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The effect of agroforestry farming on wood quality and timber industry and its supportation by Horizon 2020

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Abstract One of the goals of the European Union's agroforestry plans is to alleviate the shortage of timber in Europe caused by the growing demand for hardwoods and the declining import of tropical timber. The study shows which tree species can be considered in agroforestry systems in Europe, and which of them can be used as raw material for the wood industry and what quality of wood can be produced in agroforestry systems. Since 2005, the European Union has been officially encouraging farmers to plant the crops in an agroforestry system and parallel try to produce trunks for high quality timber. By analysing the current economic developments of the European Union, especially Horizon 2020, our study provides an overview of what can be expected by the participants of the agroforestry sector and the related primary wood industry in the European Union now and in the future. In addition to the distribution analysis, indices describing projects have also been created. Rank correlation was used to examine the relationship between them. Possible decision mechanisms were also outlined using a custom-built expert software system.

Keywords Coordinator role · Growing area · Project contribution · Sustainable development · Timber quality · Wood species

Introduction

The word 'agroforestry' was first used in 1977 to define a combined system of forestry and agriculture. The definition of Lundgren (1982) describes the concept very well: "A collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) or livestock, in a spatial arrangement, a rotation, or both; there are usually both ecological and economic interactions between the trees and other components of the system ". Although the definition is recent, the practice of integrating trees into agricultural systems existed for thousands of years (Smith 2010; Augére-Granier 2020). However, it may have been originally developed the opposite way: presumably, people first planted crops in forests, among trees.

As Lundgren (1982) implied, agroforestry can play a key role in creating a synthesis of efficient agricultural production and sustainability. Its importance is being recognized by more and more international organizations. These modern systems were scientifically introduced towards end of the 1970s and were designed to find a balance between protecting the environment and increasing yields (Smith 2010).

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Agroforestry systems have a lot of variants, and which one is used depends on local factors: environment, human habits and demands. Focused only on trees, there are two main agroforestry groups that can be further subdivided. Using trees which have valuable crops (these may also be suitable for human consumption or animal feed), or using trees only to ensure shade for newly planted trees, stabilize the soil water balance, and produce logs for industry, etc. These are fast-growing species, ensuring the necessary conditions for the supported plantation in a few years, resulting in a much higher wood yield and shorter harvesting cycles compared to the crop-tree-based agricultural systems. The demand for hardwoods in Europe has increased, while availability of tropical hardwoods has been reduced. These processes led to the expansion of agroforestry designed for the production of high quality sawlogs and thus timber. This way agroforestry may be a good solution to alleviate the timber shortage (Eichhorn et al. 2006). The wood from agroforestry systems is good for both industrial use as solid wood (timber), wood chips or pulp, and firewood. There are many tree species used around the world in different agroforestry systems to provide food, forage, industrial raw materials, fuel and mulch, while increasing income. In Asia sandalwood (*Adenanthera pavonina*) is commonly used for shade to produce various crops, e.g. coffee. Its leaves bind large amounts of nitrogen so it enriches the soil as green manure. All parts of this tree species (leaves, seeds, bark, and timber) can be utilized in many ways (Echo Community 2022). But sandalwood is just one example of the wide range of uses for a well-chosen tree species.

Decades after the introduction of modern agroforestry, financial support for agroforestry has also appeared in the European Union's (EU) support policy. The Common Agricultural Policy (CAP) has made agroforestry a priority since 2001. One of the main goals is to provide more timber for the European wood industry. Support for agroforestry is still an important element of the common agricultural policy. However, it is questionable whether the importance of agroforestry is considered an important element in the support of scientific and research and development projects in the EU. The purpose of this study is to introduce the European situation. Mainly focusing on the state of agroforestry in Europe. This study is concerned with the importance and main structural features of agroforestry projects in Horizon 2020, as well as with the tree species available in agroforestry systems and their potential use in the timber industry.

Materials and methods

As a first step in the study of the Horizon 2020 project, 174,438 records of project participations, 285,616 records of publications and 127,583 records of deliverables as downloadable data from the CORDIS database were transformed into a manageable relational database (Cordis 2020). This was quite hard work, as the dataset did not follow the database management principles in all cases. The database provides an opportunity to examine the data of all Horizon 2020 projects as of 30 September 2020. No more recent data is available by the submission of this paper. The database should be continuously updated for later research until the last project closure.

The data from the original sources (Eurostat 2019; Cordis 2020; Faostat 2020) were filtered and corrected during the analysis of the projects. Agroforestry projects were filtered using 28 keyword combinations. Then the filtered file was individually content checked. This was followed by an analysis of the supported projects using statistical methods. Then, with the help of the Doctus expert system (BME—Human Excellence Ltd, Budapest, Hungary), the hidden decision-making mechanisms of the evaluation of grants were explored, and in short, their efficiency measured by analysing the outputs of projects. The data sources and the main calculations were made available online by Novotni and Tóth (2022).

Results and discussion

In European agroforestry systems, a wide variety of tree species can be found due to the different climatic and cultural conditions. Agroforestry practices are most important in the Mediterranean and boreal regions of Europe. Since agroforestry is a very flexible system, a lot of classifications can be created. Nair (1985) defined three types of agroforestry, but a much more precise definition belongs to Mosquera-Losada et al. (2009), where agroforestry systems are divided into six main types with various tree species:

- Forest farming
- Improved fallow
- Multipurpose or high value trees
- Riparian buffer strips
- Silvoarable agroforestry (alley cropping)
- Silvopasture agroforestry (grazing livestock).

Both Nerlich et al. (2013) and Gyuricza and Borovics (2018) used similar classification types. For most people outside agroforestry, the best known version is **silvoarable** agroforestry, where the trees are spaced widely and the areas between trees are cropped with annual or perennial plants. Taghiyari and Sisi (2012) stated more than 40% of research studies in international agroforestry research institutions are devoted to this practice. Trees can be positioned in a scattered way, in alleys, and in lines. These systems usually use *Castanea sativa, Eucalyptus* spp., *Ficus carica*, *Fraxinus* spp., *Juglans* spp., *Olea europaea*, *Pinus* spp., *Populus* spp., *Prunus* spp., *Quercus* spp. including cork oak, and *Robinia* spp. species (Mosquera-Losada et al. 2009, 2011; Nerlich et al. 2013; Burgess and Rosati 2018; Augére-Granier 2020). The nitrogen-fixing capacity of trees (*Robinia*, *Prosopis*, *Alnus* and *Eleagnus*) is also an important aspect in the nutrient supply of the crops grown among them (Smith et al. 2012). Certain combinations of arable agroforestry still occur, such as cereal forests, and olive groves combined with cereals or vegetables in the Mediterranean (den Herder et al. 2017; Augére-Granier 2020). According to Reisner et al. (2007), *Juglans* spp., *Prunus avium* and *Populus* spp. are mostly appropriate for the silvoarable agroforestry in temperate climate, whilst *Pinus pinea* and *Quercus ilex* typically correspond to the Mediterranean region. Studies of lower quality farmlands have shown that silvoarable agroforestry results in land values similar to traditional farming systems (Garrett and Buck 1997).

If forested areas are used for producing natural medicinal, ornamental products, or culinary food, then we are talking about **forest farming**. The mostly used tree species in these systems are *Quercus coccifera*, *Quercus ilex, Quercus robur* for truffles; *Abies* spp., *Castanea* spp., *Fagus* spp., *Picea* spp., *Pinus* spp., *Quercus* spp. for mushroom; *Abies* spp., *Betula* spp., *Fagus* spp., *Picea* spp., *Pinus* spp., *Quercus* spp. to produce small fruits on herbaceous plants and shrubs.

But in the EU, agroforestry is characterized mainly by **silvopastures** with either deciduous forests or grasslands, where trees are rare (Mosquera-Losada et al. 2009; Nerlich et al. 2013; den Herder et al. 2017). This type of agroforestry system uses grazing livestock and normally not densely planted trees on the same land. Usually *Castanea* spp., *Eucalyptus* spp., *Fagus*, *Fraxinus* spp., *Picea* spp., *Pinus* spp. *Populus* spp. and *Quercus* spp. are used. Of course, other conifers also occur in silvopastoral systems, for example *Larix decidua* in Italy (Smith et al. 2012; Augére-Granier 2020). A newer idea in silvopastoral systems is that the leaves of several tree species (ash, alder, willow, etc.) can be used as fodder for livestock (Burgess and Rosati 2018). However, other systems also exis: traditional olive groves in the Mediterranean and orchards are crops grazed in the continental and Atlantic regions. In Mediterranean areas different oak species (e.g. *Quercus pyrenaica*) including cork oak are also planted (Augére-Granier 2020). Balander and Dupraz (1999) presented a successful large-scale experiment, where *Acer pseudoplatanus* L., *Castanea sativa* Miller, *Fraxinus excelsior* L., *Juglans* spp., *Liriodendron tulipifera* L., *Paulownia* spp., *Populus* spp., *Prunus avium* L., *Pyrus communis* L., *Quercus* spp. and *Sorbus* spp. species were used largely in silvopastoral systems and to a lesser extent in silvoarable systems in France.

For **riparian buffer strips** many tree species are used to protect surface water resources, mostly willow, alder and varieties of ash, elm, maple, oak. High quality logs can be harvested from some tree species: *Acer pseudoplatanus* L., *Alnus cordata* (Loisel.) Duby, *Alnus glutinosa, Betula alba* L., *Betula pubescens* Ehrh., *Celtis australis* L., *Fraxinus angustifolia* Vahl, *Fraxinus excelsior, Ulmus glabra* Huds, *Ulmus minor* Mill., *Populus* spp., *Quercus robur* (Mosquera-Losada et al. 2009). The term "high quality log" covers that the harvested logs can be sold to sawmills with a high grading level or even used in the veneer industry. For veneer production, only straight and well-rounded, defect-free logs (no knots, fissures, warps, spiral grain, uncentered pith, insect holes, discolouration, decay, etc.) can be used, or some very minor defects are allowed, when its diameter is large (Cassens 2004). The high-grade sawlogs may contain some small defects up to a point (knots, stress fractures, sweep, etc.) depending on the exact grading. Unfortunately, no standard log grading rule exists. The grading aspects depend on the species and the individual agreement between the partners, i.e. local and subsequent use patterns. And, of course, short logs or logs with a small diameter cannot be classified as high grade either (Taylor 2009; Self and Cunningham 2021). In order to give a clear example, a grading by Taylor (2009) is as follows: a 'Grade 1 (F1)' log has at least a 34 cm diameter inside bark at the small end, and a minimum length of 3 m; sweep may be maximum 15%. The most important and most common defects are knots, decay and shake as well as specific end defects (wormholes, bird pecks, spots and streaks), which should not extend more than half the distance from the heart zone to the bark. Stain is restricted. Any abnormality in the "heart centre" can be ignored. High quality logs are the key to high quality timber. A 'Grade 1 (F1)' log will yield at least 60% common or better timber (Wengert and Meyer 1994; Taylor 2009). A related topic is the grading of a timber; it depends mostly on the defects (knots, fissures, warp, decay, etc.) and, of course, on the dimensions. The total value of timber produced, will vary with the log grade (Wengert and Meyer 1994). Thus, if the right species are planted and properly managed, then riparian buffer strips can also be included in the category of the agroforestry system with high value trees, as discussed later.

The **improved fallows** formerly used leguminous woody species as *Cytisus striatus* (Hill) Rothm., *Genista florida* L., *Ulex europaeus* L. Nowadays only a few plantations of this kind exist, and they contain fast-growing trees during the fallow phase of shifting cultivation (Mosquera-Losada et al. 2009). These trees are valuable trees on the market, so they can also be classified as parts of the high value trees agroforestry system.

In 2001, industrial plantations accounted for only about 5% of total forest area, but provided 35% of the world's wood supply (Holding Anyonge and Roshetko 2003). The estimated area of agroforestry is 15 421 000 ha which is equivalent to 8.8% of all agricultural land (den Herder et al. 2017) and to 9.7% of the forest area in the EU. If reindeer husbandry is included in Northern Europe, the total area of agroforestry covers about 52 million hectares (Augére-Granier 2020). Köble and Seufert (2001) found 115 forest-tree species in the European Union, of which only 36 species cover 95% of the whole forest area. Most of these species can be used in European agricultural forestry. Arable lands, permanent pastures and designated permanent crops are currently eligible for direct agroforestry support, but farmers may opt out of these direct payments if the selected tree species on their arable land exceed the density of 100 trees per hectare or a certain level of land cover (Burgess and Rosati 2018; Augére-Granier 2020; European Union 2021).

There is a tendency to apply agroforestry systems using **high value trees** planted in cropland or pasture or riparian buffer strip. Thus, the agroforestry type high value trees overlaps with several other agroforestry types, but still differs from them because of its emphasis on exploiting the value-creating potential of trees. The term"high value " primarily involves the cultivation of fruit trees (e.g. apple, cherry, olive, orange, pear, different nuts, oak) and the crops can be sold directly on the market or used as animal feed is also important. Another benefit is the production of high value logs and timber, in many cases without growing fruit. Poplars (*Populus* spp.), silver maple (*Acer saccharinum* L.), willows (*Salix* spp.) and black locust (*Robinia pseudoacacia* L.) have a rapid juvenile growth, resulting in high volumes per hectare. Hardwood chips are in constant demand by various industries (Garrett et al. 2009). The preferred goal of the European Union would be to produce timber from high value trees, which is in the long-term interests of farmers and the environment. The most often used species are *Alnus* spp., *Betula* spp., *Castanea crenata* Sieb. & Zucc., *Castanea sativa* Mill., *Fraxinus* spp., *Morus* spp., *Pinus pinea*, *Populus* spp., *Robinia* spp., *Quercus ilex* L., and *Quercus suber* L. In Europe nowadays chestnut woodlands have the highest economic importance in the category "high value agroforestry trees" due to their valuable timber and nuts. That is the reason for the establishment of many chestnut hybrid plantations in the recent decades (Brix et al. 2009; Mosquera-Losada et al. 2009; Burgess and Rosati 2018).

From an environmental point of view, storing carbon in wood products for a longer period of time is very favourable. Moreover, usually the end-products made from the timber of slow-growing species last longer than pulp and paper made from fast-growing species such as *Eucalyptus* spp. (Mosquera-Losada et al. 2011). The amount of carbon stored during forest growth in sustainably managed forests is offset by the transfer of carbon to wood products and the decomposition of the residues after harvesting (Lippke et al. 2010). Globally, woodlands contain 80% of all aboveground and 40% of all belowground terrestrial carbon, and thus have a great influence to the atmospheric greenhouse gases (Geng et al. 2017). The global area of woodlands in years between 1987 and 1990 was 4165 million hectares (Mha) and its annual decrease is estimated as 15.5 Mha. Forest vegetation contains about 359 gigatons (Gt) and soil contains about 787 Gt of carbon, which means an average 0,275 kilotons/ha of carbon density (Dixon et al. 1994). As forest cover decreases, so does carbon sequestration capacity, which can be improved, for example, by long-term use of wood products. Nowadays globally 4800 Mha area (9.5% of the total land surface) is used for agriculture (Ritchie and Roser 2019). The tree density in agroforestry systems is usually sparse (Rigueiro-Rodríguez et al. 2009), but if we take into account the area of agricultural lands of the world, this could mean a huge amount of trees and carbon sequestration, by spreading agroforestry systems. Siarudin et al. (2021) found an average above ground carbon density of 0.037 kilotons/ha for agroforestry systems; so the total carbon storage capacity of the agricultural tree stock would be 177.6 Gt, a very significant amount compared to the conventional forests. Replacing fossil-based materials with wood can greatly reduce carbon dioxide in the atmosphere (Geng et al. 2017). Thus, if there is a higher proportion of high quality trunks in these areas, then more wood can be used later in the timber industry and will be able to store carbon for a long time as buildings, furniture, etc.

A wide variety of tree species have been already listed that are used in different agroforestry systems. These trees may be able to provide crops (fruit, olives, nuts, berries, and edible flowers), honey, fodder (leaves, nuts, and sprigs), raw material for craft products and medicines, gums and resins, biomass (leaves, bark, and wood chips), log, firewood, etc. Of course, the logs of the "high value trees agroforestry system" are the most interesting for both veneer and sawmill processing, especially since these systems are becoming more prevalent. It is expected that the tree species that are most suitable for agroforestry will be those that allow sunlight to pass to the plants grown under them due to their low branch density, are self-pruning and have good leaf distribution. Low branch density and self-pruning will have a significant impact on the final quality of the log (Mosquera-Losada et al. 2009; Nerlich et al. 2013). To have the most valuable trunks possible, the target is a defect-free bottom log of 3 to 6 m height, adapted to the tree species and the site potential. The reason is that 80% of the value of the tree is concentrated in the bottom log (Dupraz 1994). According to Nerlich et al. (2013) the right tree species must be pruned to a height of 7–10 m in the first years after planting to produce high quality timber in a short time, which is not possible in forests (sic!). Of course, pruning is also possible in conventional forests, but it is rarely done because it is difficult and therefore costly to do in the non-rowed forest stands, where the position of the trees is random. The production of trees with large diameter, knot-free and straight trunks can be one of the goals of modern agroforestry systems and can be sold at high market prices. Brix et al. (2009) recommends that the length of the knot-free trunk should be about 1/3 of the wood height at the time of the tree felling (50–70 years) with a minimum diameter of 55 cm. Few experimental data can be found on the effect of intercrops on the yield and quality of walnut (*Juglans regia*) and on the growth and quality of its wood. In older times the walnut trees had a clear bottom trunk about 2.5 m tall. Then around 1960, shorter trunks came into practice between 1.3 and 1.8 m. Nowadays in France growing 2.5 m long walnut trunks is spreading again, which will have good quality appropriate for timber, similarly to older times (Mary et al. 1999).

Based on growth data after 5–8 years under temperate and Mediterranean conditions, widely spaced deciduous trees in agroforestry areas have grown very satisfactorily compared to the same species in adjacent forest stands. Of course, more failures have been observed in areas with poor fertility, especially those exposed to wind and frost or with low groundwater level. Systems with low planting density require more care and pruning of trees to achieve a high value clean trunk (Balandier and Dupraz 1999; Smith et al. 2012; Nerlich et al. 2013). Fodder production is modified year by year by the increase of canopy cover, while wood production is mostly related to site conditions and tree density regulated by periodic thinnings (Etienne and Rapey 1999). Van Noordwijk and Lusiana (1999) found that wood production has always been higher in the planted timber system compared to the agroforestry system because dense planting of trees produced more wood as the trees invested less resources in canopy development, and more resources to grow the trunk. According to Schroth (1999), competition between trees and crops is acceptable if the trees produce a commercially valuable product such as fruit, fodder, or fast-growing timber. There does not appear to be a direct relationship between the growth and competitiveness of trees and crops, which means that fast-growing trees are not necessarily intolerant of the herbaceous plants grown around them. Vityi et al. (2016) compared selected properties of an intercropped area to plots without intercrop. Low-growing corn varieties let enough light pass and improved the micro-climatic parameters as well. Thus, seedlings had lower mortality in the agroforestry system: after one year they had no dried leaves and were 30% taller. According to Kovács and Vityi (2019), when the trees become taller, they provide protection to crops and livestock, a better microclimate and produces wood that later increases the income of the farmer. The positive effects are the strongest in drought periods because the daily average temperature of the intercropped area during the drought period is significantly lower. Moreover, extreme temperatures are rarer between tree rows. Trees help to keep soil moisture in the upper 20–30 cm of the soil but cause a decrease below 30 cm (Szigeti and Vityi 2019). Zhang et al. (2018) found the same: trees after a certain age may cause dryness in the deep soil. Even with this, the microclimate of the soil is more balanced in an intercropped agroforestry system (Szigeti and Vityi 2019). The growth of both trees and crops significantly improves from the nutrients added by fertilizers to intercrops. As an example, in the study of Rivest et al. (2009) the growth of poplars was positively affected by the increase in N supply provided for the intercrops. This way agroforestry maximizes the use efficiency of N and simultaneously minimizes nitrate pollution of drainage waters. Planting tree species on croplands significantly increases the organic carbon and nutrient content including N, P, exchangeable K, etc. of the soil independently of the depth (Fahad et al. 2022). More nutrients in the soil obviously improve the growth of trees. Moreover, this way agroforestry reduces the need and costs of both pest control and fertilizers.

Depending on the biogeographical properties and the characteristics determined by the specific soil conditions, some tree species are very widespread in Europe (e.g. *Pinus sylvestris*, *Quercus petraea*), while others may cover only a very small area of the continent (e.g. *Pinus pinaster*, *Quercus ilex*). Another category includes species that have been introduced to Europe due to their high growth rates, for example *Eucalyptus globulus* Labill., *Pinus radiata* D. Don, *Pseudotsuga menziesii* (Mirb.) Franco, *Quercus rubra* L. (Mosquera-Losada et al. 2009). Impressive initial growths have been achieved by species that are not common in French forestry, such as *Pyrus communis* or *Paulownia tomentosa*. Of course, some native species, e.g. *Acer saccharum* Marsh also have rapid growth (Dupraz 1994). The cultivation of *Robinia pseudoacacia* L. in an alley crop system is spreading in Germany as an additional timber source (Mosquera-Losada et al. 2011). The poplars in the European agroforestry systems are mainly hybrid poplars as *P. x euramericana* (Dode) Guinier (*P. nigra* L. × *trichocarpa* Torr. & Gray ex Hook.); *P. x interamericana* Brockh. (*P. trichocarpa x deltoides* Bartr. ex Marsh.); *P. x canadensis* Moench (*P. deltoides x nigra*). Of course, new hybrids are constantly being developed and intercropped in agroforestry to produce valuable trunks. Similarly, larger areas are planted with *Juglans regia* L. and *Juglans nigra* L. In smaller quantities *Acer pseudoplatanus* L., *Alnus glutinosa* L. Gaertner, *Catalpa bignonioides* Walt., *Cedrus* spp. *Fraxinus excelsior* L., *Gleditsia triacanthos* L., *Prunus avium*, *Quercus robur* L., *Robinia pseudacacia* L. can be found (Eichhorn et al. 2006).

From an economic point of view, in order to promote timber production, higher tree densities have been created in the Atlantic region of Europe compared to the Mediterranean region (Mosquera-Losada et al. 2011). On riparian buffer strips some wood species are able to produce high quality logs as shown before, and so attract a good price as ash, birch, elm, maple, oak, poplar. Fruit trees provide an economic return from either fruits or nuts (such as almonds and walnuts) even if the trees are ultimately used as timber in addition to litter and fuel wood. The most commonly used dual-purpose fruit trees are walnut, cherry, pear (*Pyrus communis* L.) and apple (*Malus domestica* Borkh.) (Eichhorn et al. 2006). A positive net present value can be achieved with black walnut agroforestry (Dupraz 1994). Garrett and Buck in 1997 claimed that there is no surplus production of high value wood in the USA and that the value of wood and wood products will continue to increase and is likely to remain true worldwide. As this study focusses primarily on agroforestry, it is more relevant to consider log prices than timber prices in the following. Unfortunately, information on the price of sawlogs produced in agroforestry is barely available and even if prices were known, they would only be on a daily/weekly basis as well as on a local basis, which is unacceptable in a scientific publication of this kind. For this reason, the price ratios for sawlogs are discussed below. Quarterly prices for ash, black walnut, cherry, elm, maple (soft and hard) and oak logs were compiled from the Missouri Department of Conservation (2022) database for the years 1994 through 2022. This allowed for a full comparison of the data for the selected species, so that reliable ratios can be established for their comparison. Oak, which is always highly valued everywhere, was taken as the benchmark (Table 1).

Some cheaper species have a higher volumetric growth rate than oak, so their net yield value is not as low as Table 1 indicates. There are also significant differences between the prices of the quality grades of the various species. As an example, the difference between the prices of poplar sawlog grades 1, 2 and 3 are 1.00: 0.71: 0.49, respectively. For black walnut the differences are even greater. However, the differences between grades for the individual species are constant over time. Grade is a measure of the quality of the log and the timber that will come from the log (Baumgras and Luppold 1993; Taylor 2009). This means that the prices of sawlog grades are proportional to the value of the timber derived from the sawlogs, namely

Table 1 Price ratios of different sawlog species compared to the price of oak, based on the database of the Missouri Department of Conservation (2022)

Species	Average log price ratio 1994–2022 (%)
Ash	57
Black walnut	422
Cherry	82
Elm	38
Maple (hard)	67
Maple (soft)	104
White oak	100

proportional to the profit. Moreover, slight differences in grade may cause large differences in price. The veneer logs, as the highest quality logs on the market, have significantly higher value (1.5–8.3 times) compared to average sawlog prices (Taylor 2009; Treiman 2015, 2022; Wunder 2018). Financial analysis of Bertomeu (2006) in the Philippines reveals that at the timber prices in 2006 and with low to average sawlog yields, returns from maize monocropping exceed those from maize-tree intercropping. Maize-tree agroforestry systems would be more profitable if farmers were able to produce higher quality logs or higher priced tree species. After the extraordinary rise in timber prices in the last years, it would be worthwhile to do this analysis again.

In summary, the dominant tree species in European agroforestry are ash, birch, elm, maple, oak, poplar, chestnut, black walnut and fruits (cherry, pear, apple). Poplar and walnut tree species provide most of the high quality logs. The trunks are bred purposefully for their timber, but the question arises as to whether the quality and properties of timber from agroforestry are good enough or even better compared to their counterparts in a traditional forest stand. Some studies deal with this question from different parts of the world, as follows.

Black walnut is the most valuable domestic wood in North America. That is why much research and planting is done with it (Smith et al. 2012). The stems of the black walnut plantation examined in the USA by Cutter and Garrett (1993) were 15 years old and came from an open-grown system with a spacing of 12.2 m between rows and 3.04 m between trees within a row. The stems averaged 19.3 cm in diameter in breast height and 13.1 m in height. The mean specific gravity was 0.569 g/cm^3, which is slightly higher than the literature data cited by Cutter and Garrett (1993) (0.47–0.56 g/cm^3) for open-grown walnuts. This is consistent with the finding of Paul (1943) that open-grown trees have a higher specific gravity than forest-grown trees and the lower portions of open-grown trees have the greatest specific gravity. Cutter and Garrett (1993) further found that their fibre length increased considerably in the first 10 years, indicating the end of their juvenile age and reached about 1.3 mm in length. Cultivation and open-growing conditions had no negative effect on either fiber length or the quality of the wood, while parameters such as specific gravity, trunk diameter and tree height have been improved. The growth of black walnut increases if the trees are planted in an agroforestry alley cropping system using wide spacing that facilitates the passage of farm machinery. Intensive cropping and 50–60-year rotation of veneer logs is expected instead of the usual 80–100 years. Nicolescu et al. (2020) prepared a good description of the potential of black walnut in European agroforestry. Black walnut already used in agroforestry systems such as alley cropping with the primary aim of timber production, but to a much lesser extent than in the USA. Systematic pruning is very important and the key to permanently free the crown of the potentially best trees from competition. These trees are selected on the basis of quantitative criteria (thickest and tallest), qualitative criteria (straight trunk, clear from knots, shake, spiral grain, decay and other faults) and distribution criteria (regularly spacing). Their number is reduced to a maximum of 150 trees per hectare at the age of rotation in Europe, compared to only 80 trees per hectare in America. This method ensures the best log quality, which is the key to high value veneer or timber. Garrett and Buck (1997) also recommend a sparse 12 × 3 m spacing for black walnut fruit and wood production, while Brix et al. (2009) recommends 52–78 trees per hectare for deciduous species in general. It is worth noting that afforestation uses usually about 4000 plants per hectare. The effects of tree-tree competition in northern red oak, black walnut, and yellow poplar on differences in diameter-growth rates and vessel lumen area were not significant (Chen et al. 1998). This suggests that competition between hardwoods and perennials is also unlikely to cause differences in the area of vessel lumina.

Taghiyari and Sisi (2012) reported that 8 years old *Populus deltoides* intercropped with wheat-fodder maize had larger wood volume compared to forest plantations. They stated that the trunk diameter of *Populus nigra* intercropped with alfalfa was greater than in forest plantations and the greatest difference in diameter growth occurred from age 3 to about age 7. Peszlen (1993) found that wood properties of poplars have no significant relationship with growth rate. Poplar (cultivar I-214) in France were found to have a nearly cylindrical shape in all agroforestry and forest plantation trees, indicating homogeneity of internal stress levels. The wood density, microfibril angle and modulus of elasticity are the same for trees in agroforestry and forest plantations. Thus, the wood quality of poplar from agroforestry is approximately the same as that of the wood produced in a forest. The availability of water is an important factor for the properties studied (Kouakou et al. 2016). The lack of nitrogen and sulfur reduces fiber and vessel diameter of *Populus deltoides* (Zobel and van Buijtenen 1989), so agroforestry systems can have a significant impact on wood properties through a different nutrient supply. For example, Taghiyari and Sisi (2012) reported that in agroforestry systems the intercropping with alfalfa determined fibre properties rather than initial spacing. According to Taghiyari and Sisi (2012), the mature wood of *Populus tremuloides* Michx. has a positive relationship between fiber length and tree ring width; for other poplar hybrids at early ages, the correlation between ring width and fiber length was not significant. In mature wood, a slight negative trend was found, while they found in other studies that the growth rate had no effect on fiber length of hybrid poplars. The intercropping of *Populus nigra* with alfalfa decreased wood density and shrinkage, while wider spacing increased them, due to the increase in vessel diameters and frequency. The diameter and wall thickness of fibers increased as a result of intercropping, but tree spacing had no significant effect (Taghiyari and Sisi 2012). Another possibility for the use of poplars in agroforestry is the production of wood chips in short and medium rotation time plantations, of course yielding a lower income. Compared to trees from agroforestry systems that traditionally used as firewood, this means a significantly higher income for farmers and a much faster return than traditional high value trees.

Researches on wood quality of many wood species has come to similar conclusions, such as teak (Shukla and Viswanath 2014), *Acacia auriculiformis*, *Acacia mangium*, *Grevillea Robusta* in India (Shanavas and Kumar 2006), *Cedrela odorata* in the Republic of Panama (Paul and Weber 2013), or *Terminalia catappa* in Vanuatu (Glencross et al. 2013). Unfortunately, our analysis of the literature did not find information, statistics or even an indication of what happens later to the high quality logs from agroforestry and sold to the veneer- or sawmill industry. A similar finding was made by Mosquera-Losada et al. (2009). However, some indirect conclusions can be made if material handling practices of timber industry are taken into account. After processing the logs, the veneers and timbers are treated together with materials from conventional forestry, i.e. they are fully equivalent to them. Agroforestry systems with the purpose to produce logs should therefore have two main goals: choosing the right tree species that can be sold as a valuable log decades later and producing the largest possible log volumes (maximising length and diameter) and the best possible quality (straightness, cylindrical shape, free from knots and other defects).

One of the keys to supply high quality logs and sawn timber for the wood industry in the next centuries in Europe may be agroforestry systems that produce the desired quality trunks. There is already a large area under agroforestry-type farming, but only a small proportion of these are currently dedicated to the production of high value trees (den Herder et al. 2017). In 2005, the European Union, as the largest organization in Europe, set itself the objective of establishing a large number of agroforestry systems (including agroforestry systems producing high value trees) for environmental, economic and social reasons (Augére-Granier 2020). Since then, a number of projects have addressed this issue from both the scientific side and the production side. Horizon 2020 is the most important funding package in the current period, and agroforestry is also an important part of it. Perhaps a good benchmark is that agriculture accounts for around 1.1% of the European Union's GDP (Eurostat 2019). There is no reliable data on the weight of agroforestry within agriculture, but agroforestry may play a subordinate role even within less "industrialized" agricultural systems.

24 (0.08%) of the 30,084 Horizon 2020 projects are related to agroforestry. EUR 90.7 million is spent on agroforestry projects (0.16%) of the EUR 55.2 billion in FP8 funding awarded so far, which is no longer very variable. The importance of agroforestry is therefore not central to the European Union's R&D policy. But if we compare the values obtained with similar values of agricultural projects, the picture is already much more favourable. Horizon 2020's 332 agricultural projects (1.1% of all projects, exactly as much as the share of agriculture in GDP) were supported to the tune of around € 723.9 million (1.31% of total project support). The number of agroforestry projects within agricultural projects was 7.23% and they received 12.53% of the total expenditure. These appear to be much higher proportions than would be justified by the current weight of agroforestry, so we can say that Horizon 2020 has emerged as a prominent support for agroforestry.

The role of countries in the projects examined was characterized by five criteria and the relationships between them:

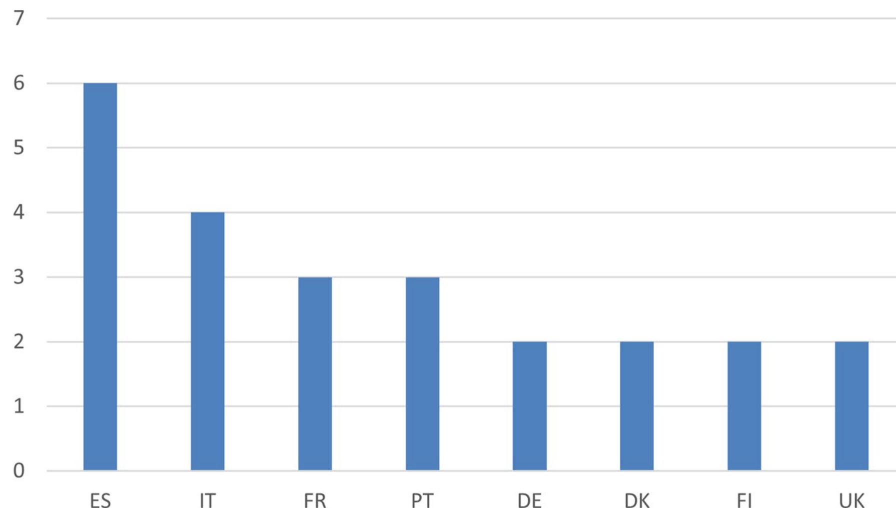
1. Number of project coordinator roles associated with companies and institutions in each country.
2. Number of project participations related to companies and institutions in each country.
3. It was not examined independently, but we have taken into consideration the average agricultural production at a constant (US) dollar price (2014–2016) by country between 2013 and 2018 as an important factor in the analysis of the relationship between the criteria
4. We calculated the EU contribution per country as an estimated indicator close to the real one.
5. We also calculated the average EU contribution per project participation (per country) in each country as an estimated indicator close to the real one.

For our last two calculated indicators, the EU contribution per project and the number of project participants were the basis for the calculation. We calculated the average contribution per project participant, and then we estimated the project contribution per country and the average contribution per project participation in each country. The result is somewhat different from the actual values, as the contribution awarded in the projects is not equal among the individual participants. However, for various reasons (e.g. lack of data), this was considered a good approximation. The first three places in the order in both Figs. 1 and 2 are Spain, Italy, and France.

The largest beneficiaries of agroforestry project support in financial terms are France, Italy and Germany (Fig. 3). The Spanish participants leading in the previous two categories receive on average lower support per project, based on estimated data.

The relationship between the five criteria (project coordinator roles, project participations, agricultural production by country, EU contribution per country, and EU contribution per project) was characterized by Spearman's rank correlation coefficients

Fig. 1 Number of project coordinator roles by country between 2013 and 2018



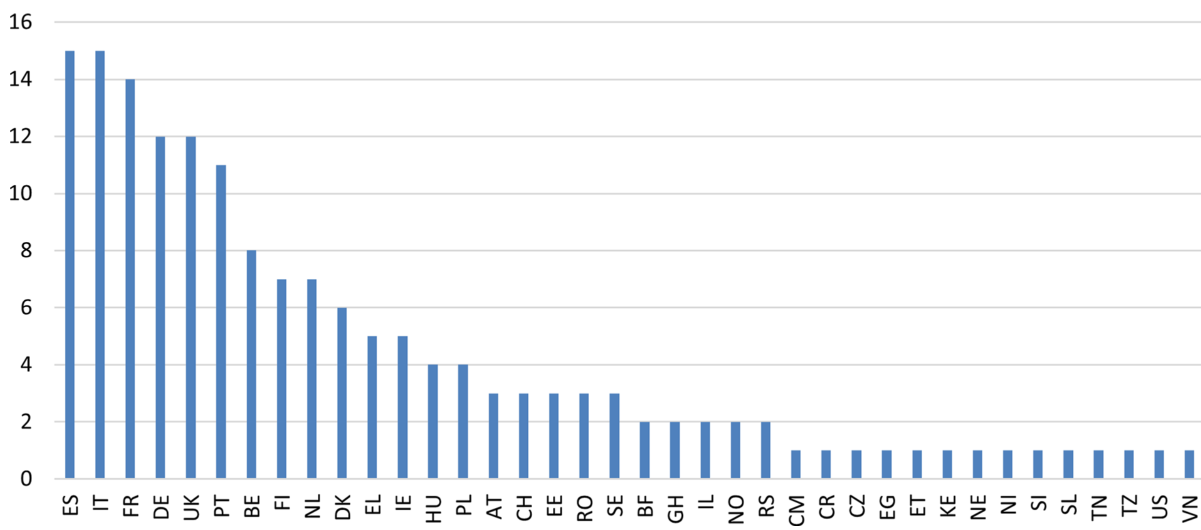


Fig. 2 Number of project participation by country between 2013 and 2018

(Reidmacher and Molnár 2000). The aim was to get an overview of what happened so far and what can be expected by the participants of the agroforestry in the EU. The strongest rank correlation was found between the number of project grants and project participation per country, as shown in Table 2 (0.96). This came as no surprise. However, the average support per project in each country and the relationship between the other criteria is neutral. This relationship should be treated with caution. After all, some of the participating countries are not members of the EU or we were forced to estimate the specific decision factors of the contributions in part, and when assessing the contributions. In addition, several hidden decision factors may arise during the "distribution" among project participants.

If we calculate the rank correlation coefficients only for the EU countries, we get a slightly different result (Table 2). Table 2 also shows that agricultural production here already reveals a medium rank correlation with the number of project coordinator roles and project contribution by country, and is quite strongly correlated with the number of project participations. The average grant per project in each country is negatively or neutrally correlated with all other indicators. So, the countries with the highest

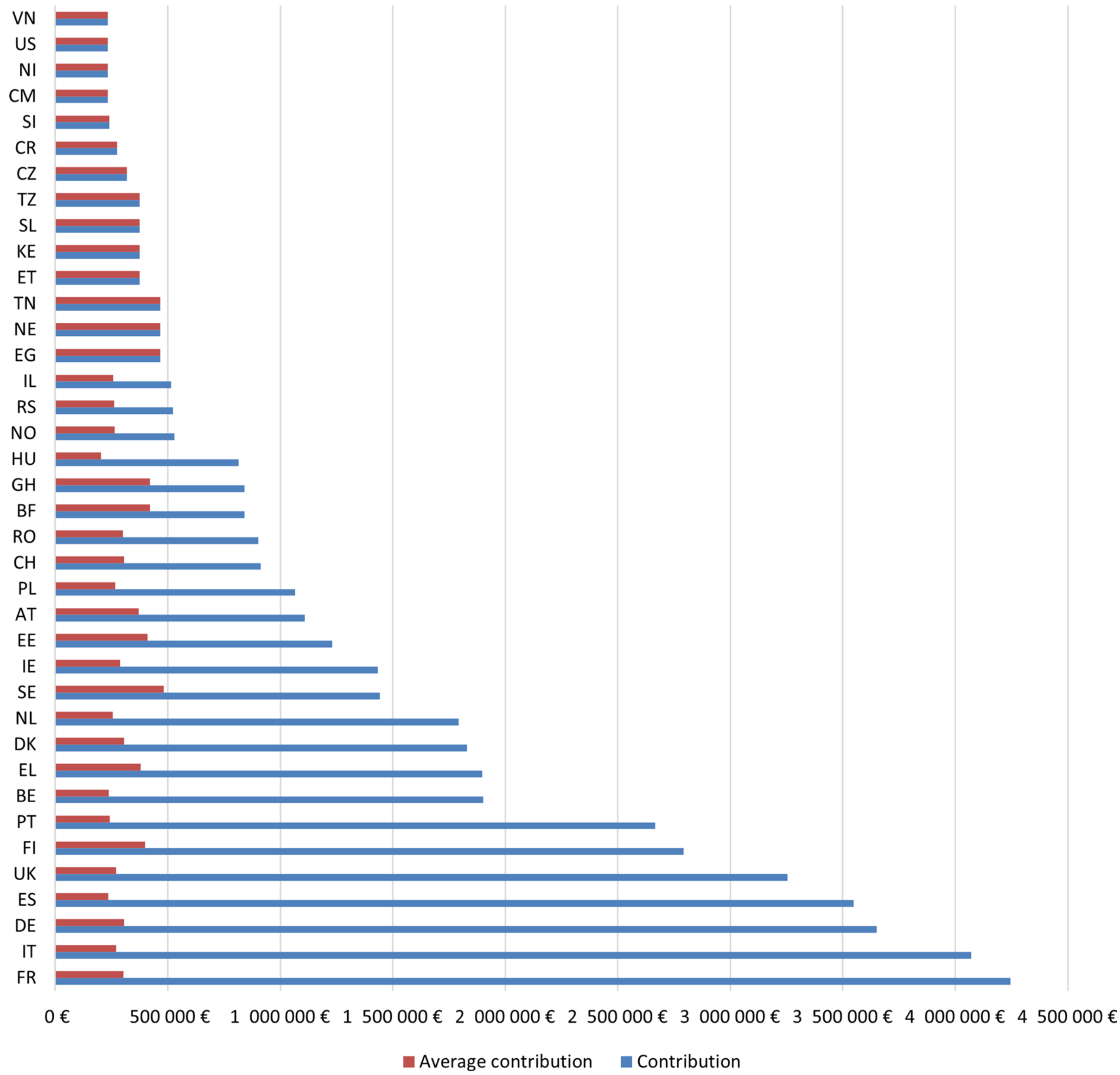


Fig. 3 EU contribution by country between 2013 and 2018. Average contribution shows the contribution per project in each country

agricultural emissions have benefited by participating in the projects. However, based on project contribution per participant, this is no longer necessarily the case. Perhaps our estimate of the specific indicator was inaccurate. Clarification of the issue requires further research.

In the second phase of the research, we used the Doctus expert system to find the hidden (if … then) decision rules behind the grant decisions. We mainly looked for the answer to whether there is a correlation between the contribution per participant received per project (as a decision variable), the country of the project coordinator and the distribution of project participants by country. The decision problem is, of course, highly theoretical, as the amount applied for is already known at the time of submitting the applications, but we believe that some partial information can be extracted from this model as well. We were most interested in the country of each of the central "actors". The decision problem can be interpreted as "What amount should we apply for?" as an issue that

Table 2 Spearman's rank correlation coefficient between each criterion (all participants, EU countries)

Criteria	Number of project coordinator roles		Number of project participations		Average agricultural production (2013–2018)		Project contribution by country		Average contribution per project participation by country	
	All	EU	All	EU	All	EU	All	EU	All	EU
Number of project coordinator roles										
All	1	–	0.71	–	0.37	–	0.70	–	− 0.11	–
EU	–	1	–	0.83	–	0.51	–	0.82	–	− 0.15
Number of project participations										
All	0.71	–	1	–	0.30	–	0.96	–	− 0.15	–
EU	–	0.83	–	1	–	0.71	–	0.93	–	− 0.33
Average agricultural production (2013–2018)										
All	0.37	–	0.30	–	1	–	0.25	–	− 0.19	–
EU	–	0.51	–	0.71	–	1	–	0.58	–	− 0.34
Project contribution by country										
All	0.70	–	0.96	–	0.25	–	1	–	0.12	–
EU	–	0.82	–	0.93	–	0.58	–	1	–	0.01
Average contribution per project participation by country										
All	− 0.11	–	− 0.15	–	− 0.19	–	0.12	–	1	–
EU	–	− 0.15	–	− 0.33	–	− 0.34	–	0.01	–	1

Table 3 Attributes of decision model

Name	Value	Decision attribute	Value ordering
Contribution	Low, under median, above median, high	Yes	Increasing
Coordinator	Value 1…8: DE…UK	No	Nominal
AT…VN (38 participants)	Yes/no	No	Nominal

also has its limitations. The attributes of the decision model are shown in Table 3 and Fig. 4.

A graph (Fig. 4) often does not provide enough information. It is also worth analysing the informativeness indicator produced by Doctus. The three most informative attributes are the identity of the coordinator (0.3904), the participation of the Belgian project partner (0.1905) and the participation of the Hungarian project partner (0.1091).

Regarding the effectiveness of the projects, formally, project results have a very high community contribution, but this is not only a feature of agroforestry projects. In fact, some projects produce very few deliverables and publications at a high cost, while other projects generate much more output at a lower cost. The "value" of project results and publications can only be decided after a very thorough professional examination. In addition, project results can range from an information website to a prototype or a completely new production process, so they are essentially incomparable. Nor should we forget that the number of outputs in the support period in question is not yet final.

There is a weak-medium relationship between project budgets and outputs (Figs. 5, 6). Low-budget projects tend to have very few or very many publications, but the statistical correlation is not convincing. Similarly, we can only very cautiously state the correlation from Fig. 6 that there were fewer project results in high-budget projects.

From a decision-maker and community perspective, two main aspects seem to be important based on the results. Firstly, the marginalisation of non-professional aspects of funding (e.g. the country of the coordinators or project participants) needs to be further strengthened. On the other hand, the recognition of the importance of basic research, the publication of project results (publications and other accurate results, even partial results) and the linking

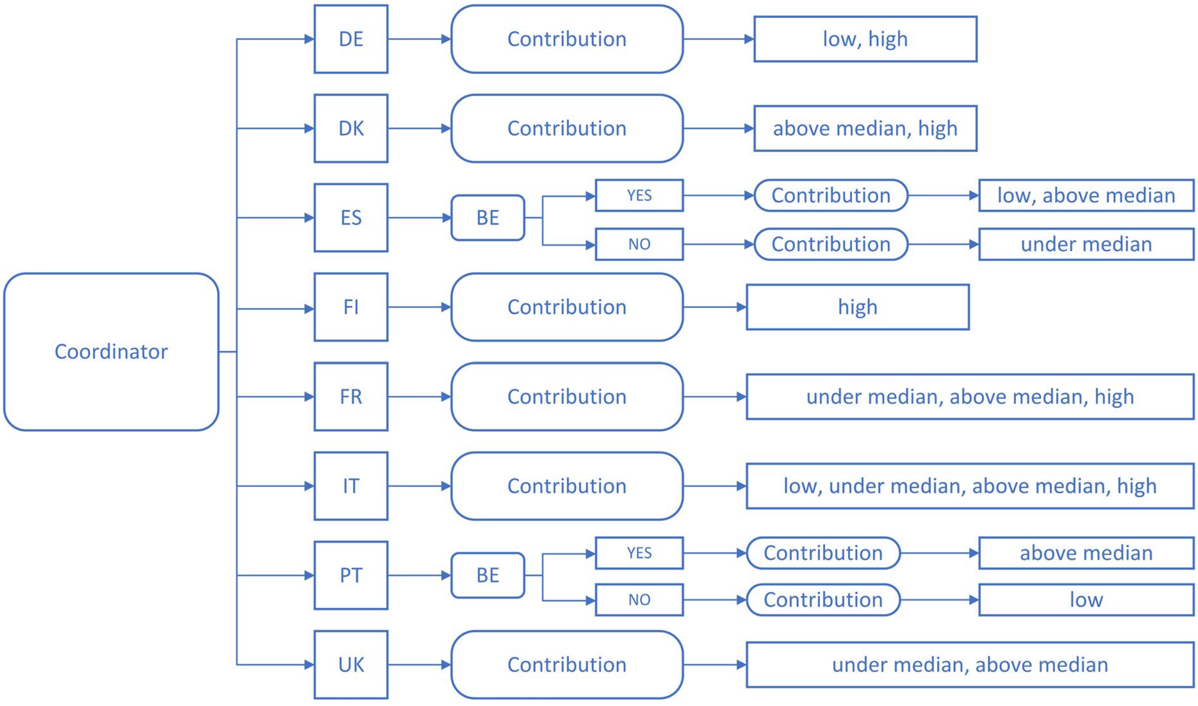


Fig. 4 Case-based graph of the model

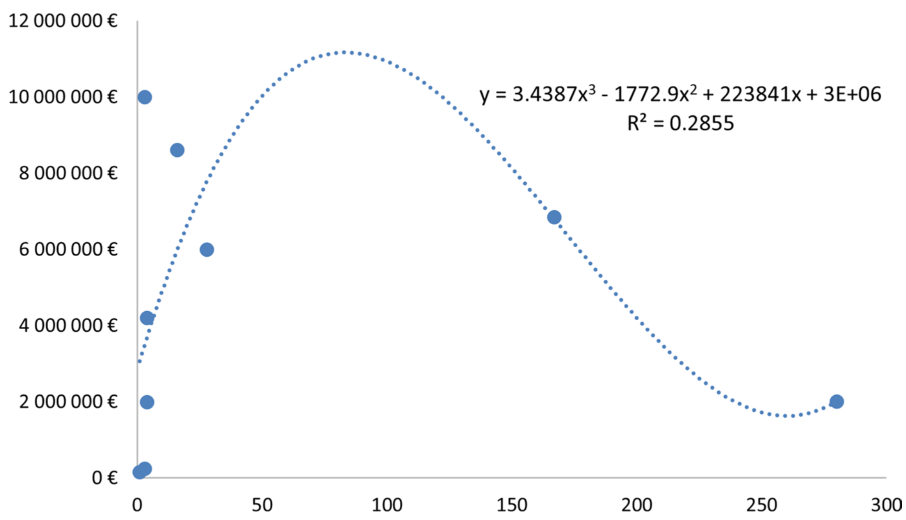


Fig. 5 Number of agricultural forestry publications and EU contribution to the project

of funding would certainly be an important aspect in future funding periods. In addition, an expert organisation could help farmers to choose the agroforestry system best suited to the characteristics of their land and their current and future needs, including the cultivation of high-value tree species. The importance of using large quantities of high-value trees is that decades later they can help alleviate the problems of the public sector and the population by alleviating timber shortages, while at the same time reducing the effects of climate change.

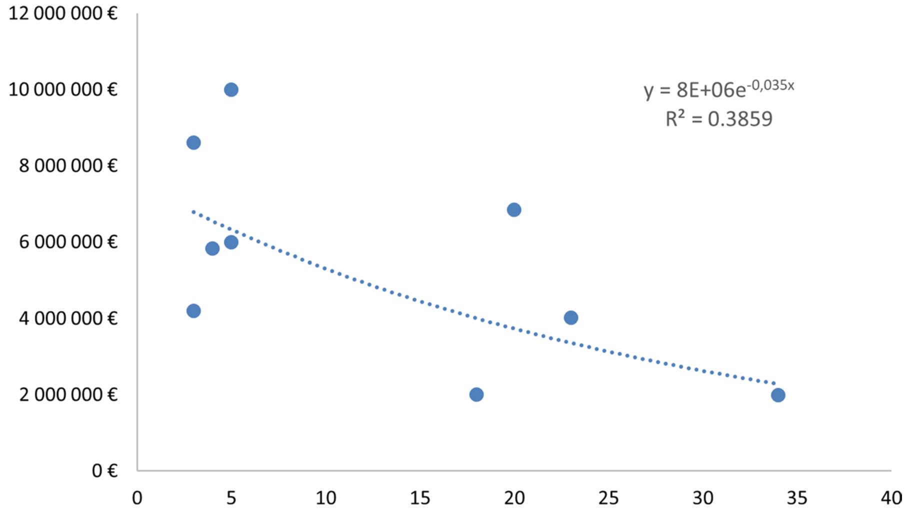


Fig. 6 Number of agroforestry project results and EU contribution by project

Summary

This paper deals with European agroforestry systems, the tree species used and wood quality produced in these systems, and analyses the current support goals and practices of the European Union for agroforestry. Agroforestry projects are of considerable importance in Horizon 2020 compared to the low impact of the sector. The issue requires further, thorough investigation which may lead to the spreading of agroforestry systems in Europe and to the use of high value trees which produce fruits and later yield high quality logs. These will play an important role in reducing the current and continuously growing timber shortage in the market. The most important tree species in European agroforestry are black walnut and poplar. With the right procedures, for example sparse spacing and pruning, the same amount of wood can be achieved from each tree in a shorter log rotation time than in the forest plantations, while the quality will not deteriorate and will result in a significant proportion of logs suitable for veneer production. Meanwhile, the environmental impact of agriculture is reduced and a similar average yield per area unit can be achieved with less fertilizer to grow perennials.

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Declarations

Conflict of interest The authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper. The results/data/figures in this manuscript have not been published elsewhere, nor are they under consideration by another publisher. All of the material is owned by the authors and/or no permissions are required.

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