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Windbreaks as an Agroforestry Practice in Residential Areas

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ABSTRACT

This study explores the significance and application potential of windbreaks as an agroforestry practice in residential areas. In the context of increasing environmental degradation, climate change, and the need for sustainable land use, windbreaks are highlighted for their multifaceted benefits to living environments. These benefits range from energy savings to ecosystem enhancements, soil conservation, and biodiversity improvement. The study examines the historical and current applications of windbreaks across different ecological regions of Turkey, emphasizing their potential contributions based on scientific data. Windbreaks established around residential areas improve microclimatic conditions, enhance quality of life, mitigate the adverse effects of strong winds and storms, and contribute to food security. Additionally, they support environmental sustainability by increasing carbon sequestration and helping to combat the impacts of climate change. For the successful implementation of windbreaks, proper species selection, precise establishment techniques, and continuous maintenance are essential. The study suggests enhancing collaboration between public and private sectors for the planning and management of windbreaks in a geographically diverse country like Turkey. Moreover, it underscores the need for awareness campaigns, educational programs, and the promotion of scientific research to scale these practices. Windbreaks demonstrate considerable potential as a sustainable land-use model and serve as a vital component for improving living standards and environmental resilience.

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Konutlarda Agroforestry Uygulaması Olarak Rüzgâr Perdeleri

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ÖZ

Bu çalışma, konutlarda agroforestry (tarımsal ormancılık) uygulamalarından biri olan rüzgâr perdelerinin önemini ve uygulama potansiyelini ele almaktadır. Artan çevresel bozulma, iklim değişikliği ve sürdürülebilir arazi kullanımı gereklilikleri bağlamında, rüzgâr perdelerinin yaşam alanlarına yönelik çok yönlü faydaları vurgulanmıştır. Rüzgâr perdeleri, enerji tasarrufu sağlamaktan ekosistem iyileştirmelerine, toprak muhafazasından biyolojik çeşitliliğin artırılmasına kadar birçok alanda etkili bir çözüm sunar. Çalışmada, rüzgâr perdelerinin tarihsel ve mevcut kullanımları Türkiye'nin farklı ekolojik bölgeleri üzerinden değerlendirilmiş ve bu uygulamanın potansiyel faydaları bilimsel veriler ışığında açıklanmıştır. Konutların çevresinde tesis edilen rüzgâr perdeleri, mikroklima koşullarını iyileştirerek yaşam kalitesini artırmakta, şiddetli rüzgâr ve fırtınaların olumsuz etkilerini azaltmakta ve gıda güvenliğine katkı sağlamaktadır. Ayrıca, çevresel sürdürülebilirliği destekleyerek karbon tutumunu artırır ve iklim değişikliğinin etkileriyle mücadeleye yardımcı olur. Sonuç olarak, rüzgâr perdelerinin başarılı bir şekilde uygulanması, uygun tür seçimi, doğru tesis teknikleri ve sürekli bakım gerektirir. Çalışmada, Türkiye gibi farklı coğrafi koşullara sahip bir ülkede, rüzgâr perdelerinin planlanması ve yönetimi için kamu ve özel sektör iş birliğinin artırılması önerilmiştir. Ayrıca, bu uygulamanın yaygınlaştırılabilmesi için farkındalık yaratma, eğitim programları ve bilimsel araştırmaların desteklenmesi gerektiği vurgulanmıştır. Rüzgâr perdelerinin, sürdürülebilir arazi kullanımı ve yaşam kalitesini artırma konusundaki potansiyeli, gelecekteki agroforestry uygulamaları için önemli bir model sunmaktadır.

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Introduction

In recent years, the concept of agroforestry has begun to attract attention in Türkiye; however, the specific practices encompassed by this concept have not been clearly defined. Although many of the applications falling under agroforestry were traditionally practiced in earlier periods, they have not been adequately developed despite advancements in modern technology. Meanwhile, growing concerns over food security and the rise of diseases resulting from environmental and climatic degradation necessitate a more sustainable and health-conscious approach to nature. Indeed, Rupasinghe et al. (2022) report that ecosystem degradation has contributed to the emergence of various diseases, including COVID-19, Ebola, malaria, swine flu, and avian influenza. Mortality rates linked to such diseases have particularly increased in underdeveloped countries and are projected to continue rising. For example, the spread of malaria-carrying mosquitoes (*Anopheles* spp.) is expected to increase significantly in the coming years due to climate change. According to Carlson et al. (2022), even if global warming remains below 2°C, the likelihood of disease transmission from wildlife to humans could double by the year 2070.

As in many parts of the world, the relationship between green spaces and human health must also be given due attention in Türkiye. Therefore, it is essential to plan, establish, and ensure the sustainability of diverse land use systems that support human health particularly in terms of nutrition and resistance to diseases. In this context, while one aim is to maximize land productivity through engineering services, equal emphasis should be placed on creating healthier environments that promote biodiversity conservation, soil protection, and sustainable land use. Among the most prominent systems are agroforestry practices, which aim to establish both healthy and sustainable living spaces and enable the production of multiple outputs simultaneously or in succession on the same land.

In regions with diverse geographical characteristics, such as Türkiye, land use must be guided by scientific data to achieve optimal land benefits including improved air and water quality, biodiversity enhancement, erosion control, and food production while also establishing sustainable and livable environments in harmony with nature. Profit-oriented land use not only hinders the multifunctional production of goods, particularly those addressing local needs such as food, but also exacerbates living conditions and threatens ecosystem sustainability. Given its diverse ecological conditions and rich cultural and historical heritage, Turkey possesses a high potential in this regard. Indeed, land surveys and historical settlement analyses have revealed the traditional use of multifunctional home gardens and the establishment of live windbreaks tailored to local ecological conditions as protective measures against wind and storm damage.

Considering Türkiye's general geographical position, topography, and climatic characteristics, it is evident that living conditions in urban areas are increasingly challenging, while there is a growing tendency toward returning to rural areas (Güreşçi, 2010). However, as a consequence of rural-to-urban migration, the young population in rural regions has declined, whereas the elderly population particularly retirees are increasingly drawn to rural life, seeking both engagement with the land and fulfillment of economic and socio-cultural aspirations. Nonetheless, climatic factors such as extreme temperatures, frost, snow, wind, and storms pose significant challenges to living conditions across many parts of the country. In particular, strong winds and storms can adversely affect the quality of life in residential areas (including homes and their surroundings), sometimes making healthy living environments difficult to maintain. In this context, windbreaks established around settlements play a critical role in both protecting residential areas and promoting environmental sustainability. Beyond their ecological contributions, windbreaks offer multiple benefits such as conserving energy, preventing soil erosion, and improving microclimatic conditions. A well-designed windbreak around a home, farm, or agricultural facility can reduce or eliminate the harmful effects of snow, storms, and wind, thereby enhancing the livability of these spaces. Properly implemented windbreaks in residential and agricultural areas contribute to energy savings, mitigate the negative impacts of wind and storm events, improve working and recreational environments, enhance wildlife populations, provide visual and dust control, and increase the production of various timber and food products (Brandle and Wight, 2007).

Despite their significant benefits, windbreaks are scarcely established in residential areas such as homes, housing complexes, farms, and industrial facilities in both urban and rural parts of Türkiye based on scientific principles. Moreover, the limited existing implementations lack sufficient scientific studies that examine their economic, ecological, aesthetic, and socio-cultural impacts. Although there are some studies focusing on home gardens and urban green spaces in both urban and rural areas (Maas et al., 2006; Hanson et al., 2021; Marques et al., 2021), long-term monitoring data and research addressing changes in biodiversity, wildlife, carbon sequestration, and similar effects remain absent.

This study explores the importance and application potential of windbreaks in residential settings (such as houses, farms, and factories) and provides evaluations supported by examples from different regions of Türkiye. Following a conceptual overview of agroforestry and windbreak systems, the study discusses the principles of establishing windbreaks in residential areas, their benefits, planting techniques, and offers recommendations regarding current practices and future potential in Türkiye.

The Concept of Agroforestry

Various definitions have been proposed for the concept of agroforestry, which differ depending on ecological, socio-economic, and biological perspectives. Ecologically, agroforestry is a dynamic, ecologically based natural resource management system that enhances and sustains productivity through the interaction of trees within farms and agricultural landscapes. This system provides increasing social, economic, and environmental benefits to land users at all levels (Leakey, 1996). From a biological standpoint, it is an intensive land management practice in which trees and/or shrubs are deliberately integrated with agricultural crops and/or livestock to maximize the benefits

arising from biological interactions (Orji et al., 2022). Socio-economically, agroforestry represents a combination of rural land resource management that involves the deliberate integration of trees or shrubs with crops or livestock. These interactions generate economic, environmental, and social benefits (Cornell, 2014).

A common theme across ecological, biological, and socio-economic definitions is the goal of obtaining diversified and maximized outputs from the same land area. Agroforestry is a collective term for land use systems and technologies where woody perennials (such as trees, shrubs, palms, and bamboos) are deliberately utilized on the same land management units as agricultural crops and/or animals. These systems involve both ecological and economic interactions among their components and may be arranged either spatially or temporally (Lundgren & Raintree, 1982).

In North America, land use management based on combined benefits is implemented through the integrated use of trees and shrubs with crops and livestock (Garrett, 2009). In Canada, trees are grown alongside agricultural or livestock production on the same parcel of land to generate economic, ecological, environmental, and cultural benefits (Gordon & Newman, 1997). In France, land is jointly managed either simultaneously or sequentially for both forest tree cultivation and agricultural or livestock production (Torquebiau, 2000). In Australia, tree-growing practices are integrated at the farm or watershed level to promote soil and water conservation while enhancing the productivity and profitability of farms and regions (Washusen & Reid, 1996).

Bene et al. (1977) define agroforestry as a sustainable land use system that increases total production by integrating agricultural crops with forest plants and/or livestock either simultaneously or sequentially, while employing management approaches that align with the cultural context of local populations. Nair (1984) describes agroforestry as a sustainable land use system aimed at benefiting from the outcomes of ecological and economic interactions through the deliberate introduction or combination of trees or other woody plants into agricultural or livestock production systems. Similarly, Okigbo (1983) defines agroforestry as a combination of compatible components of forestry and agricultural production.

"Agroforestry" refers to a continuous land use system that integrates forestry, agriculture, and livestock activities on the same land either concurrently or in succession ensuring a combined approach to land use. It enhances land productivity, incorporates culturally appropriate planning aligned with local practices, and emerges as a rural land use model shaped by social, economic, and environmental interactions (Turna, 2023; Turna et al., 2024).

Windbreaks

Windbreaks and greenbelt composed of both living and non-living materials, are established with the purpose of controlling or reducing wind speed and serving a variety of functions. In developed countries, these protective belts have gained increasing importance and are widely used. Depending on their areas of application, methods of establishment, and types of materials used, they are referred to by different names. For instance, systems utilizing living materials are generally termed greenbelts, while those composed of non-living materials are known as wind barriers or windbreaks (Turna et al., 2024).

In Türkiye, research on the significance and application of windbreaks is relatively limited. Most early studies have focused on efforts to stabilize sand dunes or on the impact of protective windbreaks on agricultural crops. The first documented establishment of windbreaks in Türkiye was conducted in 1954 on the grounds of the Bala State Production Farm, where their effects on microclimate and crop yield were investigated. Additionally, several pioneering studies in the field include Beşkök's (1957) trials titled "Protective Forest Strips and the Establishment of Bala Protective Forest Strips," Aydemir's (1975) research "The Effects of Bala Protective Forest Strips on Microclimate and Agricultural Crop Yields," and another of Aydemir's (1978) publications, "The Effects of Protective Forest Strips and Windbreaks on Microclimate and Agricultural Crop Yields." Beyond these, key contributions to Turkish silviculture have been made by scholars such as Atay (1969), Saatçioğlu (1976), Ürgenç (1990), Dirik (2005), and Boydak & Çalışkan (2014).

Windbreaks in Residential Areas

Considering the diverse ecological conditions of Türkiye, sustainable land use and management must strike a balance between conservation and utilization, encompassing not only agricultural and forestry activities but also protected areas, wetlands, and both rural and urban settlements. In particular, under the challenges posed by global climate change, desertification, erosion, floods, and avalanches as well as economic concerns, particularly related to food security agroforestry practices, which aim to sustainably maximize productivity from natural resources, stand out as one of the most effective approaches (Turna et al., 2024). When windbreak plantations are established based on agroforestry techniques, they can provide a wide range of significant benefits.

As one of the agroforestry applications, windbreaks within residential areas especially around rural homes and outbuildings such as barns offer multiple advantages. In Türkiye, agroforestry techniques aimed at multifunctional land use have recently been abandoned in rural areas due to a shift toward monoculture-based agricultural production and the growing demand for local fuelwood and construction materials. In urban areas, the rise of reinforced concrete buildings, increased migration, and the conveniences of modern life have led to a departure not only from traditional agricultural activities in rural areas but also from the cultivation of multi-purpose products in residential areas and the associated benefits of these techniques.

As a result, modern high-rise buildings, residential complexes, and massive concrete structures dominate urban landscapes, while rural areas are increasingly characterized by densely packed or closely situated reinforced concrete houses. For families with higher incomes, villas or mansions are being constructed, but landscaping is either neglected or treated solely from a decorative perspective. Consequently, in both urban and rural settings, the surroundings of buildings are often covered either entirely with hardscape elements or with ornamental plants chosen merely for park and garden aesthetics, rather than with multi-functional plant materials.

In contrast, in developed countries, residential areas and their surroundings both urban and rural prioritize the establishment of multifunctional windbreaks and home gardens, yet in Türkiye, these are increasingly being replaced by modern, rigid concrete structures.

In residential areas affected by strong winds and storms, numerous structures including homes, industrial facilities, barns, hay storage units, livestock buildings, and recreational areas are adversely impacted. With the progression of climate change, not only are material and psychological damages becoming more frequent, but loss of life is also increasingly reported (Cianconi et al., 2020). Therefore, the establishment of windbreaks serves to prevent or mitigate potential losses, while simultaneously offering multiple benefits such as improved water quality, enhanced biodiversity, increased soil fertility, economic gains, protection and security, aesthetic and visual enhancement, and recreational services. Turna (2023) lists the agroforestry models applicable in residential areas as greenbelt plantations, green spaces within urban and rural settlements, and windbreaks whether around residential zones or industrial facilities.

The general acceptance of windbreaks in residential areas stems from their dual role: providing a peaceful environment for households and contributing to the production of subsistence goods. These systems can be established either near or at a slight distance from residences. However, what is equally important as their establishment is their sustainable management. This is because the system embodies a combination of ecological functions (such as hydrological regulation, microclimatic moderation, soil erosion control, and genetic resource conservation) and the fulfillment of socio-economic needs of the population, while its core objective remains the mitigation of adverse wind effects.

Benefits of Windbreaks

To achieve the intended benefits of windbreaks established in residential areas, a comprehensive analysis and implementation of multidisciplinary engineering services biological, ecological, economic, socio-cultural, and technical are required. The planning of windbreaks in residential settings, along with establishment techniques and particularly the selection of plant species and their spacing, should be developed and implemented by taking into account design principles, establishment methods, as well as protection and maintenance requirements. Considerations such as proximity to infrastructure elements and buildings are especially important. Therefore, the design and establishment of windbreaks in residential areas are of strategic significance and require architectural and engineering services. This section discusses the use of windbreaks within the context of greenbelt establishments and planting techniques around residential areas.

Facilities classified as wind barriers, though generally included within greenbelt concepts, differ significantly in terms of establishment, maintenance, and protection due to the use of non-living materials. These structures are typically implemented along highway networks (such as roads, bridges, and overpasses) and around residential buildings to mitigate the intensity of snow, blizzards, and wind, as well as to serve as noise barriers against sound pollution. Nonetheless, these structures should be built with durable, aesthetically pleasing, and environmentally compatible materials, based on proper engineering designs. In agroforestry practices, windbreaks composed of living materials are preferred over wind barriers.

To fulfill all these functions effectively, the areas designated for windbreaks whether in residential housing or in agricultural farm zones should not exceed certain limits. In urban contexts, land value must be considered, while in rural areas, the restrictions imposed on agricultural activities must be taken into account. A widely accepted principle in this regard, as noted by Naughton et al. (2008), is that the total value of the structures protected by windbreaks should not exceed 15% of the total value of the property, and the protected portion of the agricultural land should not exceed 5% of its total value.

Windbreaks serve critical functions for various structures in both urban and rural settlements particularly for residential buildings (such as houses, housing complexes, farmhouses, barns, and industrial facilities), and notably for home gardens, which hold particular importance. It is therefore useful to examine the benefits of windbreaks under key thematic categories.

Mitigating the Adverse Effects of Wind and Storms

In rural home gardens, windbreaks primarily serve to prevent or minimize damage to buildings caused by strong winds and storms. Their role in creating safe environments for residents during severe weather events such as wind-driven snow and rain, or hurricanes highlights the critical importance of windbreaks when considering the discomfort and destruction these conditions can cause to both buildings and living organisms.

Through their influence on climatic factors such as wind speed, temperature, humidity, evaporation, and precipitation, windbreaks help create microclimates that enhance the quality of life within and around residential areas. Turna (2022) emphasizes that wind is a significant factor affecting human quality of life, and that greenbelts around cities as well as rows of trees and shrubs planted as windbreaks around properties and along roads can positively influence living conditions by mitigating the discomfort caused by cold winter air and hot, oppressive summer conditions.

Providing Recreational Services

By enhancing visual quality and adding aesthetic value to the areas where they are used, windbreaks contribute to blocking undesirable views, fostering a connection with nature, and instilling a sense of appreciation for the natural environment. Recreation is an essential part of family life. Activities such as picnicking or barbecuing, playing ball with children, or gardening in a yard enclosed by windbreaks are significantly more enjoyable in the shade provided by trees. In home gardens, the seasonal variation in color created by windbreaks enhances the landscape value of buildings, which in turn increases their market value. Naughton et al. (2008) report that farm properties protected by windbreaks are valued approximately 15% higher than comparable unprotected properties. Similarly, Çelem & Uslu (2006) indicate that in Ankara, real estate located near green spaces designed for recreational purposes experienced a value increase ranging from 22.3% to 36.4% within a single year.

Promoting Energy Efficiency in Residential Areas

In residential areas, particularly around detached buildings, windbreaks established using woody plant

materials contribute to energy savings. The degree of savings varies depending on wind conditions as well as the location and design of the windbreak. In urban high-rise buildings, the effect may be lower due to the height of the vegetation used. However, in smaller residential buildings, including those up to four or five stories, and in industrial facilities, energy savings are achieved in summer through the provision of shade, which reduces the need for indoor air conditioning, and in winter by blocking cold winds and snow, thereby decreasing heating costs.

The energy efficiency of buildings is influenced by their orientation and the insulation of structural components such as walls, floors, ceilings, and windows. Live windbreaks, however, affect energy conservation under all circumstances. Even when doors and windows are closed, air movement inside and outside of a house cannot be completely prevented. Such air movement arises partly from temperature differences between indoor and outdoor environments and partly from wind pressure. During winter, the warm, light air inside a building tends to rise and escape through openings on the upper floors, while colder, denser air enters through lower openings to replace it. In summer, a reverse flow occurs, although generally to a lesser extent. Due to wind effects, buildings located in open areas tend to experience high levels of air exchange, and it is precisely in such locations that live windbreaks are most effective.

Energy savings in buildings also vary depending on general climatic conditions, building type, and the placement and growth status of vegetation (trees, shrubs, and bushes). The configuration of the plant material should ensure protection of both walls and roofs from prevailing winter winds. This is especially critical for buildings equipped with solar energy systems. Tree canopies must be positioned so as not to obstruct solar collectors or southern-facing walls. Therefore, the crown characteristics and growth rates of the selected tree species are of particular importance in relation to their proximity to the building. In a study conducted by Heisler (1986) on the impact of trees on energy conservation, it was reported that homes protected by windbreaks could achieve a maximum energy saving of 20–25% compared to unprotected homes.

The most significant impact of windbreaks on energy savings is observed in smaller buildings (one to three stories), particularly in detached and mobile homes. In 1982, over $63 billion was spent on energy in approximately 58 million single-family detached homes in the United States. This figure excludes the value of firewood burned for heating (Thompson, 1984). In traditional detached houses, approximately 53% of total energy use is for space heating and 12% for space cooling. Based on this, it is estimated that about $40 billion is spent annually on heating these homes in cold weather and cooling them during hot summers. This accounts for approximately 8% of total energy use in the U.S., and a 1% reduction in this energy consumption corresponds to an annual savings of $400 million (Heisler, 1986). Another study by Brandle et al. (1991) states that well-established windbreaks composed of shade trees or other functionally appropriate plant species can reduce energy consumption by 15–35% during summer months.

In another study on the energy-saving potential of windbreaks, it was found that among 800,000 farmhouses in northern parts of the United States, 300,000 lacked any form of wind protection. In regions with cold climates, windbreaks are estimated to reduce home heating costs by 10–20%. The average annual fuel consumption for heating a farmhouse is 9,400 liters. If a 15% reduction is achieved (300,000 houses × 9,400 liters = 2.82 billion liters), this would result in an annual savings of approximately 424 million liters. These values correspond to the stage when windbreaks reach an effective height, typically around 10 years of age. If this benefit continues over the lifespan of the windbreaks estimated at 40 to 50 years the total energy saved would amount to roughly 1.16 billion liters. Furthermore, it has been estimated that establishing windbreaks around these 300,000 unprotected farmhouses (assuming the planting of 400 trees per house) could result in an average CO_2 storage of 13 million tons by the age of 20.

Given that two-thirds of household energy consumption is used for heating (53%) and cooling (12%), windbreaks can yield average heating savings of 10–15% (DeWalle et al., 1983). A study conducted in the Nebraska region of the U.S. also demonstrated that a well-designed windbreak could reduce winter heating costs by up to 15% annually (Naughton et al., 2008). Considering that the minimum effective lifespan of a windbreak is about 30 years, the long-term energy savings become even more significant.

For optimal energy efficiency in homes, several criteria must be considered, including the location of the house, the species selection for the windbreak based on wind direction, species mixture and ratio, and whether evergreen or deciduous species are used depending on site-specific conditions. Depending on the climate type and wind intensity, enclosing a house with windbreaks on three or four sides when established according to proper technical standards can lead to maximum energy savings. Flemer (1974) reported that windbreaks surrounding a home on all sides reduced heat loss from air leakage by approximately one-third during winter, potentially resulting in a 50% reduction in heat loss and a 17% overall energy savings. In contrast, in homes with no wind protection, energy savings are expected to be only around 10–12%.

Brandle et al. (1991) also stated that well-designed and properly established windbreaks can reduce energy costs by 20–40%. This rate varies depending on individual energy use, local site and climate conditions, building quality, lifestyle habits, and the design and implementation of the windbreak system.

In Atlanta, USA, due to the long and hot summer season, it is estimated that approximately $400 is spent annually per household for cooling purposes. The cooling effect provided by existing trees results in an average savings of $28 per household, amounting to a total annual savings of $2.8 million across the city. This also contributes to a reduction in the amount of carbon released into the atmosphere (Anonymous, 2001).

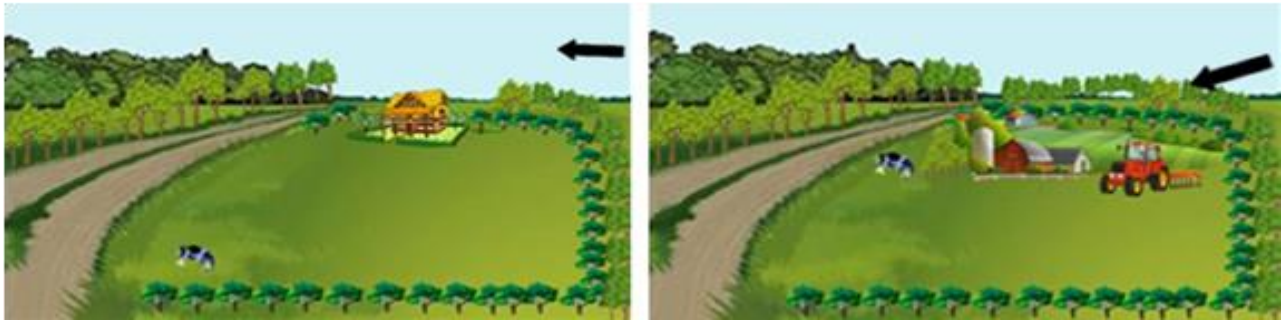

Figure 1. Windbreaks in Farmhouses and Facilities (Designed by E. Atar)

Enhancing the Ecosystem and Contributing to Biodiversity

Windbreaks contribute to ecosystem improvement and increased biodiversity through both the use of native and exotic plant materials during establishment and the creation of habitat areas for flora and fauna that naturally colonize the area post-establishment. They reduce evapotranspiration, thereby minimizing water loss from both soil and vegetation; they also mitigate dust and sand movement caused by wind, helping to prevent soil erosion. Through the accumulation of organic matter such as twigs and leaves, and the presence of subsurface roots that promote soil aeration, they ultimately enhance soil fertility and ecosystem health.

Furthermore, during heavy rainfall events, trees and shrubs through their leaves, branches, trunks, and roots help retain water or slow its flow, thereby reducing the risk of floods and creating safer environments for buildings and the organisms living within them. Windbreaks also serve as buffer zones between agricultural and residential areas, functioning as shared green spaces for both rural and urban populations. Grey and Deneke (1986) referred to trees as "nature's air conditioners," noting that vegetation helps balance air temperature through evaporation during the summer months. Under favorable site conditions with adequate water availability, a single mature tree can release up to 400 liters of water into the atmosphere per day via transpiration equivalent to the cooling capacity of five air conditioners running for 20 hours a day.

Mitigating Dust, Pollution, Pesticide Drift, and Noise Pollution

Windbreaks function as protective barriers against a variety of threats to quality of life including dust, pollution, pesticide drift, and particularly noise pollution originating from machinery, chainsaws, and other equipment within or near residential areas. They reduce noise by deflecting sound waves with large branches and trunks and absorbing them through leaves, needles, and fine twigs. It is well known that live windbreaks are among the most effective natural defenses against all types of pollutants and noise in residential zones, especially those caused by vehicles.

Exhaust emissions, pesticide drift, sound waves, toxic gases from industrial chimneys, and poor air quality negatively impact both the environment and public health, contributing to a wide range of illnesses.

Green areas act as natural filters, capturing airborne pollutants either by absorbing them or by trapping them on leaf surfaces. Windbreaks also help reduce odors and airborne particulates emanating from livestock pens, feeding areas near homes or farms, sewage treatment facilities, and other odor-emitting sources. In such cases, windbreaks composed of tall, evergreen coniferous trees and shrubs, with a recommended porosity of 50–65%, should be established near the odor source.

The visual appearance and functional roles of windbreaks around industrial sites and residential areas, in terms of controlling dust, pollutants, and noise pollution, during both summer and winter seasons, are illustrated in Figure 2. Tree rows planted around homes and buildings, as well as along roads and streets, not only provide a sense of privacy and security but also help obscure undesirable or unpleasant views. The effectiveness of these functions increases with the density of the planted trees and shrubs (Turna, 2017).

Providing Shelter, Food, and Nesting Sites for Animals

The native wild and cultivated plants, as well as exotic plant materials used in the establishment of windbreaks, serve as both nesting and food sources particularly for birds, but also for a wide variety of other wildlife. These areas also provide suitable environments for singing and breeding. Contrary to common belief, the presence of such wildlife in the vicinity tends to benefit farmers more than it harms them.

Windbreaks are also highly valuable in livestock farming. Among the artificial barriers used to reduce stress and prevent deaths caused by cold air and high winds in animals, windbreaks are one of the most effective solutions. Reducing wind speed is particularly important for farm animals, as strong winds can lower body temperature, leading to stress or even death.

Windbreaks also provide environmental benefits for livestock farms. For instance, they help block unpleasant odors carried by the wind around farm buildings and obscure unsightly views. For this reason, windbreaks are especially useful in reducing the environmental impacts of cattle farms and similar facilities. During calving or lambing seasons, surrounding animal shelters with windbreaks is also important for creating outdoor living areas that are protected from harsh weather conditions.

Providing Fuelwood and Food Products for Residents

The selection of multifunctional species adapted to the local ecological conditions of residential areas can significantly enhance the functional performance of windbreaks. Maintenance practices, especially pruning, yield stems, branches, and leaves that can be utilized for various purposes such as fencing, poles, fuelwood, construction wood, handicrafts, fodder leaves, and compost.

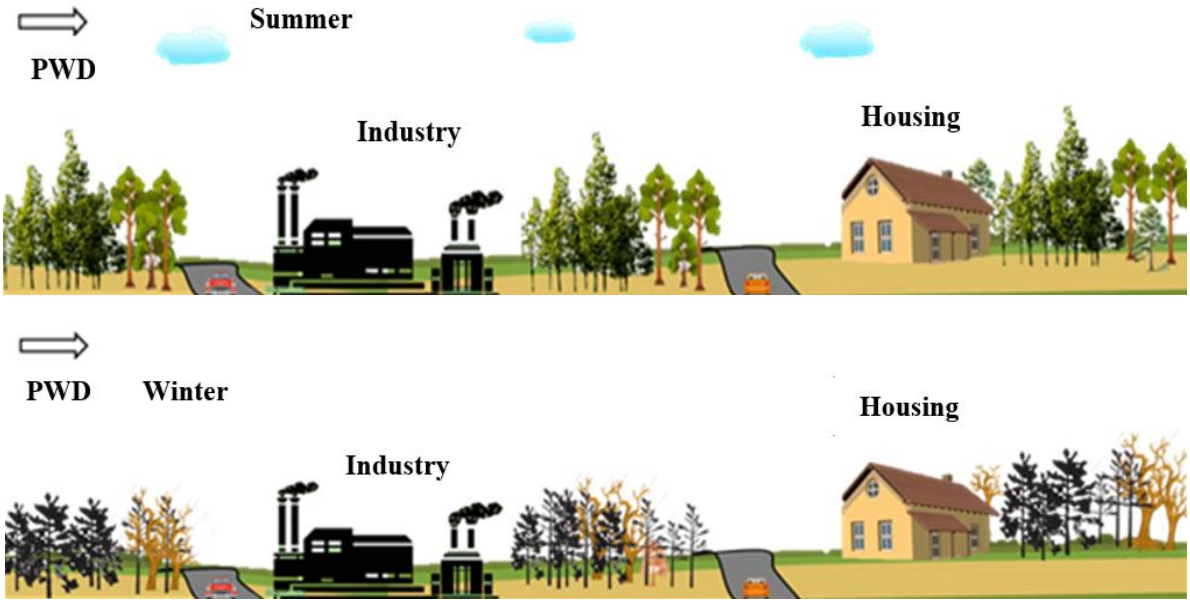

Figure 2. Summer and Winter Appearance of Windbreaks for Mitigating Dust, Pollution, and Noise in Industrial Facilities and Residential Areas (Designed by E. Atar)

The inclusion of flowering (for beekeeping) and fruit-bearing taxa can generate additional income. Depending on the plant species used in windbreaks, it is possible to cultivate a wide variety of valuable wood and non-wood products and services, such as medicinal and aromatic plants. In this way, windbreaks can serve not only their primary purpose but also contribute to meeting local food needs and providing supplementary income to the national economy through the production of timber, fruits, and vegetables. Moreover, windbreaks can offer protection for cultivated crops (e.g., fruits and vegetables) and domesticated animals in areas close to settlements. Turna et al. (2013) reported that windbreaks can help mitigate or eliminate biotic and abiotic problems, and that the choice of plant material allows for the production of a wide range of wood and non-wood products and services, especially medicinal and aromatic plants, thereby generating additional income beyond the primary function.

In a study by Turna (2001) on the use of linden trees in agroforestry systems, it was found that linden is commonly planted along the edges of tea plantations and particularly around tea collection centers and residences in the Rize region. Annual pruning of 1- to 2-year-old shoots for flower harvesting, the use of non-flowering shoots as animal feed, and management through shaped pruning in limited garden areas have been recorded. Some individuals also cultivate kiwi and grapevines in the same area to obtain multiple products from a single site.

Linden is utilized for various purposes, including leaf production, beekeeping, tea flowers, fuelwood and timber, soil conservation, landscaping, alley cropping, and beehive construction.

In a study conducted by Turna and Acar (2002) on rural home gardens containing plant materials used in residential areas, a total of 153 plant species were identified. Of these, 59 species (39%) were trees and shrubs, 43 species (28%) were bushes, and 51 species (33%) were herbaceous plants. When evaluated based on their agroforestry-related usage characteristics (17 different criteria), it was found that cumulatively 88% were used for medicinal purposes, 80% for ornamental value, and 53% for soil protection. Among trees and shrubs, the species with the highest number of functional uses were *Castanea sativa* (12 functions), *Taxus baccata* (10), *Robinia pseudoacacia* (10), and *Tilia* spp. (9). Among the shrubs, *Buxus sempervirens* (10), *Spartium junceum* (8), *Erica arborea*, and *Calluna vulgaris* (7) stood out. For herbaceous plants, *Onobrychis* spp. and *Capparis* spp. (7 each) ranked highest. The same study revealed that in an average 5-decare (0.5 hectare) home garden including the residence, approximately 57 plant species were cultivated, the vast majority of which were native species.

In regions with a continental climate, settlement tends to be clustered. In such locations, planting techniques particularly windbreaks play vital roles in protecting against summer heat and winter cold. Properly established windbreaks reduce snow accumulation in working areas, conserve fuel, and increase the overall value of the farm. In the Anatolian region, residential areas are typically located at the foothills of mountains or near water sources. In these types of settlements, windbreaks are often established not on an individual basis but rather as collective greenbelts, generally composed of *Salix* (willow), *Populus* (poplar), *Quercus* (oak), and where available coniferous species, planted in belts in the opposite direction of the prevailing wind, depending on local conditions.

Adapting to Climate Change and Contributing to Carbon Sequestration

The use of windbreaks around residential areas not only improves air quality but also contributes to carbon sequestration. In present-day Türkiye, despite the vast potential for their use in urban residential zones, industrial facilities, and especially rural home gardens, windbreaks remain largely underutilized. Historically, however, such practices were more commonly employed through traditional methods. Neither landowners nor public

institutions in Türkiye have fully grasped the importance of windbreaks. As is the case worldwide, environmental degradation due to global warming, along with increasing concerns over food security and the need for effective carbon sinks, have accelerated the search for sustainable solutions. One such solution is the implementation of windbreaks. To successfully develop and implement windbreak systems for carbon storage, it is essential to provide adequate financial support particularly for planting techniques and ongoing maintenance.

Reducing Fire Risk

In densely populated settlement areas where fire risk is high, windbreaks contribute to reducing the likelihood of fires and limiting their spread. By slowing the rate at which fires propagate, windbreaks support firefighting efforts. In rural clustered settlements, it is often difficult to combat wildfires, and controlling their spread becomes increasingly challenging. However, even in such densely built areas, the establishment of simple live windbreaks especially on the side opposite to the prevailing wind direction can help prevent fires from jumping between buildings and make fire suppression efforts more manageable.

Improving Living Spaces and Working Conditions

Green elements within residential areas such as windbreaks help regulate temperatures and can reduce or even eliminate snow accumulation around buildings, service areas, roads, and adjacent open spaces. In addition to mitigating physical damage, they help conserve valuable time and energy that would otherwise be spent on managing the impacts of wind and snowstorms, which make already difficult tasks even more challenging. Thus, protecting the living spaces around farmhouses or agricultural facilities with windbreaks provides multiple benefits, including the production of firewood and construction wood, and the provision of fodder for animals.

Windbreaks also play a role in improving mental well-being by offering sensory experiences such as the rustling of leaves, birdsong, and the colors of autumn foliage. They create a sense of privacy and security while strengthening the human connection with nature. However, in residential areas, the use and maintenance of windbreaks require far greater sensitivity compared to rural areas. Even a minor oversight can lead to loss of property and potentially life. Therefore, windbreaks established in residential zones must be maintained and protected continuously and in accordance with proper technical standards. In particular, plant materials affected by abiotic stressors especially climate change must be subjected to appropriate care measures such as pruning, structural support, and wound treatment. Individuals that have lost productivity or are no longer fulfilling their intended functions should either be replaced or restored through corrective pruning.

Structure, Composition, and Establishment of Windbreaks

Windbreaks are generally designed according to specific technical principles. The structure and design should first be determined based on their intended function, and this requires accurate site selection primarily considering site conditions. The primary goal in site selection is to ensure maximum protection for homes, buildings on farms, and associated living and working spaces. A key criterion in this process is identifying the prevailing wind direction and clearly understanding the intended purpose of the windbreak. Following this, the objective is to either minimize the impact of wind on residential buildings (e.g., homes, barns) and their surroundings or to use wind in a controlled manner to enhance quality of life.

Functionality is especially critical in traditional settlement areas and their surroundings. In older residential gardens in particular, windbreaks and other functional uses (such as shading, aesthetic enhancement, and multifunctional plantings) have traditionally involved dense use of plant materials in the form of trees, shrubs, and bushes. For instance, in the Eastern Black Sea region, *Laurus nobilis* (bay laurel) and *Prunus laurocerasus* (Caucasian whortleberry) are commonly used around scattered settlements as windbreaks, while bay laurel and linden are preferred for their aromatic leaves and flowers.

The establishment principles of windbreaks vary depending on the location of the residential area, the spatial arrangement of buildings (e.g., scattered, clustered, or grouped), and the amount of open space surrounding the structures. In regions with dispersed settlements such as the Eastern Black Sea each building is typically surrounded by its own independent greenbelt and is treated like a rural home garden. In contrast, in the more common clustered settlement patterns seen across other regions of Türkiye, windbreaks are established in a more unified manner around groups of buildings. Regardless of the type of settlement, windbreaks or greenbelts should always be established perpendicular to the prevailing wind direction.

Following site selection, a thorough analysis of site conditions particularly soil characteristics should be conducted. Unlike in agricultural fields, design parameters such as windbreak height, porosity, spacing, and length are not the primary considerations. Nevertheless, depending on wind speed, appropriate plant species selection and spacing requirements must be followed. The porosity of the windbreak may become especially relevant depending on its width. In residential areas, single-row windbreaks are commonly used, and spacing between rows is generally not applied. However, in windbreaks composed of two to five rows, the height and porosity of the barrier become just as important as species selection and spacing. Indeed, according to the USDA (URL.1), a porosity of 50–60% is recommended for windbreaks intended for roads and buildings. For practical purposes, windbreaks in high wind intensity areas should have a porosity between 60–80%, for medium wind intensities between 40–60%, and for low wind intensities, less than 40% (Kafer et al., 2022).

Selection of plant material

The plant species to be used must possess certain desirable characteristics. Selected plant materials should include multipurpose woody species such as trees, shrubs, and bushes, as well as herbaceous species such as vegetables and fruits. Additionally, species capable of providing medicinal and aromatic products or other non-wood forest products and services should be prioritized. Taxa should be chosen for their ability to enhance recreational (visual) value and create habitat areas for wildlife. Moreover, these species should exhibit resistance to biotic stressors such as insects, fungi, and other pathogens, and should not be susceptible to early or late frosts. They must also be tolerant of abiotic stress factors such as strong winds, storms, and drought.

When selecting species, priority should be given to native taxa that naturally occur in the region for wild species, while cultivated species should be capable of adapting to the local site conditions. Additionally, care must be taken to avoid species with excessive crown or root spread that could damage nearby roads, buildings, or other infrastructure components, as well as those that could serve as alternative hosts for undesirable pests or that exhibit invasive characteristics.

Türkiye possesses a wide variety of plant materials suitable for use in residential areas. The key is to select species that are well-adapted to local ecological conditions and capable of providing multiple products or functions. Although species preferences may vary by geographic region, the intended use of the plant material should guide selection. For farms and residential areas, broadleaved species are generally preferred over conifers, although evergreen broadleaved species are recommended for inclusion to ensure year-round windbreak effectiveness. In contrast, coniferous species such as pyramidal cypress may be suitable around barns or industrial facilities.

In general, suitable tree and shrub species for residential areas include hybrid black poplars, Lombardy poplar, eucalyptus, willow, ash, maple, oak, and ironwood. Among shrubs and small trees, *Pyracantha coccinea* (firethorn), *Elaeagnus* spp., *Tamarix* spp., *Crataegus* spp. (hawthorn), *Paliurus spina-christi*, *Rosa canina* (rosehip), *Vitex agnus-castus*, *Prunus laurocerasus* (Caucasian whortleberry), and *Laurus nobilis* (bay laurel) are commonly recommended. Of course, the number and diversity of potential species are much broader. Rather than focusing solely on which species or how many to select, decisions should be based on the ecological characteristics of the site and the secondary or tertiary objectives of the windbreak installation. In a study on the selection of multifunctional plant species for agroforestry applications in the Mediterranean Region, Turna (2012) evaluated a wide range of plant species in terms of ecological adaptability, productivity, functional value, individual traits, and their ability to coexist with other species.

In a study conducted by Taşçıoğlu (2022), plant species used in the home gardens of 10 different architectural examples located within the urban conservation areas of Kilis and Trabzon were examined. The study identified 35 different plant species in Trabzon and only 6 in Kilis. When the natural flora and biological characteristics of a region are well understood, species selection does not present significant challenges. The fact that many plant species originate from Türkiye, combined with the presence of rich genetic resources such as the Turkish Seed Gene Bank and a wide variety of ecotypes adapted to diverse geographical conditions, demonstrates that species selection should not be difficult. Indeed, Türkiye holds a unique position in terms of plant diversity, situated at the intersection of three major floristic regions. Due to its geomorphological, topographical, edaphic, and climatic features, it hosts a wide range of habitats, resulting in a high richness of plant species and endemism. According to Turna et al. (2018), in the Eastern Black Sea Region where hazelnut and tea cultivation dominate rural home gardens commonly feature integrated plantings such as linden + tea + various fruit trees (e.g., pear, orange, mandarin), tea + kiwi, tea + pear + mandarin + orange, and mixed rows of tea + corn + beans + linden. In areas where hazelnut cultivation prevails, hazelnut is often planted in clusters with fruit trees and linden, while species such as *Prunus laurocerasus* (Caucasian whortleberry) and *Laurus nobilis* (bay laurel) are used specifically as windbreaks.

To reduce wind speed in residential areas, both non-living structures commonly referred to as wind barriers or windbreak panels and living windbreaks are employed. In agroforestry applications, the systems utilized are primarily windbreaks established using live plant material.

The planning process consists of three main stages: office work, field inventory, and project development. During the office phase, the location of the buildings where windbreaks will be established, as well as the ecological characteristics of these areas, are analyzed. In the site preparation phase, based on wind direction and intensity, decisions are made regarding the placement (orientation and exposure), spacing, species selection, spacing values for the selected species, and planting sites, which are then marked on the ground.

Project design is carried out in accordance with soil preparation and planting methods (seed sowing or seedling planting), as well as protection and maintenance requirements. In order to reduce energy use in summer and block cold winds in winter, windbreak design should be adapted to the orientation and characteristics of the structures. Furthermore, the planning and design should always consider multifunctional purposes.

In terms of *planting techniques*, pit planting methods are preferred for woody species to ensure the rapid and effective establishment of windbreaks and to realize their benefits in a shorter period. It is recommended that seedlings be container-grown and meet the appropriate quality standards. For multifunctional plant materials to be used between the windbreak and residential buildings, other suitable planting methods may also be employed.

In terms of *planting configuration*, the use of pure stands of broadleaved trees, shrubs, and small trees is generally preferred, while incorporating evergreen broadleaved species into the mix significantly enhances effectiveness in terms of porosity. This is particularly important to maintain the windbreak effect outside the growing season. As a result, benefits such as reducing snow drift in winter, achieving a more uniform distribution of snow, and providing necessary shade for buildings can be realized.

The spacing between species in the windbreak should be determined based on the characteristics of each species, particularly their biological traits (such as flowers, fruits, and foliage). Attention must be paid to root system compatibility, ensuring a proper mix between shallow-rooted and deep tap-rooted species. To prevent roads and buildings from being adversely affected by prevailing winds, the windward side of windbreaks should be composed of evergreen species especially conifers while the leeward side, facing roads and buildings, should consist of deciduous species. The porosity of the windbreak should follow the recommended standard of 50–60%. This configuration is especially effective for protecting roads and structures from winter storms. Additionally, windbreaks should be planted at a distance equivalent to 15–35 times their height from the road to achieve optimal protection.

The planting location and configuration of windbreaks may vary depending on the position of buildings within residential areas. Windbreaks can be designed as straight, multilayered rows perpendicular to the prevailing wind direction or as curved formations. The key considerations are the location of the residence and the size and shape of the area it encloses. Additionally, the construction technique, architectural design, and structural layout of the building also influence the placement and form of vegetation.

For instance, in buildings designed to utilize solar energy, the height and crown dimensions of the selected plant species as well as their orientation with respect to sun exposure are critical. Similarly, criteria such as enhancing visual aesthetics or creating privacy around buildings also play a role in determining planting location and configuration. The geographic characteristics of the site such as aspect, slope, and elevation along with the intended purpose(s) of the windbreak and wind-related variables like speed and direction, must all be considered together when planning windbreak establishment.

The spacing between plant materials varies according to the site characteristics mentioned above, as well as the species selected for the windbreak. While the primary purpose is to reduce wind speed, it is equally important to be precise in species selection and spacing for multifunctional benefits.

It is recommended to plant trees at a spacing of 2.5–4 meters within rows and 3–6 meters between rows, alternating between coniferous and broadleaved species. Similarly, the second row should consist of a mixture of coniferous and broadleaved small trees (shrubs). For small trees, the spacing between rows and between species should be shorter than for larger trees (2–4 meters between species). Shrubs are planted at 1–2-meter intervals along the outer edge of the windbreak (Turna et al., 2024). According to Ürgenç (1966), row spacing generally ranges from 1 to 3 meters. For instance, in Lombardy poplars, the spacing is 1–1.5 meters, while in hybrid poplars, it is 2.5–3 meters. The spacing between seedlings within rows can range from 1.5–3 meters for trees and 0.5–2 meters for shrubs.

Maintenance and Protection

In individual buildings and residential areas, maintenance and protection measures must be implemented after installation to ensure that windbreaks provide the intended benefits, thereby enabling sustainable and optimal use. Therefore, maintenance activities must be carried out during both the establishment phase and throughout the development period. This includes the preparation of a maintenance and protection plan and an implementation guide, in collaboration with property owners or residents. In agroforestry applications, windbreaks formed by grasses, herbaceous plants, shrubs, and trees each serve distinct functions and roles within the ecosystem. For this reason, proper maintenance is crucial to ensure that windbreaks continue to serve the property owner's objectives over the long term. Among these, the following maintenance tasks should be implemented:

- Removing dead, damaged, and diseased individuals after installation and replacing them with suitable species,
- Managing live cover during the first three years, irrigating during dry periods, and replacing dead or underperforming individuals if necessary. Additionally, pruning should be carried out to adjust windbreak porosity and regulate snow distribution,
- Regular inspections for diseases, controlling live cover, reducing moisture loss, and applying mulching for organic matter contribution,
- Implementing silvicultural techniques to create a layered structure while producing multifunctional products. Windbreaks should be gradually renewed and repaired in cases where they reach the end of their natural life, lose growth energy, or suffer from top collapse and increased dieback due to various diseases,
- The selection, sterilization, and potential environmental impact of materials used in maintenance should be carefully considered,
- Pruning maintenance and other relevant activities should be carried out to control the development of plants.

The success of windbreak installation efforts in residential areas will be greatly enhanced if they are in harmony with nature. Indeed, Turna et al. (2021) emphasize that under the heading "Nature Conservation-Oriented Afforestation," agroforestry practices are considered among the forestry activities that are in line with nature conservation. In general, for windbreaks to be established according to technical standards and to fulfill their intended objectives, maintenance and protection measures must be carried out in a timely and continuous manner.

Conclusions

The establishment and sustainability of windbreaks, an important agroforestry practice, in residential areas requires a thorough evaluation of the contributions they provide to homes, their surroundings, and especially the users.

As outlined in the nine subheadings above, the use of windbreaks in residential areas holds great significance in geographies like Türkiye, where diverse ecological conditions prevail. As is well known, Türkiye is one of the rare countries with the ability to be self-sufficient, particularly in food production, due to its geopolitical position and favorable environmental conditions, and it is rich in a variety of natural resources. However, these resources need to be addressed, evaluated, and translated into practical applications based on scientific data. Climate change scenarios, the increasing rural-to-urban migration, an aging population, and innovative developments in industry make it necessary to adopt different land use strategies, which should adhere to nature-based land capability classes. This has led to unsustainable land-use practices, such as the conversion of agricultural land into urban areas, forested areas being turned into agricultural lands, and grasslands and pastures being afforested. As a result, significant problems are arising in land use and resource management, and improper interventions in nature are leading to various natural disasters, the most important of which is food insecurity.

In Türkiye's geographically diverse regions, different land-use and crop cultivation methods should be explored based on evolving technologies, and both scientific and practical studies should be initiated. Decisions should be made in coordination between government and civil society organizations, and necessary support should be provided. It is essential that sustainable, scientific, and technically appropriate planning, design, implementation, and management processes be approached holistically, in harmony with the general characteristics of residential areas.

Taking global climate change scenarios into account, appropriate actions should be taken to address potential biotic (living) and abiotic (wind, storms, etc.) threats, as well as food security issues that may arise during drought conditions. Windbreaks, as part of agroforestry models, should be emphasized in efforts to achieve sustainable land use and create a livable environment. One of the most important tasks to achieve maximum yield from a unit area, leveraging new technological developments, is to study and harness nature effectively.

In countries like Türkiye, where natural gas resources are limited, the use of plant material in the form of windbreaks in residential areas is of great importance. Although it is well-known that plant materials have significant effects on both solar radiation and wind, it is unfortunate that such practices have been abandoned. In some residential areas (such as hobby gardens or neighborhoods with relatively high-income levels), plant materials are often regarded solely for their aesthetic value, which should be reconsidered. However, the multifunctional roles of plant materials, especially in terms of energy savings in buildings, are crucial in residential areas. Therefore, for plant materials around residential areas, particularly around buildings, to be functional (e.g., energy savings, product diversity), they must be established according to proper techniques and maintained accordingly.

Historically, in the Anatolian region, the plant species used in the home and site gardens of ancient settlements were chosen based on their functional, socio-cultural, and ecological characteristics, rather than just their aesthetic value. In contrast, modern home and site gardens, as well as green spaces in urban areas and their surroundings, often emphasize aesthetic and visual qualities, with ornamental plants being predominantly preferred. Within these, the use of exotic species is notably high. The intended purpose, form of establishment, and expectations of plant materials in residential areas are largely influenced by the socio-economic status of the residents, their aesthetic desires, and occasionally, their traditional habits and cultural characteristics.

The use of windbreaks in agroforestry applications, especially in residential areas such as rural home gardens, requires research and adaptation efforts tailored to the socio-economic structure and, particularly, the ecological conditions of each region. For example, in a humid and sloped area like the Eastern Black Sea Region, windbreaks in dispersed rural home gardens require very different approaches in terms of design, species diversity, and use preferences compared to windbreaks to be established in locations with relatively lower slopes, clustered settlements, and a more arid climate, such as in the Southeastern Anatolia Region.

Although it varies by geographic region, understanding the importance of windbreaks in both urban and rural residential areas, along with the ability to maintain and protect them sustainably, requires raising awareness and providing education for property owners and managers. Plant materials, with their multifunctional properties, hold significant value not only for their static functions but also for their dynamic characteristics, contributing to the quality of life in both urban and rural settlements.

Reducing the adverse effects of sudden and unexpected weather events caused by global climate change in the areas where we live, and making residential areas more resilient to these impacts, is possible by utilizing scientific data according to the features provided by ecosystems and acting in accordance with land capability classes.

The establishment of windbreaks in residential areas not only provides protection against climatic challenges but also offers multifaceted benefits, such as energy savings, biodiversity, aesthetic values, and food security. Promoting agroforestry applications tailored to local conditions in Türkiye's diverse ecological regions is of great importance. In this regard, cooperation between public institutions and the private sector should be increased for the planning, establishment, and sustainable management of windbreaks, and awareness-raising and educational programs should be organized. Furthermore, scientific and applied research should be supported to encourage the development of these practices to meet local needs.

Declerations

Author Contribution Statement

İbrahim Turna: Investigation, formal analysis, supervision, conceptualization, and writing the original draft.

Fahrettin Atar: Methodology, writing the original draft, review and editing

Deniz Güney: Investigation, writing the original draft, review, and editing.

Ali Bayraktar: Investigation, review, and editing.

Conflict of Interest

The authors declare no conflict of interest.

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