A multiple criteria decision analysis approach for assessing the quality of hardwood species used by Greek timber industries

Stefanos Tsiaras[1*], Marina Chavenetidou[2], Panagiotis P. Koulelis[1]

[1]Hellenic Agricultural Organization - DIMITRA (ELGO - DIMITRA), Institute of Mediterranean Forest Ecosystems, Ilisia-Athens, Greece
[2]School of Forestry and Natural Environment, Aristotle University of Thessaloniki, Thessaloniki, Greece

Abstract
Tsiaras, S., Chavenetidou, M., Koulelis, P.P., 2024. A multiple criteria decision analysis approach for assessing the quality of hardwood species used by Greek timber industries. *Folia Oecologica*, 51 (2): 109-119.

Timber industries make an essential contribution to economies worldwide, while the sustainable supply of timber generates revenue, supports employment, and contributes to economic activity. The strategic choice of wood species using specific criteria can have substantial economic outcomes for the timber industry in Greece. This study assessed the suitability of hardwood species most commonly used by Greek timber industries. The assessment was conducted with the use of a Multiple-Criteria Decision Analysis approach, taking into consideration specific criteria that affect the quality of timber. According to the findings, walnut was the optimal alternative that outranked the other examined species. Chestnut, oak, beech, ash, and hornbeam also achieved positive scores, and therefore, they are also acceptable alternatives as broadleaved species suitable for furniture manufacturing and sawn timber production. Greek timber industries can enhance their products' value and market appeal by focusing on species that meet high-quality standards and consumer preferences.

Keywords
economic benefits, forest products; PROMETHEE, roundwood, sawn timber, sustainability

Introduction

Wood is a natural renewable resource and has supported the development of human society throughout history (Perlin, 2005). Timber is a sustainable building material that has been increasingly used in the construction sector over recent years because it is aesthetically pleasing and environmentally friendly (Trulli et al., 2017), since wood constructions store carbon dioxide (CO_2). Compared to other construction materials, wood has a lower carbon footprint, needs less energy for its production, and generates less water contamination (Ermur et al., 2022). Technical wood is an easy-to-use, biodegradable construction material with different designs and properties (Tsoumis, 1991; Zhou et al., 2016). Timber industries make an essential contribution to economies across the globe, while the sustainable supply of timber generates revenue, supports employment, and contributes to economic activity (Li et al., 2019).

Efforts towards sustainable forest management in Greece, including policy implementation and knowledge dissemination, aim to enhance operational efficiency and maximize wood resource utilization (Koulelis et al., 2022). However, despite these efforts, Greece's forests contribute comparatively less to the Gross National Product (GNP) within the European Union, conflicting with the objectives of the National Forest Strategy (Tsiaras et al., 2021). Greece faces challenges such as low productivity and heavy reliance on wood imports, exacerbated by the 2008 financial crisis, leading to a continuous decline in do-

*Corresponding author:
e-mail: stsiaras@fria.gr

mestic wood production and an uptick in imports (Koulelis, 2012; 2016). These challenges are compounded by various factors, including complex harvesting procedures, inadequate financial support, ambiguities in forest land ownership, governance issues, bureaucratic obstacles, illegal logging, and ineffective national forest policies (Koulelis, 2009; Koulelis et al., 2023). Therefore, the strategic choice of wood species, guided by specific criteria within primary and secondary processing enterprises, stands to yield favorable economic outcomes for the timber industry in Greece.

There are more than 70,000 known wood species, and almost 400 of them are used internationally with a wide range of applications. Some of these are only utilized in the countries where they grow without being exported abroad. There is a tendency to increase the use of hardwoods in Europe since there are large areas of underused forests of hardwoods that can be used as a sustainable raw material. From this aspect, proper utilization of wood demands a good knowledge of its structure, anatomical characteristics, properties and behavior during mechanical processing since the factors mentioned above are related to specific uses and products, aiming to maximize their life cycle and optimize their adjustment to every service conditions (Kakaras, 2008; Mantanis, 2008; Aicher et al., 2014).

The most common native wood species in Greece that are utilized for various products and constructions are pine (*Pinus* sp.), fir (*Abies* sp.), spruce (*Picea* sp.), oak (*Quercus* sp.), beech (*Fagus* sp.), chestnut (*Castanea* sp.), and poplar (*Populus* sp.). Furthermore, a smaller quantity of timber is produced from other species, like cypress (*Cupressus* sp.), juniper (*Juniperus* sp.), walnut (*Juglans* sp.), elm (*Ulmus* sp.), ash (*Fraxinus* sp.), plane tree (*Platanus* sp.), olive tree (*Olea* sp.), yew (*Taxus* sp.), etc. Besides the wood from native species, large quantities are imported as roundwood or sawn timber in order to cover the market needs for the production of various final products and uses. Imports from Europe and North America include species such as *Quercus* sp., *Fagus* sp., *Populus* sp., *Pinus* sp., *Abies* sp., *Picea* sp., etc., while some tropical species (e.g. teak, iroko, zebrano, etc.) are imported from Africa. Finally, large quantities are imported as wood pulp to produce paper (Voulgaridis, 1995; Mantanis, 2008; Voulgaridis, 2015). The use of locally-grown timber for multiple uses leads to economic, environmental, and social benefits (Trulli et al., 2017).

Wood quality refers to the degree of perfection of a log concerning specific uses. Since each end-use requires different properties, there is no united scale of characteristics in every case. Some characteristics may be desirable in one case but not in others. Wood features are attributed to the tree species and their genetic origin but are also affected by environmental growth conditions and treatment during and after logging. For quality optimization, it is necessary to identify the characteristics of the final product, as well as the environmental conditions of exposure, so as to be suited for each application (Jozsa and Middleton, 1994; Desch and Dinwoodie, 1996; Savidge, 2003; Gartner, 2005). Consumers consider that not only the appearance and design of a product are important but also its technical characteristics, and their judgment is based on the quality of a product in relation to pricing (Toivonen, 2012).

Knowledge of the theoretical background of wood structure and properties, mainly mechanical and physical, is necessary since these factors are strongly connected with wood's behavior and, by extension, its utilization. Moreover, the availability of wood as a raw material and its price are important factors determining the final suitability of the wood (Tsoumis, 1991; Šuhajdová et al., 2018).

Multiple Criteria Decision Analysis (MCDA) methods are useful tools for accomplishing tests related to finding the optimum solution for specific end uses. MCDA methods are widely used for complex problems with multiple conflicting criteria to rank the alternatives from best to worst, helping the decision maker select the best alternative (Behzadian et al., 2010).

Šuhajdová et al. (2018) evaluated the suitability of selected hardwood in civil engineering with the use of the PROMETHEE method, one of the main MCDA methods. In Greece, the MCDA methods were applied in several studies within the broader field of forestry. Specifically, the PROMETHEE method was applied by Tsiaras and Andreopoulou (2020) for the assessment of the forest policy implementation within the European Union's countries, focusing on Greece with the use of an input-output basis, while the selected criteria included the three sustainability pillars: economy, environment, and society. Moreover, Tsiaras and Papathanasiou (2018) used the PROMETHEE method as a tool for decision-making under the scope of Forest Policy to propose suitable agroforestry systems as a sustainable choice for the forestation of abandoned agricultural land in a mountainous, less favoured area of Greece. Furthermore, Vlachokostas et al. (2014) used a combination of PROMETHEE and ELECTRE methods to promote the planting of suitable tree species in the city of Thessaloniki, taking into consideration several mutually conflicting criteria, such as environmental, economic, social, and criteria of practical nature. A similar study was also conducted in the city of Thessaloniki by Tsiaras and Samara (2019) regarding the selection of the most suitable tree species based on their capability of capturing heavy metals with the use of the PROMETHEE method.

This study assessed the suitability of hardwood species most commonly used by Greek timber industries, such as furniture enterprises and enterprises producing roundwood, sawn timber, and plywood. The assessment was conducted with the use of a Multiple-Criteria Decision Analysis approach, taking into consideration specific criteria that affect the quality of timber.

Materials and methods

The Multiple-Criteria Decision Analysis (MCDA) method used in the present paper was the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), an MCDA method presented by Brans (1982) providing a complete ranking of the alternatives (Brans

Table 1. The values of the examined tree species under the selected criteria

	Density (kg m^{-3})	Hardness (Newton)	Rupture (Mpa)	Elasticity (Gpa)	Strength (Mpa)	Shrinkage (TR ratio)	Durability 5-point	Workability 5-point	Resistance 5-point	Pricing (€)
Acer pseudoplatanus	615	4.68	98.1	9.92	55.0	1.7	1	3	1	58.90
Carpinus betulus	740	7.26	110.4	12.10	50.5	1.7	1	1	2	60.90
Castanea sativa	545	3.00	71.4	8.61	43.8	1.6	5	5	2	81.00
Fagus sylvatica	715	6.46	110.1	14.31	57.0	2.0	1	5	1	60.90
Fraxinus excelsior	680	6.58	103.6	12.31	51.0	1.7	2	5	1	58.90
Juglans regia	640	5.41	111.5	10.81	50.2	1.4	3	4	2	97.03
Salix alba	400	2.53	56.2	7.76	26.9	1.7	1	1	2	45.10
Populus nigra	385	2.02	63.7	7.21	36.0	2.3	2	4	2	56.00
Quercus petraea	710	4.99	97.1	10.47	47.3	2.2	5	3	5	65.00
Tilia × europaea	535	3.10	85.4	11.71	44.8	1.5	2	3	2	59.00

Table 2. Preference parameters of the study (q - indifference, p - preference)

Criteria	Density (kg m^{-3})	Hardness (Newton)	Rupture (Mpa)	Elasticity (Gpa)	Strength (Mpa)	Shrinkage (TR ratio)	Durability 5-point	Workability 5-point	Resistance 5-point	Pricing (€)
Min/Max	Max	Max	Max	Max	Max	Min	Max	Max	Max	Max
Weight	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Preference function	Linear	Linear	Linear	Linear	Linear	Linear	Usual	Usual	Usual	Usual
Thresholds	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute
q	130	1.53	20.8	2.32	9.7	0.2	1	1	1	1
p	297	3.97	48.3	5.62	21.1	0.6	2	2	2	2

and De Smet, 2016). The main advantages of PROMETHEE are that it has a clear structure, it is easy to use, it can be used to solve complex problems, and it offers a good visual projection as the final step in the decision-making process for the problem (Taherdoost and Madanchian, 2023).

The PROMETHEE II method used in this study is based on a pairwise comparison of alternatives along each criterion. Alternatives are evaluated according to different criteria, which must be maximized or minimized (Behzadian et al., 2010). The complete ranking of the alternatives is provided by the net outranking flow, which is the balance between the positive and the negative outranking flows. The higher the net flow, the better the alternative (Brans and De Smet, 2016).

Net outranking flow (Phi) = positive outranking flow (Phi+) – negative outranking flow (Phi-).

$\varphi(\alpha) = \varphi$^+ $(\alpha) - \varphi$^– (α)

When $\phi(a) > 0$, a is more outranking all the alternatives on all the criteria; when $\phi(a) < 0$, it is more outranked (Brans and De Smet, 2016).

In the present study, ten hardwood species were examined under ten selected criteria that affect the wood quality and determine the final uses of timber: 1) Density, 2) Hardness, 3) Rupture, 4) Elasticity, 5) Strength, 6) Shrinkage, 7) Durability, 8) Workability, 9) Resistance, and 10) Pricing. The criteria selection was based on the main features reported in specific bibliographical sources and their importance for the wood market (Meier, 2015; Niemz et al., 2023). Similar criteria were used by Šuhajdová et al. (2018) in order to evaluate the suitability of selected hardwood species in civil engineering. The examined tree species were: 1) oak (*Quercus petraea*), 2) beech (*Fagus sylvatica*), 3) chestnut (*Castanea sativa*), 4) walnut (*Juglans regia*), 5) poplar (*Populus nigra*), 6) maple (*Acer pseudoplatanus*), 7) hornbeam (*Carpinus betulus*), 8) ash (*Fraxinus excelsior*), 9) willow (*Salix alba*), 10) lime (*Tilia × europaea*).

The data were collected from other studies (Kantay and Ünsal, 2000; Kakaras, 2008; Skarvelis and Mantanis, 2013; Voulgaridis, 2015; Kakavas et al., 2018a; Kakavas et al., 2022), the Forest Products Pricing Table of Greece for the management year 2023, and the wood database (https://www.wood-database.com/), a database specialized in wood species from all over the world, their structural characteristics and basic physical and mechanical properties, according to Forest Products Laboratory, USDA (2010). The data of the study (Table 1) were analyzed using the Visual PROMETHEE Academic Edition software.

For the criteria Durability, Workability, and Resistance, the units are described as 5-point on the Likert Scale (Table 1), with scoring values: 1 = very bad, 2 = bad, 3 = average, 4 = good, 5 = very good.

The preference functions and the thresholds of indifference (q) and preference (p) were calculated with the assistance of the "Help me" wizard of Visual PROMETHEE Academic Edition (Mareschal, 2013). For the first scenario examined, all criteria were given equal weights (Table 2).

The chosen criteria for the evaluation of wood quality and suitability in various uses include wood properties that play a substantial role in its behavior and determine its final value (Voulgaridis, 2015).

The density of wood is the ratio of the mass, which is contained in a given volume, to that volume and could be expressed as basic density (oven-dry wood to green volume), oven-dry density or might refer to a specific moisture content. Wood density is strongly related to the resilience of constructions, as wood appears to show greater strength and less probable breakage than other materials used in buildings (Tsoumis, 1991; Larjavaara and Muller-Landau, 2010; Niemz et al., 2023). As a result, density as a criterion has to be maximized.

Wood, as a natural raw material, consists of cellulose, hemicellulose, and lignin. The polymers mentioned above form a net which supports the structure and provides resistance to fungi, bacteria, or insect attacks. Some species with high extractive content, mostly deposited in heartwood, give wood natural durability to decay and ageing. Wood species show different degrees of durability according to their proportion of cellulose, hemicellulose, lignin and extractives content, which is also related to wood dimensional stability (Tsoumis, 1991; Grigoriou, 1992; Scheffer and Morrell, 1998; Filippou, 2014; Kakavas et al., 2018b). Criteria of durability and resistance need to be maximized.

Mechanical properties, such as hardness, modulus of rupture and elasticity, and resistance to breakage, are related to wood's behavior at final uses since high values of these properties provide stable constructions. Wood, as an anisotropic material, performs differently in three directions: transverse, radial and tangential. Thus, the construction timber's orientation affects the strength of the final use. Rohanová and Nunez (2014) suggest that the modulus of elasticity in bending strength, as well as wood density, are robust indicators of structural timber resilience. The properties mentioned above are also affected by the swelling and shrinkage of wood due to water absorption and anisotropic change of its dimensions (Tsoumis, 1991; Kretschmann, 2010; Niemz et al., 2023). Therefore, these properties are criteria to be maximized.

Wood shrinkage and swelling, due to water loss and absorption, respectively, are properties that significantly affect its utilization. Dimensional changes may cause defects in constructions, such as change of shape, warping, tightening or opening of joints, or, in some cases, collapse. A factor that affects dimensional stability is the extractives' content, which reduces water absorption or loss (Tsoumis, 1991; Kakavas et al., 2018b). Thus, the criterion of shrinkage has to be minimized.

Wood's processing and workability affect the effort needed for the configuration of final products. Moreover, wood behavior when processing with machines, such as cutting, drilling, planning and other procedures is connected with wood density, anatomical features, chemical composition, and quality. The resistance during manufacturing can damage the tools by causing problems like blunting. Therefore, workability as a criterion should be maximized. (Kakaras, 2008; Voulgaridis, 2015).

Timber prices define the value of wood in the market since they represent the realizable value of wood and strongly influence the optimization of forest management. The price determination is affected by social and economic factors as well as environmental conditions, that influence the volume and quality of timber (Gejdoš et al., 2019; the Forest Products Pricing Table of Greece for the management year 2023). Therefore, the price criterion must be maximized.

Besides the first scenario, in which the criteria weights were equal, two additional scenarios were examined, with different weights among the criteria, to cover different aspects of the problem. These scenarios focused on the most critical criteria for timber selection: pricing, density, and workability. In Scenario 2, more emphasis was placed on pricing, while in Scenario 3, pricing, density, and workability were given the same weights. The weights of the criteria for the three scenarios of the study are presented in Table 3.

Table 3. Weights of the criteria in the three scenarios examined in the study

Number	Criterion	Scenario 1	Scenario 2	Scenario 3
1	Density	0.10	0.15	0.20
2	Hardness	0.10	0.05	0.05
3	Rupture	0.10	0.05	0.05
4	Elasticity	0.10	0.05	0.05
5	Strength	0.10	0.05	0.05
6	Shrinkage	0.10	0.10	0.10
7	Durability	0.10	0.10	0.05
8	Workability	0.10	0.15	0.20
9	Resistance	0.10	0.10	0.05
10	Pricing	0.10	0.20	0.20

Moreover, a sensitivity analysis was conducted in the criteria weights to give different weights in the two additional scenarios examined. PROMETHEE software provides the sensitivity analysis of the criteria weights with the option "Visual Stability Interval". It is a handy tool for decision-makers because it provides the Walking Stability Intervals (WSI) for each criterion where the ranking of the alternatives remains the same within a specific weight interval (Mareschal, 2013).

Results

First Scenario: All criteria have equal weights.

According to the PROMETHEE II complete ranking (Fig. 1), walnut (*Juglans regia*) achieved the best performance among the examined broadleaf species with the highest Phi (0.3263), while willow (*Salix alba*) had the worst performance with the lowest Phi (–0.4981). Oak (*Quercus petraea*) and chestnut (*Castanea sativa*) were placed in second and third place, presenting high values of Phi (0.2110 and 0.1994, respectively). Ash (*Fraxinus excelsior*) and beech (*Fagus sylvatica*) were in the fourth and fifth place of the ranking with positive Phi (0.1115 and 0.1040, respectively), while hornbeam (*Carpinus betulus*) was also an acceptable alternative, although a marginal one since its net outranking flow (Phi) was 0.0593. On the other hand, poplar (Populus nigra) achieved the second lowest performance with –0.3492 Phi. Maple (*Acer pseudoplatanus*) was also a non-acceptable alternative according to the ranking since its net outranking flow was –0.1570, while

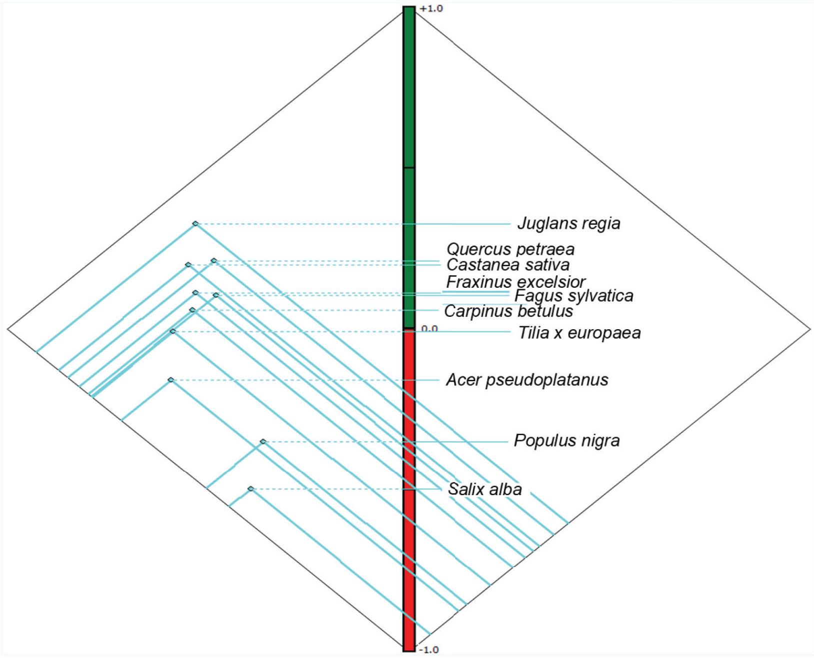

Fig. 1. PROMETHEE II Complete Ranking Scenario 1. Source: produced by Visual PROMETHEE.

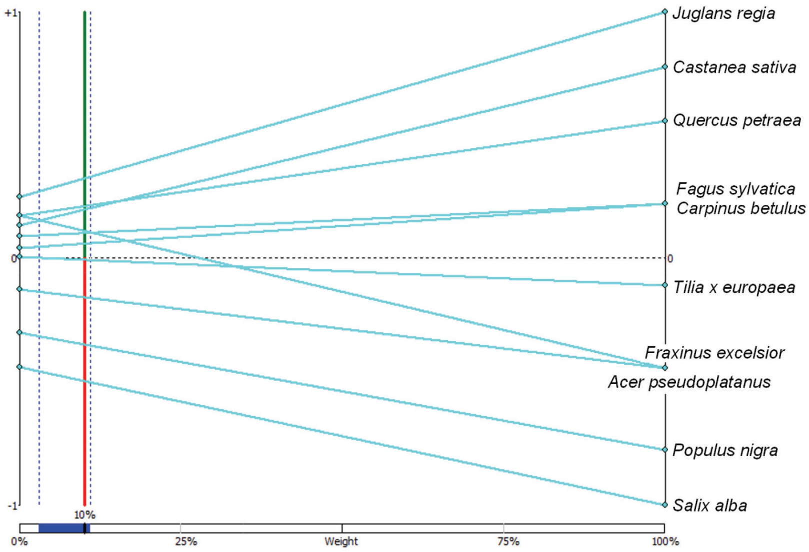

Fig. 2. Walking Stability Interval (WSI) for the criterion “Pricing”. Source: produced by Visual PROMETHEE.

lime (*Tilia × europaea*) was a marginally non-acceptable alternative with –0.0074 Phi.

Sensitivity Analysis

Figure 2 shows the Walking Stability Interval for the criterion ”Pricing”. The horizontal dimension corresponds to the weight of the selected criterion, while the vertical dimension corresponds to the Phi net flow score. For each action, a line is drawn that shows the net flow score as a function of the criterion’s weight. At the right edge of the display, the criterion’s weight is equal to 100%, and the alternatives are ranked according to that single criterion. At the left edge, the criterion’s weight is equal to 0%. The position of the vertical green and red bar corresponds to the current weight of the criterion (10% or 0.1 for “Pricing”). The intersection of the action lines with the vertical bar gives the PROMETHEE II complete ranking. The two dotted vertical lines show the weight interval within which the PROMETHEE II complete ranking of the alternatives remains the same. For the criterion “Pricing”, WSI = [3.02%–11.00%]. That means that if the criterion “Pricing” takes a weight number within the WSI, the ranking of the alternatives will remain unchanged. If its weight is 12% (0.12), the ranking of the alternatives will change, and *Fagus* (beech) will take fourth place instead of *Fraxinus* (ash). All other alternatives will have the same ranking as before. *Castanea* (chestnut) will take second place instead of *Quercus* (oak) if the criterion “Pricing” takes a weight number of 15% (0.15) or higher.

Table 4 shows the WSIs for the ten selected criteria. The criterion with the biggest WSI is “Strength”; the ranking of the alternatives remains the same if the weight for this criterion is between 0.00% and 15.39%. That means that the ranking of the alternatives will change if the criterion “Strength” takes a weight number of 0.16 (16%) or more. On the other hand, the criterion with the smallest WSI is “Shrinkage”; the ranking of the alternatives remains the same if the weight for this criterion stays between 8.57% and 11.11%. The practical meaning of this is that the ranking of the alternatives will change if the criterion “Workability” takes a weight number equal to or less than 8% (0.8) or a weight number above 12% (0.12).

Table 4. Walking Stability Intervals (WSIs) for the criteria of the study

Number	Criterion	WSI
1	Density	[6.86%– 20.06%]
2	Hardness	[7.73%–19.08%]
3	Rupture	[7.71%–18.45%]
4	Elasticity	[4.94%–12.29%]
5	Strength	[0.00%–15.39%]
6	Shrinkage	[8.57%–11.11%]
7	Durability	[9.13%–17.11%]
8	Workability	[7.52%–10.93%]
9	Resistance	[8.64% –13.85%]
10	Pricing	[3.02%–11.00%]

Second Scenario: Different weights of the criteria, more emphasis on pricing

According to the PROMETHEE II complete ranking for Scenario 2 (Fig. 3), walnut remains the best alternative, but chestnut is now in second place, followed by oak and beech. Ash is also an acceptable alternative. Four alternatives have increased their Phi compared to Scenario 1: walnut, chestnut, oak, and beech (the alternatives ranked in the first four places), while all the others have achieved a worse performance. Another significant difference with Scenario 1 is that in Scenario 2, only five alternatives are acceptable solutions. Hornbeam in Scenario 2 is a marginally unacceptable alternative with negative Phi (–0.070).

Third Scenario: Different weights of the criteria, equal emphasis on density, workability, and pricing.

According to the PROMETHEE II complete ranking for Scenario 3 (Fig. 4), *Juglans* (oak) remains the optimal solution (0.3898), followed by *Castanea* (chestnut) and *Fagus* (beech). *Fraxinus* (ash) and *Quercus* are also acceptable solutions. On the other hand, five species are evaluated as non-acceptable solutions: *Carpinus* (hornbeam), *Tilia* (lime), *Acer* (maple), *Populus* (poplar), and *Salix* (willow). Similarly to the other two scenarios, willow is the worst alternative with the lowest Phi (–0.6093).

Figure 5 presents the rankings in the three scenarios. The optimal solution (walnut) and the worst alternative (willow) remain the same in all scenarios. Also, the ranking from places 6 to 10 remains the same: 6) *Carpinus*, 7) *Tilia*, 8) *Acer*, 9) *Populus* and 10) *Salix* in all scenarios. On the other hand, the ranking changes for places 2 to 5 and the species *Castanea*, *Quercus*, *Fagus*, and *Fraxinus* among the different scenarios.

Table 5 presents the net outranking flow of each alternative in the three scenarios examined in the columns Phi1, Phi 2, and Phi 3 (Phi 1 = Scenario 1, Phi 2 = Scenario 2, Phi 3 = Scenario 3). The final column (Phi Average) shows the average net outranking flow of each alternative in the three scenarios, and the ranking of the alternatives has been made according to that number. According to that

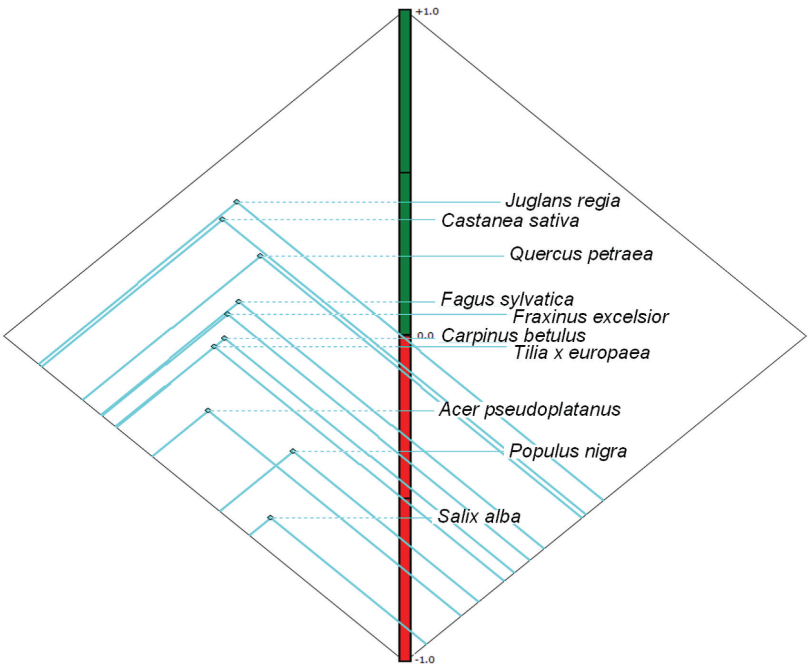

Fig. 3. PROMETHEE II Complete Ranking Scenario 2. Source: produced by Visual PROMETHEE.

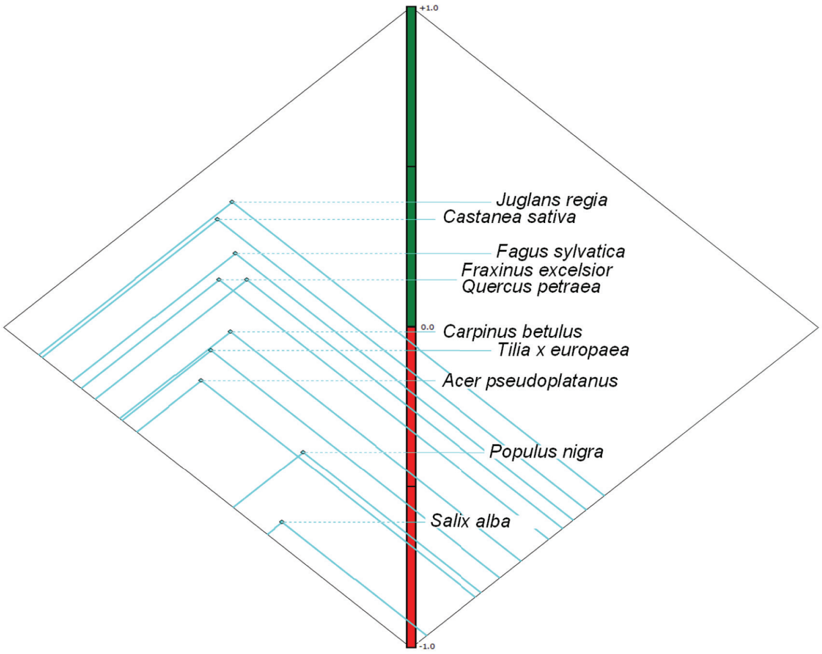

Fig. 4. PROMETHEE II Complete Ranking Scenario 3. Source: produced by Visual PROMETHEE.

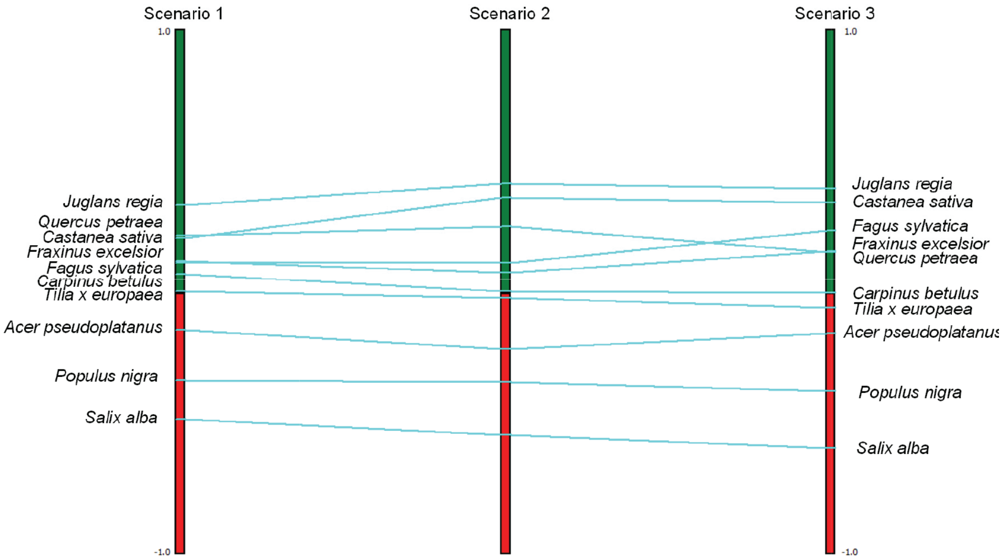

Fig. 5. PROMETHEE II Scenarios Comparison. Source: produced by Visual PROMETHEE.

Table 5. Net outranking flow of the alternatives in the scenarios of the study

Ranking	Hardwood	Phi 1	Phi 2	Phi 3	Phi Average
1	*Juglans regia* (walnut)	0.3263	0.4098	0.3898	0.3753
2	*Castanea sativa* (chestnut)	0.1994	0.3566	0.3366	0.2975
3	*Quercus petraea* (oak)	0.2110	0.2449	0.1476	0.2012
4	*Fagus sylvatica* (beech)	0.1040	0.1048	0.2300	0.1463
5	*Fraxinus excelsior* (ash)	0.1115	0.0653	0.1487	0.1085
6	*Carpinus betulus* (hornbeam)	0.0593	–0.0070	–0.0135	0.0129
7	*Tilia x europaea* (lime)	–0.0074	–0.0326	–0.0713	–0.0371
8	*Acer pseudoplatanus* (maple)	–0.1570	–0.2289	–0.1672	–0.1844
9	*Populus nigra* (poplar)	–0.3492	–0.3547	–0.3915	–0.3651
10	*Salix alba* (willow)	–0.4981	–0.5582	–0.6093	–0.5552

ranking, walnut is the optimal solution among the examined alternatives, followed by chestnut, oak, beech, and ash. At the same time, hornbeam achieves a marginally positive Phi and, therefore, is considered as a marginally acceptable alternative. On the other hand, lime, maple, poplar, and willow are non-acceptable alternatives. Willow achieves the lowest Phi and, therefore, is the least suitable hardwood among the examined species.

Discussion

Walnut is ranked first, an expected result, since its wood is regarded as one of the most valuable wood species internationally for furniture and carpentry, especially in the temperate zone. Its good properties, along with a large variety of color shades and ease of processing, make it appropriate for many high-quality and aesthetic constructions (Vassiliou and Aidinidis, 2004; Voulgaridis and Vassiliou, 2005).

Chestnut's high ranking is due to its high-quality wood, high density, resistance to biological attacks, and ease of work. In addition, the fact that it is a species widely diffused in Europe and Greece, mainly in coppice stands, contributes to more significant timber production potential (Manetti et al., 2001; Conedera et al., 2004).

In general, oak species seem to possess satisfying properties. *Quercus* genus consists of species which are widely spread all over the world and have many applications. *Quercus petraea's* high-density values and good mechanical properties make it suitable for many constructions. However, while processing, it can cause corrosion of metal tools, and it tends to crack during drying. Wood quality is also affected by forest operations and growing conditions and can result in high-valued timber (Kakaras, 2008; Brunetti et al., 2021).

Beech is ranked lower than the species mentioned above because of its low durability and natural resistance. Although beech wood has been used broadly to produce plywood or roundwood due to its significant load-bearing capacity, bonding during manufacturing is complex and requires different operations for better results. However, beech forests cover large areas in Europe and especially in Italy, where an effort to investigate the possibilities of various uses in construction is contacted (Kakaras, 2008; Aicher and Ohnesorge, 2011; Brunetti et al., 2020).

In all scenarios, willow and poplar consistently demonstrated the lowest performances, likely due to their pricing relative to their properties. According to Sennerby-Forsse (1989), these two species are approximately equal in quality. As a coppice plant, willow is utilized mainly for energy production since tension wood occurrence is a widespread defect (Gao et al., 2021). *Populus* species are also applicable for energy production since their low density, poor mechanical properties and high water concentration are limiting factors for many constructions (Kauter et al., 2003).

In a similar study Šuhajdová et al. (2018) evaluated the suitability of four hardwood species in civil engineering: 1) *Fagus sylvatica*, 2) *Quercus robur*, 3) *Carpinus betulus,* and 4) *Acer platanoides* under eight criteria: bending strength, elasticity modulus, compression strength, density, shrinkage, occurrence of knots and straight grains, workability and the increase of individual species representation in forest composition. According to the findings of the study of Šuhajdová et al. (2018), the most suitable hardwood was beech (*Fagus sylvatica*), a reasonable outcome because criteria that affect the quality of beech such as durability to decay and resistance to fungi were not used.

The classification of species above unarguably provides valuable guidance for the national forest sector as it moves forward into the future. From a policy perspective, this evaluation can inform the development of more targeted forest management policies and regulations. Timber production and other forest-derived products must remain competitive in the market to drive sustainable economic growth, as Forest Europe (2018) emphasizes. The action plan outlined by the European parliament (2015) underscores the importance of innovative products with high added value, distinguishing these commodities and translating overarching goals into competitive advantages. Moreover, the ability of the Greek timber industry to demonstrate product quality and reliability would be further improved by the implementation of a national Forest Products Certification System, which is currently absent in Greece (Georgiadis and Cooper, 2007; Koulelis, 2011). The creation of a national Forest Products Certification System in Greece can lead to increased revenues, job creation, and overall growth within the forest sector.

Conclusions

The present paper examined the suitability of ten of the most common species of hardwood used in the Greek timber industry. Greek timber industries can enhance their products' value and market appeal by focusing on species that meet high-quality standards and suit consumer preferences.

According to the findings, walnut was the optimal alternative that outranked the other examined species. Chestnut, oak, beech, ash, and hornbeam also achieved positive scores, and therefore, they are also acceptable alternatives as broadleaved species suitable for furniture manufacturing and sawn timber production. On the other hand, willow achieved the lowest score under the selected criteria among the alternatives, while poplar, maple, and lime were evaluated as non-acceptable alternatives.

Some limitations in this research may arise from assumptions about validity, subjectivity in criteria selection, and data interpretation. In addition, future research plans could explore more advanced decision analysis models, the inclusion of more criteria with different weights, socio-economic impacts, and the integration of emerging technologies for hardwood quality assessment in Greek timber industries.

The results demonstrate that the MCDA approach with the PROMETHEE method analysis can be applied to evaluate the suitability of wood species and can be used as a decision-making tool by the Greek timber industry.

References

Aicher, S., Christian, Z., Dill-langer, G., 2014. Hardwood Glulams—emerging timber products of superior mechanical properties. In *Proceedings of the World Conference on Timber Engineering (WCTE 2014). Quebec, Canada, 10-14 August 2014.* Quebec City, Canada: FPInnovations. 10 p. DOI: 10.13140/2.1.5170.1120

Aicher, S., Ohnesorge, D., 2011. Shear strength of glued laminated timber made from European beech timber. *European Journal of Wood and Wood Products*, 69: 143–154. https://doi.org/10.1007/s0010 7-009-0399-9

Behzadian, M., Kazemzadeh, R.B., Albadvi, A., Aghdasi, M., 2010. PROMETHEE: a comprehensive literature review on methodologies and applications. *European Journal of Operational Research*, 200 (1): 198–215. https://doi.org/10.1016/j.ejor.2009.01.021

Brans, J.P., 1982. L'ingénierie de la décision; elaboration d'instruments d'aide à la décision. La méthode PROMETHEE [Decision engineering; development of decision support tools. The PROMETHEE method]. In Nadeau, R., Landry, M. (eds). *L'aide à la décision: nature, instruments et perspectives d'avenir.* Québec: Presses de l'Université Laval, p. 183–213.

Brans, J.P., De Smet, Y., 2016. PROMETHEE methods. In Greco, S., Ehrgott, M., Figueira, J. (eds). *Multiple criteria decision analysis*. International Series in Operations Research & Management Science, vol. 233. New York, NY: Springer, p. 187–220.

Brunetti, M., Macchioni, N., Grifoni, F., Lazzeri, S., Sozzi, L., Cutini, A., 2021. Anatomical, physical and mechanical characterization of sessile oak (Quercus petraea Liebl.) wood from central Italy aged coppices. *Annals of Silvicultural Research*, 46 (1): 1–7. http://dx.doi.org/10.12899/asr-1672

Brunetti, M., Nocetti, M., Pizzo, B., Aminti, G., Cremonini, C., Negro, F., Zanuttini, R., Romagnoli, M., Scarascia Mugnozza, G., 2020. Structural products made of beech wood: quality assessment of the raw material. *European Journal of Wood and Wood Products*, 78: 961–970. https://doi.org/10.1007/s00107-020-01542-9

Conedera, M., Manetti, M. C., Giudici, F., Amorini, E., 2004. Distribution and economic potential of the Sweet chestnut (Castanea sativa Mill.) in Europe. *Ecologia Mediterranea*, 30 (2): 179–193.

Desch, H.E., Dinwoodie, J.M., 1996. *Timber: structure, properties, conversion and use*. 7th edition. London, UK: Red Globe Press. 320 p.

Ernur, A.M., Akiner, İ., Akiner, N., Zileska, P.V., 2022. Using wood as a new generation building material in the context of sustainable development. *Zaštita Materijala*, 63 (1): 68–78. https://doi.org/10.5937/zasmat2201068A

European Parliament, 2015. *A new EU forest strategy: for forests and the forest-based sector.* Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Publications Office of the European Union, Luxembourg. Brussels: European Commission, p. 1–17. [cit. 2023-12-15]. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:52013DC0659

Filippou, I., 2014. *Chemistry and chemical technology of wood*. Thessaloniki, Greece: Giachoudi Press. 357 p. (In Greek).

Forest Europe, 2018. *Enhancing the long-term competitiveness of the forest sector in a green economy: policies for forest-based bioeconomy in Europe.* Workshop report. Brussels, 29 May 2018. Zvolen: Liaison Unit Bratislava. 12 p. [cit. 2023-12-15]. https://foresteurope.org/wp-content/uploads/2017/08/Workshop-report_final-1.pdf

Forest Products Laboratory (USDA), 2010. *Wood handbook: wood as an engineering material.* Madison, Wisconsin: US Department of Agriculture, Forest Service, Forest Products Laboratory. 508 p.

Forest Products Pricing Table, 2023. Forest products pricing table, management year 2023. *Greek Government Gazzette*, 17 October 2023, 6013 (2): 67419–67426. [cit. 2023-11-30]. https://www.geotee.gr/MainNewsDetail.aspx?CatID=1&RefID=27004&TabID=4. (In Greek).

Gao, J., Jebrane, M., Terziev, N., Daniel, G., 2021. Evaluation of wood quality traits in Salix viminalis useful for biofuels: characterization and method development. *Forests*, 12 (8): 1048. DOI: 10.3390/f12081048

Gartner, B.L., 2005. Assessing wood characteristics and wood quality in intensively managed plantations. *Journal of Forestry*, 103 (2): 75.

Gejdoš, M., Lieskovský, M., Giertliová, B., Němec, M., Danihelová, Z., 2019. Prices of raw-wood assortments in selected markets of central Europe and their development in the future. *BioResources*, 14 (2): 2995–3011. DOI: 10.15376/biores.14.2.2995-3011

Georgiadis, N.M., Cooper, R.J., 2007. Development of a forest certification standard compatible with PEFC and FSC's management requirements. A case study from Greece. *Forestry: An International Journal of Forest Research*, 80 (2): 113–135. https://doi.org/10.1093/forestry/cpm004

Grigoriou, A., 1992. *Chemistry and chemical technology of wood*. Teaching material. Thessaloniki, Greece: Publications Office of Aristotle University of Thessaloniki. 32 p. (In Greek).

Jozsa, L.A., Middleton, G.R., 1994. *A discussion of wood quality attributes and their practical implications*. Vancouver, Canada: Forintek Canada Corp. 51 p.

Kakaras, I., 2008. *Wood as raw material. Types of wood-properties-applications*. Karditsa, Greece: University of Thessaly. 186 p. (In Greek).

Kakavas, K., Chavenetidou, M., Birbilis, D., 2018a. Effect of ring shakes on mechanical properties of chestnut wood from a Greek coppice forest. *The Forestry Chronicle*, 94 (1): 61–67. https://doi.org/10.5558/tfc2018-008

Kakavas, K., Chavenetidou, M., Birbilis, D., 2018b. Chemical properties of Greek stump chestnut (Castanea sativa

Mill.). *Natural Products Chemistry & Research*, 6 (4): 1–4. DOI: 10.4172/2329-6836.1000331

Kakavas, K., Chavenetidou, M., Birbilis, D., 2022. Dimensional changes of sweet chestnut wood (Castanea sativa Mill.) of Greek origin. *Euro-Mediterranean Journal for Environmental Integration*, 7 (3): 377–379. https://doi.org/10.1007/s41207-022-00320-8

Kantay, R., As, N., Ünsal, Ö., 2000. The mechanical properties of walnut (Juglans regia L.) wood. *Turkish Journal of Agriculture and Forestry*, 24 (6): 751–756.

Kauter, D., Lewandowski, I., Claupein, W., 2003. Quantity and quality of harvestable biomass from Populus short rotation coppice for solid fuel use—a review of the physiological basis and management influences. *Biomass and Bioenergy*, 24 (6): 411–427. https://doi.org/10.1016/S0961-9534(02)00177-0

Koulelis, P.P., Solomou, A.D., Fassouli, V.P., Tsiaras, S., Petrakis, P.V., 2022. Greece on a sustainable future: reviewing constraints and practices regarding forest and water resources management, flora and fauna biodiversity. *International Journal of Agricultural Resources, Governance and Ecology*, 18 (1-2): 38–54. https://doi.org/10.1504/IJARGE.2022.124637

Koulelis, P.P., 2009. Cluster analysis in primary roundwood production of 25 countries of European Union. *Annals of Forest Research*, 52: 163–168. https://doi.org/10.15287/afr.2009.133

Koulelis, P.P., 2011. Greek timber industries and wood product markets over the last century: development constraints and future directions. *Annals of Forest Research*, 54 (2): 229–240. https://doi.org/10.15287/afr.2011.92

Koulelis, P.P., 2012. A study of the Greek trade deficit in forest products. Current conditions and prospects. *Forest Systems*, 21: 549–554. http://dx.doi.org/10.5424/fs/2012213-02776

Koulelis, P.P., 2016. Forest products consumption and trade deficit in Greece during the financial crisis: A quantitative statistical analysis. *Open Journal of Business and Management,* 4: 258–265. DOI: 10.4236/ojbm.2016.42027

Koulelis, P.P., Tsiaras, S., Andreopoulou, Z.S., 2023. Greece's forest sector from the perspective of timber production: evolution or decline? *Forests*, 14: 2331. https://doi.org/10.3390/f14122331

Kretschmann, D.E., 2010. Mechanical properties of wood. Chapter 5. In Ross, R.J. (ed.). *Wood handbook. Wood as an engineering material*. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, p. 100–145 (5-1–5-46).

Larjavaara, M., Muller-Landau, H.C., 2010. Rethinking the value of high wood density. *Functional Ecology*, 24: 701–705. DOI: 10.1111/j.1365-2435.2010.01698.x

Li, Y., Mei, B., Linhares-Juvenal, T., 2019. The economic contribution of the world's forest sector. *Forest Policy and Economics*, 100: 236–253. https://doi.org/10.1016/j.forpol.2019.01.004

Manetti, M.C., Amorini, E., Becagli, C., Conedera, M., Giudici, F., 2001. Productive potential of chestnut (Castanea sativa Mill.) stands in Europe. *Forest Snow and Landscape Research*, 76 (3): 471–476.

Mantanis, G., 2008. *Applications of wood species in Greek market.* Teaching material. Thessaly, Greece: University of Thessaly. 4 p. [cit. 2023-11-14]. http://mantanis.users.uth.gr/2008-19.pdf (In Greek).

Mareschal, B., 2013. *Visual PROMETHEE 1.4 manual*. VP Solutions. 192 p.

Meier, E.W., 2015. *Wood! Identifying and using hundreds of woods worldwide*. Wisconsin, USA: The Wood Database. 272 p.

Niemz, P., Teischinger, A., Sandberg, D., 2023. *Springer handbook of wood science and technology*. Heidelberg, Germany: Springer. 2069 p.

Perlin, J., 2005. *A forest journey: the story of wood and civilization*. Vermont, USA: The Countryman Press. 464 p.

Rohanová, A., Nunez, E., 2014. Prediction models of Slovakian structural timber. *Wood Research*, 5: 757–767.

Savidge, R.A., 2003. Tree growth and wood quality. In Bar nett, J.R., Jeronimidis, G. (eds). W*ood quality and its biological basis*. New Jersey, USA: Blackwell, p. 1–29.

Scheffer, T.C., Morrell, J.J., 1998. *Natural durability of wood: a worldwide checklist of species.* Oregon State University, USA: Forest Research Laboratory. 58 p.

Sennerby-Forsse, L., 1989. Wood structure and quality in natural stands of Salix caprea L. and Salix pentandra L. *Studia Forestalia Suecica*, 182: 1–17.

Skarvelis, M., Mantanis, G.I., 2013. Physical and mechanical properties of beech wood harvested in the Greek public forests. *Wood Research*, 58 (1): 123–130.

Šuhajdová, E., Novotný, M., Pěnčík, J., Šuhajda, K., Schmid, P., Straka, B., 2018. Evaluation of suitability of selected hardwood in civil engineering. *Building Materials and Structure*, 61 (2): 73–82. DOI: 10.5937/GRMK1802073S

Taherdoost, H., Madanchian, M., 2023. Using PROMETHEE method for multi- criteria decision making: applications and procedures. *Iris Journal of Economics & Business Management*, 1 (1): 1–7. DOI: 10.33552/IJEBM.2023.01.000502

Toivonen, R.M., 2012. Product quality and value from consumer perspective—An application to wooden products. *Journal of Forest Economics*, 18 (2): 157–173. https://doi.org/10.1016/j.jfe.2011.12.004

Trulli, N., Valdés, M., De Nicolo, B., Fragiacomo, M., 2017. Grading of low-quality wood for use in structural elements. In Concu, G. (ed.) *Wood in civil engineering*. IntechOpen, p. 3–24). DOI: 10.5772/67129

Tsiaras, S., Andreopoulou, Z., 2020. Forest policy evaluation in European countries using the PROMETHEE method. In *Advances in operational research in the Balkans: XIII Balkan Conference on Operational Research*. Cham: Springer International Publishing, p. 95–109.

Tsiaras, S., Koulelis, P., Tsiroukis, A., Spanos, I., 2021. The contribution of forests in regional development: the role of National Forest Strategy in Greece. *MIBES Transactions*, 14: 110–122.

Tsiaras, S., Papathanasiou, J., 2018. Decision making under the scope of forest policy: sustainable agroforestry systems in less favoured areas. *International Journal of Sustainable Agricultural Management and Informatics*, 4 (3-4): 205–218. https://doi.org/10.1504/IJSAMI.2018.099232

Tsiaras, S., Samara, T., 2019. Selection of the most suitable tree species in urban areas based on their capability of capturing heavy metals: A forest policy approach. *International Journal of Sustainable Agricultural Management and Informatics*, 5 (1): 15–24. https://doi.org/10.1504/IJSAMI.2019.101374

Tsoumis, G., 1991. *Science and technology of wood: structure, properties, utilization*. New York, USA: Van Nostrand Reinhold. 351 p.

Vassiliou, V., Aidinidis, E., 2004. *Walnut's wood and the technology of its utilization*. Thessaloniki, Greece: Xristodoulidis. 185 p. (In Greek).

Vlachokostas, C., Michailidou, A. V., Matziris, E., Achillas, C., Moussiopoulos, N., 2014. A multiple criteria decision-making approach to put forward tree species in urban environment. *Urban Climate*, 10: 105–118. https://doi.org/10.1016/j.uclim.2014.10.003

Voulgaridis, E.V., 1995. Research on forest biomass utilization in Greece. *Forêt Méditerranéenne*, 16 (1): 99–101.

Voulgaridis, E.V.,Vassiliou, V.G., 2005. Wood properties and utilization potentials of walnut wood (Juglans regia L.) grown in Greece. *ISHS Acta Horticulturae 705: V International Walnut Symposium*, article number 705_78: 535–542. https://doi.org/10.17660/ActaHortic.2005.705.78

Voulgaridis, H., 2015. *Quality and uses of wood*. Kallipos repository. 280 p. [cit. 2024-08-03]. https://repository.kallipos.gr/handle/11419/5260. (In Greek).

Zhu, H., Luo, W., Ciesielski, P.N., Fang, Z., Zhu, J.Y., Henriksson, G., Himmel, M., Hu, L., 2016. Wood-derived materials for green electronics, biological devices, and energy applications. *Chemical Reviews*, 116 (16): 9305–9374. https://doi.org/10.1021/acs.chemrev.6b00225

Received March 22, 2024
Accepted May 22, 2024