generates employment opportunities across production, distribution, and associated sectors, creating a ripple effect of economic activity in rural areas (Rodriguez, Geiger, & Pavlidis, 2020). By fostering sustainable agricultural productivity, these circular economy initiatives also contribute to the resilience of rural economies, ensuring long-term profitability for farmers.

The broader context of the bioeconomy highlights its critical role in Europe, where it employs over 8% of the workforce and contributes an annual added value of €614 billion. The sector is poised to create up to 1 million new green jobs by 2030, particularly in rural and coastal areas such as forestry and blue bioeconomy industries that leverage aquatic biomass. Much of this employment growth is expected in nonfood sectors, including liquid biofuels, bioenergy, and support services such as logistics and equipment production (Allthings, 2020).

Using data from the ΟΠΕΚΕΠΕ dataset, we'll calculate the total pruning wood yield for each crop type by multiplying the area in hectares by the pruning yield per hectare. This calculation provides a comprehensive view of the pruning wood potential per crop and highlights areas with high biomass availability for reuse.

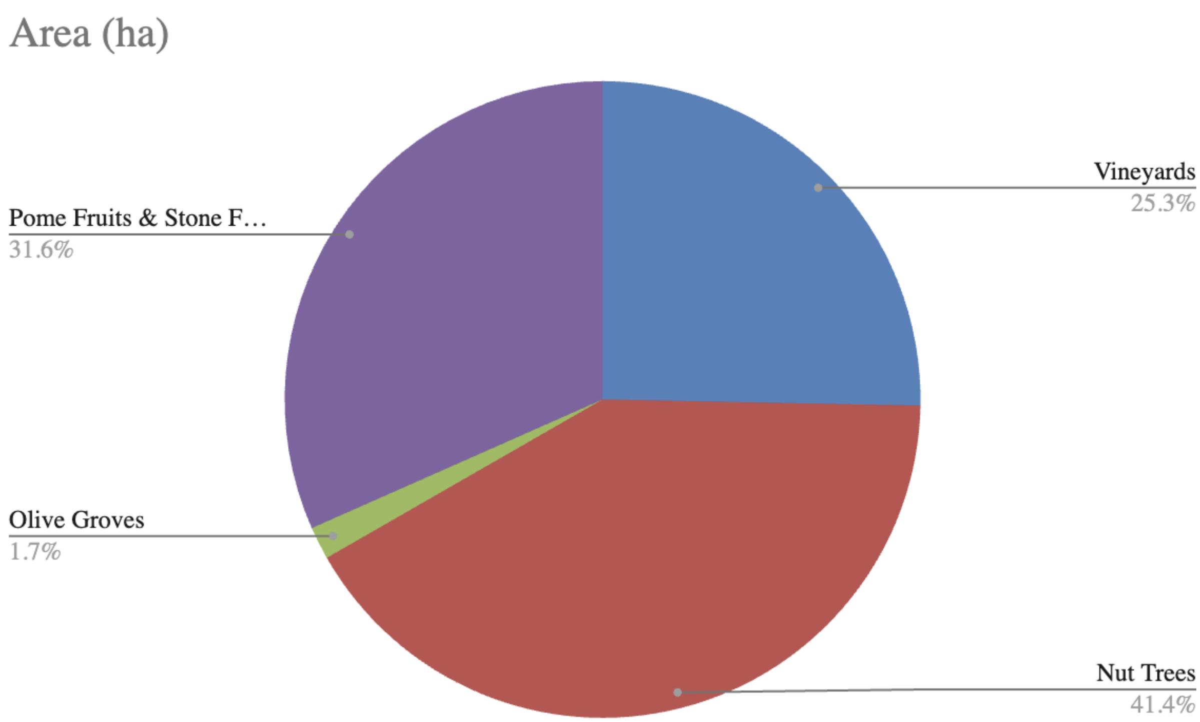

Diagram 4. Crop types in Tegea Area (ΟΠΕΚΕΠΕ)

Table 1. Calculations for Estimated Pruning Wood in Tegea (ΟΠΕΚΕΠΕ)

Crop Type	Area (ha)	Estimated Pruning Yield (tons/ha)	Potential Wood Waste (tons)	Notes on Potential Use
Vineyards	79.52	2-5	159.04 - 397.6	Biochar, biomass energy
Nut Trees	130.12	1-4	130.12 - 520.48	Bioenergy, animal bedding
Olive Groves	5.24	1-3	5.24 - 15.72	Compost, renewable energy
Pome Fruits & Stone Fruits	99.37	1-4	99.37 - 397.48	Biochar, mulch

Using data from the ΟΠΕΚΕΠΕ dataset, Table 1 summarizes the main crops in Tegea with estimates for annual pruning wood production. This analysis enables a clear view of the potential pruning wood available for reuse, helping to shape targeted strategies for sustainable waste management in Tegea's agricultural sector.

Based on these calculations, Tegea has an estimated potential of approximately:

- **Vineyards**: 159-398 tons of pruning wood
- **Nut Trees**: 130-520 tons of pruning wood
- **Olive Groves**: 5-16 tons of pruning wood
- **Pome and Stone Fruits**: 99-397 tons of pruning wood

This results in a cumulative total of **393-1,331 tons of pruning wood** annually from these four high-waste crops.

The agricultural profile of Tegea offers a significant opportunity to integrate circular economy principles, particularly through the reuse of pruning residues. With an estimated total of 400–1,359 tons of pruning wood produced annually, Tegea's agricultural sector can adopt innovative practices to enhance both environmental sustainability and economic resilience.

Nut Orchards and Pome Fruits: Major Contributors to Biomass

Nut orchards, including walnuts and almonds, occupy 148.31 hectares, while pome fruits such as apples cover 231.87 hectares, making them the dominant contributors to pruning residue production in Tegea. These crops require annual pruning to maintain productivity and fruit quality, generating a steady supply of wood waste. Nut trees produce approximately 1–4 tons of pruning wood per hectare annually, translating to an estimated biomass yield of 130–520 tons. Similarly, pome fruits contribute an additional 150–464 tons of pruning wood each year, making these crops a cornerstone of Tegea's biomass resources.

The reuse of pruning residues from nut orchards and pome fruits can significantly improve agricultural sustainability. Techniques like mulching and composting utilize these residues to conserve soil moisture, suppress weed growth, and replenish soil nutrients, particularly in Mediterranean regions like Tegea where water scarcity and soil degradation pose significant challenges. Furthermore, converting pruning wood into biochar offers a transformative solution for soil enhancement and carbon sequestration. Biochar's high carbon content improves soil structure, increases water retention, and mitigates the impacts of climate change while reducing reliance on chemical inputs.

Stone Fruits: A Robust Source of Renewable Biomass

Stone fruit orchards, covering 119.45 hectares, are another significant component of Tegea's agricultural economy. Crops such as peaches, nectarines, and apricots demand regular pruning, yielding 1–4 tons of wood residues per hectare annually. This results in an estimated annual biomass potential of 119–478 tons, underscoring their importance in sustainable agricultural practices.

The dense and fibrous pruning residues from stone fruits are ideal for biomass energy production, supporting renewable energy initiatives and reducing dependence on fossil fuels. These prunings can be processed into biofuel for localized energy systems, aligning with Greece's National Energy and Climate Plan (2020). Additionally, chipped residues can serve as animal bedding, which, after decomposition, becomes nutrient-rich compost that can be returned to the soil. Converting stone fruit prunings into biochar also offers long-term benefits by enhancing soil resilience and capturing atmospheric carbon, contributing to climate change mitigation efforts.

Vineyards: A Consistent Source of Pruning Residues

Vineyards in Tegea span 86.17 hectares and produce a substantial amount of biomass annually due to their routine pruning cycles. Each hectare generates approximately 2–5 tons of pruning wood, resulting in a total potential biomass of 172–430 tons per year. This steady supply of residues offers multiple avenues for reuse within the framework of a circular economy.

Pruning residues from vineyards can be converted into biochar, enhancing soil fertility and water retention while sequestering carbon for centuries. Alternatively, chipped prunings can be used as mulch within vineyards, regulating soil temperature, suppressing weeds, and conserving moisture. This practice is particularly valuable in Tegea's arid climate, where water conservation is critical. Additionally, vine prunings can be utilized as biomass fuel in wine production facilities, reducing reliance on external energy sources and promoting energy self-sufficiency.

Other Tree Crops: A Modest but Meaningful Contribution

Miscellaneous tree crops in Tegea, covering 7.03 hectares, provide a smaller yet diverse source of pruning residues. These trees include species like chestnuts, almonds, and other regional varieties, which collectively produce 7–28 tons of pruning wood annually. While their contribution to the total biomass is modest, these residues are valuable for niche applications. Mulching and composting these prunings enhance soil biodiversity, reduce the need for chemical fertilizers, and support a balanced agroecosystem.

Additionally, localized biochar production from these residues can provide targeted soil improvements for smaller farms.

Total Biomass Potential and Strategic Implications

The combined pruning wood potential from Tegea’s agricultural sector includes approximately 159–398 tons from vineyards, 130–520 tons from nut trees, 10–21 tons from olive groves, 119–478 tons from stone fruits, and 7–28 tons from other tree crops. This cumulative total of 400–1,359 tons annually highlights the region’s significant potential for implementing circular agriculture practices.

By prioritizing high-area crops like pome fruits, nut orchards, and stone fruits, Tegea can establish scalable reuse programs that transform pruning residues into valuable resources. Techniques such as biochar production, composting, and biomass energy generation align with circular economy principles, reducing waste, improving soil health, and mitigating climate change impacts. Additionally, these practices lower farming costs by decreasing reliance on synthetic inputs and external energy sources, creating economic opportunities for the region’s agricultural community.

Tegea’s strategic adoption of circular economy practices not only promotes environmental sustainability but also enhances economic resilience, positioning the region as a model for sustainable agricultural development in Mediterranean climates.

4.6. Analysis in Arcadia

An important measure of resource efficiency and ecosystem health in sustainable agricultural systems is the extensive recycling that results from reutilization (wood pruning). This part discusses current state of the reuse in Tripolis area, mentioning means and benefits but also some constraints.

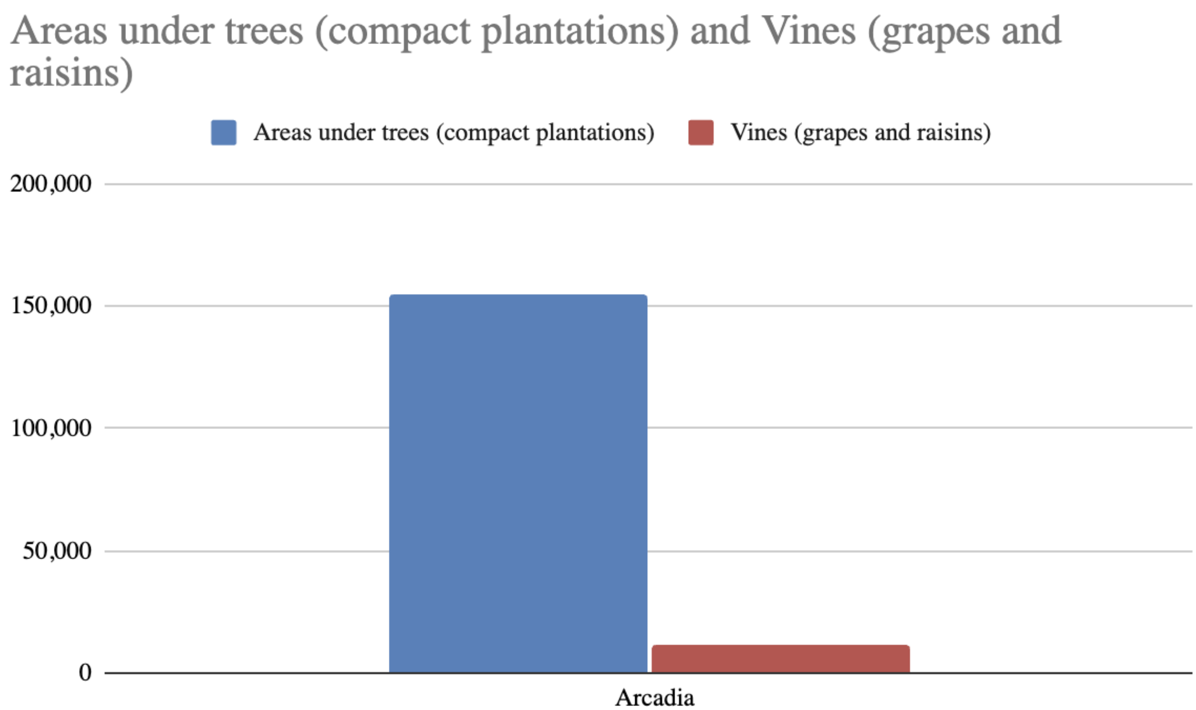

Diagram 5. Areas under trees and vines in Arcadia (Hellenic Statistical Authority, Areas and Production, 2022, Reuse Techniques for Each Crop Type in Arcadia)

The agricultural profile of Arcadia reveals a significant potential for utilizing pruning residues for circular economy practices. Based on the provided data:

Areas Under Trees (Compact Plantations)

- **Total Area:** 154,813 hectares
- **Key Crops:** Olive groves, nut trees, and fruit orchards dominate this category, generating substantial pruning residues annually.

<u>Agricultural Composition and Potential for Pruning Residue Reuse in Arcadia</u>

Arcadia's diverse agricultural landscape presents significant opportunities for implementing circular economy practices, particularly through the efficient reuse of pruning residues. According to the Hellenic Statistical Authority (2022), Arcadia's agricultural areas comprise approximately 154,813 hectares of compact tree plantations, which include olive groves, fruit orchards, vineyards, and nut orchards. These crops not only dominate the regional agricultural economy but also generate substantial volumes of pruning residues, making Arcadia a prime candidate for adopting sustainable resource management techniques.

Olive Groves: Dominating Arcadian Agriculture

Olive groves are the cornerstone of Arcadia's agricultural landscape, with an estimated 2,081,906 trees producing 2,034,185 kilograms of olives annually. These plantations generate significant pruning residues, ranging from 2 to 4 tons per hectare per year. Based on these estimates, olive groves in Arcadia produce approximately 8,327 tons of pruning residues annually. This biomass can be repurposed for composting, biochar production, or biomass energy, all of which contribute to soil fertility, enhanced water retention, and reduced dependence on synthetic fertilizers. The production of biochar from olive pruning residues not only enriches soil organic matter but also sequesters carbon, aligning with climate action goals and supporting long-term agricultural sustainability.

Nut Orchards: A Growing Resource

Nut orchards, including walnuts and almonds, contribute significantly to the region's agricultural output and pruning residue potential. Arcadia is home to approximately 65,510 walnut trees, producing 1,395 tons of walnuts annually, and 37,322 almond trees, yielding 284 tons. These orchards generate between 1 and 4 tons of pruning residues per hectare annually, translating to an estimated 130–520 tons of biomass. Walnut and almond pruning residues are particularly suited for biochar production, which enhances soil moisture retention, nutrient availability, and microbial activity. Additionally, these residues can be incorporated into composting systems, reducing reliance on chemical fertilizers and promoting sustainable nutrient cycling.

Fruit Orchards: Supporting Soil Enrichment

Fruit orchards, including apples, peaches, and nectarines, play a vital role in Arcadia's agricultural economy. Apple orchards consist of 67,598 trees, producing 65,202 kilograms annually, while peach and nectarine orchards include 76,545 trees, yielding 1,922 tons of fruit. Together, these fruit orchards generate an estimated 300–400 tons of pruning residues annually. These residues can be processed into biochar, which improves soil structure and pH, or incorporated into compost to create nutrient-rich organic fertilizers. Peach and nectarine pruning residues, in particular, support the development of high-quality compost that enhances fruit yield and quality.

Vineyards: A Steady Source of Biomass

Vineyards occupy 11,604 hectares in Arcadia, primarily dedicated to grape and raisin production. Annual maintenance pruning generates approximately 1–2 tons of biomass per hectare, contributing an estimated 11,604–23,208 tons of pruning residues annually. Vine prunings are well-suited for biochar production, which enhances soil aeration, nutrient retention, and water conservation—critical factors for vineyard sustainability in Mediterranean climates. Additionally, vine prunings can be chipped and reapplied as mulch within vineyards, regulating soil temperature, reducing evaporation, and suppressing weeds. This practice promotes biodiversity in vineyard ecosystems and supports the region's goals for sustainable wine production.

Chestnuts, Figs, and Other Tree Crops

Arcadia also cultivates smaller-scale crops such as chestnuts and figs, contributing to the diversity of the region's agricultural landscape. Chestnut trees, numbering 2,358, produce 1,221 tons annually, while fig orchards include 65,510 trees. Although these crops generate smaller volumes of pruning residues, their biomass can be effectively utilized in localized biochar production or composting systems. These applications improve soil organic content, reduce erosion, and enhance biodiversity, particularly in areas prone to soil degradation.

Vegetables and Smaller Agricultural Systems

Vegetable cultivation, though less prominent, is essential for local consumption and market sales. Crops like tomatoes, peppers, and cucumbers are grown in mixed farming systems, contributing to food security and regional self-sufficiency. Residues from vegetable cultivation can be integrated into composting systems, supporting soil enrichment and minimizing waste. Although the volume of residues from vegetables is lower than that of tree crops, their inclusion in circular practices further strengthens Arcadia’s sustainable agricultural framework.

Total Potential for Pruning Residue Reuse

Based on available data, the estimated annual pruning residue production in Arcadia includes:

- Olive Groves: Approximately 8,327 tons
- Nut Orchards: 130–520 tons
- Fruit Orchards: 300–400 tons
- Vineyards: 11,604–23,208 tons
- Other Tree Crops: Smaller but significant contributions

This totals an estimated 20,361–32,455 tons of pruning residues annually. Such a volume represents a substantial resource for circular agricultural practices, offering opportunities for biochar production, composting, and biomass energy generation. These practices align with regional and national sustainability goals, reducing waste, improving soil health, and supporting renewable energy initiatives.

Environmental and Economic Implications

The reuse of pruning residues supports carbon sequestration, reduces greenhouse gas emissions, and enhances soil resilience. By adopting these practices, Arcadia can reduce its reliance on chemical fertilizers, mitigate climate change impacts, and promote economic resilience within its agricultural sector. The integration of biochar, compost, and biomass energy solutions not only enhances the region's environmental sustainability but also creates economic opportunities for farmers through value-added products and reduced input costs.

5. Quantitative and Economic Analysis of Circular Agricultural Practices

5.1. Market Opportunities: Biochar, Compost, and Biomass Fuel in Arcadia

5.1.1. Biochar Use in Arcadia: A Strategy for Sustainable Agriculture

Figure 1. Biochar image

The production and application of biochar present a transformative opportunity for advancing sustainable agricultural practices in Arcadia. Derived from the gasification of pruning residues, biochar is a stable, compact form of carbon that offers multiple environmental and economic benefits. This innovative solution aligns with the area's need to enhance soil quality, mitigate environmental challenges, and add economic value to agricultural practices. Biochar is a carbon-rich byproduct produced during the gasification process, with its characteristics determined by the ash content of the biomass used. It serves as a long-term carbon sink, storing greenhouse gases underground for hundreds of years while improving water quality when integrated into soils. Biochar is particularly effective for crops requiring high potassium levels and a high pH, such as olives and vineyards. Its soil-enhancing properties include improving water retention, reducing greenhouse gas emissions, decreasing nutrient loss, alleviating soil acidity, and reducing irrigation and fertilization needs (Glaser, Lehmann, & Zech, 2002).

The application of soil improvement products derived from pruning residues has demonstrated improvements in crop productivity. Research shows yield increases of 10-20%, driven by improved nutrient availability and microbial activity. For instance, a vineyard yielding 10 tons per hectare could achieve an additional 1.5 tons annually with a 15% increase (Blanco-Canqui & Lal, 2009). Furthermore, the reduction of fertilizer use by 10-30% translates to significant savings. A farm using 100 kg of nitrogen fertilizer per hectare could save up to 30 kg annually, lowering both costs and environmental pollution (Sutton et al., 2013). Additionally, improved soil moisture retention can reduce irrigation needs by 15-25%, conserving valuable water resources and reducing operational costs (Gebbers & Adamchuk, 2010).

The use of pruning residues also addresses climate change concerns through effective carbon stabilization. Approximately 50% of the carbon in biomass can be sequestered through pyrolysis. For example, one ton of pruning residue generates 0.3 tons of stable material containing 50% carbon, sequestering 0.15 tons of carbon per ton of residue. Olive orchards in Tegea producing 2 tons of pruning residues per hectare annually can sequester 0.3 tons of carbon per hectare, significantly contributing to climate mitigation efforts (Lal, 2004).

Incorporating such practices into agricultural systems reduces emissions from nitrogen fertilizers by minimizing nitrous oxide release, a potent greenhouse gas. Enhanced soil biodiversity supports nutrient cycling and organic matter decomposition, further promoting ecosystem health (Pretty, 2008; Scarlat et al., 2015).

Establishing systems for material transformation involves capital investments. Small-scale units for processing cost approximately €5,000-€10,000, while larger systems may require €30,000-€100,000. Composting facilities, being less capital-intensive, range from €2,000-€5,000. Operational costs for labor, maintenance, and residue transportation range from €2,000-€5,000 annually, depending on the system's scale (Carvalho et al., 2020).

Farmers benefit from reduced fertilizer costs and improved water efficiency. For example, a farmer spending €500 per hectare on fertilizers could save €100 annually with a 20% reduction in usage. Government programs, such as the European Union’s Green Deal and Common Agricultural Policy (CAP), provide funding to offset up to 50% of initial investments in sustainable technologies, significantly lowering financial barriers (European Commission, 2022). Additionally, marketable by-products offer new revenue streams, with prices ranging from €100-€400 per ton, depending on demand and quality. By adopting practices that transform agricultural residues, Tegea’s farmers can enhance soil health, increase crop yields, and mitigate climate impacts while benefiting economically. Such strategies align with circular economy principles and global sustainability goals, ensuring a resilient and sustainable future for the area's agriculture.

Biochar significantly increases the soil's moisture-holding capacity, reducing irrigation requirements by up to 25% in semi-arid conditions like those in Tegea. This is especially valuable in water-scarce areas where efficient water management is critical to sustaining agricultural productivity (Lehmann, 2007). The ability of biochar to enhance nutrient retention and promote microbial activity results in higher crop yields, reducing the reliance on chemical fertilizers. This improvement aligns with sustainability goals and provides economic benefits to farmers by lowering input costs (Steiner et al., 2007). Biochar contributes to climate change mitigation by sequestering atmospheric carbon into stable forms. This carbon remains locked within the soil for extended periods, helping offset greenhouse gas emissions. Additionally, farmers in Tegea could potentially access carbon credit markets, creating new revenue streams while promoting environmental stewardship (Joseph et al., 2010).

Pruning residues from vineyards and orchards serve as ideal feedstocks for biochar production. These residues, which are abundant in Arcadia due to the territory's agricultural composition, can be converted into biochar using local pyrolysis facilities or mobile units. Establishing such infrastructure minimizes transportation costs and enhances accessibility for farmers. Mobile pyrolysis units, in particular, offer a decentralized solution that aligns with the scale and structure of Arcadia's agricultural sector (Bracmort, 2009).

The increasing demand for organic products and the ongoing degradation of cultivated land due to intensive agriculture underscore the urgent need for biochar adoption in these areas. By improving soil health, reducing environmental impacts, and offering economic incentives, biochar aligns with both global sustainability goals and local agricultural needs. Promoting biochar through farmer education and emphasizing its long-term benefits could catalyze its widespread use, positioning Arcadia as a leader in sustainable agricultural practices (https://aegean-biomass.gr).

5.1.2. Compost: Versatility and Market Demand

Composting residues offer a practical and sustainable solution for enhancing soil fertility while reducing dependence on synthetic fertilizers. This practice enriches the soil with organic matter, fostering long-term agricultural sustainability and supporting healthy crop yields (Blanco-Canqui & Lal, 2009). Vineyard and nut tree prunings, in particular, present significant potential for composting, providing a natural fertilizer alternative that improves soil organic matter, reduces chemical input reliance, and promotes soil biodiversity (Pretty, 2008).

Prunings, when composted, create an organic matter rich in essential nutrients such as nitrogen, potassium, and phosphorus, all of which are critical for crop health (Evans, 2001). Composting transforms agricultural waste into a valuable soil amendment that can be reintroduced into the same fields, creating a closed-loop system. This process not only minimizes waste but also increases soil organic matter, a cornerstone for maintaining soil fertility and ensuring sustainable crop productivity (Steiner et al., 2007). Moreover, compost supports the principles of organic agriculture and horticulture by providing a natural recycling method for organic waste, thus promoting environmentally friendly farming practices.

Compost has diverse applications in vegetable gardens, orchards, vineyards, and landscaping, ensuring consistent market demand. In areas like Tripolis, where agriculture drives economic activity, the demand for compost remains strong, providing opportunities for local production and distribution (Blanco-Canqui & Lal, 2009). The typical price of compost ranges from €20 to €50 per cubic meter, creating a lucrative market for producers. Localized production in Tripolis could capitalize on these rates, catering to nearby farms, greenhouses, and nurseries. By reducing transportation costs and prioritizing local sales, composting initiatives could generate substantial economic benefits while promoting sustainable practices.

Potential buyers for compost include neighboring farms seeking organic fertilizers to improve soil health, local greenhouses aiming for sustainable input alternatives, and community gardens or municipal landscaping projects. Given the prevalence of vineyards and olive orchards in the area, compost production from pruning residues aligns perfectly with local agricultural practices. By addressing local demand, composting initiatives not only provide an economically viable solution but also support sustainable land management, ensuring long-term soil health and agricultural productivity.

5.1.3. Biomass Gasification: Processes and Applications

Biomass gasification is a technology that converts any organic matter, e.g. solid biomass, into energy. This is done by first converting this matter into a gaseous mixture through successive chemical reactions.

According to these, the organic matter is pyrolyzed and reacts with oxygen or air, so it breaks down into smaller molecules, into a gaseous mixture of carbon monoxide, hydrogen, etc., removing pollutants and impurities. This gaseous mixture is the synthesis gas or syngas, which can then be converted into electricity and heat as well as other products. In the case where the final process is carried out using air (the most economical and common option), syngas has a net calorific value on average of 4.5 - 5.5 MJ/m^3 (about 1/7 that of natural gas). When pure oxygen is used instead of air, the calorific value of syngas can be tripled.

In both cases, however, the calorific value of the synthesis gas makes it suitable for the production of heat and/or electricity, with its appropriate use in burners, gas turbines or MEK.

Undoubtedly, biomass gasification is a more complex technology with fewer commercial applications compared to the usual combustion of biomass. However, the advantages it presents, most importantly the very large increase in the energy efficiency of the unit, have led in recent years to the continuous proliferation of such units at the "cutting edge of technology".

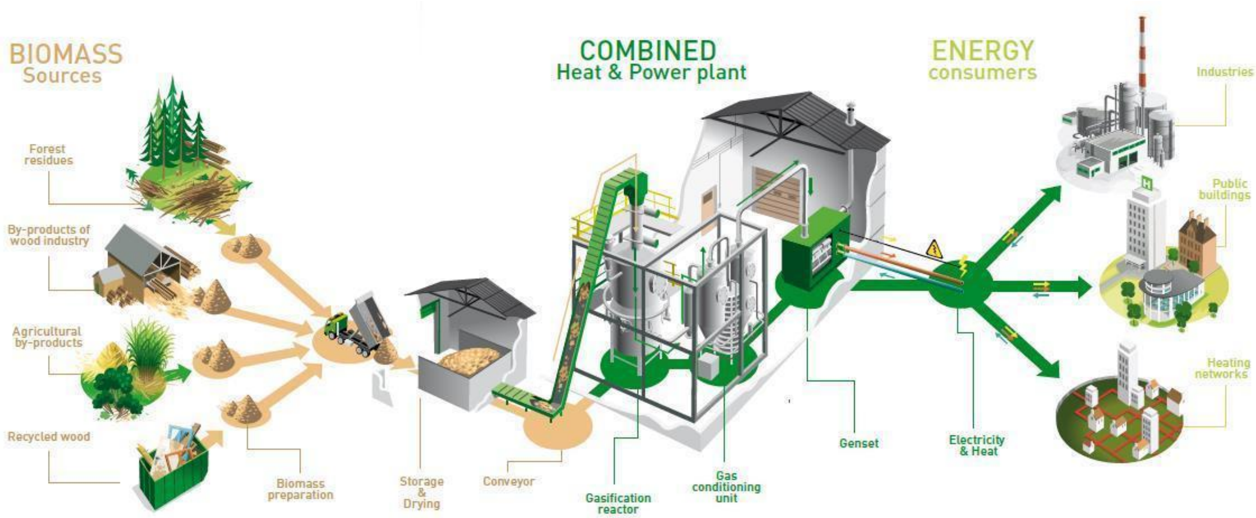

Figure 2. Biomass (Agroenergy, n.d.)

Gasification has been used worldwide for more than 75 years by the chemical industry, refineries, fertilizer production industries and for more than 35 years for the production of electricity. (Agroenergy, n.d.)

For its production activities, the enterprise will annually utilize approximately 7,000 tons of raw material, consisting of:

- Agricultural cultivation residues (olive prunings, urban green waste prunings, olive pits, agricultural residues, etc.).

Specifically, the raw material for the plant will be plant biomass sourced from local suppliers (converted to a dry weight basis) per year:

Table 2. Biomass requirements for plant operations

No.	Type
1	Olive prunings
2	Urban green waste prunings
3	Olive pits
4	Agricultural residues
5	Fruit seeds

The production process at the biomass-based electricity generation plant involves the gasification of biomass to produce bio-syngas. Figure 4 schematically illustrates the stages of biomass utilization for bio-syngas production.

The gasification technology involves converting biomass into a mixture of combustible gases through the partial oxidation of organic matter at high temperatures, typically exceeding 900°C. Biomass is well-suited for gasification due to its high volatile matter content (70–86% on a dry weight basis).

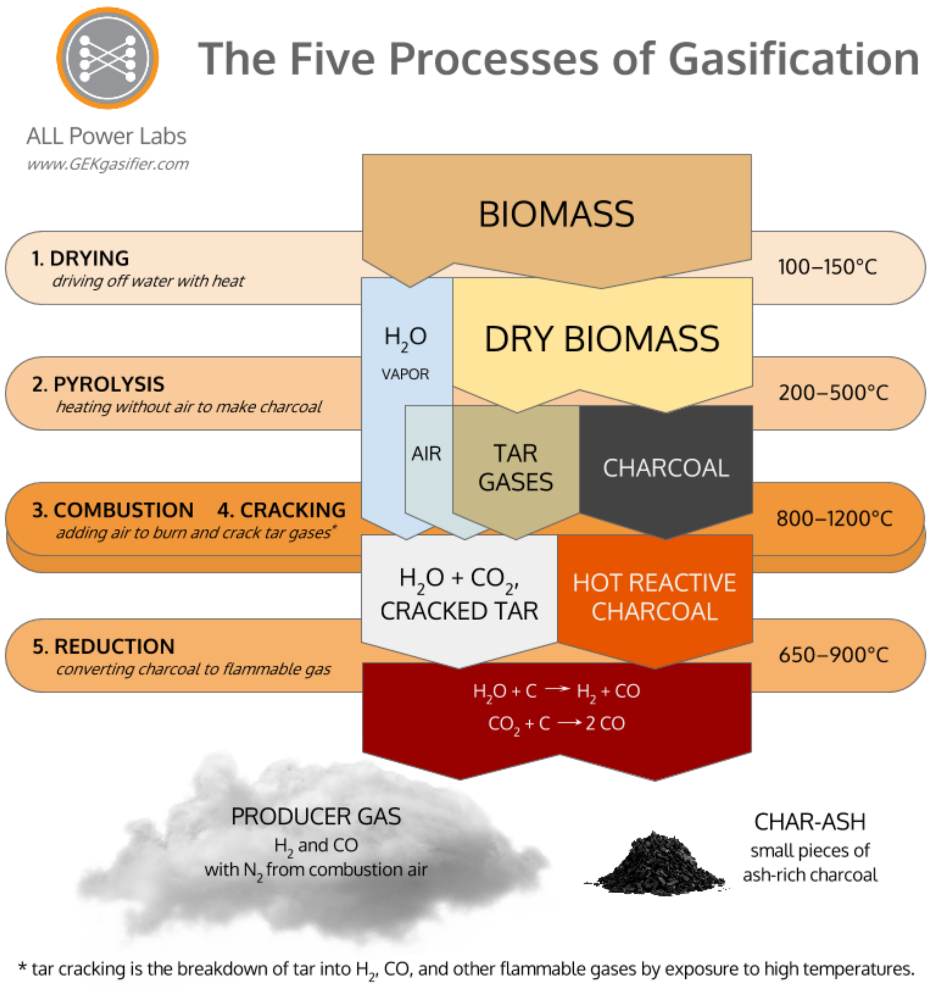

Figure 3. The five processes of gasification (Allpowerlabs, n.d.) https://www.allpowerlabs.com/gasification-explained

The gasification process occurs in the following stages within the gasifiers:

1. **Pyrolysis**: Between 200°C and 500°C, biomass decomposes into carbon (C) and a mixture of gases, including CO, H_2, and hydrocarbons (CH_nO_m). This reaction takes place in the upper section of the gasifier.
2. **Oxidation (Combustion and Cracking)**: Gases from pyrolysis are oxidized at high temperatures, breaking the hydrocarbon bonds. This increases the syngas composition of CO_2 and H_2O.
3. **Reduction**: In the final stage, the quantities of CO_2 and H_2O are reduced via reaction with active carbon, producing syngas primarily composed of H_2 and CO.

Before entering internal combustion engines (ICE) for power generation, the syngas undergoes cooling and purification. Through a series of cyclone systems, syngas is cooled from an initial 700°C to 100°C while large suspended particles are filtered out. Further purification occurs in ceramic filter systems, removing smaller particulates and reducing the temperature to 30–40°C before being directed to the ICEs.

During the combustion of syngas in the ICEs, both electricity and thermal energy are produced. A portion of the thermal energy is used in dryers to dry raw materials, as previously mentioned, while another portion is recirculated back to the gasifier to maintain the necessary high operating temperatures.

The following flow diagram illustrates the production process for the biomass gasification-based electricity generation plant.

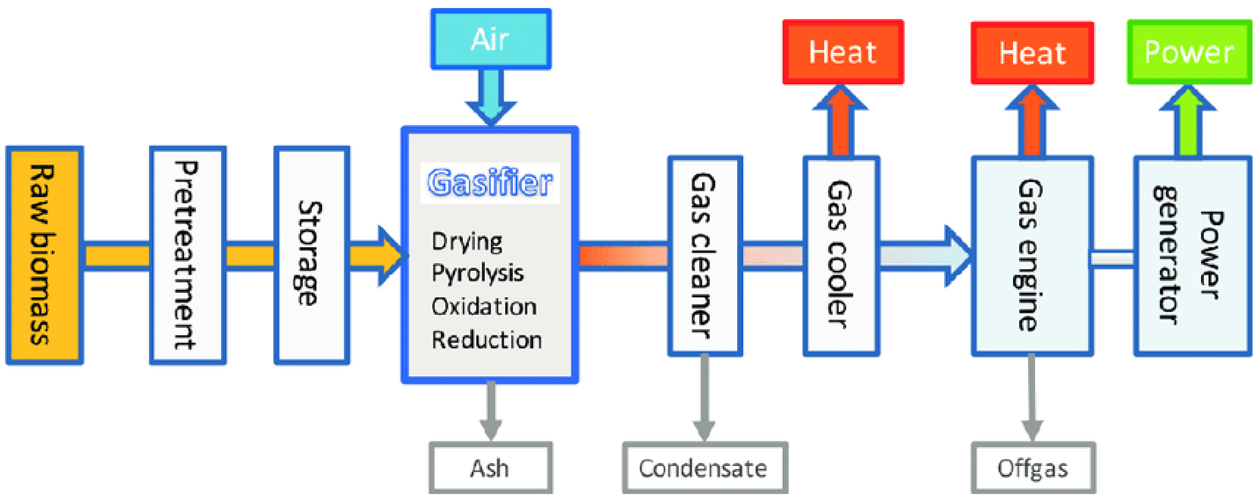

Diagram 6. Production process for the biomass gasification

Biomass fuel, derived from agricultural residues, represents a renewable energy source that addresses local energy needs while reducing dependence on fossil fuels. This sustainable energy option is gaining traction as a heating fuel for greenhouses, individual households, and biomass energy facilities. The rising demand for biomass aligns with Greece's broader goals of promoting renewable energy and circular economy principles, emphasizing resource efficiency and environmental sustainability (Scarlat et al., 2015).

Agricultural biomass typically sells for €30-€60 per ton, depending on its calorific value and moisture content. For producers in Tripolis, employing effective drying and processing methods can ensure competitiveness within this pricing range. Potential buyers include local biomass energy facilities that utilize agricultural residues for energy production, greenhouses employing biomass heating systems, and households adopting renewable heating solutions. Directly selling pruning residues as biomass fuel provides a cost-effective solution; however, ensuring the proximity of buyers is critical for profitability, as transportation costs can significantly affect margins (Carvalho et al., 2020).

To enhance the adoption of biomass utilization and other circular practices, supportive policies and incentives are necessary to alleviate financial barriers. Subsidies under the Common Agricultural Policy (CAP) for biochar and composting equipment can help offset initial investment costs. Additionally, carbon credit programs offer financial rewards for carbon sequestration efforts, providing a dual benefit of economic support and environmental impact mitigation. Introducing tax incentives for sustainable farming inputs and by-products would further promote the financial viability of circular practices. Cooperative farming models, supported through targeted policies, can provide logistical and financial assistance, enabling shared biochar and composting facilities to flourish, thereby reducing individual farmer costs and encouraging collaborative approaches (Papadopoulos & Markakis, 2019).

This framework highlights the potential for biomass fuel not only as an energy solution but also as a means to drive economic and environmental sustainability in Greece’s agricultural areas.

5.2. Financial Incentives and Funding for Circular Agriculture

The adoption of circular practices in agriculture, while offering long-term benefits, often requires substantial initial investments that can be a barrier for farmers. However, multiple funding opportunities are available to support farmers in Tegea in overcoming these challenges and integrating sustainable practices into their operations.

European Union Funding Programs

CAP Green Direct Payments

The Common Agricultural Policy (CAP) provides direct payments to incentivize sustainable agricultural practices, including the application of biochar and composting. These payments align with the European Union's sustainability goals and offer financial support to farmers adopting circular practices. For farmers in Tegea, these payments could help reduce operational costs while simultaneously improving soil health and resilience (European Commission, 2020). The adoption of circular agricultural practices in Tegea offers a dual advantage of environmental sustainability and economic resilience. However, the initial financial outlay for implementing practices such as biochar production, composting, and the use of biomass energy poses a significant barrier. Fortunately, multiple funding programs are available to support farmers in overcoming these challenges. Under the European Union's Common Agricultural Policy (CAP) 2023-2027, specific eco-schemes encourage sustainable farming practices. These include

Measure P1-31.3 ("Improved Vegetative Cover with Enhanced Biodiversity"), **Measure P1-31.4** ("Applications of Circular Economy in Agriculture"), and **Measure P1-31.8** ("Preservation and Protection of Crops in Terraced Areas") (European Commission, 2020; Hellenic Ministry of Rural Development and Food, 2023). These interventions aim to enhance biodiversity, promote circular economy principles, and support traditional agricultural systems.

CAP Green Direct Payments specifically target these eco-schemes, offering direct subsidies to farmers who integrate sustainable techniques into their operations, such as reduced tillage or the application of compost and biochar. Additional European Union funding programs, such as **Horizon Europe**, provide grants for innovative projects that align with circular economy goals, encouraging collaborative initiatives between researchers and local farmers (European Commission, 2020). The **LIFE Programme** further supports climate-focused projects, making it an ideal funding source for initiatives involving biochar production or biomass use due to their carbon-sequestration benefits.

National and regional programs also play a crucial role. The Greek Ministry of Agriculture offers subsidies for renewable energy projects, including biomass energy facilities, and allocates funds for cooperative composting and biochar facilities under Regional Development Funds. Moreover, international financial institutions like the European Investment Bank (EIB) provide low-interest loans to facilitate the transition to sustainable practices, further reducing the financial burden on farmers (European Investment Bank, 2021).

To ensure effective adoption, it is essential to provide clear guidance on accessing these funds. Simplified application processes, targeted workshops, and localized pilot programs could demonstrate the economic and environmental benefits of these measures, thereby fostering greater acceptance and implementation among the agricultural community in Tegea.

Horizon Europe

Horizon Europe, the EU's flagship research and innovation program, funds innovative projects that promote circular economy principles. By partnering with research institutions, Tegea's agricultural community could secure grants to pilot biochar or composting initiatives, fostering innovation and scaling these practices in the area. (European Parliament, 2020).

Horizon Europe, the European Union's premier research and innovation program, provides significant funding opportunities for projects that promote circular economy principles, including sustainable agricultural practices. For Tegea's agricultural community, this program offers an invaluable platform to secure grants for piloting biochar and composting initiatives tailored to the region's specific needs.

Tegea, with its rich agricultural landscape dominated by olive groves, vineyards, and orchards, stands to benefit from Horizon Europe's funding for cluster-specific actions, such as Cluster 6: Food, Bioeconomy, Natural Resources, Agriculture, and Environment. This cluster focuses on enhancing sustainability and resilience in agriculture by encouraging innovative approaches to soil management, resource recycling, and climate change mitigation.

By collaborating with research institutions like the Agricultural University of Athens or the University of Peloponnese, stakeholders in Tegea could propose projects that align with Horizon Europe's Missions, particularly the "Soil Deal for Europe." This mission emphasizes the adoption of sustainable soil practices, where biochar and compost applications can play a transformative role by improving soil health, enhancing carbon sequestration, and reducing dependence on chemical inputs.

Specific funding calls under Horizon Europe, such as HORIZON-CL6-2025-BIODIV-01, which focuses on biodiversity restoration and sustainable resource use, or HORIZON-CL6-2025-FARM2FORK-01, targeting innovative farm-to-fork solutions, present clear opportunities for Tegea's agricultural initiatives. Proposals that demonstrate the potential to scale circular practices and integrate local agricultural waste streams into biochar or compost production would align well with these funding priorities.

To enhance the likelihood of success, Tegea’s stakeholders should prepare detailed project proposals highlighting:

- The environmental benefits of biochar and composting, such as improved soil fertility and reduced greenhouse gas emissions.
- The potential to create economic value by reducing input costs and generating income from by-products.
- The scalability of the initiatives across Mediterranean regions, addressing shared challenges like soil degradation and water scarcity.

Horizon Europe also encourages multi-stakeholder partnerships, allowing farmers, local cooperatives, and academic institutions in Tegea to collaborate on research, implementation, and knowledge-sharing. Leveraging these partnerships can enhance the region's capacity to adopt innovative agricultural practices, ensuring that projects align with both local needs and Horizon Europe’s objectives.

LIFE Programme

The LIFE Programme focuses on funding projects that mitigate climate change and enhance environmental sustainability. Tegea's proposals for biochar production and compost application, both of which have proven climate-positive impacts, could qualify for grants under this initiative, providing the financial backing needed to implement these practices on a broader scale (European Commission, 2020).

The LIFE Programme, the EU's funding instrument for environment and climate action, offers substantial support for projects that mitigate climate change and enhance environmental sustainability. In the Arcadia region of Greece, including Tegea, proposals focusing on biochar production and compost application are well-positioned to qualify for grants under this initiative. These practices align with the programme's objectives by promoting carbon sequestration and improving soil health, thereby contributing to climate change mitigation.

The LIFE Programme's sub-programmes, such as "Climate Change Mitigation and Adaptation" and "Circular Economy and Quality of Life," are particularly relevant. These sub-programmes support innovative techniques and approaches that facilitate the transition to a sustainable, circular, and climate-resilient economy. Projects in Arcadia that demonstrate the potential for large-scale deployment of biochar and composting solutions can leverage these funding opportunities to implement sustainable practices on a broader scale.

For instance, the LIFE Programme has previously funded projects in Greece that focus on environmental sustainability and climate action. While specific projects in Arcadia are limited, the region can draw inspiration from national initiatives to develop proposals that meet the programme's criteria. By aligning project objectives with the LIFE Programme's priorities, stakeholders in Arcadia can enhance their chances of securing funding for climate-positive agricultural practices.

To apply for LIFE Programme funding, it is essential to develop comprehensive project proposals that clearly outline the environmental benefits, innovative aspects, and scalability of the proposed practices. Engaging with local authorities, agricultural cooperatives, and research institutions can strengthen the proposal by demonstrating broad support and collaboration. Additionally, consulting the latest LIFE Programme guidelines and calls for proposals will provide up-to-date information on eligibility criteria and application procedures.

By capitalizing on the LIFE Programme's funding opportunities, the Arcadia region can advance its efforts in adopting sustainable agricultural practices, thereby contributing to broader environmental and climate objectives.

National and Regional Support

Greek Government Grants and Subsidies

The Greek government offers subsidies for renewable energy projects, which can be extended to biomass or biochar facilities. Additionally, grants targeted at sustainable farming practices can make composting and biochar production more feasible for local farmers, reducing the upfront costs associated with these transitions (Greek Ministry of Agriculture, 2021).

The Greek government has developed a series of grants and subsidies aimed at promoting sustainable agricultural practices and renewable energy projects, aligning with national commitments to the European Green Deal and the Common Agricultural Policy (CAP) for 2023–2027. These measures are designed to reduce financial barriers for farmers in adopting circular economy principles, with specific provisions that can support biomass and biochar facilities in Tegea and other parts of Arcadia.

Subsidies for Biomass and Biochar Facilities

From 2025 onwards, the **National Recovery and Resilience Plan (NRRP)** includes targeted subsidies for renewable energy infrastructure, including biomass and biochar production units. Farmers and cooperatives in Tegea could benefit from these programs, which offer grants covering up to 50% of the capital expenditure required to establish small-scale biomass or biochar facilities. These facilities can utilize agricultural residues, such as pruning waste from olive groves and vineyards, to produce renewable energy or soil amendments.

The subsidies prioritize:

1. **Small-to-Medium-Scale Facilities**: Supporting decentralized biomass and biochar production, reducing transportation costs and fostering local economic activity.
2. **Innovative Technologies**: Funding is available for pyrolysis units, composting setups, and integrated bioenergy systems that align with circular economy objectives.

Grants for Sustainable Farming Practices

Under the revised CAP eco-schemes for 2023–2027, Greek farmers can access additional payments for implementing sustainable farming practices. Key measures include:

- **Measure P1-31.4**: Annual payments for adopting circular practices such as on-farm composting, biochar application, and organic soil amendments.

- **Measure P4-30.2**: Grants for transitioning to precision farming techniques, which complement biochar use by optimizing nutrient and water management.

  These grants aim to offset upfront costs for farmers, making it feasible to adopt circular practices while enhancing productivity and sustainability.

  Specific Programs for Composting and Biochar Production

  Programs under the Greek Ministry of Rural Development and Food will prioritize funding for projects that integrate composting and biochar into regional agricultural systems. From 2025, new initiatives under the Green Growth Program will focus on:

1. **Demonstration Projects**: Establishing pilot composting and biochar facilities in regions like Arcadia to showcase their feasibility and benefits.
2. **Training and Technical Support**: Offering workshops and expert consultations to ensure farmers understand the practical applications and economic advantages of these technologies.

Financial Incentives for Energy Independence

In addition to subsidies, the Greek government offers low-interest loans through partnerships with the **European Investment Bank (EIB)** and domestic financial institutions. These loans, tailored for renewable energy and circular agriculture projects, can help farmers in Tegea finance the initial setup of biochar or composting units.

Targeting Tegea's Needs

Given Tegea's reliance on high-value crops like olives, vineyards, and orchards, these subsidies and grants provide an essential framework for transitioning to sustainable practices. For instance, olive grove prunings can be converted into biochar to enhance soil quality, while vineyard waste can support on-farm composting projects. These measures address the dual challenges of agricultural waste management and soil degradation prevalent in the region.

Implementation Recommendations

To maximize these opportunities, Tegea farmers and cooperatives should:

1. Collaborate with local government bodies and agricultural organizations to submit grant proposals that highlight the region's specific needs and capacities.
2. Establish partnerships with academic institutions, such as the Agricultural University of Athens, for technical support in project design and implementation.

3. Actively participate in training programs and workshops funded by the Ministry of Agriculture to build capacity for using subsidized technologies.

Regional Development Funds

The Peloponnese regional government could play a pivotal role in promoting circular practices by allocating funds specifically for cooperative projects. Subsidizing the establishment of composting or biochar production facilities that serve multiple farmers would spread financial risks and make these practices more accessible. Such initiatives foster collaboration and reduce the burden on individual farmers, encouraging widespread adoption (Thun et al., 2021).

The Peloponnese regional government has the potential to significantly advance the adoption of circular agricultural practices by allocating targeted funds and support programs for 2025 and beyond. These initiatives are closely aligned with Greece's regional development priorities under the framework of the European Union's sustainability goals, particularly the Common Agricultural Policy (CAP) for 2023–2027 and Greece's National Recovery and Resilience Plan (NRRP). By promoting cooperative projects, the regional government can drive the establishment of composting and biochar production facilities, fostering collaboration among farmers and reducing the financial burden on individuals.

From 2025 onwards, the Peloponnese Regional Development Fund is expected to prioritize projects aimed at enhancing sustainability and resource efficiency in agriculture. A key focus will be on providing grants and subsidies for setting up shared composting or biochar facilities. These shared-use units will allow farmers, especially those cultivating high-value crops like olive groves and vineyards, to process large volumes of pruning waste into valuable soil amendments or renewable energy sources. By covering up to 60% of the capital costs for these facilities, the regional government aims to make these initiatives accessible and financially viable. Additionally, technical assistance programs will be established to educate farmers on the economic and operational benefits of adopting circular practices. Collaborations with academic and research institutions, such as the University of Peloponnese, will provide the technical expertise needed to implement these projects effectively.

To further encourage cooperative farming models, the regional government will offer preferential access to funding for farmer associations committed to circular practices. This approach aligns with the CAP's Measure P1-31.4, which supports shared environmental projects. By pooling resources, farmers can achieve economies of scale in adopting technologies such as pyrolysis units for biochar or advanced composting systems. This strategy not only reduces individual financial risks but also promotes a culture of collaboration and shared responsibility within the agricultural community.

In Tegea, where pruning residues from olive groves, vineyards, and orchards are abundant, these initiatives could address specific challenges while leveraging local agricultural strengths. For olive groves and vineyards, shared composting facilities can process pruning residues to produce high-value compost, which enhances soil health and reduces reliance on chemical fertilizers. Biochar facilities, on the other hand, can convert dense pruning waste into soil amendments, helping to combat soil degradation and build resilience against climate variability. For orchards and other tree crops, cooperative models will ensure that smaller-scale farmers have equitable access to the benefits of circular practices, fostering inclusivity and economic resilience.

The Peloponnese region's efforts to promote circular agriculture are also part of its broader Green Growth Strategy for 2030. This strategy includes the development of logistics networks to transport agricultural residues to centralized processing facilities and the subsidization of precision agriculture technologies. These measures complement circular practices by optimizing input use and further reducing costs for farmers. The regional government's commitment to sustainability aims to position the Peloponnese as a hub for innovative and eco-friendly agricultural practices.

To maximize the effectiveness of these initiatives, the regional government should establish clear eligibility criteria for cooperative projects, ensuring equitable access for small and medium-sized farms. Public-private partnerships can be facilitated to attract additional investments into circular agriculture initiatives. Furthermore, monitoring and evaluation mechanisms should be put in place to assess the impact of funded projects, identify best practices, and replicate successful models across other areas in the Peloponnese.

These measures not only align with regional and national priorities but also provide a roadmap for the agricultural community in Tegea to transition towards sustainable practices. By addressing financial barriers, fostering collaboration, and leveraging local resources, the Peloponnese regional government can play a transformative role in promoting circular agriculture and enhancing the resilience of its agricultural sector.

International Financial Support

European Investment Bank (EIB)

The European Investment Bank provides low-interest loans aimed at sustainable agriculture projects. For farmers in Tegea, these loans represent a viable option for establishing small-scale facilities for biochar or compost production, aligning with circular economy objectives and improving access to necessary infrastructure (European Investment Bank, 2021).

The European Investment Bank (EIB) plays a critical role in supporting sustainable agricultural development by offering low-interest loans tailored to projects that align with circular economy objectives. For the agricultural community in Tegea, these loans provide an accessible and cost-effective means to establish small-scale facilities for biochar and compost production. Such infrastructure is essential for adopting circular practices that enhance soil health, reduce waste, and improve long-term agricultural resilience.

From 2025 onwards, the EIB is expected to prioritize funding for projects that promote resource efficiency and climate adaptation in rural areas, in line with the European Union's Green Deal and the Common Agricultural Policy (CAP). Farmers in Tegea can leverage these loans to set up pyrolysis units for biochar production or advanced composting systems to process pruning residues from olive groves, vineyards, and orchards. By doing so, they can convert agricultural waste into valuable soil amendments, addressing soil degradation and reducing dependency on chemical fertilizers.

The EIB's financing framework supports both individual farmers and cooperative projects, making it particularly suited to the diverse agricultural landscape of Tegea. Cooperative ventures involving multiple farmers can access larger loans to establish shared-use facilities, distributing costs and risks while fostering collaboration within the agricultural community. For instance, a cooperative in Tegea could use EIB loans to fund the construction of a centralized composting facility capable of serving multiple farms. This approach not only reduces upfront costs for individual farmers but also enhances the scalability and economic viability of circular practices.

Moreover, the EIB offers technical assistance as part of its loan packages, ensuring that funded projects are implemented efficiently and meet sustainability standards. This support includes guidance on project design, implementation, and monitoring, which is particularly valuable for first-time adopters of biochar or composting technologies. By partnering with local agronomists and research institutions, farmers in Tegea can maximize the impact of these loans, ensuring that investments translate into measurable improvements in soil quality, crop yields, and environmental sustainability.

The availability of EIB loans also aligns with broader efforts to promote rural development and climate resilience in the Peloponnese region. By investing in circular practices, farmers contribute to regional and national sustainability goals while enhancing their own economic stability. The combination of low-interest financing, technical support, and collaborative opportunities makes the EIB an indispensable resource for driving the adoption of circular agriculture in Tegea.

To ensure the successful uptake of EIB financing, farmers and cooperatives in Tegea should receive targeted outreach and education about the application process and loan terms. Workshops and informational sessions can demystify the requirements and benefits of EIB loans, encouraging broader participation. Additionally, collaboration with local government agencies and agricultural organizations can streamline the application process and provide farmers with the administrative support needed to secure funding.

Financial Resources and Farmer Engagement

The successful adoption of circular economy practices depends not only on the availability of funding but also on the ability of farmers to navigate funding mechanisms and perceive the financial returns on their investments.

Simplifying Subsidy Applications

Many farmers find subsidy applications for EU programs like CAP to be complex and time-consuming. Hosting workshops or training sessions to simplify these processes and provide step-by-step guidance could significantly increase participation and ease adoption (European Commission, 2020).

ROI Models for Biochar and Compost

Demonstrating clear return on investment (ROI) models is crucial. Presenting data on reduced fertilizer costs, water savings, and improved crop yields can highlight the tangible financial benefits of adopting practices like biochar and composting. For example, reduced nitrogen fertilizer usage or lower irrigation needs directly translate to improved profitability and cost savings.

Collaborative Buying Initiatives

Encouraging farmers to form cooperatives for joint investments in facilities and equipment can reduce individual costs. Shared resources, such as biochar production units or composting facilities, lower financial barriers while promoting community collaboration and mutual benefit.

By integrating these funding mechanisms and support structures, Tegea’s agricultural community can overcome financial challenges and transition toward a circular economy model that emphasizes sustainability, economic resilience, and environmental stewardship.

5.3. Social and Community Engagement in Circular Agriculture in Tripolis

Farmers in Tripolis are increasingly recognizing the value of circular economy (CE) practices in agriculture, though their readiness to adopt these practices varies significantly. Interviews with local farmers highlight a growing awareness of the potential benefits, such as reduced input costs, improved soil health, and enhanced sustainability.

However, barriers such as limited knowledge, logistical challenges, and financial constraints hinder widespread adoption. Farmers appreciate the environmental benefits of practices like composting, renewable energy generation from agricultural residues, and soil improvement substances. Nevertheless, many emphasize the need for practical training and financial support to transition from awareness to implementation (Rodriguez, Geiger, & Pavlidis, 2020).

A targeted pilot program could serve as a vital tool for encouraging community engagement with CE practices. This initiative would showcase the tangible benefits of composting and pruning residue reuse under local conditions. Detailed data collection on key metrics, such as organic matter levels, moisture retention, and crop yields, would provide empirical evidence of the benefits of CE practices specific to Mediterranean soils. Transparent sharing of this data through community events like workshops and open farm days would allow farmers to observe the outcomes firsthand, fostering greater trust and willingness to adopt such methods (Rodriguez et al., 2020).

Mediterranean soils, often suffer from degradation and low fertility, making them a prime target for improvement through CE practices. Farmers sometimes prioritize short-term yield improvements over long-term soil health benefits. Workshops focused on soil resilience could illustrate how compost applications reduce erosion, increase organic matter, and improve water retention. Collaborations with local agronomists to conduct on-site demonstrations would address specific soil issues and help bridge knowledge gaps. For example, field visits where farmers see the results of improved soil management techniques could significantly enhance understanding and acceptance (Blanco-Canqui & Lal, 2009).

Knowledge transfer and skill development are essential to the success of CE practices. Training sessions organized by institutions like Νέα Γεωργία για τη Νέα Γενιά could provide hands-on experience in composting techniques and pruning residue management. These sessions should target not only current farmers but also younger generations to address rural youth migration and the aging farming population. Programs designed for youth engagement can ensure the sustainability of CE practices by modernizing agricultural perspectives and fostering a new generation of farmers committed to sustainable methods.

Peer-based learning is critical in fostering trust and engagement within the farming community. Early adopters or experienced practitioners of CE practices can lead peer-learning groups, sharing their successes and challenges to guide others in the community. Exchanges with farmers from other Mediterranean areas, such as Andalusia or Puglia, could offer valuable insights and strengthen confidence through shared experiences. These peer-to-peer interactions create a supportive environment that encourages the adoption of innovative methods while reducing resistance to change (Carvalho et al., 2020).

Educational institutions, including the Agricultural University of Athens and the University of Peloponnese, can play a significant role in supporting CE adoption. These institutions can provide technical training in composting and sustainable residue management while developing mentorship and internship programs to engage youth. By aligning agricultural innovation with sustainability goals, these programs can modernize farming and counteract the demographic challenges facing rural areas.

Suggested Implementation Steps for Tegea and Arcadia area in general

1. Pilot Programs: Small-scale pyrolysis units could be introduced through pilot programs to demonstrate the economic and environmental benefits of biochar production. Funding from agricultural grants or EU sustainability programs could support these initiatives.
2. Farmer Training and Outreach: Local agricultural organizations should provide workshops and training sessions to familiarize farmers with biochar production, application techniques, and its benefits for Mediterranean soils.
3. Policy Support: Government incentives, such as subsidies or tax breaks, could encourage farmers to adopt biochar and composting practices, aligning with Greece's circular economy goals (European Commission, 2022).

Community buy-in is crucial for the success of circular agriculture initiatives. Encouraging early adopters to share their experiences and hosting public demonstrations can build trust and awareness within the farming community. Open farm days showcasing the results of CE practices provide tangible evidence of their benefits, helping hesitant farmers overcome skepticism and fostering a collective movement toward sustainability.

Implementing circular agriculture requires a multifaceted approach combining technical support, policy incentives, and community engagement. By leveraging educational institutions, local cooperatives, and policymakers, the area can transition to a sustainable agricultural model that balances economic resilience with environmental stewardship. This collaborative effort offers a clear path toward long-term sustainability, positioning Tegea as a leader in adopting circular economy principles.

6. Conclusions and Recommendations

This thesis underscores the transformative potential of circular economy (CE) practices in enhancing the sustainability and resilience of agriculture in Tripolis, with a specific focus on the reuse of pruning residues. Integrating these practices addresses significant environmental, economic, and social challenges, paving the way for long-term sustainable development.

The reuse of pruning residues offers numerous environmental benefits, including enhanced soil health, improved water retention, and reduced dependency on synthetic fertilizers. The incorporation of compost and biochar improves soil structure and biodiversity while reducing greenhouse gas emissions through carbon sequestration. These practices play a pivotal role in mitigating climate change and aligning agricultural activities with global environmental goals.

From an economic perspective, the adoption of CE practices generates tangible financial benefits. Transforming agricultural waste into value-added products like compost and biochar reduces input costs for farmers, such as those related to chemical fertilizers and irrigation. Additionally, the commercialization of surplus compost and biochar creates new revenue streams, bolstering the economic resilience of the agricultural sector. These practices also contribute to job creation in production, distribution, and support services, which is particularly significant in rural areas like Tripolis.

Socially, the findings highlight varying levels of readiness among farmers to adopt circular practices. While younger farmers and cooperatives exhibit a strong willingness to embrace innovative solutions, older farmers and small-scale operators face challenges due to limited awareness and financial constraints. Community engagement and tailored training programs are crucial for addressing these gaps and ensuring widespread adoption of CE practices.

The policy and financial landscape plays a critical role in enabling the transition to circular agriculture. Supportive policies under European Union programs such as the Common Agricultural Policy (CAP) and the LIFE Programme, along with national and regional subsidies, provide a foundation for farmers to overcome financial barriers. These mechanisms must be expanded to include specific support for biochar and composting technologies.

Despite these opportunities, challenges remain, including high initial investment costs, fragmented landholdings, logistical difficulties, and inadequate local infrastructure for waste processing. Addressing these barriers requires a multi-faceted approach that includes technical support, financial incentives, and collaborative efforts among stakeholders.

To build on these findings, the following **recommendations** are proposed to accelerate the adoption of CE practices:

1. **Awareness and Education**: Farmers need greater access to practical knowledge about the benefits of composting, biochar production, and other circular practices. Workshops, field demonstrations, and partnerships with educational institutions can facilitate this process. Collaborations with organizations such as "Νέα Γεωργία για τη Νέα Γενιά" can enhance knowledge-sharing and skill development.
2. **Policy and Financial Support**: Expanding subsidies and grants under EU programs to cover equipment for composting and biochar production is essential. Tax incentives for sustainable farming inputs and cooperative initiatives can reduce financial burdens and promote adoption.
3. **Cooperative Models**: Encouraging the formation of cooperatives allows farmers to share resources and logistical challenges associated with CE practices. Shared facilities for composting and biochar production can significantly reduce individual costs and foster community collaboration.
4. **Local Infrastructure Development**: Investing in localized composting and biomass facilities is crucial for efficiently processing pruning residues. This infrastructure will reduce transportation costs and improve access for small-scale farmers.
5. **Pilot Programs**: Establishing pilot programs in key agricultural areas, such as vineyards and olive groves, can showcase the economic and environmental benefits of CE practices. Detailed monitoring of pilot projects, with data shared through community events and workshops, will encourage wider adoption by providing localized evidence of success.
6. **Market Development**: Developing local markets for compost and biochar will enable farmers to capitalize on the demand for sustainable agricultural inputs. Targeting greenhouses, landscaping projects, and organic farming enterprises ensures consistent market demand while reducing transportation costs.
7. **Research and Innovation**: Partnering with research institutions to develop cost-effective and scalable CE technologies is essential for tailoring solutions to the region's needs. Long-term studies on soil health, crop productivity, and biodiversity impacts will strengthen the scientific basis for CE practices and provide actionable insights for farmers.

The agricultural sector in Tripolis stands at the cusp of a transformative shift towards sustainability. By leveraging the outlined strategies and addressing the identified barriers, the area can lead by example in adopting circular economy principles. These efforts will not only strengthen local agriculture but also contribute to broader environmental and economic objectives, positioning Tripolis as a model for sustainable rural development.

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7.2. Diagrams

Diagram 1. Packaging waste recycling and national targets for 2025 and 2030. Source: YPEN, National waste management plan.

Diagram 2. Packaging recycling, Greece and EU-27 (%). Source: Eurostat

Diagram 3. Objectives of the European plan for the circular economy. Source: COM (2020) 98 - The new Circular Economy Action Plan – For a cleaner and more competitive Europe.

Diagram 4. Crop types in Tegea Area, (Percentages). Source: Aggregate plant capital data EAE2023 Tegea Tripolis, Greece, organization OPEKEPE

Diagram 5. Areas under trees and vines in Arcadia area. Source: Hellenic Statistical Authority, Areas and Production, 2022 https://www.statistics.gr/el/statistics/-/publication/SPG06/-

Diagram 6. Production process for the biomass gasification. Source: https://www.researchgate.net/figure/Flow-diagram-of-power-generation-from-biomass-gasification_fig4_323927618

7.3. Figures

Figure 1. Biochar image

Figure 2. Biomass (Agroenergy, n.d.)
http://www.agroenergy.gr/content/%cf%84%ce%b9-%ce%b5%ce%af%ce%bd%ce%b1%ce%b9-%ce%b7-%ce%b1%ce%b5%cf%81%ce%b9%ce%bf%cf%80%ce%bf%ce%af%ce%b7%cf%83%ce%b7-%ce%b2%ce%b9%ce%bf%ce%bc%ce%ac%ce%b6%ce%b1%cf%82

Figure 3. The five processes of gasification, (Allpowerlabs, n.d.)
https://www.allpowerlabs.com/gasification-explained

7.4. Tables

Table 1. Calculations for Estimated Pruning Wood in Tegea, ΟΠΕΚΕΠΕ

Table 2. Biomass requirements for plant operations

7.5. Survey Discussion Guide

Discussion Guide

Introduction

- Can you briefly introduce yourself and your role?
- What do you know about the concept of a circular economy in agriculture and its potential benefits?

Current Practices

- Are circular economy practices being implemented in the area?

Circular Economy Potential

- In your opinion, what opportunities do you see for applying circular economy principles in the local agricultural sector?
- Are there any initiatives or practices related to the reuse of pruning residues in agriculture here?

Barriers and Challenges

- What do you consider to be the main barriers or challenges to adopting circular economy practices, such as the reuse of pruning residues in agriculture, in this area?
- Are there regulatory (e.g., bans) or socio-cultural (e.g., waste management) obstacles that need to be addressed?

Economic Considerations

- Are there potential cost-saving or revenue-generating opportunities from pruning residue reuse practices?

Environmental Impacts

- How might these practices affect soil health, biodiversity, or the carbon footprint?

Collaboration and Partnerships

- Who do you think should be involved in such a process? Are there specific organizations, government bodies, or stakeholders you know of who could contribute to this?
- How can collaboration between different stakeholders be facilitated?

Policy and Regulatory Framework

- What role do you think public policies (regulatory and/or incentive-based) should play in promoting circular economy practices?
- Are there specific policy changes or incentives you believe would be effective in promoting pruning residue reuse practices in the area?

Knowledge and Training

- Do you think there is a need for training programs to raise awareness among farmers and stakeholders about circular economy principles and pruning residue reuse practices?
- How can knowledge exchange between producers themselves, as well as between experts and producers, be improved to build capacity?

Implementation and Scaling

- What steps do you envision for the successful implementation of circular economy projects in the area?
- How can these initiatives be scaled up to benefit a larger part of the local agricultural sector?

Next Steps

- What do you consider to be the next steps for promoting the circular economy project related to the reuse of pruning residues in the area of Tegea in Tripoli?
- Are there specific actions or tasks you would suggest as a top priority?

Conclusion and Commitment

- Would you be willing to participate actively in the development and implementation of the circular economy project?
- Do you have any final thoughts or suggestions regarding the project?
- Would you be willing to actively participate in promoting circular economy practices?

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