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Master Thesis

Decarbonisation Potential Through the Integration of Multifunctional Land Management Based on Urban Agroforestry: A Case Study of La Punta (Valencia, Spain)

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THESIS APPROVAL

I, Salvatore Pappalardo, as supervisor of the student Luana Izzicupo Borges, hereby APPROVE the thesis entitled “Decarbonisation Potential Through the Integration of Multifunctional Land Management Based on Urban Agroforestry: A Case Study of La Punta (Valencia, Spain)”.

Padova

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Signature

DECLARATION OF MOBILITY

This thesis is the result of the Joint Master's degree in Climate Change and Diversity: Sustainable Territorial Development (CCD-STeDe).

This program is offered by a consortium made up of the following universities: Università degli Studi di Padova (UNIPD, Italy), The Universidad Andina Simón Bolívar (UASB, Ecuador), Universidade da Madeira (Portugal), the University of Johannesburg (South Africa) and Université Joseph Ki Zerbo de Ouagadougou (Burkina Faso).

This program has a duration of 24 months. The course started at UNIPD in Italy, followed by Quito in Ecuador at UASB. The third semester was blended with the International Summer School in Madeira Island (Portugal). The fourth semester was spent on an internship and thesis at Finnova Foundation EU in Spain under the supervision of Professor Salvatore Pappalardo of UNIPD.

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PREFACE

Our eyes can only see as far as they can reach. However, increasing this perception is a matter of practice.

I discovered this double master's degree at a time when I was facing a sense of professional and personal loss. Yet, I was confident that I had to overcome obstacles, find new inspirations—and continue, even if it meant exploring avenues I had not previously considered.

Feeling lost is the first step towards finding yourself. From there, the process of transformation begins. It is never easy, but the rewards are worth the effort. It brings the protagonism of your life, the desire to see beyond, the intention to move, to embrace experimentation, and the confidence to think differently. After all, everything is always changing and why shouldn't it be any different with us?

The CCD-STeDe programme has provided an excellent opportunity for learning and professional development. Experiencing diverse countries and cultures in under two years has undoubtedly brought the expansion of perception I was seeking. Nevertheless, all that was made possible by the exceptional individuals with whom I have been fortunate to be surrounded. For that reason, I reinforced my recognition of the value of gratitude.

To my parents, Paulo and Adriana, I extend my gratitude for their consistent guidance and support, regardless of my decisions, and in the face of numerous changes and challenges. Thank you for your continued dedication to my well-being and happiness.

To my grandmothers, Joana and Maria, who have been my example of strong and empowered women. Thank you for providing wise advice. To my siblings, Leandro and Paola, thank you for listening and giving me distinct perspectives.

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Luana Izzicupo Borges

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Thank you all for helping me to see further ahead. With this practice, I can now navigate back to find myself if I ever get lost.

"Doubt everything. Find your own light."

– Gautama Buddha

Luana Izzicupo Borges

Decarbonisation Potential Through the Integration of Multifunctional Land Management Based on Urban Agroforestry: A Case Study of La Punta

ABSTRACT

The contemporary global environment is characterised by a multitude of interrelated challenges, including urbanisation, climate change, and the necessity of urgent mitigation actions. With most of the world's population now residing in urban areas and at the core of environmental issues, cities offer opportunities for positive transformations to address these challenges; however, this potential must be explored and investigated. Consequently, it becomes increasingly pertinent to its decarbonisation in the present and coming decades. This is to achieve zero net emissions and transition to smart, sustainable, and resilient cities.

The study area of the present thesis is the city of Valencia, designated as the European Green Capital for 2024 by the EU Commission. Despite this accolade, significant challenges remain, including the notable presence of unused and degraded land. One potential solution would be an integrated and multifunctional agroforestry systems within an urban environment. Accordingly, the objective of this research is the development of an outcomes-oriented strategy. To this end, remote sensing and Geographic Information System (GIS) mapping are conducted in the *La Punta* neighbourhood, followed by land planning and design based on the most suitable nature-based solution (NBS). Subsequently, an estimation of potential carbon sequestration and storage and bioenergy production are provided.

The research yielded several interconnected results and findings related to decarbonisation, energy security, economic prospects and sustainable communities. The potential net carbon storage results for the 30-year timeframe are 189,332.2 $tCO^{2}e$, 666,035 $tCO^{2}e$ and 633,993.7 $tCO^{2}e$ by each method employed, demonstrating a positive cumulative trend over time. Furthermore, the estimated yields of bioenergy production from a four-year rotation are 5,245.71 GJ/ha for Populus and 4,172.73 GJ/ha for Salix.

The strategy is based on the concept of "Aptness to people, Aptness to place, Aptness to purpose" and the Principle of Synergy. This strategy is designed to facilitate the generation of social justice and the revitalisation of community involvement, as well as to achieve land regeneration, nature connectivity and conservation. This dynamic, ecologically based natural resources management system is presented in an overview as a Climate Transition Story Map.

Therefore, this master's thesis contributes significantly to the global climate action objective and serves as an exemplar for sustainable transitions in the future.

Luana Izzicupo Borges

RESUMEN

El entorno global contemporáneo se caracteriza por una multitud de retos interrelacionados, como la urbanización, el cambio climático y la necesidad de medidas urgentes para su mitigación. Dado que la mayoría de la población mundial reside actualmente en zonas urbanas y está en el centro de los problemas medioambientales, las ciudades ofrecen oportunidades de transformaciones positivas; sin embargo, este potencial debe ser explorado e investigado. En consecuencia, resulta cada vez más pertinente su descarbonización en las décadas actuales y venideras. Con ello se pretende lograr cero emisiones netas y la transición hacia ciudades inteligentes, sostenibles y resilientes.

El área de estudio de la presente tesis es la ciudad de Valencia, designada Capital Verde Europea para 2024 por la Comisión Europea. A pesar de este logro, persisten importantes retos, como la notable presencia de terrenos sin uso y degradados. Una posible solución sería un sistema agroforestal integrado y multifuncional dentro de un entorno urbano. En consecuencia, el objetivo de esta investigación es el desarrollo de una estrategia orientada a los resultados. Con este fin, se lleva a cabo una cartografía por teledetección y Sistema de Información Geográfica (SIG) en el barrio de La Punta, seguida de una planificación y diseño del terreno a partir de la solución basada en la naturaleza (SBN) más adecuada. Posteriormente, se realiza una estimación del potencial de secuestro y almacenamiento de carbono y de producción de bioenergía.

La investigación produjo varios resultados y constataciones interconectados, relacionados con la descarbonización, la seguridad energética, las perspectivas económicas y las comunidades sostenibles. Los resultados potenciales de almacenamiento neto de carbono, en un plazo de 30 años, son de 189.332,2 tCO^2e, 666.035 tCO^2e y 633.993,7 tCO^2e por cada método empleado, demostrando una tendencia acumulativa positiva a lo largo del tiempo. Asimismo, los rendimientos estimados de producción de bioenergía a partir de una rotación de cuatro años son 5.245,71 GJ/ha para el Populus y 4.172,73 GJ/ha para el Salix.

La estrategia se basa en el concepto de «Aptitud para las personas, Aptitud para el lugar, Aptitud para el propósito» y el Principio de Sinergia. Esta estrategia está diseñada para facilitar la generación de justicia social y la revitalización de la participación comunitaria, así como para lograr la regeneración del territorio y la conectividad y conservación de la naturaleza. Este

sistema de gestión de los recursos naturales, dinámico y de base ecológica, es presentado de forma resumida como un *Story Map* de la Transición Climática

Por lo tanto, esta tesis de máster contribuye al objetivo global de acción por el clima de manera significativa y sirve de ejemplo para transiciones sostenibles futuras.

RESUMO

O ambiente global contemporâneo é caracterizado por uma multiplicidade de desafios inter-relacionados, incluindo a urbanização, as mudanças climáticas e a necessidade de ações urgentes de mitigação. Como a maioria da população mundial reside atualmente em áreas urbanas e, no centro das questões ambientais, as cidades oferecem oportunidades de transformações positivas; no entanto, esse potencial deve ser explorado e investigado. Consequentemente, torna-se cada vez mais pertinente a sua descarbonização nas décadas atuais e futuras. O objetivo é atingir zero emissões líquidas e a transição para cidades inteligentes, sustentáveis e resilientes.

A área de estudo da presente tese é a cidade de Valência, designada como a capital verde europeia para 2024 pela Comissão Europeia. Apesar desta distinção, subsistem desafios significativos, incluindo a presença notável de terrenos não utilizados e degradados. Uma solução potencial seria um sistema agroflorestal integrado e multifuncional inserido no ambiente urbano. Neste sentido, o objetivo desta investigação é o desenvolvimento de uma estratégia orientada aos resultados. Para tal, é realizado um mapeamento por sensoriamento remoto e Sistema de Informações Geográficas (SIG) no bairro de *La Punta*, seguido de planejamento e design do terreno com base na solução baseada na natureza (SBN) mais adequada. Subsequentemente, é estimado o potencial de sequestro e armazenamento de carbono e de produção de bioenergia.

A investigação gerou diversos resultados e constatações interconectados referentes à descarbonização, segurança energética, perspectivas económicas e comunidades sustentáveis. Os potenciais resultados líquidos de armazenamento de carbono, ao longo de 30 anos, são de 189.332,2 tCO^2e, 666.035 tCO^2e e 633.993,7 tCO^2e para cada método utilizado, demonstrando uma tendência cumulativa positiva ao longo do tempo. Além disso, os rendimentos estimados de produção de bioenergia, a partir de uma rotação de quatro anos, são de 5.245,71 GJ/ha para a Populus e 4.172,73 GJ/ha para a Salix.

A estratégia baseia-se no conceito de "Aptidão para as pessoas, Aptidão para o local, Aptidão para o propósito" e no Princípio da Sinergia. Esta estratégia foi desenvolvida para facilitar a geração de justiça social e a revitalização do envolvimento da comunidade bem como para alcançar a regeneração da terra, a conectividade e a conservação da natureza. Esse sistema de

gerenciamento de recursos naturais dinâmico e de base ecológica é apresentado de forma geral como um *Story Map* da Transição Climática.

Portanto, esta tese de mestrado contribui para o objetivo de ação climática global de forma significativa e serve como exemplo para transições sustentáveis futuras.

CONTENT

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1. INTRODUCTION

1.1. From Climate Crisis to Climate Action

Six planetary limits have been exceeded, in addition to the effects of climate change, there are also concerns regarding the integrity of the biosphere, changes in terrestrial systems and biogeochemical flows (Richardson et. al., 2023). Several climate variables have been observed to repeatedly break long-term records in recent years, accompanied by an increase in the occurrence of weather and climate extremes (EEA, 2019). Even under the most optimistic scenario, global temperature is predicted to rise, accompanied by changes in regional average temperature, precipitation, and soil moisture (IPCC, 2021).

Further, Hansen et al. (2023) states that the Intergovernmental Panel on Climate Change (IPCC) has underestimated its assessment of climate sensitivity, and this has resulted in a transgression of the IPCC's best estimates. These findings suggest that human activity has had a significant impact on the Earth system, resulting in transformation at an unprecedented level. The situation is likely to become even more complex if atmospheric CO^2 concentrations exceed 550ppm and deforestation persists (Richardson et al., 2023). Consequently, the hazards associated with climate change are becoming more severe and are anticipated to intensify soon (EEA, 2019).

In response to this global challenge, several proposals have emerged. These include the Sustainable Development Goals (SDGs) and the Paris Agreement as measures and targets with differing degrees of interdependence[1] (Laumann et al., 2022). Furthermore, the European Commission (2019) announced the European Green Deal, which aims to accelerate GHG reduction across the European Union (EU). The ambitious plan is on track to achieve net-zero emissions by 2050 (D'Aprile et al., 2019) and is further reinforced by the EU Adaptation

[1] The interdependence between the proposed actions varies in degree. As an illustration, the achievement of SDG 2 – zero hunger – depends on the eradication of poverty, which implies a first-degree interdependence. Likewise, the attainment of SDG 8 – economic growth – hinges on both SDGs being implemented, thus establishing a second-degree interdependence. This implies that when people achieve greater stability, their economic power also increases. Therefore, the interdependency between this relationship and the previous one is less than that observed in the first case but still significant. Similarly, it may be argued that there are links between sustainable cities (SDG 11). In this instance, while the degree of interdependence between the two relationships is arguably less, they remain fully interconnected. In a community where there is no food security or poverty, it is unlikely that the goal of a sustainable city will be achieved.

Strategy of 2021. This strategy delineates a plan for the EU to adapt to the unavoidable impacts of climate change and to achieve climate resilience (European Commission, 2021).

Conversely, despite the urgency of the climate crisis and its potential consequences, the effective measures taken have been relatively cautious (Eichhorn et al., 2020). There is a significant discrepancy between the planned behavioural and policy changes to mitigate and adapt to climate change and the actual climate action taken. As outlined by Laumann et al. (2022), this discrepancy is further reinforced by the complexity of global sustainability and its interconnected elements, which must encompass the socio-economic, climatological, and ecological spheres.

Moreover, similar complexities can be identified when considering urban environments. Cities currently account for over 50% of the global population; by 2050, this figure is projected to exceed 70% (Urrutia-Azcona et al., 2019). These environments also account for approximately 60-80% of global energy consumption and 75% of global carbon emissions (United Nations, 2023), exerting a direct influence on temperature rises, air pollution, and the expansion of slum areas (Laumann et al., 2022). Furthermore, 92% of the global population resides in regions with atmospheric pollution levels that exceed the World Health Organization's established standards. This evidence highlights the urgency for immediate climate action (Urrutia-Azcona et al., 2019).

In this context, challenges may become opportunities when the appropriate initiatives are taken to advance sustainable development, including cities and communities (SDG 11) (United Nations, 2023). This approach can be integrated into new paradigms, such as Nature-Based Solutions (NBS), which have multiple co-benefits, i.e. the interconnection between human health and well-being (SDG 3) and the conservation and resilience of ecosystems (SDG 15) (Varshney, Zari & Bakshi, 2022). Consequently, a strategic approach could prove a valuable solution, as it would facilitate a just transition.

1.2. Post-Carbon Cities

"We are now in an era of transformation in which ecosystem management must build and maintain ecological resilience as well as the social flexibility needed to cope, innovate and adapt." — C. S. Holling (2001)

The transition to a new urban era is a complicated and challenging process. As the nature of the problem is not linear and therefore cannot be solved with a single solution (Lerch, 2007), it becomes necessary to understand the associated risks and critical limits to deal with it. In urban areas, it is crucial to conduct a comprehensive analysis of the economic and social activities in which humanity is currently engaged (Richarson et al., 2023), as well as to determine the growing uncertainty surrounding energy and climate change that is already underway. In other words, the transformation process requires continuous management and a multifaceted approach (Ballesteros et al., 2020).

The deployment of multifunctional and sustainable solutions can facilitate the advancement of urban metabolism in an environmentally conscious manner. Such an approach can assist in reducing the ecological impact of cities while simultaneously providing a diverse range of services (Van Broekhoven & Vernay, 2018).

The urban landscape requires innovative actions across numerous sectors. It seems inevitable that the integration of NBS, eco-design, and regenerative systems may become a pivotal strategy in the effort to decarbonise the built environment (Varshney, Zari & Bakshi, 2022). Furthermore, it can enable transformations, such as neighbourhoods generating renewable energy, rather than merely consuming it (Ballesteros et al., 2020).

1.3. Motivation and Justification

Valencia was designated the European Green Capital for 2024 in recognition of its past and current achievements in climate neutrality, and inclusive green transition (EU Commission, 2024). Nevertheless, the city continues to confront several challenges, including a significant increase in the extent of unused land in decentralised neighbourhoods (Valencia Plaza, 2024).

The *Quatre Carreres* district provides an illustrative example of this phenomenon. The *Ciutat de les Arts i les Ciènces* neighbourhood (10.7) is connected to the city centre by a park and has an average annual income of €15,305.96 per person. Nevertheless, the neighbourhoods situated around it and within the same district, but farther from the city centre, are grouped within the lowest-income areas of the city, with an average annual income of less than 10,146.38€ per person in *Fuente San Luis* (10.4), *Na Rovella* (10.5), and *La Punta* (10.6) (*Ajuntament de València*, 2023).

The low income rates of these areas are a likely driver of migration and the consequential abandonment of land. This contributes to the recently established record of uninhabited land in the Valencian community, a colossal 173,676 km² (*Valencia Plaza*, 2024).

In addition to these issues, the Valencia Port Authority has initiated the Logistics Activity Zone (ZAL) project (Valencia Port, 2024), which concerns the utilisation of an area of land that has been in a state of disuse and degradation for 20 years, as documented by *La Vanguardia* (2021). It should be noted that this is the same land that was previously rendered uninhabitable due to the expansion of this port. Consequently, the implementation of this project is likely to result in increased pollution and greenhouse gas (GHG) emissions.

Therefore, it can be argued that these measures are inconsistent with the city's declared objective of fostering a more sustainable and environmentally responsible future. From a global perspective, the proposed developments contravene the urgent climate crisis that is currently unfolding and contradict the desires of the local community, as evidenced by the protests "*No a l'ampliació del port*" on 31 May 2024 and numerous similar protests that occurred in recent years, such as *Recuperem la Punta, Aturem la ZAL* and *Per l'Horta*.

Accordingly, a multifunctional approach is essential to ensure a profound climate action, which encompasses meticulously planned urban environmental sustainability, as well as social awareness and involvement. Thus, the implementation of NBS represents a substantial opportunity for the transition towards a sustainable, smart, and resilient city (SSRC). The anticipated outcomes are numerous. These include improvements in air, soil, and water quality; enhanced citizen well-being; conservation of biodiversity; the creation of green jobs; and a reduction in energy costs (Cingolani, 2021).

In consideration of the aforementioned factors, the present study is focused on advancing the concept of urban agroforestry as a solution to the problem of unused land in urban environments. The proposed solution is an integrative and multifunctional land management plan with the potential to facilitate an inclusive and equitable transition, as well as contribute to decarbonisation and energy security for the local community. It is therefore imperative to engage with several disciplines at the outset to address the inherent complexity of this issue. The initial stage of the process is to evaluate the area in question and conduct a critical geographical analysis to gain a comprehensive understanding of the land context and site conditions.

Subsequently, the optimal NBS solution is designed and planned under the data and stated purposes. Consequently, an outcome-oriented strategy is employed to maximise the benefits of the solution, and it may also serve as an example for the implementation of the concept in other cities. The case study is centred on the *La Punta* neighbourhood, which is located within the *Quatre Carreres* district of Valencia City.

1.4. Research Question and Objectives

This master thesis aims to explore a set of potential climate solutions consisting of outcomes-oriented practices for carbon sequestration, bioenergy production, community inclusion and economic resilience. Thus, the main research question is:

What action could be considered an effective strategy for the mitigation of climate change and the adaptation to its impact while concurrently yielding a range of outcomes for the urban environment?

The specific objectives of this research study are as follows:

- Determine the most suitable land and its characteristics by conducting a critical geographical analysis of the case study, including environmental, social, and economic aspects.
- Identify the most appropriate agroforestry system through an investigation of its multifunctionality and develop a land management plan and design with an outcomes-oriented strategy.
- Simulate carbon sequestration and bioenergy production to predict the potential decarbonisation and energy security, as well as to evaluate the results.
- Geo-visualise successful initiatives and guidance, as well as best practices towards a just transition by developing a Climate Transition WILDSCAR (CTW) story map based on urban agroforestry systems.
- Explore future research and actions to be followed to improve and complete the study conducted.

1.5. Structure

This document is divided into nine defined chapters to organise the information developed throughout.

This first chapter, the introduction, includes the background, motivation and justification for conducting the study, the research question and specific objectives, and this section on the organisation of the different chapters in the document.

The second chapter is about the theoretical frame & literature review regarding theoretical approaches and related concepts. These include a review of the state-of-the-art agroforestry systems and their potential as an integrated, multifunctional land-use management strategy, encompassing forest potential for carbon sequestration and woody biomass for bioenergy production. Additionally, the chapter considers the role of urban agroforestry.

The third is a summary of the tools used to conduct this study as well as the reason and purpose for its use. This includes the data collection process, as it is essential to utilise geospatial information systems to map, plan and design future activities.

The fourth chapter contains diagrams and explanations of the actions and schedule of the methodology developed and followed in this study, with the main steps presented. The fifth chapter is devoted to delimitations, limitations and assumptions that may be present in this research and must be further considered. The sixth chapter presents the case study, which encompasses the optimal land selection in its context and conditions.

The seventh chapter is about the results, findings and discussion including the planning, design, simulation, evaluation, results, and discussion of applying the methodology to the neighbourhood of *La Punta* in the *Quatre Carreres* district in the city of Valencia. Moreover, presenting the CTW story map, which provides an overview of urban agroforestry systems based on outcomes-oriented strategy and situated within the context of climate transition regarding environmental, social, and economic aspects.

The eighth chapter presents the main conclusions of the study. The ninth chapter contains the further recommendations for future research. Finally, the bibliography used to develop this study with the separated webliography, and a series of annexes are provided to furnish detailed information on the development of this study and to clarify some aspects of the work carried out.

2. THEORETICAL FRAME & LITERATURE REVIEW

2.1. State-of-the-arf Agroforestry Systems

The observation originally made by William Rees (2010) that industrial society remains dependent on ecosystems to sustain life remains pertinent. Amongst the various types of dependency, direct dependency is advantageous if the ecosystems can inspire and support solutions that simultaneously provide environmental, social and economic benefits and help build resilience. This is also the definition of NBS given by the European Commission (2020). Therefore, an NBS that simultaneously increases local biodiversity and improves the health of local ecosystems can be identified as agroforestry (Global Centre on Adaptation, 2022).

Authors have defined agroforestry systems in various ways. In 1994, Garrett et al. defined it as "an intensive land management that optimises the benefits (physical, biological, ecological, economic, social) arising from biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock." Nair (1993) defined it as practices which involve "the deliberate integration wither simultaneously or sequentially on the same unit of land". In 2018, Burgess & Rosati defined such systems, which include wood pasture and hedgerow systems, as "agroforestry of high nature and cultural value." The International Centre for Research in Agroforestry (ICRAF) defines the term agroforestry as "a dynamic, ecologically based natural resources management system."

It can be further proposed that the system in question represents a "new name for an old practice," as Nair, Kumar & Nair (2022) asserted and that it is being employed in integrated land management across the globe in which the categorisation may be approached in a variety of ways. However, the most appropriate methodology is dependent on the purpose of the categorisation (Nair, 1993). Figure 1 provides an illustrative overview of agroforestry systems.

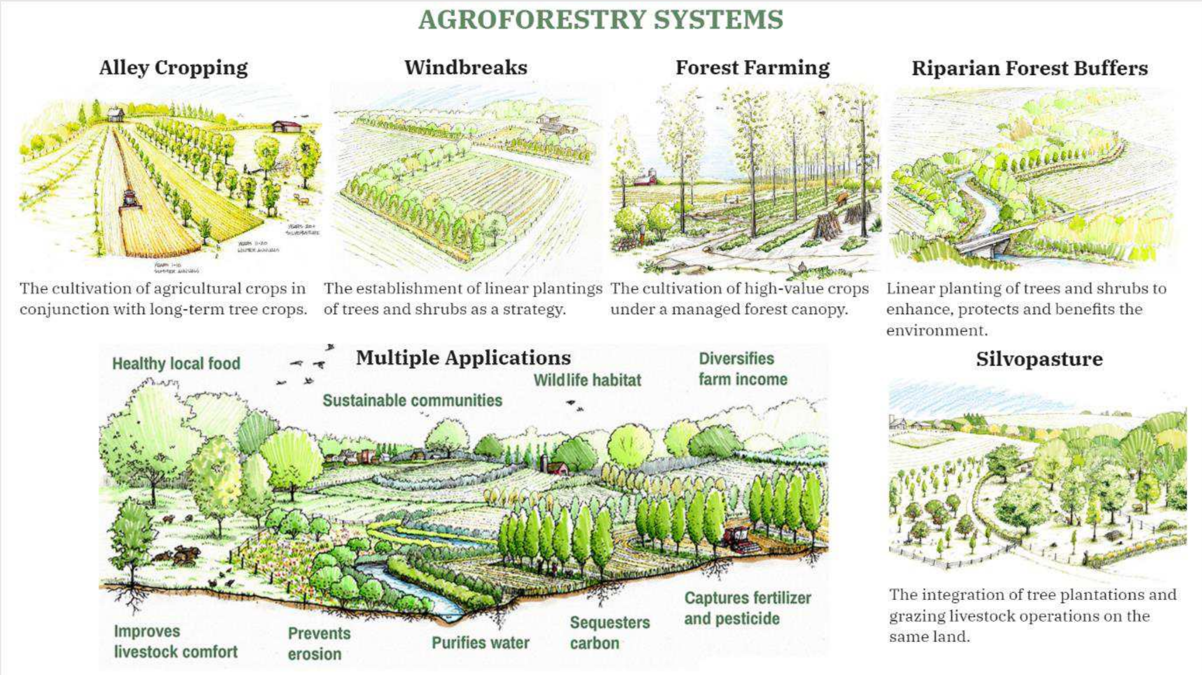

Figure 1. Overview of agroforestry systems.
Source: Adapted from USDA (2024). Illustration by Paul Littleton, the Savanna Institute.

The figure depicts five currently utilised agroforestry systems, including alley cropping, windbreaks, forest farming, riparian forest buffers, and silvopasture. Additionally, numerous other applications may be defined according to specific purposes, as indicated by the USDA (2024). Table 1 presents these and other practices, accompanied by a brief description.

Table 1. Brief description of the diversity of agroforestry practices.

Agroforestry Practices	Brief Description	
Alley cropping	Fast-growing woody species are cultivated in crop fields with close in-row spacing of 0.5m and wide between-row spacing of 4m or more	Preferably leguminous
	Woody species are pruned at low height, below 1m periodically aiming to reduce shading of crops	
Home gardens	Combination of several tree species with crops in homesteads	Especially fruits and nuts
	The garden is small, measuring less than one hectare, and is managed intensively	
	Livestock is optional	
Improved fallow	Fast-growing species of woody plants allowed to grow between cropping years during short fallow phases	Preferably leguminous Not exceeding 3 years Improvement of the site
Multipurpose trees on farms and rangelands	The planting of fruit trees and other multifunctional trees in crop and animal production fields (either in a scattered or systematic manner)	Variety of useful products: fruits, fuelwood, fodder, and timber
Silvopasture	Integration of trees into animal production systems	Grazing systems Cut and carry system

Shaded perennial crop	Cultivation of shade-tolerant species in or among commercial tree crops to create a shade environment	Species such as cacao and coffee
Windbreaks	The use of trees to protect fields from damage can be caused by wind, sea incursion, flooding, etc	
Taungya	The cultivation of crops during the initial stages of establishing a timber plantation	
	Cropping is conducted for a period of two or three years, contingent on the rate of tree canopy development and soil fertility	Generate shading of crops

Source: Adapted from Nair, Gordon & Mosquera-Losada. (2008).

There is a considerable degree of variability in agroforestry, which serves a range of purposes and is characterised by differing attributes. This is clearly illustrated in Table 1, which presents a comprehensive overview of this diversity.

Furthermore, it follows that agroforestry represents a pivotal role and considerable potential for food security, poverty alleviation, ecological restoration, and climate change mitigation (Nair, Kumar & Nair, 2022). Additionally, it provides evidence-based strategies for soil enrichment and biodiversity conservation, as well as air and water quality enhancement (Shibu et al., 2022).

It can be argued that well-managed land has the potential to increase agricultural yields and incomes, whilst also stocking carbon and reducing deforestation (Dale et al. 2011). Consequently, it can be posited that this is a fundamental aspect of rural and rural peri-urban development agendas at various scales, including local, regional, and international (Nair, Kumar & Nair, 2022).

2.2 Agroforestry as an Integrated and Multifunctional Land Use Management Strategy

Integrated land use strategies have been employed by Indigenous populations in North America and European settlers alike. Similarly, in the contemporary era, analogous practices can be observed among native populations in developing countries (Shibu et al., 2022). The typical agroforestry systems are multifunctional (Kuyah et al., 2016) and can be designed and managed to favour specific ecosystem services (García-López, 2024).

Therefore, landscape multifunctionality represents an analytical framework for the interdependence between social and ecological dimensions within the system (Lovell & Taylor, 2013). It is thus of the utmost importance that sustainable solutions be developed to address the interconnected issues of land degradation, energy and food insecurity, and climate change (García-López, 2024).

Accordingly, the term "management" can be defined as a purposeful intervention in natural processes to ensure predictable outcomes (Shibu et al., 2022). Consequently, these management strategies should aim to achieve results that are beneficial to both the environment and humans, including disadvantaged social groups (Lovell & Taylor, 2013).

In this context, a review of the literature reveals a strong indication that agroforestry offers a more substantial potential for carbon sequestration compared to pastures or field crops (Nair, Kumar & Nair, 2022). Furthermore, wood biomass could serve as a sustainable and renewable source of energy (Gonçalves et al., 2019).

2.2.1. Forest Potential for Carbon Sequestration and Storage

It is widely acknowledged that trees function as a terrestrial carbon sink (Houghton et al., 1993). The proposition that the climatic benefits of tropical and temperate forest conservation and reforestation may exceed previous estimations has been put forward by Gauci et al. (2024).

Nevertheless, the total amount of carbon absorbed and stored varies depending on a range of factors, including the region, the type of forest or woodland system, the composition of the forest floor, the age of the trees and their perennial nature (Ramachandran Nair et al., 2010). Furthermore, it is subject to the influence of interactions between climatic, edaphic, and topographic factors, as well as land-use and disturbance-related factors at the level of the forest stand (Arasa-Gisbert et al., 2018; Xu et al., 2015; Yuan et al., 2018).

Carbon sequestration is defined as comprising the removal of carbon from the atmosphere and its subsequent deposition in a reservoir (UNFCC, 2007). Two principal methods may be employed to achieve this objective: in situ, within the biomass and soil, and ex-situ, as products (Montagnini & Nair, 2004). Carbon storage initially occurs in situ in specific plant parts, including stems and leaves, and subsequently in living biomass such as roots. Consequently, belowground carbon stocks occur in soil organisms and various soil horizons (Ramachandran Nair et al., 2010).

Empirical evidence indicates that younger forests have an enhanced capacity for carbon sequestration, whereas older forests demonstrate greater potential for long-term carbon storage (Bioenergy Europe, 2024). Additionally, a positive correlation has been established between tree diversity and forest carbon (Arasa-Gisbert et al., 2018).

Accordingly, it may be proposed that the implementation of agroforestry systems has the potential to significantly advance this process (Nair & Nair, 2003). Therefore, it may be inferred that agroforestry systems possess considerable potential for carbon sequestration and storage, representing a viable strategy for mitigating climate change.

2.2.2. Woody Biomass to Bioenergy Production

An additional potential method, following Gonçalves et al. (2019), for reducing the amount of carbon caused by human activities is the utilisation of wood biomass as an alternative source of renewable energy. This source offers a high degree of versatility (Gonçalves et al., 2019), and this solid biomass can be employed to generate fuel sources such as firewood, charcoal, and electricity (Sharma et al., 2016).

Bioenergy can be defined as the utilisation of solid biomass to produce energy with a variety of raw materials, including residues and wood, which are not currently utilised by other industrial sectors (Bioenergy Europe, 2023).

Therefore, bioenergy production systems designed with the optimal configuration may serve as a significant contributor to the achievement of various climate change mitigation objectives (Casillas & Kammen, 2010). Such systems can additionally facilitate greater access to energy and thereby be employed to reduce poverty in rural communities, the maintenance of forest resilience, the provision of energy security, GHG reduction, and the economic viability of sustainable practices (Bioenergy Europe, 2023).

In practice, forest biomass is predominantly used for the generation of heat and electricity (Brown, 2011; Ge et al., 2016). Figure 2 is a schematic representation of the process of bioenergy production.

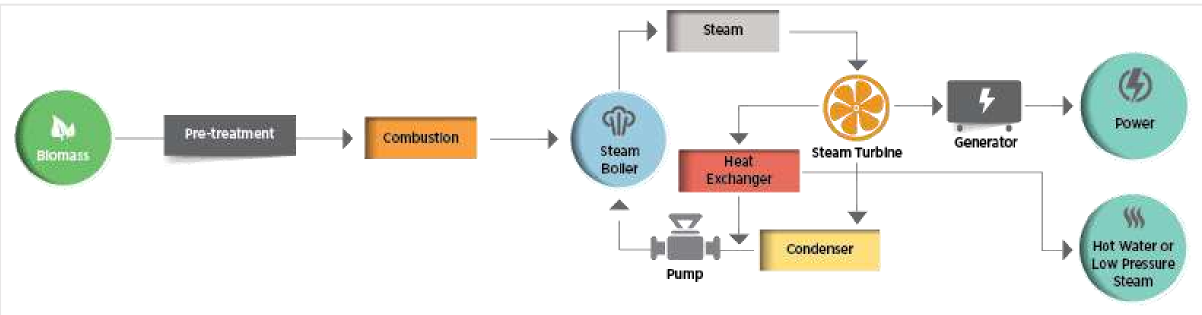

Figure 2. A schematic representation of the process of bioenergy production.
Source: International Renewable Energy Agency - IRENA (2024).

Combined heat and power (CHP) are generated by the process described in Annex D using a steam turbine with heat recovery, as shown in Figure 2.

A practical example of this system has been proposed by García-López et al. (2024), where tree logs are processed into wood chips and used in small-scale combined CHP plants for electricity generation. The initiative is based on an integrated agroforestry-bioenergy system designed to improve the energy and food security of rural communities in sub-Saharan Africa.

Hence, bioenergy systems that are scientifically developed and locally adapted have the potential to address a range of challenges at the same time, including energy security for a growing population (Sharma et al., 2016).

2.3 Urban Agroforestry

In the 1980s, there was an increase in interest in science-based agroforestry biophysical and socioeconomic research and practice; this interest has continued to grow (Garrett et al., 1994; Jose, Gold, & Garrett, 2022).

Urban agroforestry systems may present a promising alternative solution that has the potential to overcome critical barriers (Lovell et al., 2018). In the context of urban areas, such practices in currently unused land can be beneficial in terms of both socioeconomic considerations and environmental impact.

Moreover, these practices have the potential to empower marginalised groups and local communities. Such systems can facilitate the production of urban environments that reflect the aspirations, values, and ideals of those who live in them (Lovell & Taylor, 2013). Furthermore, these can be exploited to create areas that enhance various desirable functions, as outlined by Mell (2009).

The proposed land management strategy may be based on principles of urban ecology, sustainable development, and landscape multifunctionality (Mell, 2009), to establish a "multifunctional woody polyculture" (Lovell et al., 2018).

It can thus be posited that the outcomes extend beyond the boundaries of a single sector and may encompass several different areas, as evidenced by the scheme illustrated in Figure 3.

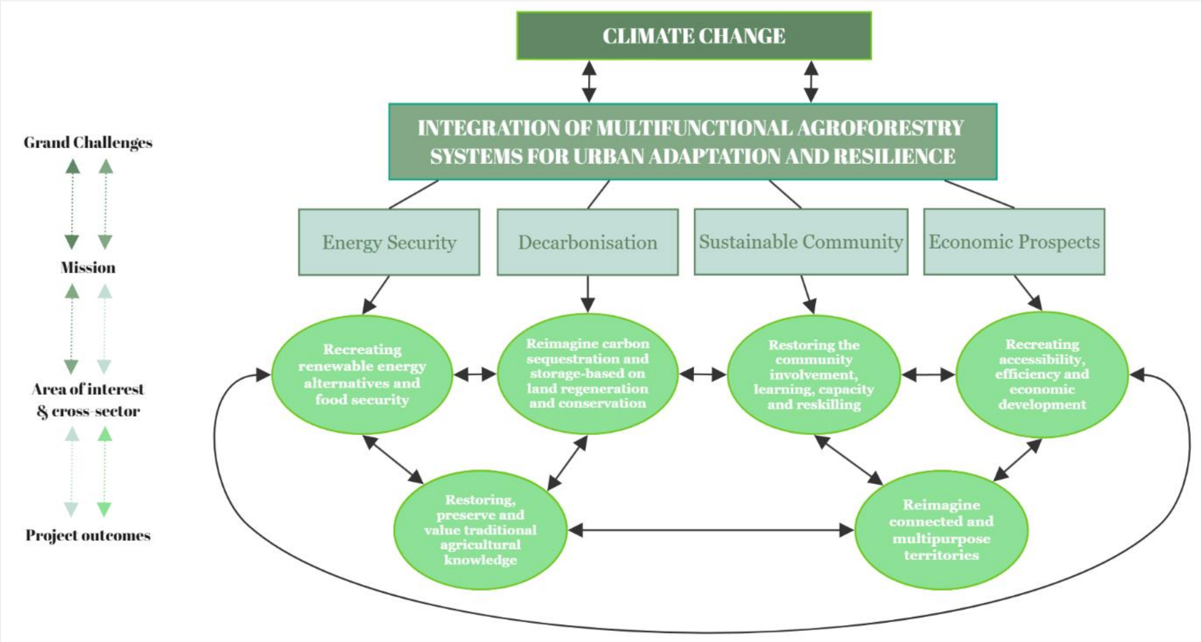

Figure 3. A schematic representation of the intersectoral participation required to achieve urban agroforestry based on an outcomes-oriented strategy.
Personal Graphical Elaboration. Inspired by the IIPP UCL project by Mariana Mazzucato, 2024.

Following the preceding figure, the grand challenge of this thesis research is to mitigate climate change. This mission may be achieved through the integration of multifunctional agroforestry systems for urban adaptation and resilience, involving cross-sectoral participation fostering decarbonisation, energy security, economic prospects, and sustainable communities.

It is anticipated that the project will result in the recreation of scenarios of renewable energy alternatives, food security, accessibility, efficiency, and economic development. Furthermore, it will facilitate the restoration of community involvement, learning, capacity, and re-skilling. Additionally, it will enable opportunities to reimage land regeneration and conservation based on carbon sequestration and storage, as well as interconnected and multi-purpose areas. These outcomes contribute to the effective climate action needed to achieve smart, sustainable, and resilient cities.

3. TOOLS

In this part of the document, the tools used to develop this project are presented and explained.

3.1. QGIS

QGIS (Quantum Geographic Information System) is a software suite that is both free and open source. The software provides a range of capabilities to users, including the creation, editing, visualisation, analysis, and publication of geospatial data. Providing access to spatial visualisation and decision-making tools for all users (QGIS, 2024).

In the context of this thesis, the software was employed to identify the optimal land area and to plan and design the integration of this area into a multifunctional agroecosystem. The initial step involved the critical geographical analysis of the site conditions and landscape context, which yielded four maps.

(1) Geographical Location: Two maps have been prepared to assess the geographical location of the case study and to indicate the territorial division, district boundaries and the zoning of the neighbourhood.
(2) Green Spaces Map: The map assesses the green spaces of the zone, including natural parks within the Valencian Community and gardens and protected zones within the city of Valencia.
(3) Geospatial sensitivity map: The map assesses a range of factors pertinent to the neighbourhood, including educational institutions, photovoltaics, small forests, transport operations, rural areas, recovery sectors, protection zones, green spaces and industrial parks.

Following the generation of the maps and the investigation of relevant information about the neighbourhood, it became evident that the optimal land for this project could potentially be located between two distinct natural parks in the vicinity of the city and other green spaces within it. This conclusion was reached based on an analysis of the available data, which indicated that this area offered many potential advantages. This would effectively constitute the creation of a system of interconnected and protected landscapes.

Consequently, a further map was produced to illustrate the potential interconnection between these areas, with a particular emphasis on the *La Punta* neighbourhood.

3.2. Google Earth Pro

Google Earth Pro (GEP) is a freely accessible software program that provides a plethora of mapping tools and collaborative features. Furthermore, the software can be utilised for remote sensing applications, thereby facilitating the observation of high-resolution satellite imagery and the investigation of three-dimensional terrain and urban environments. Additionally, it is capable of importing, exporting, and analysing GIS data, as well as accessing historical imagery and generating geospatial data sets (Google Earth, 2024).

In this research, GEP has been used as a remote sensing tool to gain insight into various aspects of the selected area on a map, offering both spatial and temporal perspectives. Furthermore, this analytical tool has been employed to examine the changes in the spatial and temporal dimensions. To this end, the following maps were created:

(1) Spatial changes in the *La Punta* neighbourhood between the years 2001 and 2024.

(2) High-spatial resolution and temporal analysis of changes in land use.

(3) Spatial-temporal analysis of the land in the years preceding the ZAL project.

(4) Spatial-temporal overview of the land between the years 2004, 2012, and 2024.

(5) High-spatial resolution of the landscape over time: 2001, 2004, 2010, 2016, 2020, and 2024.

(6) Temporal map of ZAL expansion between the years 2001, 2006, 2019, and 2023.

Additionally, GEP was employed throughout the planning and design process, utilising high-spatial resolution maps to illustrate the prospective land use plan and the selected agroforestry practices. The generated maps were integrated into the "*La Punta* master plan," "Urban agroforestry in a rural neighbourhood," "The principle of synergy," and "The trial design of the land and its activities," which are detailed in Chapter 7.

It was of the utmost importance to obtain data that would allow for the prediction of subsequent steps concerning carbon sequestration potential, carbon storage capacity, and bioenergy production.

3.3. Excel

Microsoft Excel is a spreadsheet program that enables the creation of worksheets or spreadsheets for the management and organisation of data presented in tabular form. The software is employed for the storage, processing, and analysis of data, as well as for the presentation of the results of these processes (Excel X, 2020).

The utilisation of Excel in this study was driven by two distinct objectives. Firstly, it was used for the calculation and prediction of potential outcomes associated with carbon sequestration and storage. The measures presented are based on three distinct methods due to the variability observed in results across the various approaches. The first is the Forest Stewardship Council (FSC) International tool, the second is CO^2fix software, and the third is based on an article in the American Journal of Environmental Protection. Further details on the methods are provided in Annexes A, B, and C, respectively.

The methods yielded three distinct simulations, which were subsequently subjected to further analysis using Excel. It is therefore necessary to provide the data detailed below:

- General information regarding biome, area, species, and strata.
- Default values such as the carbon fraction, wood density, biomass factor of expansion, and mean bulk density.
- The standing volume per year is generated with the height and diameter breast height of each species.

The data provided by the simulation tool is used to generate time-based outcomes under a range of proposed scenarios, which are subsequently represented in graphical form. These outcomes are subjected to analysis and comparison, which facilitates a more comprehensive understanding of the provided data, and the decarbonisation obtained.

Secondly, an Excel spreadsheet has been created to present the Bio-Simulator results from the Irena project following the species and technology to be used for the conversion process. The spreadsheet is employed to:

- Provide an in-depth understanding and analysis of the potential for bioenergy generation from the solid biomass of the forest type, containing the selected species, area and other data, as detailed further. Moreover, the selected technology, containing the bioenergy end-use, conversion technology and energy efficiency, is to be evaluated.

- Analyse the results obtained at the end of the rotation period, which encompass the total woody biomass production and total bioenergy production. Therefore, to comprehend how energy security might increase and be contrasted with the energy demands of the surrounding area.

3.4. ArcGIS Story Maps

ArcGIS Story Maps is an ESRI digital storytelling tool that enables the integration of maps, 3D scenes, embedded content, multimedia, and other elements into an interactive narrative. The narrative can be employed to enhance awareness, influence opinion, and effect transformations. The tool facilitates the integration of dynamic GIS data and external content. Furthermore, stories and briefings can be grouped into collections and tailored to specific themes (ESRI, 2024).

The tool is therefore employed to provide storytelling of the core concept of this thesis, which is an urban agroforestry system based on an outcomes-oriented strategy. Furthermore, it comprises a compilation of successful initiatives and guidance, as well as identifies the most effective practices for achieving a just transition.

4. METHODOLOGY

The methodology employed in the present study is a synthesis of quantitative and qualitative analytical techniques, the particulars of which will be elaborated upon subsequently.

4.1. General Procedure

The procedure developed and carried out for this study is indicated in Figure 4, a scheme based on the Standards of Practice to Guide Ecosystem Restoration (FAO, SER & IUCN CEM, 2023) with all the steps followed to achieve the results obtained and expressed in this document.

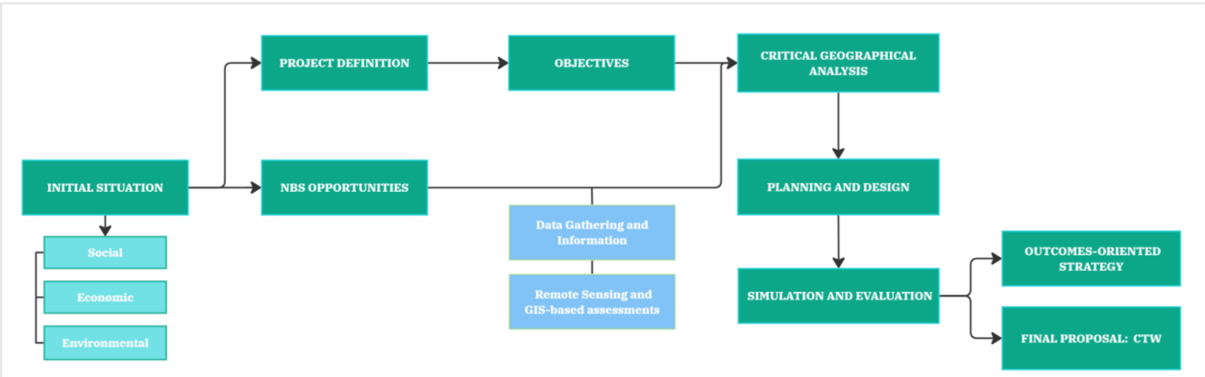

Figure 4. Scheme of general procedure methodology.
Personal Graphical Elaboration, 2024.

Subsequently, the various stages of this methodology are presented and elucidated.

<u>Project Definition and Objectives</u>

The preliminary phase of the project entails a quantitative analysis for the definition of the study's scope, objectives, and anticipated outcomes. To delineate this phase and the primary parameters of the project, it is essential to devise a series of queries to be addressed. These questions are outlined in Table 2.

Table 2. Matrix used to organise the information related to agroforestry in the study.

Dimension	**Themes**		
	Institutional Intervention	**Community participation**	**Impacts**
Social	What is happening on the land and in the community? Who will be involved in the implementation, maintenance, and succession, now and in the future?	Does the agroforestry is inclusive and help in the empowerment of the local community? What is the influence of the local community in the design of the agroforestry system?	What does this land look like in 50 years? Considering plants, animals, people, community

	Who will be doing the work? Who has the knowledge and skills?	
Environmental	What are the environmental characteristics used to define the site of the agroforestry systems?	What are the expected results of the agroforestry systems?
Economic	What strategies are going to be developed to create a market for the outcomes?	What are the impacts on the land, business, and community?

In this instance, the appropriate course of action would be to pursue urban agroforestry as an objective. Thus, a set of initial data was gathered and evaluated, as illustrated in Figure 5.

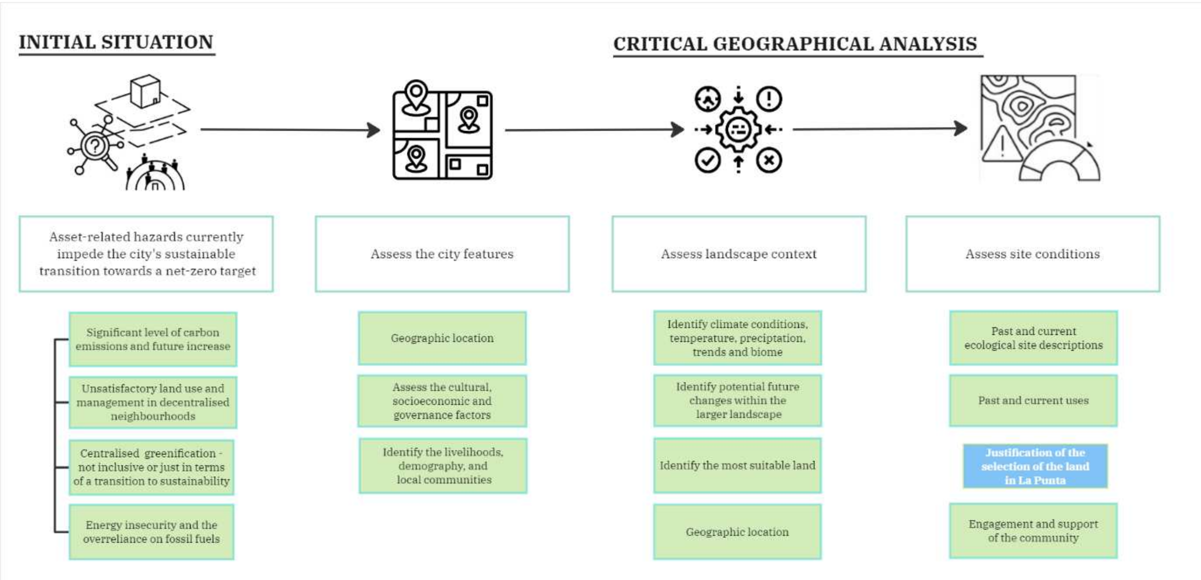

Figure 5. The phases of the study: Initial Situation and Critical Geographical Analysis.
Personal Graphical Elaboration, 2024.

Initial Situation

Based on this premise, a series of points are identified for consideration:

- A review of the potential hazards in Valencia, to gain a better understanding of the obstacles to achieving the net zero goal of the green city within the EU.
- An evaluation of the city's features, incorporating an analysis of the cultural, socioeconomic, and governance factors. Moreover, the identification of the livelihoods, demographics and local communities is crucial, as this will allow the best possible alignment with the project's objectives.
- Quantify and evaluate the related hazards associated with the selected zone to align with the potential solution. A detailed examination of the questions outlined in Table 2, accompanied by the creation of maps for enhanced geospatial analysis.

Once the requisite data and concepts have been explained—the process has required approximately one month of research—the subsequent step is to provide a comprehensive account of the requirements for the area in which the project will be implemented.

Critical Geographical Analysis

This phase of the study comprised the assessment of urban features through remote sensing and GIS-based assessments for analysis and the creation of geographical location, geospatial sensitivity, and green spaces using QGIS software. Furthermore, high-spatial resolution and temporal maps produced by GEP illustrated the changes in land use over time, which provided a comprehensive understanding of the landscape context and the site conditions under consideration. This, therefore, enabled the identification of suitable land based on the criteria.

In turn, Figure 6 provides an account of the subsequent stages.

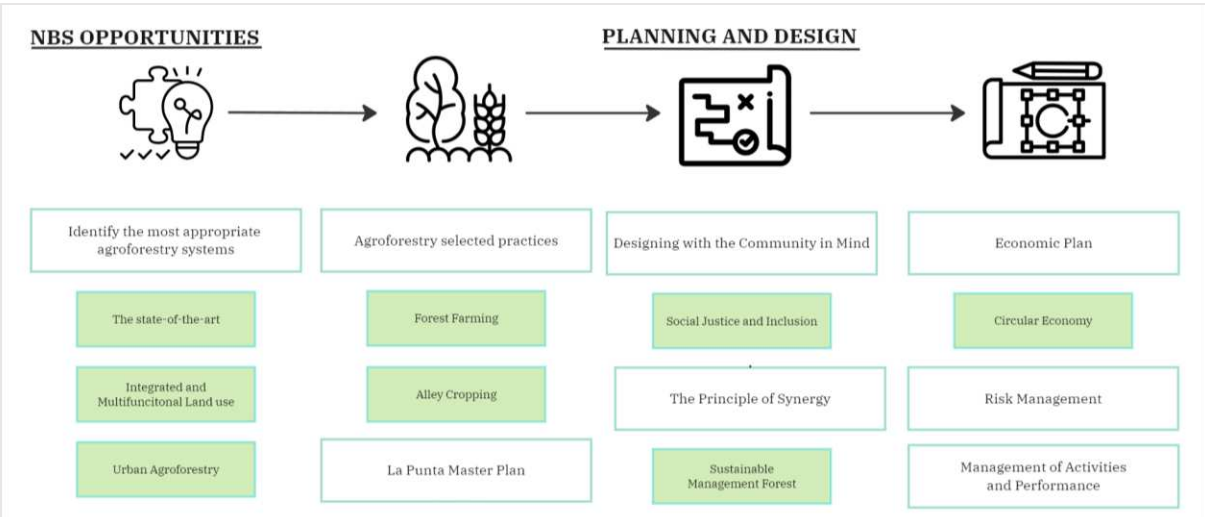

Figure 6. The phases of the study: NBS Opportunities and Planning and Design.
Personal Graphical Elaboration, 2024.

Nature-Based Solution Opportunities

Subsequently, the potential of NBS is explored, as it offers a range of benefits that extend beyond the general scope of the present study. To this end, a comprehensive examination of diverse agroforestry systems is undertaken, coupled with a critical assessment of the geographical context of the region. This enables the identification of the most optimal system for the land in question.

Planning and Design

Once the most optimal systems have been identified, which in this case are alley cropping and forest farming, the subsequent step is to plan and design an integrated and multifunctional land management strategy for an urban context.

Figure 7 provides a more detailed account of the information presented in Figure 4, offering greater insight into the various stages outlined previously.

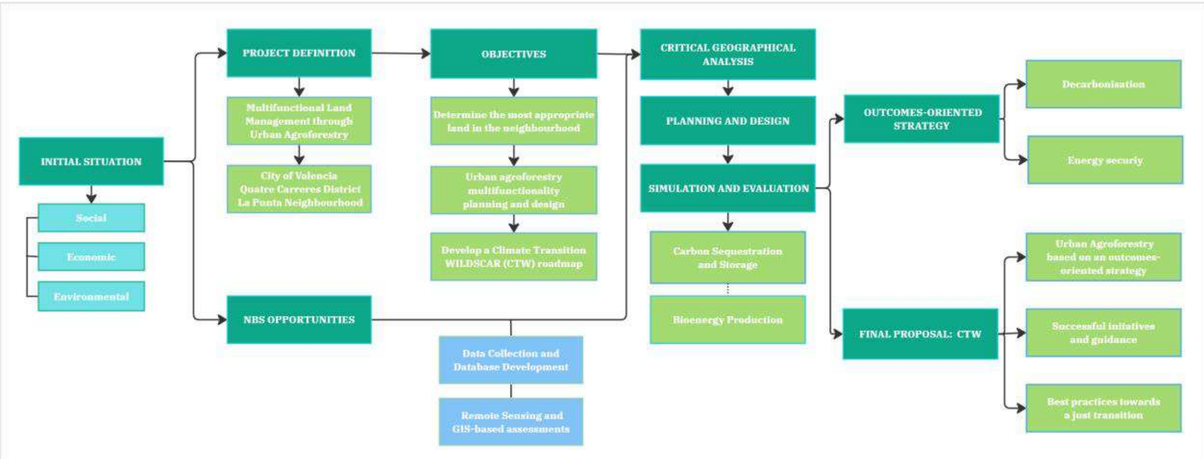

Figure 7. Detailed scheme of general procedure methodology.
Personal Graphical Elaboration, 2024.

Simulation and Evaluation

In consequence of the aforementioned information and maps having been duly established, a spreadsheet modelling exercise is conducted to input all the collected data. The output thus obtained is used to estimate the levels of carbon sequestration and storage and bioenergy production. Additionally, an evaluation of the proposed land use with which to achieve this purpose is conducted.

Final Proposal with CTW

A story map for the transition to a climate-friendly urban environment was devised. The aim is to provide guidance on the integration of NBS in urban areas, which can help conserve ecosystems and mitigate climate change.

4.2 Outcomes-oriented Strategy

At the 1st Forum Economic and Social of Mediterranean (2024), Mariana Mazzucato presented an outcomes-orientated strategy, which included policy design, institution/tool design, a new social contract, co-creation and participation, and dynamic capabilities. This study is focused on the latter two, specifically related to community engagement that must be incorporated into the process, as well as mission-oriented thinking, risk-taking, and experimentation.

Accordingly, the analytical approach described here focuses on the role of carbon, its circular cycle, and associated factors, as circularity is a fundamental prerequisite for achieving climate neutrality (European Commission, 2020). To this end, Figure 8 presents a general overview of the carbon cycle with the implementation of forestation.

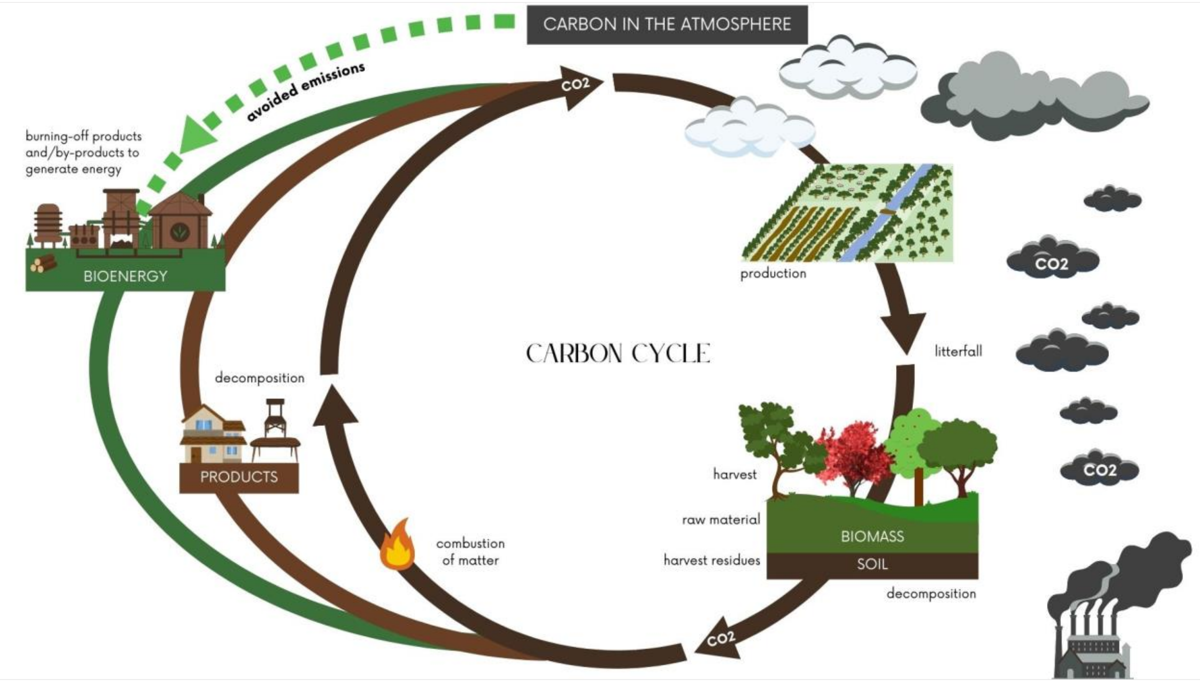

Figure 8. Carbon cycle and agroforestry.
Personal Graphical Elaboration, 2024. Inspired by the webinar presented by Peter Woodbury and Jenifer Wightman, entitled "Using Former Agricultural Land to Help Meet Climate Goals," 2023.

As demonstrated in Figure 8, the process commencing with the conversion of land to forest is followed by the generation of biomass and the impact on the soil. Upon tracing the arrows in the figure, it can be observed the matter that undergoes a process of combustion, through the increasing frequency of extreme events such as forest fires, resulting in the release of carbon into the atmosphere. This is illustrated by the dark-brown arrow. Although the harvest of timber can be used and reused to create wood products (light-brown arrow), this also represents an alternative to materials that emit elevated levels of carbon. Furthermore, the green arrow illustrates the potential for bioenergy derived from wood biomass to replace fossil fuel energies, thereby reducing emissions into the atmosphere.

Considering the explanations, an Excel simulation was developed to gain a deeper understanding of the carbon stock potential in the selected land. This qualitative analysis aims to ascertain the viability of two research project objectives: firstly, the sequestration of carbon and its storage in pursuit of decarbonisation; and secondly, the production of bioenergy to enhance energy security.

Carbon Sequestration and Storage

The carbon sequestration and storage simulations presented in this study are based on three distinct methods (Annexes A, B, and C). The application of these methods necessitates the input of specific data, as outlined below: the biome, stratum, species, area, and standing volume of the forest in question.

(1) Biome and Stratum:

In consideration of the case study's geographical location in Spain, the pertinent biome is classified as temperate. Furthermore, the stratum agroforestry systems selected are forest farming and alley cropping, with a detailed rationale provided in Chapter 5.

(2) Species:

The species were selected following the principle of diversity of trees proposed by Martin Crawford (2010), one of the pioneers of forest gardening. The principle is a specific type of agroforestry that attempts to emulate natural ecosystems and sustainably utilise the available space. It is therefore recommended that forest gardens be created which integrate fruit and nut trees, shrubs and perennial vegetables.

Under the principle, the six species illustrated in Figure 9 were selected for inclusion in the study. The following details are included in the information provided:

- Species name.
- Photograph of its appearance.
- Number of trees per hectare at the start and end of the rotation cycle.
- Expected results based on the outcomes-oriented strategy proposed.

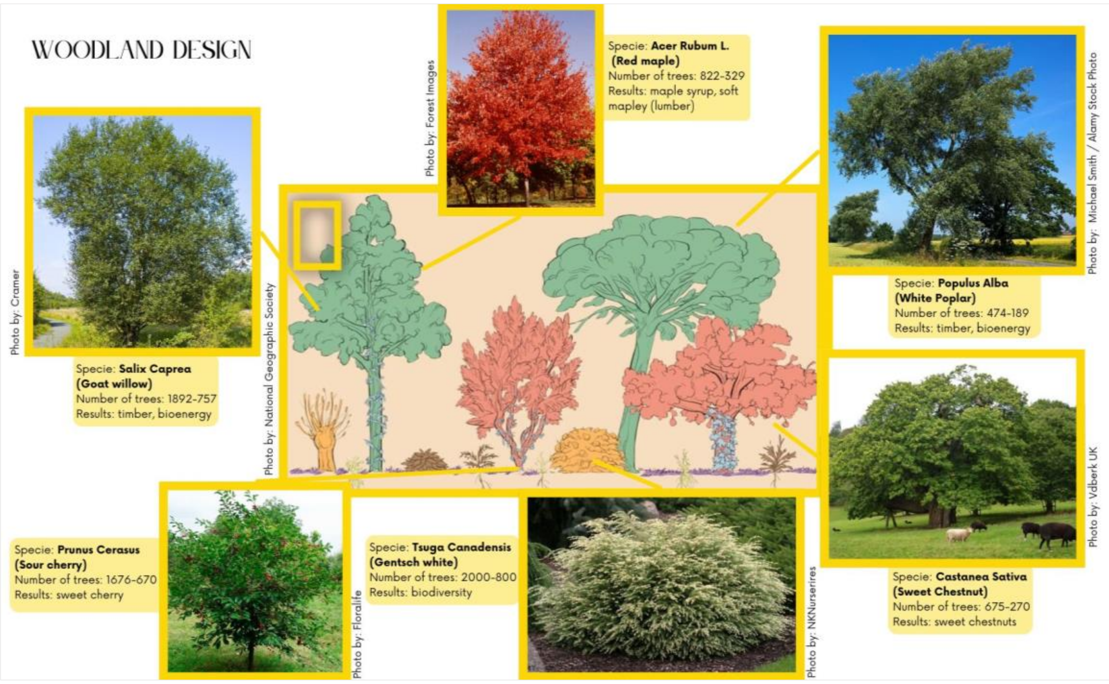

Figure 9. Woodland design.
Personal Graphical Elaboration, 2024.

Furthermore, additional information is provided in Table 3, which outlines the wood density, carbon fraction, and biomass expansion factor (BEF) for each species.

Table 3. Species details, including woody density, carbon fraction and BEF.

Specie	Wood density (t d.m. /m-3)	Carbon fraction (Default value)	BEF
Acer Rubum L.	0,52	0,47	1,4
Castanea Sativa	0,48	0,47	1,4
Populus Alba	0,35	0,47	1,4
Prunus Cerasus	0,49	0,47	1,4
Salix Caprea	0,45	0,47	1,4
Tsuga Canadensis	0,42	0,47	1,3

Source: IPCC Table 3A.1.9-1 and Table 3A.1.10.

(3) Timeline, Area, and Standing Volume by Species

The proposed project initiation is scheduled for 2025, with initial anticipated results projected to be achieved by 2030. These results indicate that the projected timeline is consistent with the city's net zero targets by 2050. Therefore, the most optimal outcomes are estimated to be achieved by 2055 and beyond.

Moreover, it is imperative to establish the diameter at breast height and the respective height for each species to calculate the standing volume. Table 4 presents a comprehensive overview of the delineation of the area allocated to each species within each system, accompanied by a detailed account of the standing volume by species at the end of the rotation length.

Table 4. Overview of the area and standing volume in 30 years.

Specie	Forest Farming		Alley Cropping	
	Area (ha)	Standing Volume (m3/ha)	Area (ha)	Standing Volume (m3/ha)
Acer Rubum L.	3	3.353,8		
Castanea Sativa	3	11.451,1	3	11.451,1
Populus Alba	3	5.937,6		
Prunus Cerasus	3	1.841,8	1,95	1.226,0
Salix Caprea	2,24	5.096,9		
Tsuga Canadensis	2	169,6		
Total	16,24	27.850,8	4,95	12.677,1

Source: Adapted from FSC Carbon Monitoring Tool, 2024.

As previously stated, agroforestry is based on the diversity of species and the diversification of the land. Consequently, the forest farming system may employ six distinct species, whereas the alley cropping system uses two species.

In the context of alley cropping, the strategy entails the integration of tree species between plantation crops that bear fruits or nuts. Consequently, nut (Castanea sativa) and cherry (Prunus cerasus) trees have been selected, thus also enhancing food security for the surrounding community.

A graphical representation of the data is provided in Figure 10, which is calculated based on the standing volume (m^3/ha over 30 years) and the area (ha) attributed to each species.

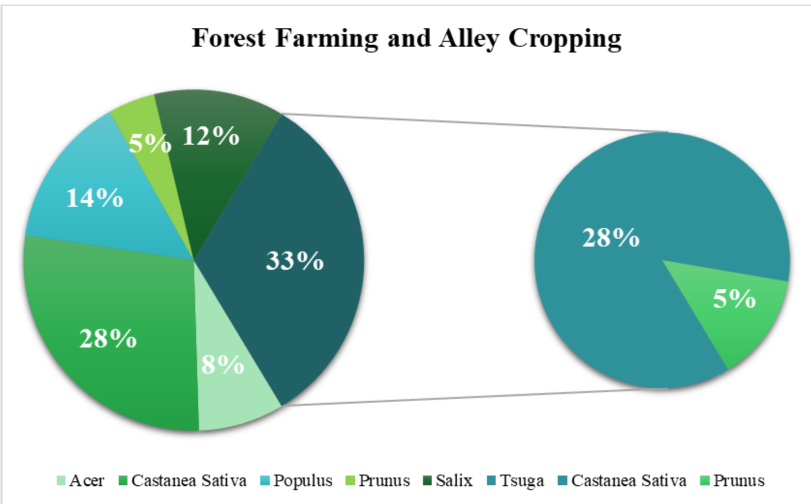

Figure 10. Land use for forest farming and alley cropping.
Personal Graphical Elaboration, 2024.

Accordingly, the overarching urban agroforestry system is constituted by 69% forest farming and 31% alley cropping. Most of the planted areas are comprised of Castanea Sativa, Populus, and Salix species.

Bioenergy Production

The bioenergy production model is based on the IRENA Bio-Simulator (2024). It incorporates the specified forest characterisation data and the selected technology, as detailed in Table 5.

Table 5. Forest and Technology used in bioenergy production.

Forest							
Biomass supply			Forest plantations				
Scenarios per specie			5				
Biomass produced			Solid biomass				
Species	Area (ha)		MAI (m3/ha/year)	Rotation Length			Moisture content (%)
Populus	1	2	30	4 (default)	15	30	15
Salix	1	2	25	4 (default)	15	30	15
Technology							
Bioenergy end-use			Heat and Power				
Bioenergy conversion technology			Combustion CHP - steam turbine				
The overall energy efficiency of the selected technology (default)							
Overall electrical efficiency			0,2	Overall thermal efficiency			0,5

Source: Adapted from IRENA Bio-Simulator, 2024.

Table 5 provides a summary of the selections made within the simulator. For the parameters associated with the forest information, the following variables have been assigned the default value: MAI, moisture content and rotation length. Nevertheless, concerning the latter (rotation length), two further rotation lengths have been incorporated to ensure concordance with the research methodology and the CSS projections.

Populus and Salix species were selected for this study due to their rapid growth, suitability for bioenergy production, and established use in this capacity. Accordingly, the five scenarios developed for each species are delineated below:

- Scenario 1: The area in question is 1 hectare, with a 4-year rotation length.
- Scenario 2: The plot size is 2 hectares, with a 4-year rotation period.
- Scenario 3: The area is once again 1 hectare, but the rotation length is 15 years.

- Scenario 4: The same 1-hectare area as in the first scenario, with the rotation length extended to 30 years.
- Scenario 5: A 2-hectare plot is employed, with an extended 30-year rotation length.

Furthermore, heat and electricity are the selected bioenergy end-use in terms of the technology used. This is because the primary objective of this study is to ensure the energy security of the neighbouring community and to provide potential economic growth. The selected conversion technology is steaming turbine combustion. The overall energy efficiency values are set by default. Further information on the forest and associated technologies can be found in Annex D.

5. DELIMITATIONS, LIMITATIONS & ASSUMPTIONS

The initial limitation identified pertains to the knowledge base surrounding agroforestry systems. These systems exhibit a high degree of complexity, with numerous potential configurations and a multitude of influencing factors. Moreover, during the practical implementation of such systems, a variety of characteristics tend to emerge. To illustrate, the diameter at the breast height of each species is variable in centimetres and depends on several aspects, including the biome, the soil, the surrounding land, whether other trees are competing for resources, and so on.

Yet about agroforestry systems, a considerable number of species can be planted to increase the anticipated outcomes. However, due to the limitations of time and a lack of in-depth awareness about trees, the decision was made to select six species that have been investigated and deemed to be the most appropriate. Nevertheless, the potential to plant a greater number of species is a valuable avenue for further exploration, as it could contribute to greater diversity within the landscape.

Furthermore, another limitation of this solution is that it is intended to be introduced into urban environments, which makes it dependent on the surrounding area and its context. It is therefore assumed that local communities have expectations regarding the potential for regeneration in their neighbourhood, and these expectations must be considered by those who make decisions affecting these communities. These assumptions regard the desire of local people to be included in the plans for a greener city, and the need for justice about the previous exploitation and displacement. In addition, another assumption concerns the creation of solutions that must be based on the reality of the climate crisis and the deployment of strategies to mitigate its effects.

A further limitation identified in the preceding research for the construction of geospatial maps may be the tendentious nature of the data sources. Thus, this has resulted in discrepancies between the presented data and the real-world circumstances. To address this limitation, a comprehensive investigation was conducted, incorporating a variety of local news sources, websites, and journals about Valencia City, as well as a fieldwork activity in the area itself. This approach facilitated the generation of a more accurate and realistic representation of the scenario. Consequently, the selection of data for the geospatial analysis was made with consideration of these factors, to maintain consistency with the actual situation.

Moreover, further delimitation concerns pertain to the methods employed to quantify carbon sequestration and storage. To this end, three distinct methods were selected for simulations. However, it should be noted that this research has not examined each method in depth, with particular attention to its development processes, algorithms, and data sources. Consequently, there is a significant possibility that, despite the utilisation of identical data in the methods, disparate results be obtained. A similar phenomenon occurs with financial estimation, which is predicated on professional expertise but lacks a comprehensive examination of the underlying assumptions.

Ultimately, it can be reasonably assumed that the inherent restrictions of bioenergy production can be attributed to the sector's initial reliance on the industrial domain. Consequently, it is of great importance to align the land-based community with the relevant industries to facilitate collaborative working and to enable the achievement of outcomes that are mutually beneficial for all parties involved, including the city and the local community.

6. CASE STUDY

6.1. Critical Geographical Analysis: A remote sensing and GIS-based assessment of the study area

Assess the city features

The city of Valencia (Valencian: *València*) is the capital of the Valencian Community and the third most populous municipality in Spain, with a population of 814,208 (World Population Review, 2024). The wider metropolitan area, which includes neighbouring municipalities, has a population of 1,547 million and an urban population density of 3,930 hab/km², making it one of the largest urban areas on the European side of the Mediterranean and 345th in the world (Demographia World Urban Areas, 2023). Figure 11 represents the geographical location of Valencia.

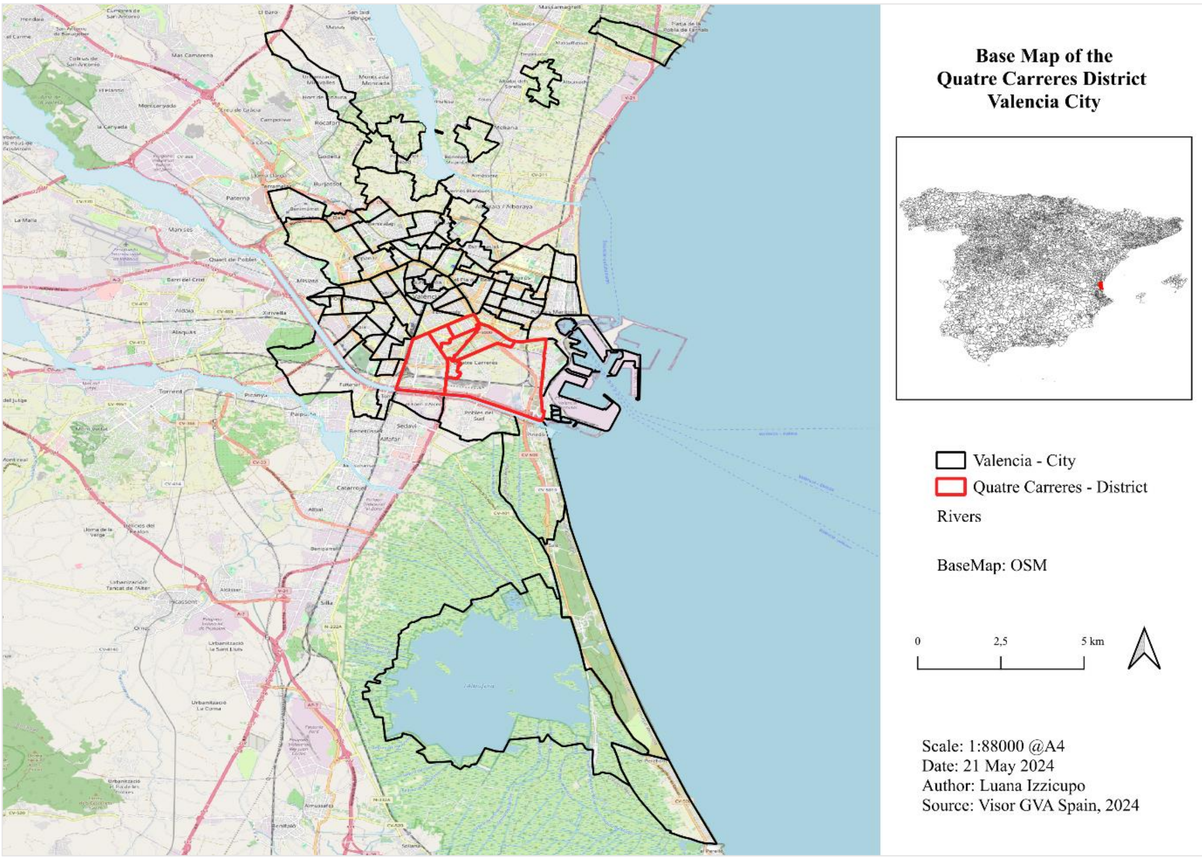

Figure 11. Geographical location of the city of Valencia and district the *Quatre Carreres* District. Elaborated from QGIS.

Spain encompasses a diverse range of forest ecosystems. In general, the most prevalent type of forest found in Spain is the temperate forest (Nunes, 2023), which characterises the Valencia biome. The city is situated on the eastern coast of the Iberian Peninsula, within the

Mediterranean coastal plain (Gonzaléz, 2002), with an area of 13,465 km² (*Ajutament de València*, 2024). Moreover, there has been a discernible upward trend in temperature in this urban area over the past few decades, which may be attributed to the phenomenon of climate change (Meteoblue, 2024), as evidenced by Figure 12.

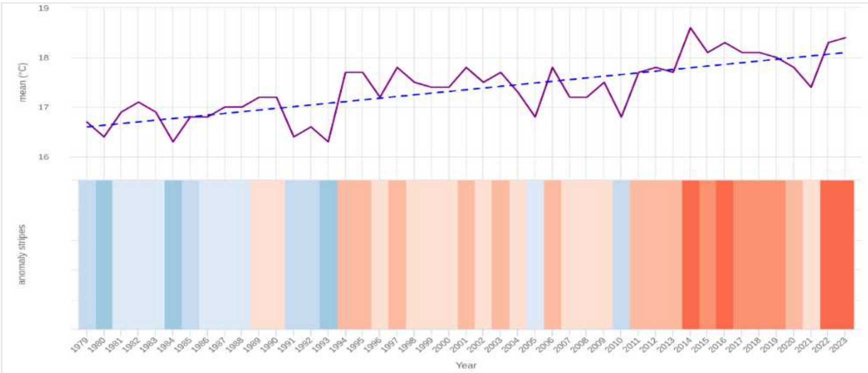

Figure 12. Valencia's mean yearly temperature, trend and anomaly, 1979-2023.
Source: Meteoblue, 2024.

The upward trend provides evidence of the projected rise in Valencia's mean temperature. The data set shows the yearly mean temperature, trend and anomaly over the period 1979-2023. Consequently, it may be extrapolated that future predictions will follow this pattern.

Furthermore, in a recent report published in the Spanish newspaper *Levante EMV*, Rafel Montaner (2023) stated that the lack of significant rainfall in Valencia over the past few days has resulted in the city experiencing the driest November in the last century and one of the driest Novembers on record since at least 1950. Figure 13 depicts the annual precipitation and temperature patterns in the city of Valencia.

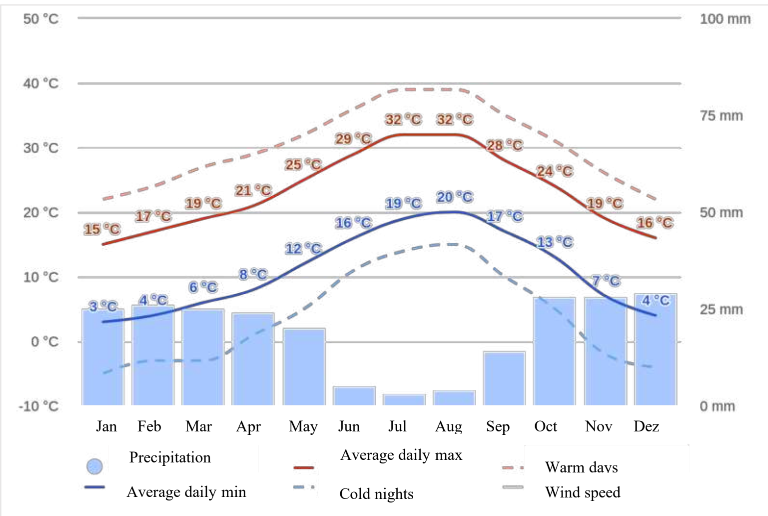

Figure 13. Precipitation and average daily min and max temperatures for Valencia in 2023.
Source: Adapted from Meteoblue, 2024.

The data presented in the graph demonstrates a low precipitation rate throughout the year, with a notable decline in rainfall during the summer months when temperatures are the highest. Moreover, the AEMET, a Spanish meteorological agency, has reported that the Valencia region has been experiencing "extremely dry" conditions over a prolonged period, resulting in the area being one of the least humid locations in the country over the past seven decades (*Levante EMV*, 2023).

Assess Landscape Context

The district of this study, designated *Quatre Carreres* (Four Roads), is, as indicated by its name, derived from the four principal routes traversing the city from the central district of Ruzafa to the other districts. The region historically had a predominantly rural character with a limited population density. Indeed, the district was sparsely populated by farmhouses and cottages until the nineteenth century (Valencia Actúa, 2016).

Quatre Carreres is the 10th district of the city of Valencia, with a population of 76,572, a noteworthy area of 1,132 km², and a population density of 67.6 hab/km². Most of the population is male with an average age of 44 years and a comparison of the years 2022 and 2023 reveals a negative vegetative growth. The industrial sector accounts for 54.9% of industrial products, with the mechanical industry representing 37.4% (*Ajuntament de València*, 2024).

The district is comprised of seven distinct neighbourhoods: *Mont Olivet* (10.1), *En Corts* (10.2), *Malilla* (10.3), *Fuente San Luís* (10.4), *Na Rovella* (10.5), *La Punta* (10.6), *Ciutat de les Arts y les Ciències* (10.7), as delineated in Figure 14.

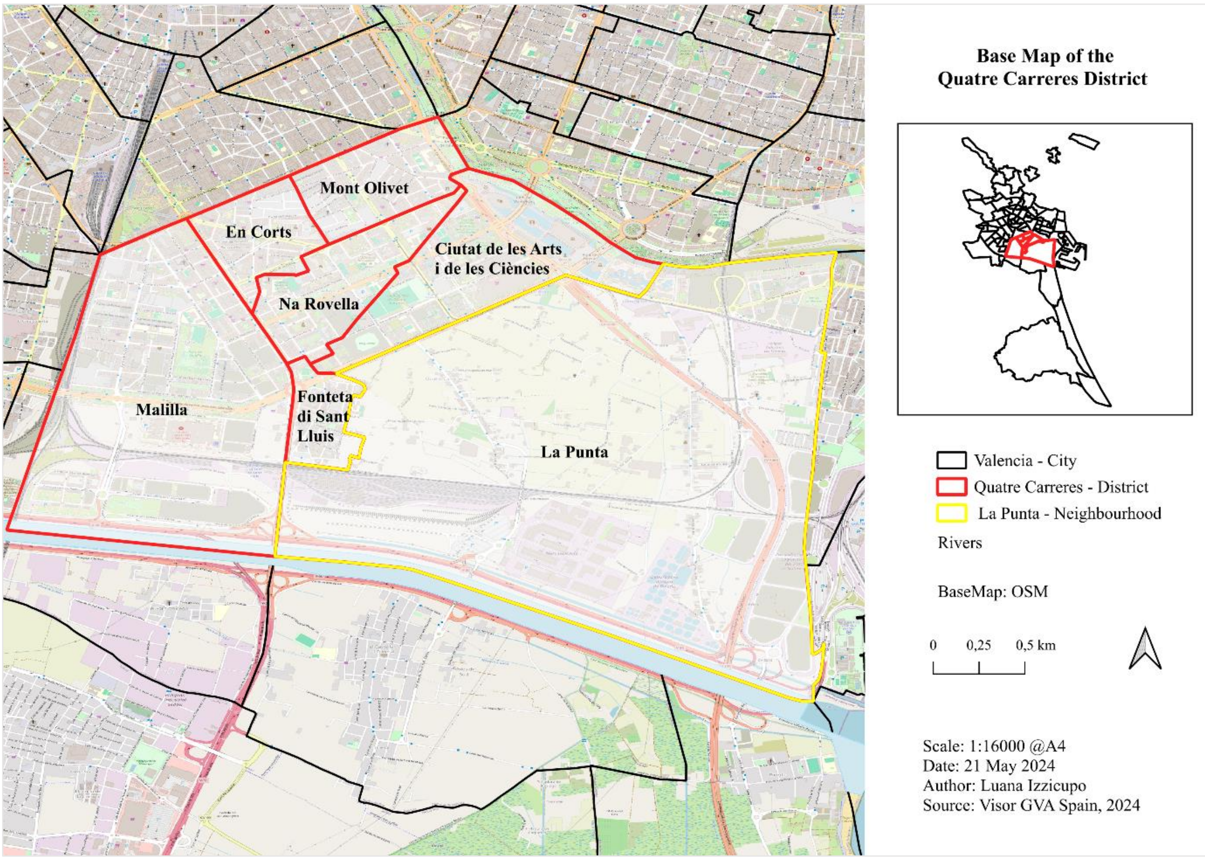

Figure 14. Geographical location of the district of *Quatre Carreres* and *La Punta* neighbourhood. Elaborated from QGIS.

A comparative analysis of the map, data, and conditions of the neighbourhoods, conducted through fieldwork visits, has revealed a significant disparity between the neighbourhoods within the district.

For instance, the *Ciutat de les Arts i les Ciènces* (CAC) has undergone a substantial modernisation, entirely funded by the *Generalitat Valenciana*. The CAC complex has since become a globally renowned venue, representing the commitment to cultural tourism and the dynamism with which the Valencian Community presents itself to the world (CAC, 2024). In contrast, *La Punta*, situated to the south of the city and the neighbouring CAC as indicated by the yellow lines on the map, has retained its traditional agricultural landscape despite the introduction of modern infrastructure, particularly in the period following the second half of the 20th century (*Levante EMV*, 2021). This phenomenon can be observed in Figure 15.

Figure 15. *La Punta* and *Ciutat de les Arts i les Ciències* neighbourhoods.
Fieldwork activities, *La Punta*, 13th June 2024.

It is evident from Figure 15 that *La Punta* continues to represent one of the area's most significant agricultural regions, designated *Huerta de La Punta*. In addition to its productivity, the area exhibits notable environmental sensitivity. Over centuries, the development of this ecosystem has occurred concurrently with the urbanisation of the city of Valencia. However, various construction projects have harmed this area (*El Salto Diario*, 2019). Figure 16 illustrates the conditions in the *La Punta* neighbourhood.

Figure 16. Conditions of *La Punta* neighbourhood.
Fieldwork activities, *La Punta*, 13th June 2024.

As evidenced in Figure 16, a site visit revealed the presence of buildings and land that had been subjected to prolonged abandonment and degradation. Despite the considerable depreciatory effects of urban expansion over the past 60 years, the community has exhibited resilience and is reluctant to allow "progress and development" to encroach upon it (*El Salto Diario*, 2019).

The historical and cultural heritage of the neighbourhood is predominantly agrarian and oriented towards maintaining the existing landscape (*El Salto Diario*, 2019). The local community wishes to advance the region's development by implementing a novel territorial model and initiatives aimed at restoring and preserving *Huerta* de Valencia's agricultural, environmental, cultural, and historical significance (*Per L'Horta*, 2015).

La Punta has a land area of 621.3 km², a total population is 3,015 inhabitants, with an average population density of 4.9 inhabitants per km². The population is approximately evenly divided between men and women, and most of the population falls within the 35-44 age range (559 inhabitants), with the lowest number of inhabitants in the 20-24 age group (98 inhabitants). It is noteworthy that the interurban immigration rate is 81.6% (*Ajuntament de València*, 2023).

Additionally, *La Punta* occupies a pivotal position, serving as a nexus between the Turia River's former channel, *L'Albufera* Park, and the southern *Huerta* region surrounding Valencia City. Another noteworthy aspect is the city of Valencia's strategic location between *Capçalera* Park and the Natural Park of *L'Albufera*. Figure 17 represents the map of green spaces in the Valencian Community.

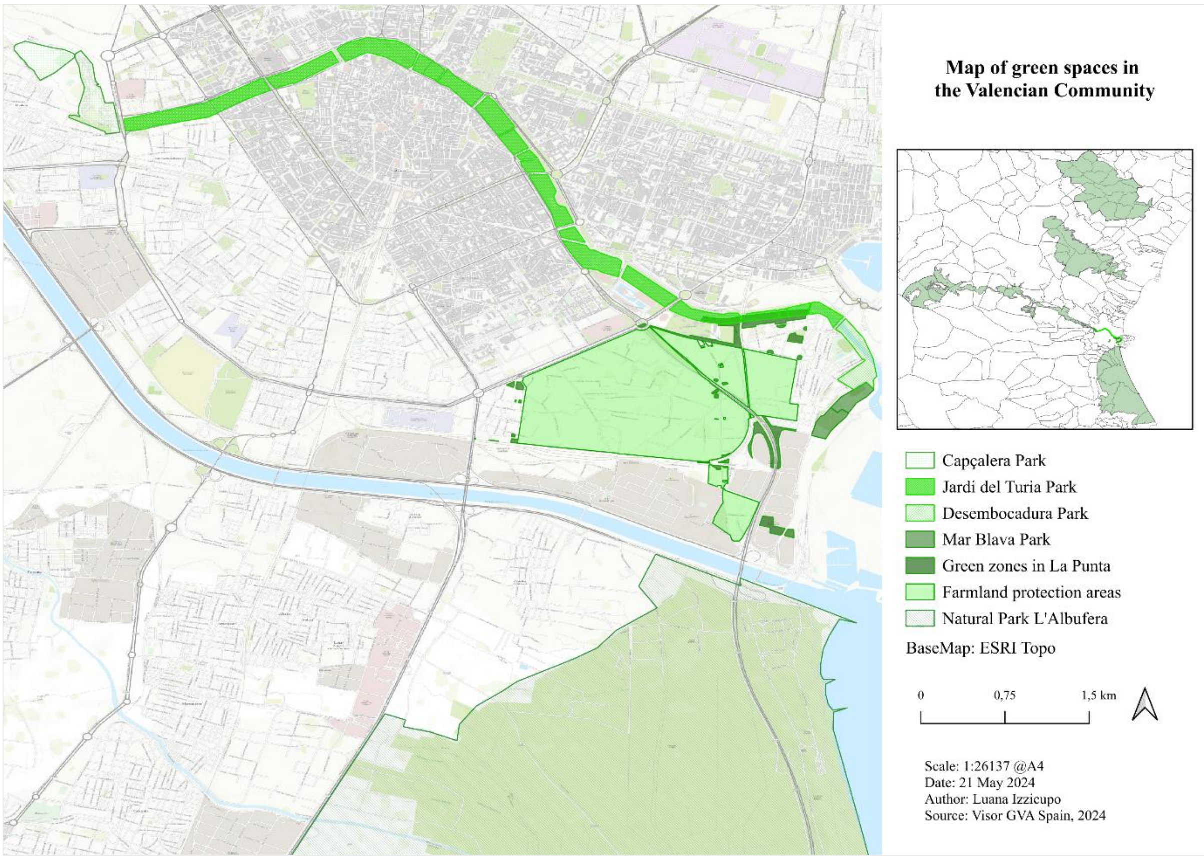

Figure 17. Map of green spaces in the Valencian Community.
Elaborated from QGIS.

Figure 17 provides a visual representation of an expansive green infrastructure. Of particular interest is the *Jardin de Turia* public garden, which traverses the city and nearly fully interconnects the two natural parks. This integration offers a promising foundation for the potential construction of a future green ring.

Nevertheless, a critical evaluation of the green spaces map concerning the farmland protection zone in this neighbourhood demonstrates a notable discrepancy between the designated protection area (depicted in light green on the map) and its actual condition. This leads to the reasonable conclusion that the result is widespread land abandonment, partial loss of landscape heritage, displacement of local communities and agricultural livelihoods.

A more detailed analysis of this discrepancy can be observed in Figure 18 through an examination of the spatial change map of the neighbourhood, with data comparison from 2001 and 2024.

Figure 18. Spatial changes in the *La Punta* neighbourhood between the years 2001 and 2024.
Elaborated from GEP.

Figure 18 demonstrates the considerable extent of destruction and subsequent abandonment of the *Huerta de la Punta* neighbourhood over recent decades, as evidenced by remote sensing images. It is noteworthy that construction of the ZAL also commenced approximately 20 years ago, in 2003.

Therefore, the destruction of irreplaceable cultural and historical sites has had a significant impact on the livelihoods of local communities and the very existence of entire families, due to the lack of consideration and violent behaviour displayed by those involved (*Per L'Horta*, 2015). Figure 19 provides a visual representation of the contrast between the rural surrounding area and the construction of the ZAL.

Figure 19. *La Punta* with the ZAL situated in the background and "ZAL Illegal" on the wall of ZAL itself.
Fieldwork activities, *La Punta*, 13th June 2024.

As can be seen in Figure 19 from *La Punta*, it is possible to discern the presence of ZAL in the background of the first image and an inscription indicating its illegality in the second image.

The latter is located on the wall of ZAL itself and represents a form of protest against its expansion.

The proposed expansion would represent a significant increase in large-scale industrial complexes, which are specialised in the receipt, storage, preparation, shipment, and distribution of a diverse range of goods (*Levante EMV*, 2017). Consequently, this would result in an elevated risk of environmental degradation, encompassing pollution and emissions, which may further marginalise local communities and intensify climate-related events in the region. Moreover, this expansion is inconsistent with the vision of a net zero city, which represents a stated objective.

In consideration of the aforementioned factors, this study proposes a potential alternative that deviates from the prevailing approach to addressing the climate crisis. The proposal is to establish urban agroforestry in the selected land, specifically covering a 36.77-hectare plot situated between the ZAL port and *La Punta*. The objective is to establish a system of protected and interconnected landscapes, as elaborated in Figure 20, which comprise a green corridor within the city.

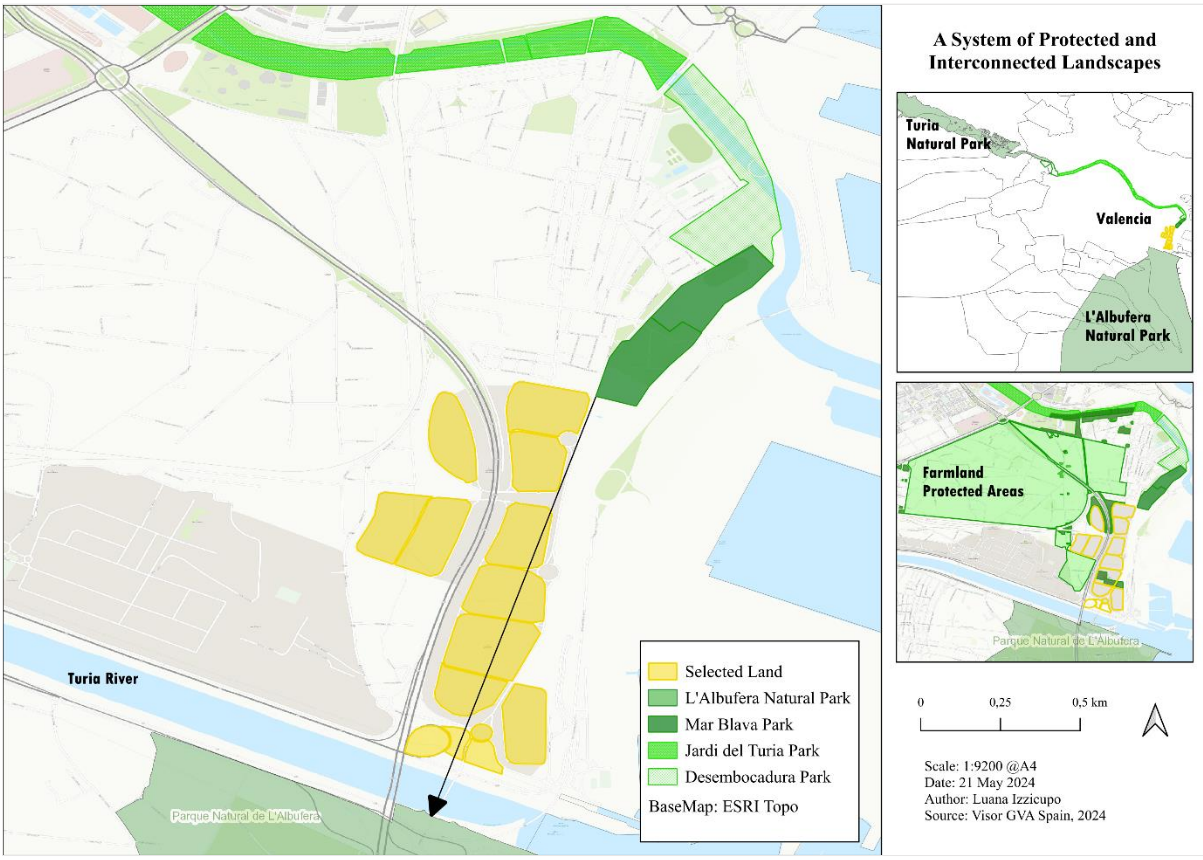

Figure 20. System of protected and interconnected landscapes with the selected land.
Elaborated from QGIS. Geographical coordinates: 39.436563, -0.336926.

The GIS-mapped corridor, as illustrated in Figure 20, will connect existing natural parks in a manner that respects and incorporates the local rural communities. Additionally, the implementation of NBS in this land has the potential to facilitate citywide decarbonisation and local energy security, due to the considerable impact that forestation could have on carbon sequestration and bioenergy production. Furthermore, the proposed initiative is consistent with the city's designation as a Green City and the community's aspirations for the *La Punta* area.

Assess Site Conditions

A comprehensive assessment of the suitability of the selected land is contingent upon an analysis of the site's conditions, which encompass not only the previous and current uses, as indicated by the sensitivity map of the zone (Figure 22) but also an evaluation of the past and present ecological descriptions. Figure 21 presents a high spatial resolution of the ZAL and *La Punta* areas, accompanied by a temporal analysis of land use.

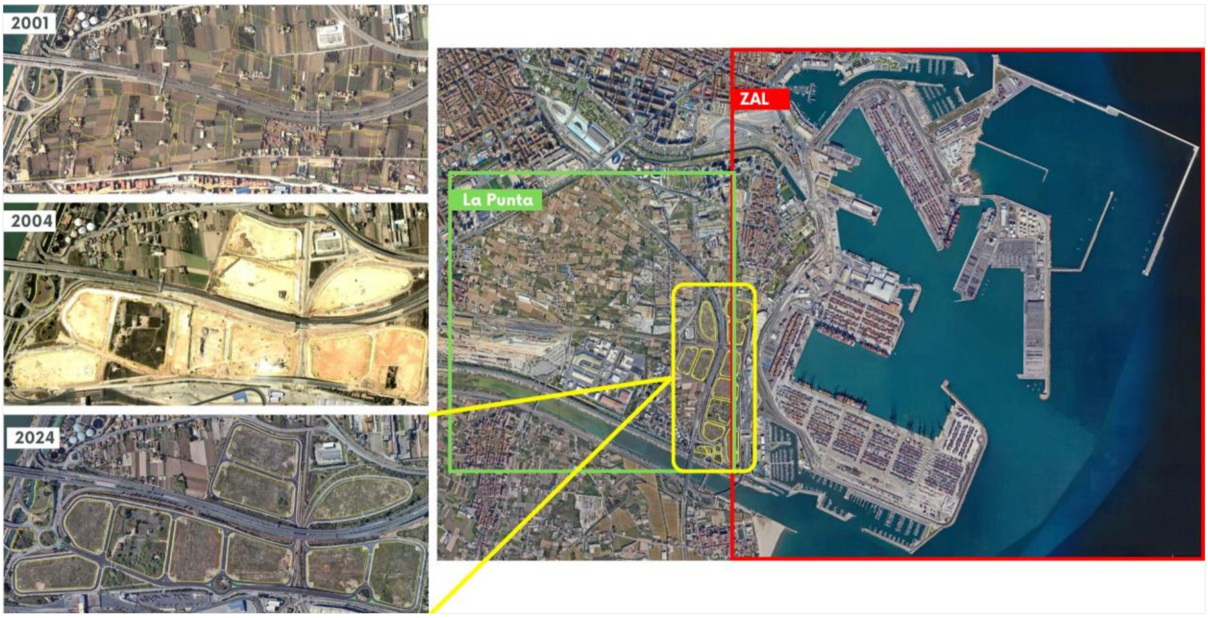

Figure 21. High-spatial resolution and temporal analysis of changes in land use.
Elaborated from GEP.

The selected land exhibits a notable phenomenon of change, as illustrated in Figure 21. The land in question, situated between La Punta and ZAL port, has been observed to have experienced temporal soil depletion and to have undergone significant destruction over time. In comparison, the initial map of 2001 depicts the land as being utilised for agricultural purposes, with crops visible. However, by 2004 the land had been completely degraded and destroyed, and in 2024 it remained in a state of abandonment.

Figure 22 presents a geospatial sensitivity map delineating the distribution of various types of land use within the specified study area. The map was constructed using a database procured from the Cartographic Institute of Valencia in the Visor Cartographic database (2024), which is a government open-source database.

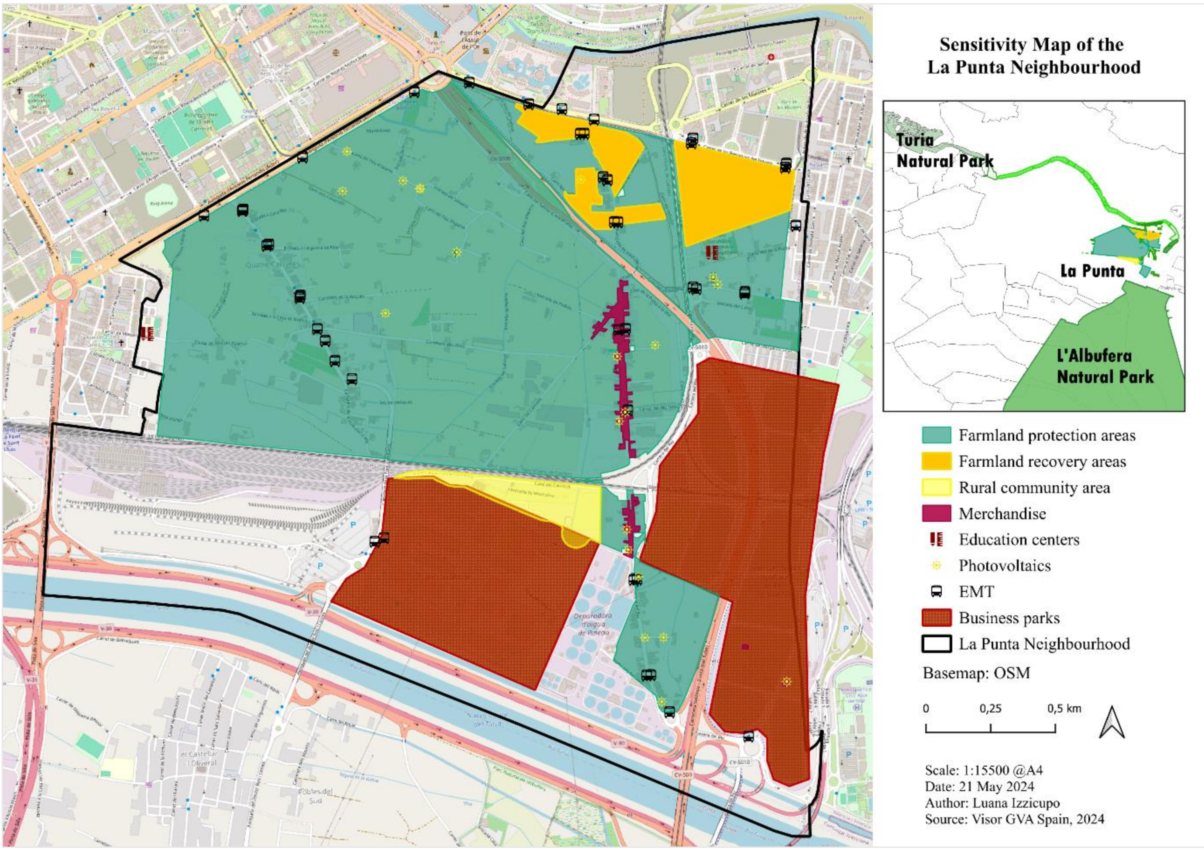

Figure 22. Geospatial sensitivity map of the *La Punta* neighbourhood.
Elaborated from QGIS.

The selected land has been categorised as a business park (illustrated on the map by a red delineation) by the definitions provided in the database. As can be seen in the figure, the area under consideration is starkly distinct from its surrounding territory, which is predominantly defined by rural community zones, farmland conservation areas, and recovery zones, indicated in yellow, gold, and teal, respectively.

Furthermore, the map demonstrates the inadequate public transportation infrastructure in the area, as evidenced by the presence of EMT buses. The only available bus route, designated fifteen, operates at intervals of approximately 90 minutes, which has resulted in the absence of public facilities in the neighbourhood and its isolation from the city, situated as it is 15 minutes away. This is incongruent with the urban context of Valencia, particularly considering its proximity to the CAC (Valencia News, 2021).

Additionally, the area designated for merchandise, indicated in magenta, exhibits a concentration along only a single street. This scarcity of merchandise in the neighbourhood serves to reinforce the perception that the area has been overlooked and forgotten (Valencia

News, 2021). Conversely to the past, as *El Salto Diario* (2019) notes, the zone has traditionally been characterised by a strong village consciousness, with local small landowners cultivating their produce and selling it in urban markets.

The changes commenced on 1 July 2002 with the deployment of construction machinery in the orchard fields of *La Punta*, resulting in the demolition of houses, farmhouses, plots of land and centuries-old huts (*Levante EMV*, 2013). The removal of these communities and their way of life represents a profound loss in urban settings (*La Vanguardia*, 2021). Figure 23 provides further details regarding this chronology, including accounts of the adverse circumstances that ensued.

Figure 23. Spatial-temporal analysis of the land in the years preceding the ZAL project (2001–2003). Source: Adapted from Natzaretpedia, 2024. Elaborated from GEP.

A historical context of the site, as illustrated in Figure 23, reveals that, prior construction of the ZAL, the local community was not adequately considered in decisions affecting them, as evidenced by the news items from the period in the journal. This is corroborated by the expropriation of 68.3 ha of land, which had a considerable adverse impact on hundreds of individuals and resulted in the destruction of numerous family businesses (*La Vanguardia*, 2021).

Moreover, the data analysed has indicated a decline in the comparison between the pre-and post-port expansion periods. The number of inhabitants increased from 1991 to 1996, reaching a maximum of 8,579 in 2001. Nevertheless, the population declined to its lowest point of 2,306 inhabitants between 2001 and 2013. It is notable that in subsequent years, there was a slight increase in the population, yet the average remained between 2,300 and 3,000 inhabitants (*Ajuntament de València*, 2023).

Consequently, the implementation of the ZAL project has led to the devastation of a territory, as evidenced in Figure 24, that previously displayed characteristics of fertile soil and a diverse range of crops, neighbouring settlements, and a traditional way of life (*El Salto Diario*, 2019).

Figure 24. Spatial-temporal overview of the land between the years 2004, 2012, and 2024.
Photo credit: *Levante EMV* – Jose Alexandre, 2013 (image from 2004), *Las Provincias* – Irene Marsillla, 2022 (image from 2012), and Fieldwork activities (image from 13th June 2024). Elaborated from GEP.

Figure 24 provides an illustrative overview of the spatial and temporal changes observed in the ecological conditions of the site. The figure commences with a substantial alteration following the inception of the ZAL project in 2004, a notable divergence between the present and historical ecological circumstances at the subject site. The site characteristics include aridity, absence of ridges, low productivity, and biodiversity. This decline can thus be attributed to a deficit of intervention, coupled with the effects of prolonged environmental degradation over a period exceeding two decades.

6.2. Justification of the Selection of the Land in *La Punta*

The choice of an appropriate land was based on a thorough assessment of urban, environmental, economic, and social considerations. In making the decision, priority was given to the availability of unoccupied land for an extended period, in addition to its current state of deterioration. Furthermore, the location within the city and its proximity to a rural peri-urban community were also taken into consideration in the decision-making process. The objective was to achieve environmental and social justice by incorporating the interests of the local community and facilitating their involvement in the NBS.

The land in question has been in a state of total neglect for the past 22 years since it received approval for construction as a ZAL. Similarly, *La Vanguardia* (2021) observed parallels between the circumstances of the current situation and those that preceded the approval for the project's expansion, noting the inconsistency in the perceived urgency of the project as an imminent and indispensable necessity but its continued postponement for over two decades.

The maps produced over the following periods demonstrate the significant degradation that has occurred in the landscape over time: 2001, 2004, 2010, 2016, 2020, and 2024, as can be observed in Figure 25.

Figure 25. High-spatial resolution of the landscape over time: 2001, 2004, 2010, 2016, 2020, and 2024. Elaborated from GEP.

It is, consequently, of great importance to connect both the landscape context and the prevailing site conditions which preceded and occurred concurrently with the expansion of the ZAL project (Figure 26).

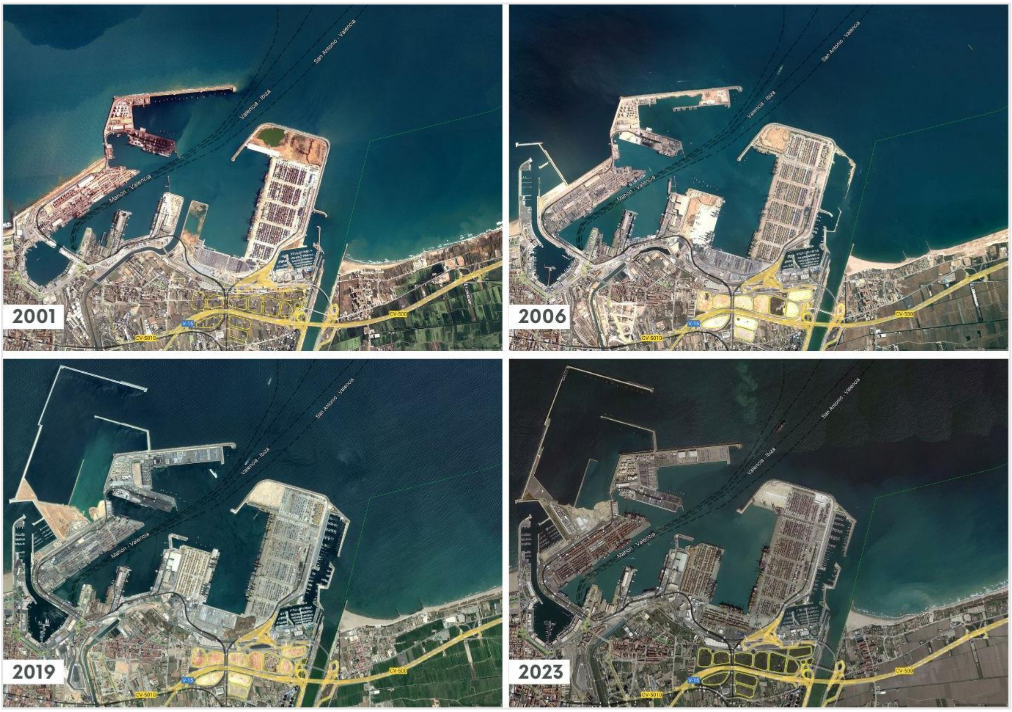

Figure 26. Temporal map of ZAL expansion between the years 2001, 2006, 2019, and 2023. Elaborated from GEP.

The findings have demonstrated a detrimental effect on the area, the transformation of the land into a novel terrain, a lack of consideration for local people's preferences and the marginalisation of the local community. However, at present, on the 26th of March, the Board of Directors of the Valencia Intermodal and Logistics Platform (VPI-Logistica) convened with the activation of the ZAL expansion of the port of Valencia, as published by Valencia Port (2024). Nevertheless, the local community was once again denied the opportunity to participate in the decision-making process, despite the consistent expression of their opposition.

Social movements such as *Recuperem La Huerta* and *Per L'Horta* have consistently demonstrated opposition to the proposed expansion, intending to require the restoration and safeguarding of the *Huerta de Valencia (La Punta).* The activities and policy initiatives of these movements are designed to guarantee the conservation of the area, its agricultural, environmental, historical and cultural legacy, and its associated assets. Furthermore, solutions are proposed to ensure that these outcomes are achieved.

Currently, on the 31st of May, a manifestation was held in opposition to this expansion, as illustrated in Figure 27.

Figure 27. Manifestation against the ZAL expansion.
Source: *Ecologistes en accio Valencia*, 2024. Fieldwork activities, *Pont d'Aragó*, 31st May 2024.

The manifestation was attended by individuals from a diverse range of age groups and social backgrounds unified in their opposition to the decision to expand the port. Figure 28 comprises images captured during the event, symbolising the collective indignation of the people.

Figure 28. Population manifestation to the port expansion.
Fieldwork activities, *Pont d'Aragó*, 31st May 2024.

It seems reasonable to posit that, based on the statements made and subsequent actions taken, there is a continued imposition of a port-based model that is predicated on the import and export of large goods. The model has been demonstrated to be anti-climactic and socially exclusionary, as evidenced by the population banners depicted in Figure 28. Moreover, this model is antithetical to a productive one that prioritizes local food consumption *(El Salto Diario*, 2019).

However, a duality of support is reflected in the wider community of the city. On the one hand, there are people as Borja Sanjuán, a spokesperson for the socialist party, who have stated that it is not feasible to return the space to its original designation as a residential plot, given that the physical characteristics of the land have undergone a significant transformation over the past 16 years. "It is imperative that the potential for generating employment opportunities within the ZAL is not foregone." On the other hand, environmental organisations have proposed the conversion of the site into a wildlife corridor, whereas the women of *La Punta*, who were involuntarily displaced from their land, have asserted that their fundamental right to decide, which aims to recover their fields, must prevail (*La Vanguardia*, 2021).

It is thus this study's position that the *La Punta* neighbourhood is in urgent need of regeneration, while simultaneously ensuring the preservation of its farmland and local community wishes. Furthermore, the provision of the necessary infrastructure is crucial to facilitate its integration into the city of Valencia (Valencia News, 2021).

<u>Engagement and support of the community</u>

It is therefore proposed that this land be utilised for the implementation of an urban agroforestry system for the creation of the green corridor and associated infrastructure. This approach is expected to yield several benefits, as illustrated in Figure 29, which demonstrates an outcomes-oriented strategy.

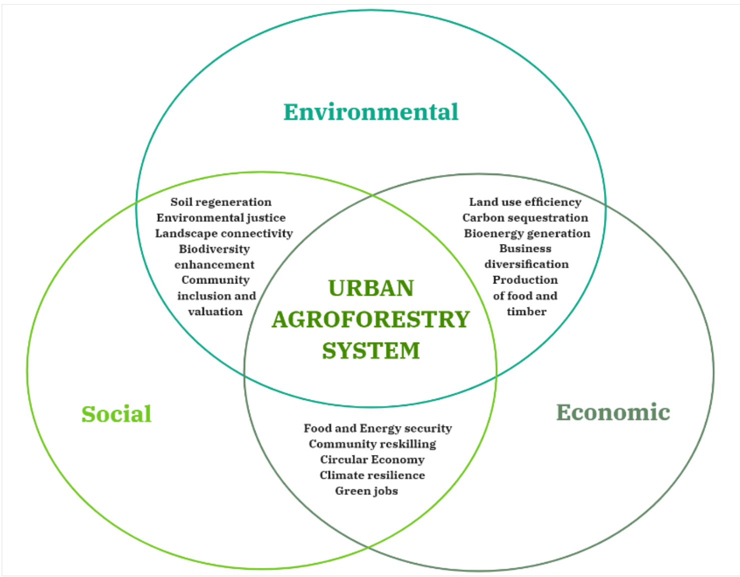

Figure 29. Urban Agroforestry Systems Outcomes.
Personal Graphical Elaboration, 2024.

As illustrated in Figure 29, this strategy entails the integration of land for the dual purpose of facilitating the production of food and timber, while also facilitating soil restoration. Moreover, this would assist the city in achieving its 2050 net-zero target by facilitating carbon sequestration and storage. It may also be possible to generate bioenergy through the planting of wood biomass on this land, which could help to ensure a proportionate provision of energy security.

Consequently, the urban agroforestry systems represent an integration of a multifunctional approach to sustainable development that includes the local community, generates employment opportunities, and facilitates the return of the neighbourhood to its original rural state. Concurrently, it may ensure economic growth and environmental conservation.

7. RESULTS, FINDINGS & DISCUSSION

7.1 Integration of a Multifunctional Agroforestry for Urban Adaptation and Resilience

***La Punta* Master Plan**

The *La Punta* Master Plan represents a complete compilation of the project's information, as illustrated in Figure 30.

Figure 30. *La Punta* Master Plan.
Personal Graphical Elaboration, 2024. Map from GEP.

It can be observed that the total area available for urban agroforestry is 36.77 hectares. The area on the left side of the figure represents a proposed implementation of forest farming practices, occupying 16.24 hectares. The current species include Acer rubrum L., Castanea sativa, Populus alba, Prunus cerasus, Salix caprea and Tsuga canadensis, which comply with the requisite diversity. Nevertheless, the area is considered suitable for the introduction of additional species in the future.

The right side of the image depicts the total area designated for alley cropping, which encompasses 20.53 hectares. However, only 4.95 hectares are available for the planting of Castanea sativa and Prunus cerasus, with the remaining 15.58 hectares allocated for community allotments.

Designing with the community in mind

It is of the utmost importance that the objectives of the urban agroforestry initiative are aligned with the needs and aspirations of the rural community in which it is situated. Figure 31 illustrates the timeline of the engagement process, which involves an understanding of the farmers' goals and aspirations, the application of the principle of farmers' centrality, and the generation of valuable products, such as food and bioenergy, while simultaneously reducing the risks faced by farmers' households.

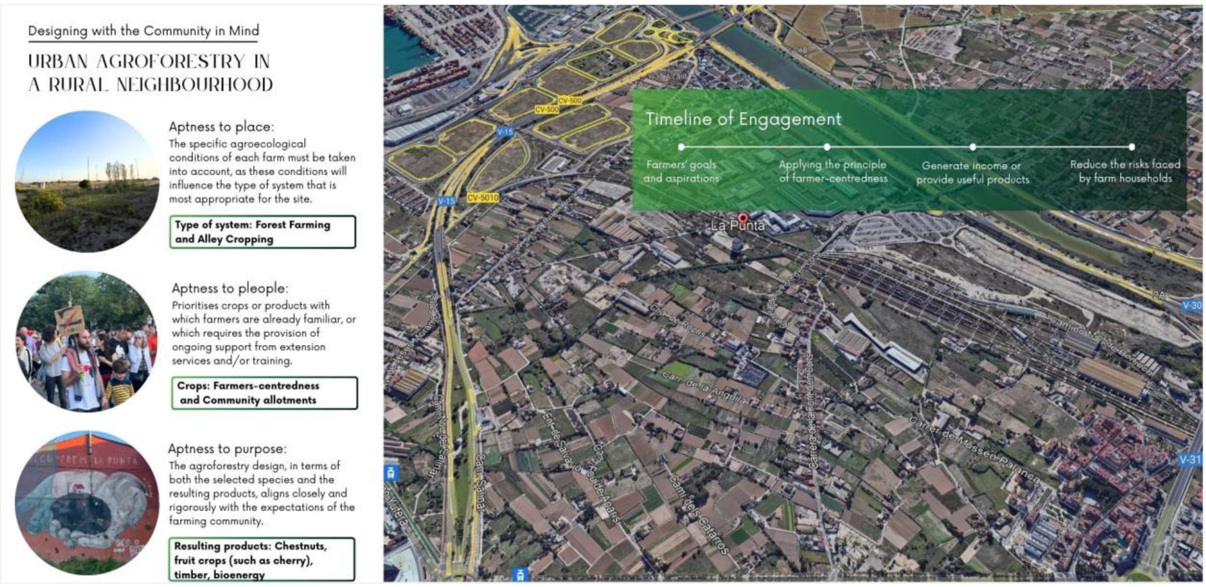

Figure 31. Urban Agroforestry in a Rural Neighbourhood.
Personal Graphical Elaboration, 2024. Information adapted from Gassner & Dobie, 2022. Map from GEP.

Furthermore, the design of the figure is based on the principles set forth by the CIFOR (2022) in their document entitled "Principles of Agroforestry Design", specifically the approach proposed by Anja Gassner and Philip Dobie (2022). This approach is based on the concept of "Aptness to Place, People and Purpose", which is described in detail below.

- Aptness to place: It regards the significance of the surrounding environment. In a rural context, agricultural practices are an integral aspect of the local culture. The cultivation of crops is a fundamental and traditional practice, exemplified by the concept of alley cropping.

- Aptness to people: This is reliant upon their integration into the community, and the provision of a platform through which local farmers can express their opinions and advocate for their rights. As such, allotments may facilitate the development of locally grown produce and the restoration of traditional agricultural practices. Furthermore, there is a clear emphasis on fostering connections between people and nature. The forest farming area will act as a space for this, and it will be connected to the River Turia.

- Aptness to purpose: It is determined by the restoration of the area under the criteria of environmental sustainability, social equity and economic stability. The regeneration of the ecosystem and biodiversity is achieved by the utilisation of the trees, which yield a variety of products including chestnuts, fruit crops and timber. Additionally, the generation of bioenergy may guarantee energy security, while the cultivation of crops may ensure food security.

The principle of synergy

In the context of urban agroforestry, the principle of synergy is applied. Synergistic systems may be defined as a system in which the components are selected and arranged in a manner that allows them to complement each other, thereby fully realising the potential of agroforestry (CIFOR, 2022).

The principle is represented in Figure 32, which depicts the layout of this case study. The arrow indicates that the alley cropping zone is designed as a private area, while the forest farming zone will be accessible to the public and situated in a natural setting, connecting the previously mentioned nature parks.

Figure 32. The principle of synergy.
Personal Graphical Elaboration, 2024. Information adapted from Bioenergy Europe, 2023. Map from GEP.

It is therefore proposed that a sustainable forest management strategy be adopted, which aims to achieve a state of balance through the conservation and utilisation of forest resources. The approach acknowledges the interrelated nature of various factors, including environmental, economic, and social aspects. This is exemplified in Figure 32 and is outlined below:

- Selective Harvesting: The process involves the selective removal of single trees or small groups of trees. The resulting gaps and borders allow species that cannot withstand shade to regenerate, while the formation of stands with varying ages allows for the sustainable production of bioenergy (Bioenergy Europe, 2023). In this context, Salix caprea and Populus alba, fast-growing trees (Daugaviete et al., 2022), are the most suitable for this harvesting. Their final use is in bioenergy production.

- Community Allotments: A pivotal role within the community garden, farm, and growing area ecosystem among residents. The activity will take place within the designated cropping area. Consequently, the advantages of such activities will be disseminated throughout the community in a multitude of ways, including educational programmes, initiatives promoting healthy lifestyles, vocational training, volunteer opportunities, environmental schemes, horticulture, and so forth (Social Farms & Gardens, 2018).

- Local farmers reskilling: Enable the local communities to assume responsibility for the agroforestry systems, from initial implementation and maintenance through to long-term success. Therefore, they may be the primary implementers of these systems, developing the required skills and evaluating any traditional knowledge that may be relevant to them. Moreover, it is also essential to ensure equality in agroforestry practices, with opportunities for women to specialise in this area.

The aforementioned factors interact synergistically, ensuring the efficacy of a strategy conducive to urban adaptation and resilience. This, in turn, facilitates the enhancement of environmental and social justice, thereby promoting the sustenance of local livelihoods. Furthermore, it serves as a direct catalyst for the mitigation of climate change.

Economic Plan

From an economic perspective, urban forestry is a rational investment. A new paradigm that views trees as an intelligent public investment strategy, and as an asset with the potential for generating profit, is gaining traction in the movement to quantify the economic benefits of trees at all levels, including direct economic benefits and indirect cost savings from environmental, health, and psychological factors (USDA Forest Service, 2016).

It can therefore be seen that the urban agroforestry proposed in this study is both relevant and reinforced by a fundamental interconnection between this NBS and the circular economy; the direct relationship between carbon removal and the increase in carbon circularity (European Commission, 2020) provides evidence of this interconnection, represented in Figure 33.

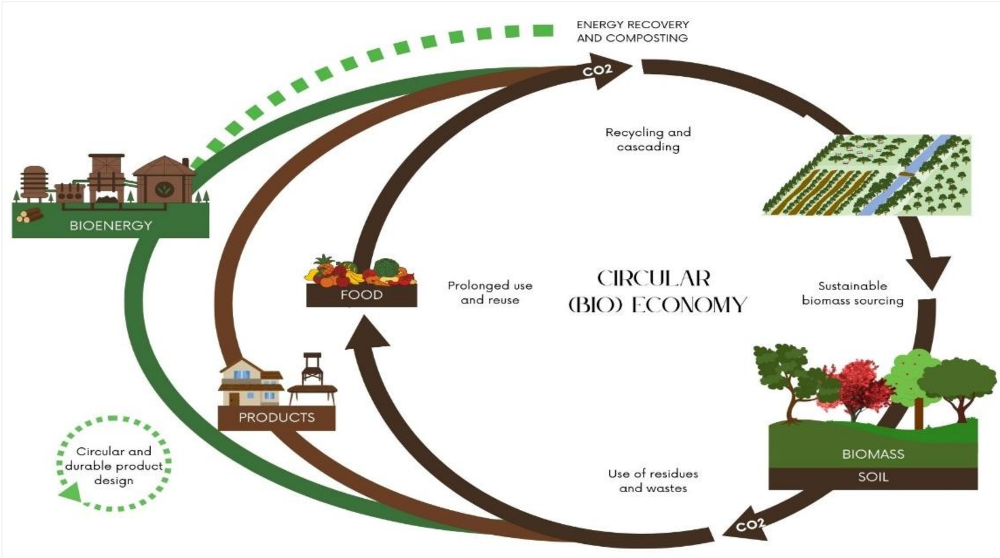

Figure 33. Circular (bio)economy.
Personal Graphical Elaboration, 2024. Information adapted from Poonam Nigam, 2022.

Figure 33 illustrates the circularity of outcomes from an NBS, which encompasses the utilisation of residues and wastes, as well as bio-based products, food and feed. This cycle is distinguished by its longevity and continued shared use, offering the potential for both recycling and cascading solutions. This concept is comparable to that described in Figure 8 (Carbon cycle and agroforestry), particularly relevant in the present context.

Furthermore, it can be reasonably deduced that this urban agroforestry project would be compatible with the objectives of the EU Circular Economy Finance Support Platform. Therefore, it may be eligible to receive the benefits of the ongoing guidance provided to the implementation of circular projects, including the provision of circular incentives, capacity building, and risk management (European Commission, 2020).

Nevertheless, as recommended by the USDA Forest Service (2016), a creative funding strategy is an optimal approach to ensuring the long-term financial sustainability of budget cycles. The funds encompass a variety of sources, including public funding, private investment, community support, and international grants.

In alignment with this strategy, alternative sources of funding may be sought, including the European Union’s budget, which is estimated to have a value of €1.8 trillion for the period spanning 2021-2027. The financial backing would be distributed across a multitude of areas, including innovation, environmental protection, education, training and culture (CINEA, 2024). Among other sources, the LIFE Programme would be the most appropriate for the project.

The LIFE programme represents a considerable commitment to environmental protection and climate action for the 2021-2027 period, with an estimated value of 5.43 billion euros. This represents one of the most substantial investments made by the European Union. The ratio of co-financing is between 60% and 95% (CINEA, 2024). This project may be classified within both the Climate Action Area, which encompasses the subprograms Climate Change Mitigation and Adaptation, as well as the Environment Area, which comprises the Nature and Biodiversity, Circular Economy, and Quality of Life.

Furthermore, the sixth IPCC Assessment Report for 2022 indicates that technical mitigation capability is available at a rate of USD 100 $GtCO^2eq$ annually, with a range of 0.8 (0.4-1.1) $GtCO^2eq$. This could be used to continue the project, receiving financial funding from stakeholders who are willing to purchase carbon credits. Moreover, the establishment of a capital improvement fund could facilitate the acquisition of financial resources from multiple sources, including donations designated for tree preservation.

Nonetheless, it would be advantageous to engage with non-profit organisations to supplement current tree-funding sources, with the allocation of these funds to urban forestry improvements potentially offering considerable benefits for the local economy. Consequently, community involvement may facilitate the development of a local market for food and other agricultural products. Additionally, the sale of the timber produced could result in an additional income source.

Risk Management

It is of the utmost importance to conduct a comprehensive examination of the potential risks and difficulties inherent to an urban agroforestry system, along with the implementation of effective measures to reduce or mitigate these challenges. Table 6, based on the Food and Agriculture Organization's (FAO) Forward NDCs, illustrates some of this.

Table 6. Overview of challenges and its measures to an Urban Agroforestry.

Challenge	Measure
Inadequate extension services and inappropriate community training	Development of financial models which guarantee an ample supply of materials, training and assistance to farmers
Insufficient financial resources or lack of access to credit to finance long-term investments	Adequate provision of input supplies and advisory services for farmers
Potential for competition and conflict between tree, crop and livestock species concerning access to resources	Suitable selection of crops, trees, and livestock species and breeds should be made to reduce competition
Potential discrepancy between the time taken to implement an investment and the subsequent financial return.	Linking project costs with existing governmental programmes and support (such as carbon credits), as well as donor funding and blended finance
Trees may compete with food crops for space, sunlight, moisture, and nutrients, which could ultimately result in a reduction in crop yields.	Optimise the productivity of woody species, by cultivating them in a spatial design and seasonal cycles that minimise the competition for resources with crops

Source: Adapted from Food Forward NDCs, 2024.

Management of Activities and Performance

The management of activities is outcomes-oriented, which makes the significance of intersectoral participation evident. To illustrate this, Figure 3 was connected to Figure 34, which presents a trial design of multifunctional and integrated land and associated activities. These include forest farming and alley cropping systems within an urban context. The inspiration for this approach was the land design of the Urban Food Forest at Brown's Mill project, created by Sustenance Design in 2017.

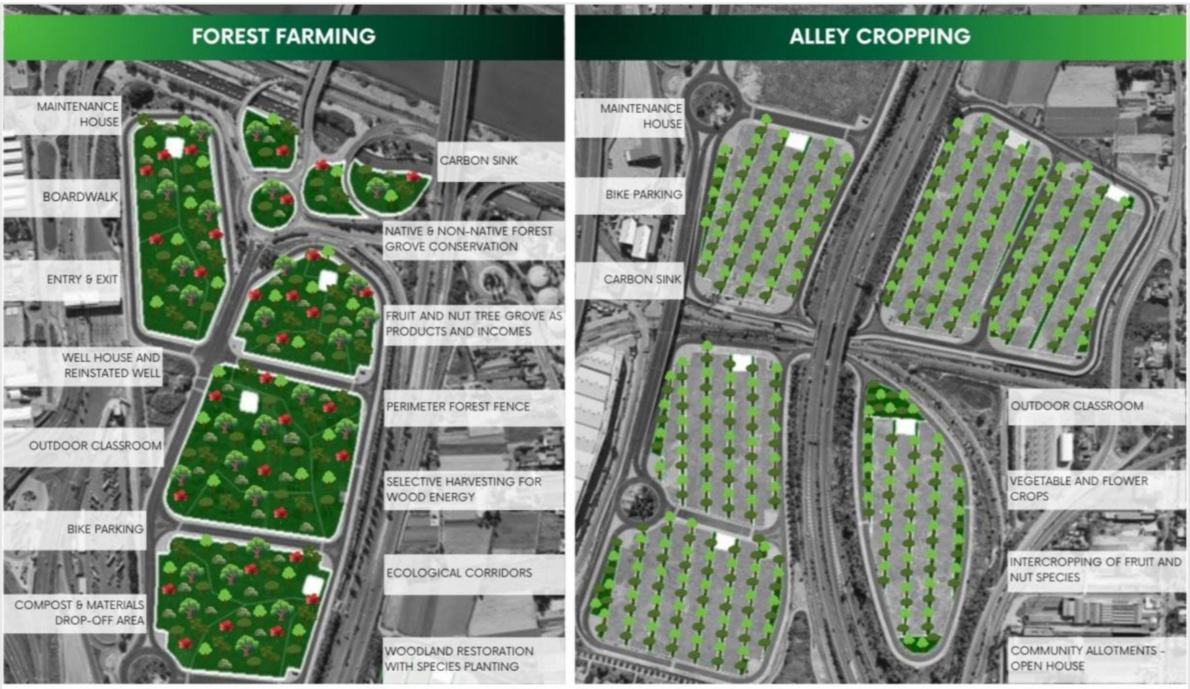

Figure 34. A trial design of a multifunctional and integrated land and its activities.
Personal Graphical Elaboration, 2024. Map from GEP.

Under the aforementioned "project outcomes" (Figure 3), the anticipated results are demonstrated in Figure 34 and explained through the implementation of the following activities, which are designed to recreate, restore, and reimagine an urban environment under the UN Decade on Ecosystem Restoration 2021-2030.

- **Recreating energy and food security** through selective harvesting, whereby the wood biomass will be used to produce bioenergy. Furthermore, the establishment of fruit and nut tree groves is a potential source of revenue and income.
- **Restoring community involvement, learning, capacity, and reskilling** by promoting their active participation in the implementation, maintenance, and ongoing management activities related to the project. This will guarantee that the outdoor learning space is utilised optimally for educational purposes and that the community is equipped with the requisite knowledge and skills for its maintenance.
- **Reimagine carbon sequestration and storage based on land regeneration and conservation** through the practice of woodland restoration, which encompasses long-lived and urban adapted species planting and the conservation of forest groves. Thus, ensuring the continued storage and sequestration of carbon.

- **Recreating accessibility, efficiency, and economic development** by guaranteeing the community allotment open house, which is also aligned with food security. Furthermore, the provision of bike parking and a perimeter forest fence will not only encourage the use of the land but will also enhance the security of both workers and the community.

- **Restoring, preserving, and valuing traditional agriculture** to enable the local rural population to assume responsibility for the urban agroforestry system. This can be achieved by planting a variety of vegetable and flower crops, as well as fruit and nut trees. These crops are consistent with the local economy and facilitate neighbourhood economic growth and expansion.

- **Reimagine connected and multipurpose territories** with appropriate land management strategies that facilitate the generation of incomes, as well as the creation of a just and inclusive society. Such a strategy would facilitate the decarbonisation, energy security and economic prospects. Moreover, the implementation of green corridors connecting disparate natural parks may serve to guarantee environmental justice.

Therefore, it encompasses the environmental, social, and economic aspects of an urban agroforestry solution. Nevertheless, it becomes increasingly important to maintain the project's efficacy. This may be accomplished effectively using performance indicators, as illustrated in Table 7.

Table 7. Urban Agroforestry Performance Indicators.

Dimension	Themes	
	Indicator	**Method of Measurement**
Social	Community Awareness and Engagement	Maintain attendance records for all sessions and activities Conduct pre- and post-project surveys to evaluate changes in awareness and engagement Track local community participation in the planning, implementation, and maintenance of urban agroforestry initiatives
	Energy and Food Security	Monitor the bioenergy produced and track how it gets distributed to the community Track access to local urban agroforestry products for fresh, nutritious food
	Equity and Access	Monitor access to green spaces and urban agriculture opportunities for diverse social and economic groups Track the inclusion of marginalised communities in the decision-making processes related to green infrastructure in urban areas
	Workshops and Training	Record and track all educational events organised as part of the project

	Working Conditions, Health and Well-being	Monitor working conditions, inclusion, skills development, and equal opportunities
		Track the benefits of green spaces and outdoor activities on physical and mental health
	Cultural Acceptability and Social Cohesion	Survey the local community to assess cultural acceptability
		Monitor social cohesion and community building using shared green spaces
Environmental	Environmental Justice and Equity	Ensure that the benefits of urban forests are made available to all, especially to those in greatest need of tree benefits
	Ecosystem Diversity, Connectivity and Protection	Conduct periodic surveys to assess and enhance ecological diversity, including monitoring diverse plant species, habitat creation, and ecological niches within the urban landscape
		Record and report on the protection and restoration of natural habitats and ecosystems
	Biodiversity Enhancement	Conduct periodic biodiversity surveys in the project area
		Monitor the presence and diversity of species
		Record the support for local wildlife habitats and corridors
	Land use Change	Track the evolution of land use, ecological regeneration and restoration
		Monitor the degree of tree cover and species diversity (tree inventory)
	Natural Resource Efficiency	Regularly monitor the efficiency of water and nutrient recycling
		Monitor the optimisation of energy use. This includes using available renewable energy sources and recycling
	Soil Health and Urban Agriculture Suitability	Monitor the improvement of the quality and fertility of the soil
		Perform risk assessment and management of soil contamination
	Climate Change Mitigation	Monitoring long-term carbon storage in the agroforestry systems
		Conduct a survey to assess the contribution of greening to reducing the urban heat island effect
Economic	Income from Products, Bioenergy, and Carbon Credits	Track sales and income from agroforestry products
		Monitor bioenergy production and sales
		Monitor the carbon market, sales, and income
	Resource Efficiency	Monitor the efficient use of resources (water, nutrients, and land)
		Conduct and report on the optimisation of inputs to maximise productivity and minimise environmental impact
	Cost-Benefit Analysis	Assess the economic returns and benefits
		Monitor financial feasibility and payback times
		Track the use of financial records and the value of ecosystem services delivered
	Employment Generation	Record levels of employment generation and community support received
	Economic Stability	Survey to measure the economic stability of the community before, during, and after the project
	Market Value	Track the economic value of agroforestry products such as fruits, nuts, and timber
		Monitor the demand for and prices of locally produced goods in the market
	Funding and Donations	Record financial contributions and support received

Source: Adapted from Buchholz et al. (2009) and USDA Forest Service (2016).

7.2 Simulation and Evaluation

Carbon Sequestration and Storage Results

As previously indicated, the three methods used to estimate this proposed system's carbon sequestration and storage result in three simulations, outlined below.

- Simulation 1:

The initial simulation, created with the SFC Carbon Monitoring tool (Method 1), is developed with the stipulation that results would be generated every five years. It is thus estimated that the implementation will commence in 2025 to achieve the net zero goal of the city by 2030. Consequently, the initial year of results should be 2030, and the simulation will continue for 30 years, resulting in a study period that will end in 2055.

Figure 35 presents a graphical illustration of the simulation, which depicts the total potential carbon storage in the urban agroforestry system over the years.

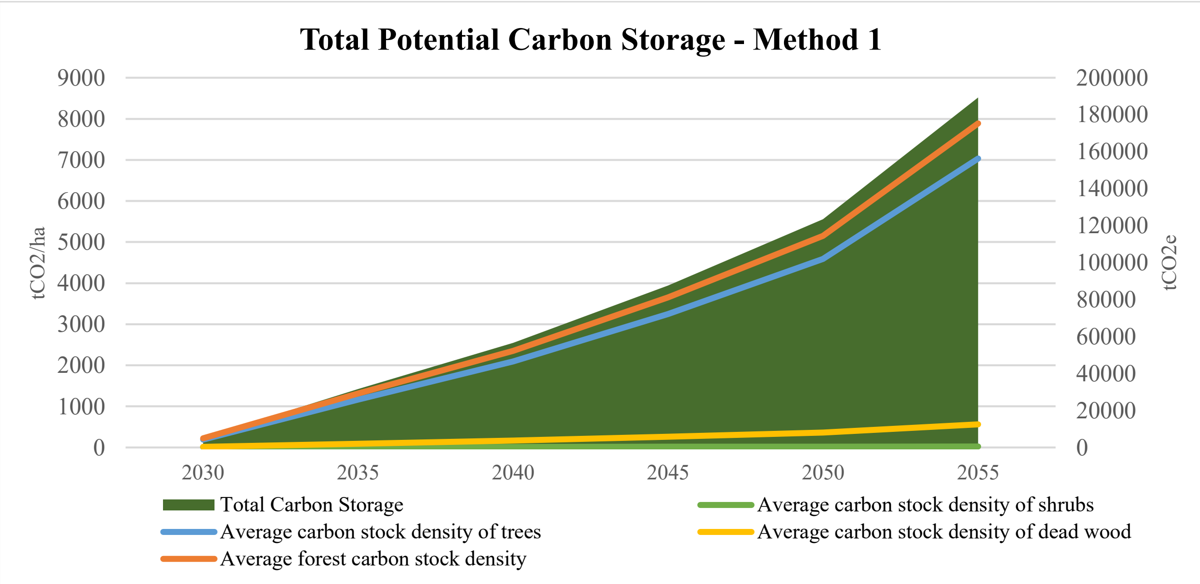

Figure 35. Total Potential Carbon Storage in the Urban Agroforestry System over the years - Method 1. Personal Graphical Elaboration, 2024.

As evidenced by the graphical representation, the quantity of carbon storage demonstrates an upward trajectory over time. This cumulative total is represented in green. It can thus be estimated that the stock will be approximately ten times greater than the initial value after five years, at 5,364.32 tCO^2e, and 35 times greater after 30 years, at 189,322.17 tCO^2e. Furthermore, the forest carbon stock density, which encompasses the mean values of the three components—the average carbon stock density of trees (depicted in orange), the average carbon stock density of shrubs (shown in blue), and the average carbon stock density of dead wood (represented in light green)—yields the following results: 224 tCO^2/ha after five years and 7,889 tCO^2/ha after 30 years.

In this case, the component that exerts the most influence over the average forest carbon stock density is the average carbon stocking density of trees. This average is estimated that in 5 years equates to 191.7 tCO^2/ha, whereas in 30 years, the figure is 7,033.1 tCO^2/ha.

- Simulation 2:

The second simulation, which was created using CO^2fix software, generated results on an annual basis. However, to establish a standard concerning method 1, the results presented in the graph have also been expressed on a five-year basis. This is illustrated in Figure 36.

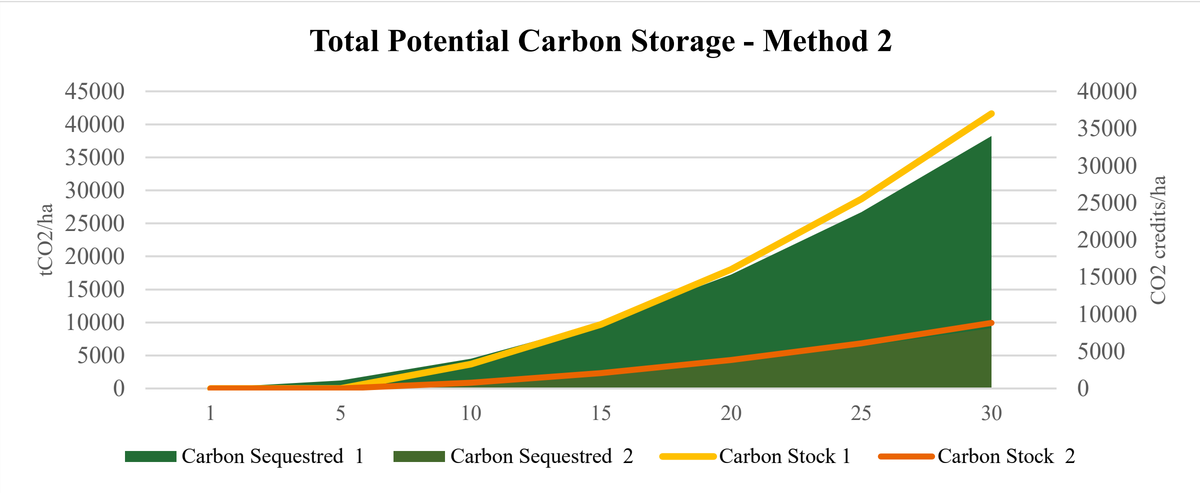

Figure 36. Total Potential Carbon Storage in the Urban Agroforestry System over the years - Method 2. Personal Graphical Elaboration, 2024.

In this instance, two distinct scenarios are presented for the two systems that are in operation within this geographical location: forest farming (Scenario 1) and alley cropping (Scenario 2). Subsequently, the green area and blue line represent the first scenario, with a carbon sequestration of 38,242.41 tCO^2/ha over 30 years. Additionally, the dark blue area and orange line represent the second scenario, with a carbon sequestration of 9,119 tCO^2/ha (over the same period), resulting in a total carbon sequestration of 47,352.77 tCO^2/ha over 30 years.

Moreover, as evidenced by the graphs depicted in Figure 36, the quantity of carbon sequestered during the initial phase is greater than the carbon stock up to 10 years in the initial scenario and

5 years in the second. This can be attributed to the fact that the storage process occurs within the trees themselves, as well as in the leaves, soil, and other elements undergoing growth.

As previously stated, the rate of capture during this phase is higher, and the potential for storage is increasing until the trees have reached a specific maturity level that allows for optimal carbon stocks. Consequently, following a period of growth, a mature forest will exhibit elevated carbon sink capacity, as illustrated in the accompanying graphical representation.

- Simulation 3:

It is of further significance to emphasise that a considerable proportion of carbon storage occurs in the soil. Consequently, using the methodology proposed by Yohannes (2015), which is analogous to that described in Method 3, the following results are presented in Figure 36.

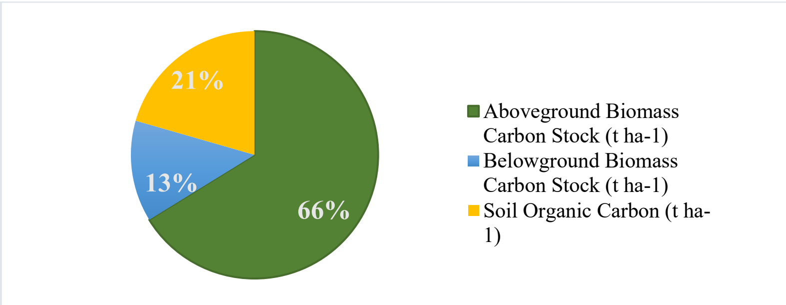

Figure 37. Overview of the Carbon Storage.
Personal Graphical Elaboration, 2024.

It can be stated that most of the carbon stock in this agroforestry system is derived from the aboveground biomass, which constitutes 66% of the total. The remaining 21% and 13%, attributed to soil organic carbon and belowground biomass respectively, are observed in Figure 37. The exclusion of other elements from this simulation is justified by their negligible contribution. To ensure the accuracy of the results, the percentage values have been cross-referenced with those presented by Yohannes (2015), as illustrated in Table 8.

Table 8. A comparative of the percentage results among the two studies.

	AGBC	BGBC	SOC	LBC	DWDBC	Total Carbon
	66	13	21	-	-	100
Yohannes (2015)	53	11	35.5	0.07	0.45	100

ABGD and BGBC (Aboveground and Belowground biomass carbon, respectively); SOC (Soil Organic Carbon); LBC (Litter biomass carbon); DWDBC (Deadwood biomass carbon).

Accordingly, the findings of simulation 3 are illustrated in Figure 38, which portrays the total carbon storage and its correlation with the ABGD, BGBC and SOC throughout the study period.

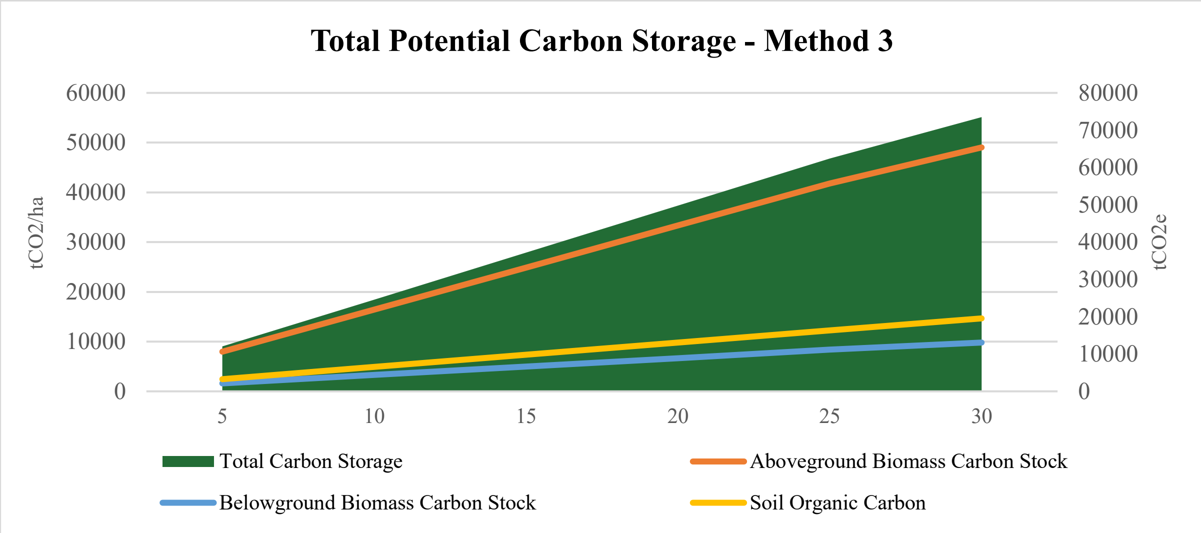

Figure 38. Total Potential Carbon Storage in the Urban Agroforestry System - Method 3.
Personal Graphical Elaboration, 2024.

Figure 38 illustrates a pattern comparable to those observed in previous simulations, exhibiting a cumulative crescent over time. It should be noted, however, that the total carbon storage estimate incorporates both belowground biomass and soil organic carbon, with an additional 1,634.51 tCO^2/ha and 2,444 tCO^2/ha per year, respectively.

Evaluation of the Findings - Carbon Sequestration and Storage

Dave Nowak, a research forester from the USDA Forest Service, highlighted the existence of a net effect between the sequestration and decomposition processes at the Urban Tree Conference, "Managing Urban Forests in a Changing Climate" (2015). The functioning of a natural forest system can be illustrated by a graph, as demonstrated in Figure 39.

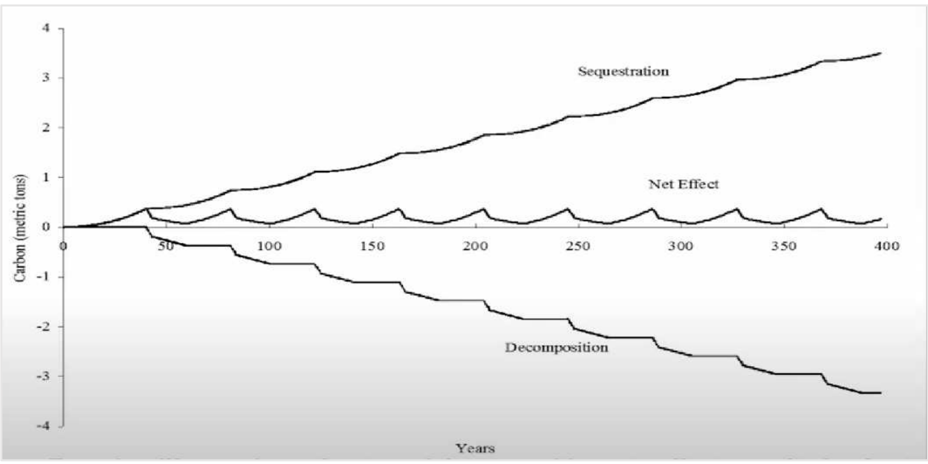

Figure 39. The net effect between the sequestration and decomposition processes.
Source: Dave Nowak, 2015.

The optimal height for sequestration is determined by the number of trees in each area, while transition points are based on the average lifespan of the stand, as illustrated in Figure 39. Consequently, trees with a long lifespan are particularly well suited to urban agroforestry, a concept that informed the selection of the carbon sources in this study.

Moreover, the continuous planting and maintenance of this land has the potential to enhance the system's long-term achievements over time. Additionally, the use of renewable energy in the maintenance processes is essential for the optimal functioning of the system and the attainment of even better outcomes. It is thus possible to posit that the results of this study have the potential to be developed and built upon.

Nevertheless, it is also important to note that the values presented as results are subject to fluctuation due to the numerous variables involved and the different methods employed[2]. Figure 40 illustrates the comparative analysis of the three simulations on the estimation of aboveground carbon storage.

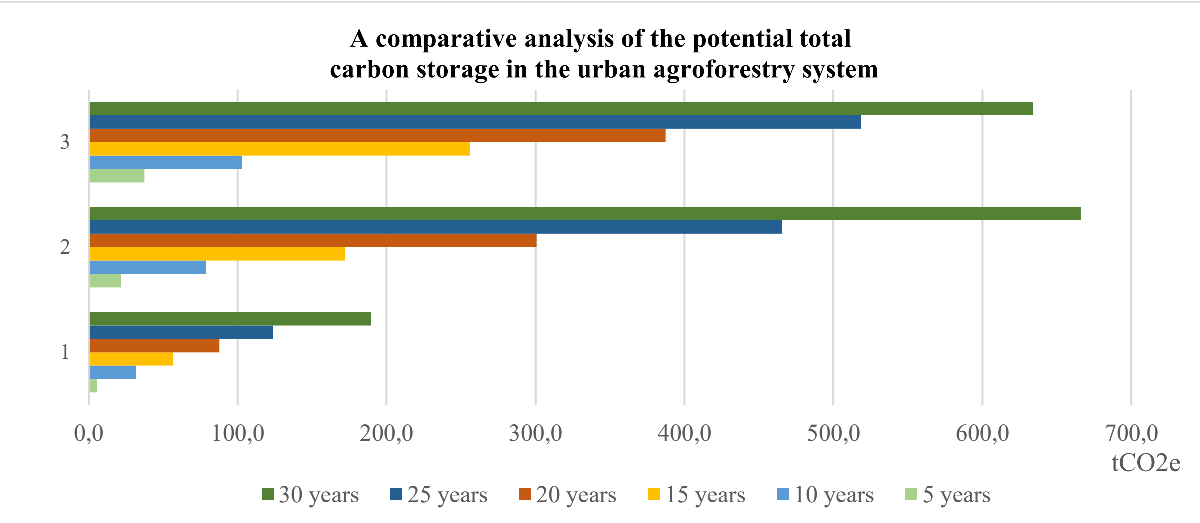

Figure 40. A comparative analysis of the potential total carbon storage in the urban agroforestry system. Personal Graphical Elaboration, 2024.

Figure 40 presents the results of the carbon dioxide equivalent (tCO^2e) emissions for the 30-year period, which encompass 189,332.2 tCO^2e, 666,035 tCO^2e and 633,993.7 tCO^2e.

[2] The fluctuations in results, particularly concerning Simulation 1, present a significant challenge to comprehension. In the absence of knowledge regarding the algorithm or the underlying model, there are inherent limitations in the estimation of carbon storage, necessitating the use of cross-validation or ground truth to assess accuracy.

Therefore, the outcomes of simulations 2 and 3 are comparable to each other and exhibit a notable discrepancy with those of simulation 1.

Despite the current lack of certainty and consistency in the calculations – also because the relevant implementation is still forthcoming – the overview provided by Figure 40 demonstrates that the outcomes for both carbon sequestration and storage are positive. Furthermore, it has the potential to yield a range of outcomes as time progresses. Given that the total land area included in the project amounts to 21.19 hectares it can be extrapolated that the formation of a crescent carbon stock is guaranteed over the coming years, as well as the expected net effect.

Bioenergy Production Results

The simulation of bioenergy production is contingent upon three principal variables: land area, rotation length, and wood biomass after the rotation length. The bioenergy output is then calculated through the Bio-Simulator for IRENA (2024) by employing this data. The results are presented in 5 scenarios that employ wood from either Populus or Salix species.

Both tables exhibit a variation in the values of land area and rotation length, which facilitates a more nuanced understanding of the relative merits of each. Moreover, it is noteworthy that the rotation length of four years for both species represents the default value within the Bio-Simulator.

Table 9. Bioenergy Simulation – Populus and Salix.

Bioenergy Simulation					
Land area (ha)	1	2	1	1	2
Rotation Length	4	4	15	30	30
Populus					
Woody biomass yield at the end of the rotation length (t/ha)	291.43	291.43	1,092.86	2,185.71	2,185.71
Bioenergy yield (GJ/ha)	5,245.71	5,245.71	19,671.43	39,342.86	39,342.86
Woody biomass yield (t/year)	72.86				
Salix					
Woody biomass yield at the end of the rotation length (t/ha)	231.82	231.82	869.32	1,738.64	1,738.64
Bioenergy yield (GJ/ha)	4,172.73	4,172.73	15,647.73	31,295.46	31,295.46
Woody biomass yield (t/year)	57.95				

Elaborated from IRENA Bio-Simulator, 2024.

The data presented in Table 9 illustrate that the Populus species has a yield of 72.86 t/year, while the Salix species has a yield of 57.95 t/year. The highlighted data in green represent the yield of woody biomass. It may thus be concluded that Populus exhibits greater potential for biomass production. A graphical illustration is provided to facilitate the visualisation and understanding of the data, as depicted in Figures 41 and 42.

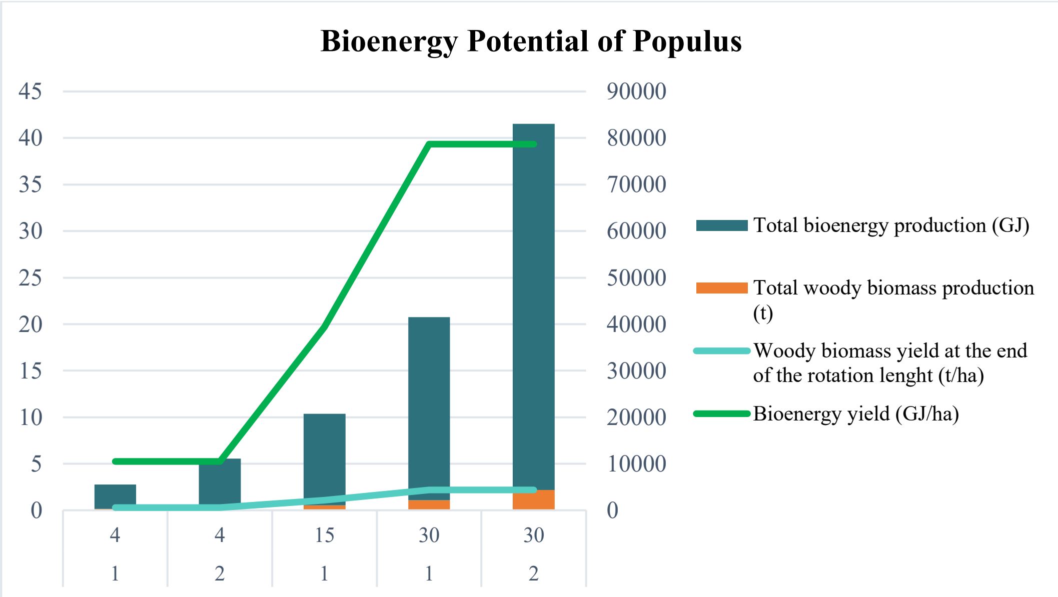

Figure 41. A graphical representation of the bioenergy potential of Populus.
Personal Graphical Elaboration, 2024.

Figure 41 provides a visual representation of the bioenergy potential of Populus in five distinct scenarios, each represented by a single bar. A review of the data presented reveals that the total biomass yield (depicted in orange) is directly influenced by the wood biomass yield at the end of the rotation length (in blue). Moreover, the total bioenergy production (in petrol blue) is dependent on both the bioenergy yield (in green) and the total wood biomass production.

The estimated total bioenergy production of this species for one hectare can be extrapolated to 5,245.71 GJ (as illustrated by the first bar). This illustrates a proportional growth in line with that observed in the hectarage under consideration. It can thus be seen that for a plot of two hectares, the figure is twice that of one hectare, equating to 10,491.43 GJ (second bar). The estimates are based on a default rotation length of four years.

An additional analysis demonstrates that the bioenergy yield, represented by the green line, is dependent on the rotation length. Consequently, when the rotation period is set at 15 years, the total bioenergy yield is 19,671.43 GJ (third bar), indicating that this variable also exerts an influence on the outcome. Moreover, a 30-year rotation period yields the highest total bioenergy production, at 78,685.71 GJ (see fifth bar). This value represents the upper limit achievable over the longest period with the greatest number of hectares included in the simulation. A comparable pattern is observed in Salix, as illustrated in Figure 42.

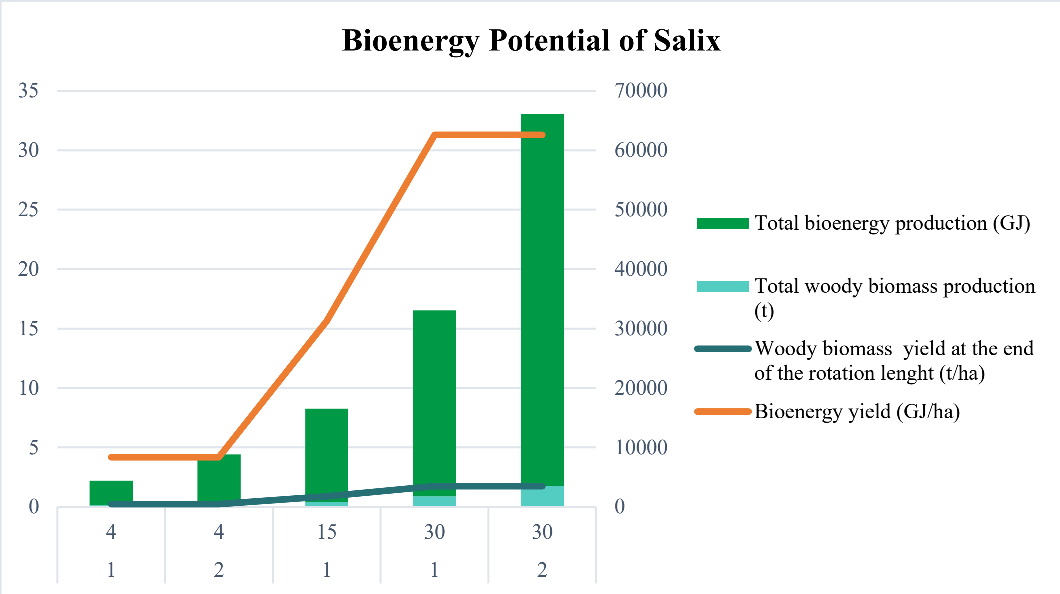

Figure 42. A graphical representation of the bioenergy potential of Salix.
Personal Graphical Elaboration, 2024.

In this case, the total bioenergy potential produced by Salix for a single hectare of land is 4,172.73 GJ. Moreover, the total bioenergy production is found to be 15,647.73 GJ when the rotation length is set at 15 years. A rotation length of 30 years results in a total bioenergy production of 31,295.46 GJ (1 hectare) and 62,590.91 GJ (2 hectares).

The graph presented below affords a more comprehensive visualisation of the estimated results.

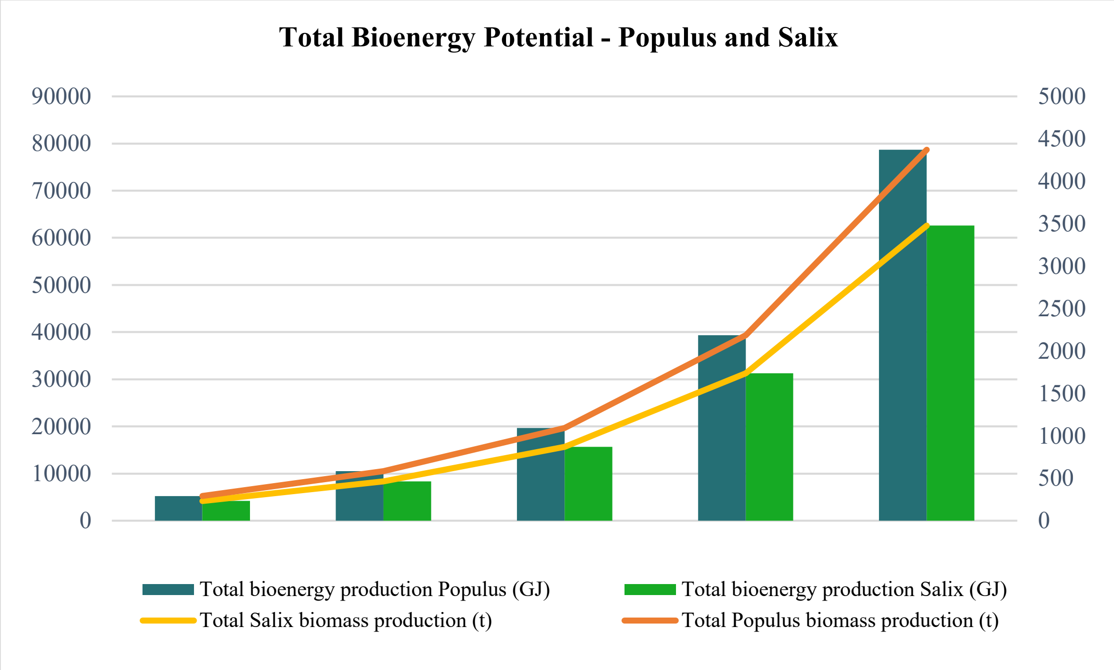

Figure 43. Total Bioenergy Potential – Populus and Salix.
Personal Graphical Elaboration, 2024.

A noteworthy observation in Figure 43 is that, despite both Populus and Salix being excellent trees for such a purpose, Populus produces a greater quantity of material than Salix.

Evaluation of the Findings - Bioenergy

A calculation was performed to gain insight into the quantity of bioenergy potential generated. The initial stage of the process involved the collection of open data concerning energy consumption in Valencia from the Datadis database. Subsequently, the data were imported into Excel to calculate the mean value over the final six months of the current year (January to June 2024). The resulting mean is presented in Table 10.

Table 10. Average energy consumption in Valencia.

Location	Total energy Monthly (MWh)	Total energy Daily (MWh)	Nº contracts
Valencia	198,238.21	6,535.30	477,904

The findings encompassed the total energy consumption on a monthly and daily basis, as well as the total number of contracts. Based on these results, the subsequent step was to estimate energy consumption within the *Quatre Carreres* district and the *La Punta* neighbourhood, employing the findings from the Valencia city analysis as a reference. This estimation is presented in Table 11.

Table 11. Estimation of Energy consumption in *Quatre Carreres* and *La Punta*.

Location	Total energy Monthly (MWh)	Total energy Daily (MWh)	Nº contracts	Population
Valencia	198,238.21	6,535.30	477,904	814,208
Quatre Carreres	18,643.29	614.61	44,944	76,572
La Punta	734.07	24.20	1,770	3,015

To obtain estimates of energy consumption for each month and day, it was first necessary to identify the population and number of contracts in each area of interest. These were then combined to provide a total energy estimate for *Quatre Carreres* and *La Punta*.

Subsequently, the final phase of the assessment process involved the transformation of the GJ results to MWh into the five scenarios, which are illustrated in Table 12.

Table 12. Total bioenergy production in the 5 scenarios.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Total bioenergy production Populus and Salix (MWh)	2,616	5,232	9,811	19,622	39,244

It can thus be evaluated that in scenario 1, with the utilisation of 2 hectares of land and a 4-year rotation length, the bioenergy produced could potentially be employed as an energy supply to the *La Punta* community for 2 months. Furthermore, scenario 3, which employs a 2-hectare plot and a 15-year rotational period, has the potential to sustain the neighbourhood for a minimum of seven months.

Moreover, modifying the scenario to include a 30-year rotation length for the same 2 hectares of land as in scenario 4 would provide energy to the entirety of *Quatre Carreres* for one month. Extending the area of land used, as illustrated in scenarios 2 and 4 with 4 hectares of land, would result in a greater yield which could be distributed in different ways.

7.3 Expected Outcomes

Decarbonisation

The decarbonisation of cities represents a significant challenge, particularly given the intricate nature of their operational complexity. Nevertheless, given that urban areas currently account for most emissions, sustainable solutions must be appropriately implemented within these environments to mitigate the effects of climate change. This is of particular importance, given the increasing prevalence and intensification of this phenomenon over time.

It is therefore imperative that solutions be devised in a manner that transforms the environment and facilitates a transition to a smart, sustainable, and resilient city, which must be inclusive and equitable for its residents. The implementation of NBS has demonstrated the potential for urban spaces to contribute to the attainment of ambitious environmental goals, such as the net-zero target by 2050. The findings of this study are fully aligned with the objectives and serve to reinforce the value of traditional practices such as agroforestry in the context of contemporary challenges.

The strategy of implementing urban agroforestry in unused land, particularly in neighbourhoods that are marginalised or present rural lifestyle aspects, has the potential to be a significant solution that yields notable outcomes. This is evidenced by the results presented in this thesis, particularly about the sequestration and storage of carbon, which have been demonstrated to increase over time. These outcomes reflect a long-term trajectory, as does the tree species itself. Similarly, the carbon cycle is a long-term phenomenon.

Consequently, promising decarbonisation results may be achieved by implementing an urban agroforestry system with a diversity of six species over three decades. Even the simulation with the most conservative estimated outcomes is positive in the context of the current climate crisis. In this instance, the total amount of carbon stored in 30 years of Simulation 1 is calculated to be 7,888.84 tCO^2e/ha. In comparison, Simulation 2 shows a significantly higher value of 45,824.29 tCO^2e/ha. Simulation 3 demonstrates the highest estimated amount, at 49,035.32 tCO^2e/ha, which would represent an exceptional result.

Given the above, it seems prudent to consider the potential of this proposed decarbonisation strategy in urban environments as a means of contributing to global climate action. Furthermore, the expansion of this practice beyond its current scope, to encompass other territories, settlements, or urban areas, offers the potential for enhanced carbon sequestration and storage. This may be achieved by incorporating further species and optimising the available space in the city, thus augmenting the project's overall capacity.

Energy Security

In the context of climate change, it becomes imperative to consider the issue of energy security as a crucial factor affecting urban development. Those who are most vulnerable to the consequences of climate change are typically those who live in marginalised areas with a smaller income. Consequently, solutions to this problem should prioritise this demographic.

The findings of this study suggest that the potential for bioenergy production in *La Punta* is significant. Due to its limited population, the neighbourhood has the potential to guarantee the energy security of its local community while enabling the implementation of diverse strategies to achieve optimal outcomes on the land. Moreover, if the objective is economic, it may also present opportunities.

In the scenarios created, estimation was made using varying numbers of hectares of land. Even with minimal use, positive outcomes were observed. It is therefore reasonable to consider the possibility of combining agroforestry practices with bioenergy production, as this approach is also circular and may avoid emissions in the atmosphere.

Economic prospects

The advent of urban agroforestry systems is anticipated to generate employment opportunities at various stages of the project, from its inception to its continued development. Once a certain threshold of land use has been reached, economic advancement may be assured through the provision of a communal space for the local population. This could facilitate the establishment of local markets for the sale of produce or even savings derived from the reduction in food expenditure. A similar approach can be adopted to bioenergy, whereby the energy can be utilised by the local population or sold as electricity and heat, thereby generating income. Therefore, these crops are aligned with the local economic landscape, facilitating neighbourhood-level economic growth and expansion.

Additionally, the estimation provided by Dave Nowak (Urban Tree Conference, Managing Urban Forests in a Changing Climate, 2014), indicates that the avoidance of 19,800,000 tCO^2/year equates to a savings of 425 million dollars per year. The application of the data to the current findings of this research would result in Table 13.

Table 13. Estimation of the economic savings – Carbon Sequestration and Storage.

Scenario 1		**Scenario 2**		
tonnes avoided/year	**$/year**	**tonnes avoided/year**	**$/year**	**years of simulation**
19,800,000.0	**425,000,000.00**	**19,800,000.0**	**425,000,000.00**	**USDA, 2014**
947.2	20,332.37	4,297.0	92,233.30	5
2,790.9	59,904.66	7,877.8	169,094.80	10
3,326.2	71,394.92	11,458.7	245,956.31	15
3,870.8	83,085.45	15,039.5	322,817.64	20
4,363.1	93,651.44	18,620.3	399,679.03	25

5,572.2	119,604.25	22,201.2	476,540.32	30

Source: Adapted from Dave Nowak of the USDA Forest Service at the Urban Tree Conference on 18-19 November 2014 entitled "Managing Urban Forests in a Changing Climate".

It can be observed that as the trees expand, the quantity of carbon dioxide avoided per year also increases. As demonstrated by the data presented in Table 13, the projected cost savings over 30 years are estimated to be $119,604.25 for 5,572.2 tonnes avoided per year and $476,540.32 for 22,201.2 tonnes avoided per year. It must be noted that these values are the minimum and maximum projections derived from the analysis of Scenarios 1 and 2, respectively. However, due to the potential inaccuracies associated with such projections, it is crucial to recognise that the estimates provided here are approximations based on the simulation model's findings.

In the context of bioenergy, it has been demonstrated that the avoidance of 36 million MWh of energy production on an annual basis is equivalent to 4,3 billion dollars (USDA, 2014). The same conceptual approach is employed in the study, with the results presented in Table 14 for reference.

Table 14. Estimation of the avoidance cost – Bioenergy Production.

MWh	$/year	Scenario
36000000	**4300000000**	**USDA, 2014**
654,06	78123,71	1
1308,12	156247,41	2
654,06	78123,71	3
654,06	78123,71	4
1308,12	156247,42	5

Source: Adapted from Dave Nowak of the USDA Forest Service at the Urban Tree Conference on 18-19 November 2014 entitled "Managing Urban Forests in a Changing Climate".

Notably, the quantity of bioenergy provided on an annual basis varies following the land area utilised, with scenarios involving 2 or 4 hectares exhibiting a discrepancy of 654,06 MWh. Consequently, the estimated avoidance cost is projected to be $78,223.71 per year for a 2-hectare plot.

Sustainable Community

Urban agroforestry has the potential to serve as an effective strategy for achieving sustainability. The path to achieving this goal may necessitate the implementation of a multifaceted approach, tailored to the specific needs and circumstances of each community. Despite the diversity of strategies, there are common elements that are fundamental to the success of any community endeavour. These include the promotion of a healthy environment, the fostering of a resilient economy, and the advancement of the well-being of the community's inhabitants.

This NBS-proposed model offers a framework that aligns with these principles. As its sustainability areas are addressed in a synergic manner, it has the potential to exert a profound and positive influence on the quality of life and prospects of a community. By integrating efforts across these domains, efficiencies are realised, and superior outcomes are achieved.

Climate Transition WILDSCAR

The Climate Transition WILDSCAR represents a storytelling model that offers an overview of a core concept of this thesis: urban agroforestry systems based on an outcomes-oriented strategy. These systems are designated by the acronym WILDSCAR, which stands for "Woodland Integration for Landscape Diversity and Sustainable City Adaptation and Resilience." The model can be adapted to suit the specific requirements of different urban landscapes and to provide the desired results.

Moreover, it incorporates a few successful initiatives and guidance that bear a resemblance to the NBS proposed in this thesis. The initiatives are presented as evidence of the feasibility of the proposed approach in practical contexts. Furthermore, the best practices towards a just transition in an urban context are presented, encompassing environmental, social, and economic dimensions. Consequently, the practices facilitate the creation of smart, sustainable, and resilient cities.

It thus offers an exemplary model for pursuing environmentally friendly initiatives that simultaneously conserve ecosystems, promote well-being among communities, and mitigate climate change, thereby advancing environmental and social justice objectives.

For further reference, the link for access is https://arcg.is/11m8OP.

8. CONCLUSIONS

The impact of climate change is global; however, it is reasonable to conclude that the most effective solutions must be developed and implemented at the local level. It follows, then, that as urban environments are the primary sources of carbon emissions and energy consumption an optimal solution would be a strategy that concurrently reduces their ecological impact, provides diverse services, and empowers marginalised groups and local communities. Thus, a multifaceted, integrated approach must be devised to ensure environmental and social justice and facilitate a transition towards a more sustainable development paradigm.

The current climate crisis provides compelling evidence of the necessity for immediate climate action. Consequently, the deployment of NBS represents a promising avenue for the resolution of this complex challenge: mitigate climate change. To this end, it is essential to develop effective alternatives that engage cross-sectoral participation to solve critical issues on urban adaptation and resilience. This master's thesis is concerned with the interrelated challenges of decarbonisation, energy security, economic prospects, and sustainable community. This approach is designed to facilitate the creation of post-carbon cities that exemplify an environmentally smart, sustainable, and resilient urban environment.

This study proposes the development of urban agroforestry based on an outcomes-oriented strategy. The plan is therefore predicated on the concept of "Aptness to people, Aptness to place, Aptness to purpose" and on the principle of synergy, thereby optimising the potential for the generation of multiple results.

In the field of decarbonisation, it can be argued that it presents a substantial challenge for urban areas. Nevertheless, there is considerable merit in transforming this challenge into an opportunity, with a foundation in tree-based ecosystems. The urban agroforestry systems proposed in this thesis have the potential to sequester and store significant quantities of carbon since trees function as terrestrial carbon sinks.

Moreover, this study presents a feasible plan and design within the context of the neighbourhood, comprising two systems: forest farming (Scenario 1) and alley cropping (Scenario 2). The systems were designed with the objective of land regeneration and conservation, encompassing systems for woodland restoration, the planting of long-lived species, and the conservation of forest groves. This approach ensures the sustained storage and sequestration of carbon over time.

Additionally, to enhance greater accuracy and reduce variability in the findings, three distinct methods were employed throughout the measurement process. From the results of Simulation 1, it can be concluded that the component with the greatest influence over the average forest carbon stock density is the average carbon stock density of trees. From Simulation 2, it can be inferred that there is a greater capture of carbon in young forests and an enhanced long-term carbon storage capacity following a period of growth. Simulation 3 indicates that a significant proportion of the carbon storage occurs within the soil. Most of the carbon stock within this agroforestry system is derived sequentially from the aboveground biomass, soil organic carbon, and belowground biomass.

In consequence, the study demonstrates that the implementation of NBS has the potential to contribute to the achievement of ambitious environmental objectives, including the attainment of the net-zero target by 2050. This is evidenced by outcomes that are both positive and cumulative over time. The net carbon storage results over 30 years yielded 189,332.2 tCO^2e, 666,035 tCO^2e and 633,993.7 tCO^2e, respectively, for the three simulations. As time progresses, a range of potential outcomes may be yielded. Furthermore, it can be extrapolated that a crescent carbon stock with the expected net effect occurs at the proper time. In the field of energy security, it can be argued that Salix caprea and Populus alba are the most suitable trees for the selective harvesting proposed, given their resilience and adaptability to various environmental conditions.

Firstly, they are fast-growing trees. Secondly, in the context of bioenergy production, the results are of considerable significance. The data indicate that the Populus species has yield of 72.86 t/year, while the Salix species 57.95 t/year. It thus follows that both species are highly suitable for this purpose and present a great potential for adaptation, as observed within the five scenarios created using a variance of hectares and/or rotation length. Consequently, it allows the development of a modelled system that is aligned with the specific requirements of the land, whether to ensure energy security or for the sale of the resulting bioenergy end-use heat and electricity.

It is estimated that a hectare with a four-year rotation length will yield 5,245.71 GJ of bioenergy from Populus and 4,172.73 GJ from Salix. A rotation length of 30 years is estimated to yield a total bioenergy production of 31,295.46 GJ in a single hectare for Salix, while Populus is expected to produce 78,685.71 GJ. Accordingly, the initiation of production would be contingent upon the maturation of the trees, although a harvesting strategy could be devised to facilitate the continuous generation of bioenergy.

In synthesis, the total bioenergy produced in Scenario 1 is estimated to be 2,626 MWh, whereas Scenarios 3 and 5 yield 9,811 MWh and 39,244 MWh, respectively (two-hectare plot size). It can thus be concluded that the results indicate that the energy source in question can serve the *La Punta* community as a supply for approximately two months (Scenario 1), thereby providing an opportunity to recreate energy security in the neighbourhood. While Scenario 3 has the potential to sustain the neighbourhood for a minimum of seven months, Scenario 5 would provide energy to the entirety of *Quatre Carreres* for one month. However, it should be noted that although the results of this study are of great significance, the emissions generated by production were not included in the scope of this study.

In the field of economic prospects, it can be posited that employment opportunities will be generated across all phases of the development of urban agroforestry systems. As the project places a strong emphasis on the local population, it is they who will constitute the primary beneficiaries. Consequently, the restoration, preservation, and valuation of traditional agricultural practices may be facilitated, as well as the establishment of local markets, due to the planting of a variety of vegetables, flower crops, fruit, and nut trees.

The projected cost savings over thirty years are estimated to be $119,604.25 for 5,572.2 tonnes avoided per year (Scenario 1) and $476,540.32 for 22,201.2 tonnes avoided per year (Scenario 3). It is therefore anticipated that these projections will increase in line with the quantity of carbon dioxide avoided on an annual basis. It should be noted, however, that these figures are approximations based on the findings of the simulation model and, as such, may be subject to error.

Additionally, the quantity of bioenergy produced on an annual basis exhibits fluctuations under the land area used for a two-hectare plot; as a result, the projected cost of avoidance is estimated to be $78,223.71 per year.

In conclusion, the establishment of a sustainable community can be achieved through the implementation of connected and multipurpose territories, accompanied by an appropriate land management strategy. The strategy should facilitate the generation of income and the creation of a just and inclusive society. The simultaneous revitalisation of community involvement, learning, capacity and re-skilling is an additional outcome of this process. Concurrently, this approach facilitates decarbonisation, energy and food security, accessibility, efficiency and economic prospects. Moreover, the establishment of green corridors connecting disparate natural parks may serve to guarantee environmental justice, land regeneration, nature connectivity and conservation.

It follows that this urban agroforestry system, which incorporates multi-purpose areas and addresses them synergistically, has the potential to exert a profound and positive influence on the quality of life and prospects of a community. Furthermore, it allows the realisation of efficiencies and the achievement of multiple outcomes. Consequently, this dynamic, ecologically based natural resources management system constitutes a tangible form of climate action.

9. RECOMMENDATIONS FOR THE FUTURE RESEARCH

Further investigation could be undertaken to analyse the underlying algorithm or model of the methods used for carbon sequestration and storage. This may facilitate the understanding of the discrepancies observed in the study. In addition, further research may prove beneficial in facilitating comparison between the results obtained from practical observation of agroforestry systems and those calculated using previously mentioned methods.

Moreover, a comprehensive assessment should be conducted to ascertain the suitability of alternative tree species and potential combinations for planting in an urban agroforestry context. Such measures must be accompanied by continuous monitoring of the decarbonisation, regeneration and restoration processes. It would therefore be beneficial to maintain progress towards the development and achievement of a smart, sustainable and resilient city.

Concerning the context of social movements, it is advised that research continue to be conducted so that an approach that fosters active involvement may be developed. Such an approach would enhance the ability of social movements to collaborate and amplify their voice in decision-making processes concerning land use. Furthermore, the monitoring of subsequent decisions taken in this regard is recommended.

Additionally, further research about the emissions generated by bioenergy production in this agroforestry systems could be beneficial to fully to understand the implications of the results. Furthermore, an investigation of strategic alliances could prove valuable into this land use, particularly in the context of bioenergy production and to ensure energy security.

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ANNEXES

A. Method 1 - FSC Carbon Monitoring Tool

Method 1 is founded upon the FSC Carbon Monitoring Tool, an Excel-based model designed to facilitate the monitoring and simulation of carbon stocks in forest ecosystems. This tool is accessible for download on the website, and the initial set of data is presented in Figure 44.

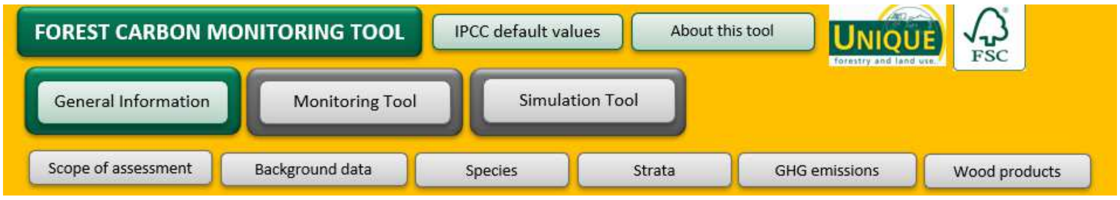

Figure 44. FSC Pannel - General Information.
Source: FSC, 2024.

Figure 44 provides an overview of the essential data elements required for the tool, including background information, species data, and strata definitions. These are detailed in subsequent figures, 45, 46, and 47, respectively.

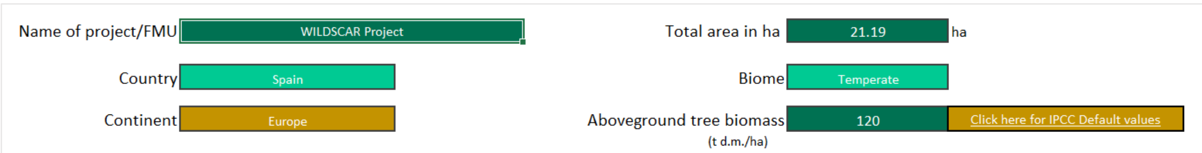

Figure 45. General Information – Background data.
Source: FSC, 2024.

Species or group of species (dimensionless)	Wood density (t d.m. /m^{-3})	Carbon fraction Default value = 0.47 (dimensionless)	Biomass expansion factor (dimensionless)
Acer	0,52	0,47	1,4
Castanea sativa	0,48	0,47	1,4
Poplus	0,35	0,47	1,4
Prunus	0,49	0,47	1,4
Salix	0,45	0,47	1,4
Tsuga	0,42	0,47	1,3
Castanea sativa	0,48	0,47	1,4
Prunus	0,49	0,47	1,4

Figure 46. General Information – Species.
Source: FSC, 2024.

Stratum	Area within FMU (ha)	Elevation	Precipitation
Forest Farming	3	< 2000m	< 1000 mm/yr
Forest Farming	3	< 2000m	< 1000 mm/yr
Forest Farming	3	< 2000m	< 1000 mm/yr
Forest Farming	3	< 2000m	< 1000 mm/yr
Forest Farming	3	< 2000m	< 1000 mm/yr
Forest Farming	1,24	< 2000m	< 1000 mm/yr
Alley cropping	2,95	< 2000m	< 1000 mm/yr
Alley cropping	2	< 2000m	< 1000 mm/yr

Figure 47. General Information – Strata.
Source: FSC, 2024.

Subsequently, the simulation tool represents the next step following the stated objectives of this thesis. For illustrative purposes, the panel is presented in Figure 48.

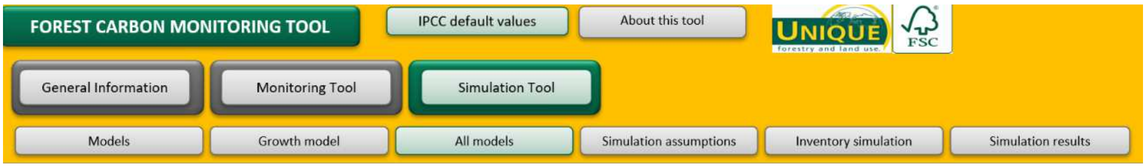

Figure 48. FSC Pannel – Simulation Tool.
Source: FSC, 2024.

Consequently, to obtain results from the simulation, it is necessary to enter data of the models, growth model, overall model, assumptions inherent to the simulation, and inventory simulation. The results of these inputs can be seen in the figures that follow.

Enter the number of models			8
Model number	Stratum	Species	Rotation period
1	Forest Farming	Acer	30
2	Forest Farming	Castanea sativa	30
3	Forest Farming	Poplus	30
4	Forest Farming	Prunus	30
5	Forest Farming	Salix	30
6	Forest Farming	Tsuga	30
7	Alley cropping	Castanea sativa	30
8	Alley cropping	Prunus	30

Click to enter rows

Click to add to "All models"

Figure 49. Simulation Tool - Models.
Source: FSC, 2024.

Figure 49 provides a visual representation of the data essential for the modelling process, whilst Figure 50 serves as an auxiliary tool for forecasting the growth patterns of each species.

Age	Number of trees per ha	Height (m)	Mean diameter at breast height (DBH) (cm)	Basal area (m²/ha)	Standing volume (m³/ha)	Form factor
1,0	894	1,0	10,0	7,0	3,5	0,5
5,0	830	2,0	20,0	26,1	26,1	0,5
8,0	766	3,0	30,0	54,1	81,2	0,5
10,0	702	4,0	40,0	88,2	176,4	0,5
15,0	638	5,0	50,0	125,3	313,2	0,5
20,0	574	6,0	60,0	162,3	486,9	0,5
25,0	510	7,0	70,0	196,3	686,9	0,5

Figure 50. Simulation Tool – Growth Model.
Source: FSC, 2024.

Accordingly, with the requisite data incorporated, the subsequent phase is the synthesis of all models, as illustrated in Figure 51.

Model number	Stratum	Species	Age	Standing volume (m³/ha)
1	Forest Farming	Acer	1	3,2
1	Forest Farming	Acer	2	11
1	Forest Farming	Acer	3	22
1	Forest Farming	Acer	4	30
1	Forest Farming	Acer	5	59,3

Select model number

Stratum model	1

Click to Get All

Figure 51. Simulation Tool – All Models.
Source: FSC, 2024.

The final iteration of the simulation results is presented in the last spreadsheet, which is illustrated in Figure 52.

Year	Year of simulation	Average carbon stock density of trees (tCO_2/ha)	Average carbon stock density of shrubs (tCO_2/ha)	Average carbon stock density of dead wood (tCO_2/ha)	Average carbon stock density of litter (tCO_2/ha)	Average forest carbon stock density (tCO_2e/ha)	Total carbon stocks (tCO_2e)
5	2020	191,7	8,9	15,3	7,7	223,5	5342,0
10	2025	1165,4	11,8	93,2	46,6	1317,1	31477,8
15	2030	2091,7	11,8	167,3	83,7	2354,5	56273,2
20	2035	3251,4	11,8	260,1	130,1	3653,4	87316,9
25	2040	4585,5	11,8	366,8	183,4	5147,5	123026,2
30	2045	7033,1	11,8	562,6	281,3	7888,8	188543,3

Figure 52. Simulation Tool – Simulation Results.
Source: FSC, 2024.

Accordingly, the results presented herein are evaluated and compared with the other findings derived from Simulations 2 and 3, as part of the wider analysis conducted in the thesis.

B. Method 2 - CO^2Fix software

Method 2 is based on the CO^2Fix software, which is a model for the simulation of carbon dynamics in forest ecosystems and soil. The software also considers the fate of carbon in wood products, and it operates at the hectare scale with a one-year temporal resolution (Efi, 2024). The model is publicly available for research purposes as can be observed in Figure 53.

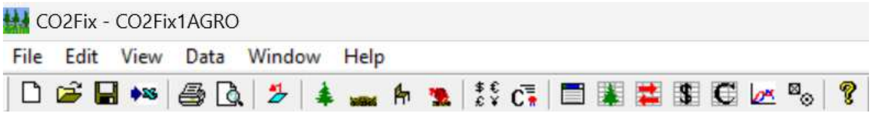

Figure 53. CO^2Fix Pannel.
Source: CO^2Fix software, 2024.

The preliminary step in the software is the input of study information, which includes the scenarios, general parameters and cohorts, which are illustrated in the accompanying figures.

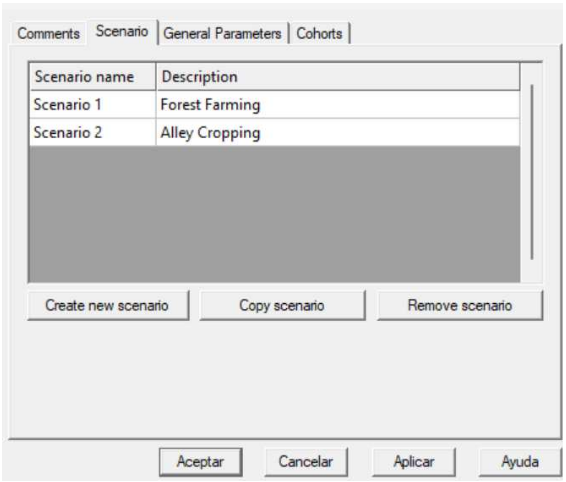

Figure 54. Scenario.
Source: Adapted from CO2Fix software.

Figure 54 illustrates the scenario input, which in this thesis is represented by forest farming and alley cropping.

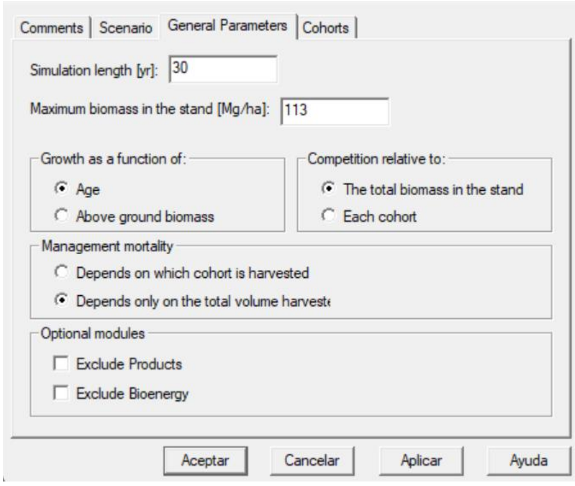

Figure 55. General Parameters.
Source: Adapted from CO2Fix software.

Figure 55 represents the General Parameters, which include the simulation length (years), maximum biomass in the stand (Mg/ha), growth as a function, competition relative to, management mortality and optional modules.

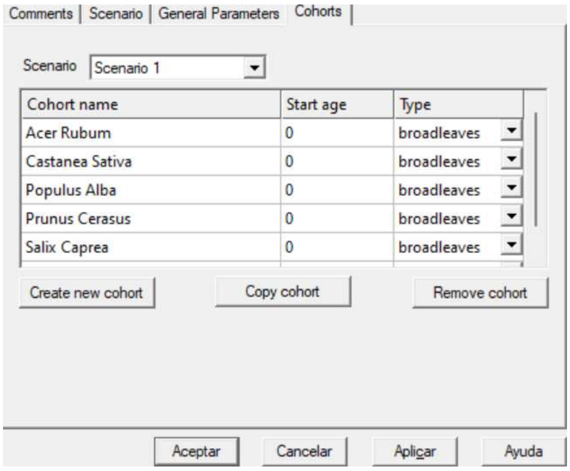

Figure 56. Cohort – Scenarios.
Source: Adapted from CO2Fix software.

Figure 56 refers to the cohort or species to be employed in each scenario. The data required is the cohort's name, start age and type.

Furthermore, the objective of utilising this software is to quantify carbon emissions. Consequently, the subsequent step is to input data on this matter, as illustrated in Figure 57.

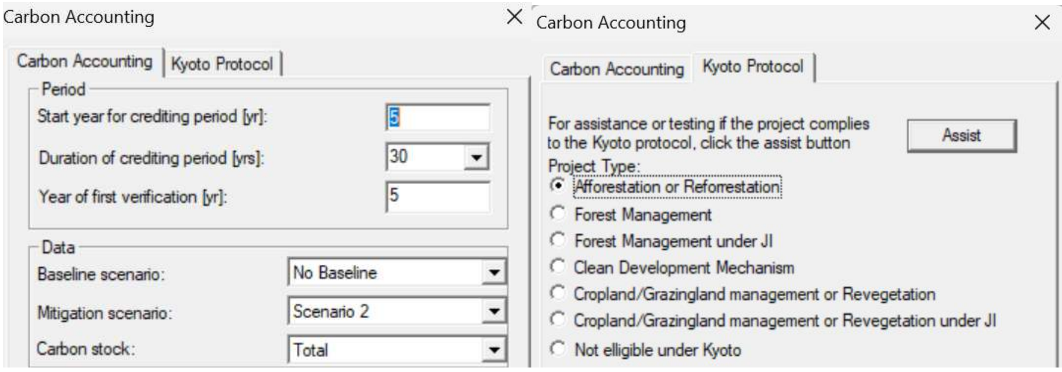

Figure 57. Carbon Accounting.
Source: Adapted from CO^{2}Fix software.

As evidenced in Figure 57, the essential data is the commencement year for the crediting period, which in this thesis is five years. Additionally, the crediting period is 30 years, with the initial verification occurring after five years. Along with the baseline scenario, the mitigation scenario, and the carbon stock total, this generates the following results.

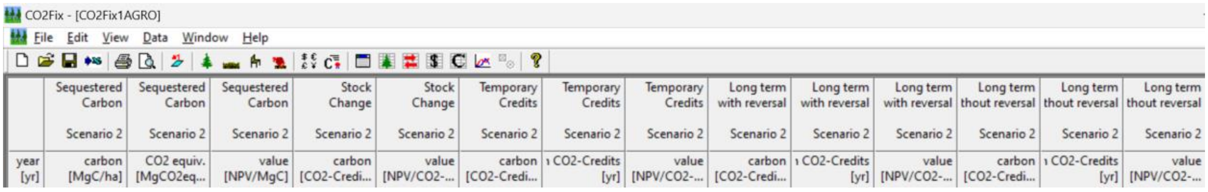

Figure 58. Results.
Source: Adapted from CO^{2}Fix software.

The final stage of this process entails expressing the results in the manner depicted in Figure 58. This data is then employed in the simulations and evaluations of carbon sequestration and storage.

C. Method 3 - The American Journal of Environmental Protection

Method 3 is informed by and builds upon, the insights presented in the article "Carbon Stock Analysis Along Altitudinal Gradient in Gedo Forest: Implications for Forest Management and Climate Change Mitigation" (Yohannes, 2015) published in The American Journal of Environmental Protection. This approach shares similarities with the methodology proposed in this thesis.

The estimation of carbon in each pool's above-ground biomass (AGB) is based on the equation provided below.

$$Y= 34.4703 - 8.0671(DBH) + 0.6589(DBH2) \qquad \text{(i)}$$

In the equation, 'Y' represents the above-ground biomass in kilograms, while 'DBH' denotes the diameter at breast height in centimetres. The carbon content of the biomass was estimated by multiplying the value 0.47, with the multiplication factor 3.67 required for the estimation of the CO2 equivalent.

The below-ground biomass (BGB) carbon stock is calculated using the following equation:

$$BGB = AGB \times 0.2 \qquad \text{(ii)}$$

In this context, BGB represents below-ground biomass, while AGB denotes above-ground biomass. The conversion factor employed is 0.2, which equates to 20% of the AGB value.

Soil organic carbon is estimated using the following formula:

$$SOC = BD * d * \% C \qquad \text{(iii)}$$

SOC represents soil organic carbon stock per unit area (t/ha), BD denotes soil bulk density (g/cm^3), D signifies the total depth at which the sample was taken (30 cm), and C is carbon concentration (%), expressed as a percentage.

The carbon stock density is calculated through a cumulative assessment of the carbon stock densities of the carbon pools, as delineated by the following equation:

$$C\ density = CAGB + CBGB + C\ Lit + CDWD +SOC \qquad \text{(iv)}$$

The variables are defined as follows:

C: Carbon stock density for all pools [t C ha-1]

CAGB: Carbon in above-ground tree biomass [t C ha-1]

CBGB: Carbon in below-ground biomass [t C ha-1]

CLit: Carbon in dead litter [t C ha-1]

CDWD = Carbon in dead wood biomass [t C ha-1]

SOC = Soil organic carbon [t C ha-1]

In this study, however, the calculation of the carbon stock density did not include the CLit and CDWD due to the lack of available information and the relatively minor contribution of these variables to the total result.

The equations employed are derived from the works of Pearson, et al. (2005), as presented in Winrock International and the Bio-Carbon Fund of the World Bank, and MacDicken (1997), as documented in a Guide to Monitoring Carbon Storage in Forestry and Agro-forestry Projects.

D. IRENA Bio-Simulator

The Bioenergy simulator is a publicly accessible geospatial tool developed by the International Renewable Energy Agency (IRENA). Based on a designated area, the simulator provides initial estimates of prospective bioenergy production for electricity generation, heating, and transportation fuels. This analysis incorporates a vast array of biomass resources, technological options, energy efficiency conversion coefficients, and final applications (IRENA, 2024). Figure 59 illustrates the requisite data in the following format.

Figure 59. IRENA Bio-Simulator.
Source: IRENA, 2024.

As illustrated in Figure 59, the simulator should be followed through four distinct stages: 1. Select a biomass supply, 2. Define the area, 3. Define the process and 4. See results. Therefore, the initial selection was forest plantations (Stage 1), followed by the hectares available (Stage 2). Figure 60 depicts the third stage.

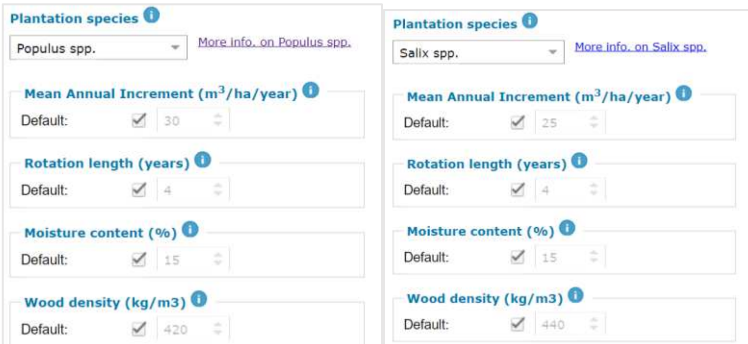

Figure 60. Define the process Forest – Stage 3.
Source: Adapted from IRENA, 2024.

Figure 61 depicts the information on the forest in stage 3 of the simulation, which encompasses the plantation species, the mean annual increment (m³/ha/year), the rotation length (years), the moisture content (%), and the wood density (kg/m³), thereby providing a default data set. Table 15 provides a more detailed overview.

Table 15. Forest information.

Forest Information	
MAI	The Mean Annual Increment (MAI) represents the average annual growth in the volume of merchantable timber on a hectare of forest. It is expressed in m³/ha/year. The default values for the MAI are obtained from the average global estimation of selected forest plantations. However, this information does not take into consideration the local agroecological

	conditions. Therefore, this section does not support spatial information on biomass productivity, but only quantitative values.
Rotation Length	Rotation length (RL) is defined as the number of years that elapse between initial plantation establishment and the final harvest of the crop. The default values for rotation length RL are derived from the mean global estimation of forest plantations selected for this study.
Moisture content	In the context of biomass feedstock, the term "wet basis moisture content" is used to describe the proportion of water present in the material, expressed as a percentage. This is determined through the calculation of the ratio between the water weight and the total weight of the biomass material.
Wood density	The term wood density is used to refer to the mass of a given volume of wood expressed in kg/m³ units.
Plantation Species	The selection of a plantation species as a biomass feedstock represents a pivotal factor in determining the performance and output of bioenergy along the supply chain. A thorough technical investigation must be conducted to ascertain the economic viability, the scale of production and the associated environmental impacts of the selected biomass feedstock for use in bioenergy.

Source: Adapted from IRENA, 2024.

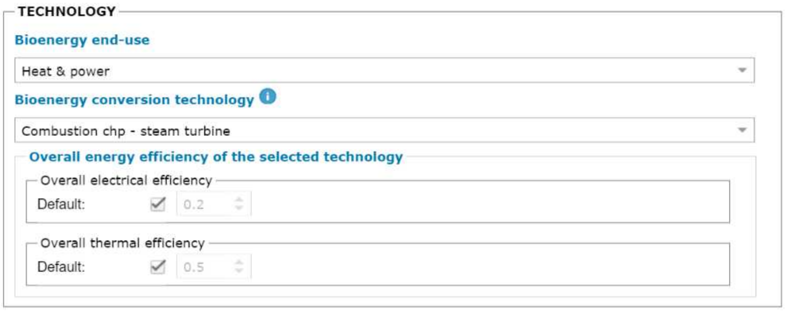

Figure 61. Define the process Technology – Stage 3.
Source: Adapted from IRENA, 2024.

The data presented in Figure 61 provides an overview of the technology at the third stage of the simulation. This encompasses the bioenergy end-use, the technology employed in the bioenergy conversion process and the overall energy efficiency of the selected technology. Table 16 provides a more detailed overview.

Table 16. Technology Information.

Technology Information	
Biofuel used	The characteristics of solid biomass can vary considerably depending on its provenance and the conditions prevailing during the harvesting and storage phases of the crop. Thus, to ensure the optimal characteristics for the bioenergy supply chain, solid biomass is typically subjected to appropriate processing technologies.
Bioenergy conversion technology	Combined heat and power (CHP) represent a technological approach to enhancing the energy efficiency of a given system through the concurrent creation of both heat and power within a single operational facility. This is achieved via the use of a steam turbine incorporating heat recovery mechanisms. High-pressure steam is generated in the boiler and then enters the steam turbine. In the latter, the thermal energy of the steam is converted to mechanical work, which is then used to run a generator that produces electricity. The steam turbine exhausts steam with

	sufficient pressure for utilisation within the industrial process or the district heating system. Subsequently, the condensate is conveyed by the boiler feed-water system back to the boiler, where it is reintroduced for further utilisation (Figure 2).

Source: Adapted from IRENA, 2024.

Ultimately, figure 62 represents stage 4, with the results available for observation as detailed below.

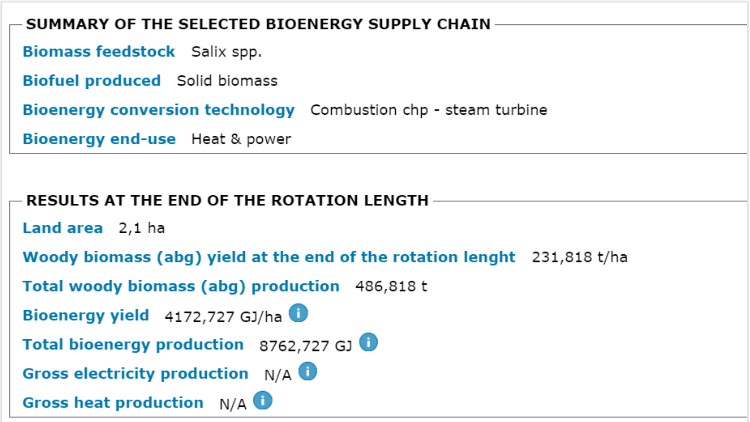

Figure 62. See Results - Stage 4.
Source: Adapted from IRENA, 2024.

Figure 62 illustrates that Stage 4 presents a summary of the selected biogas supply chain, encompassing the findings after the rotation period. This comprises the land area, the final yield of woody biomass, the total production of woody biomass, the yield of bioenergy, and the total production of bioenergy. The data presented is therefore employed in this thesis to simulate and evaluate bioenergy production and energy efficiency.