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Climate Change Mitigation in Forestry: Paying for Carbon Stock or for Sequestration?

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Abstract: Climate change requires mitigation actions, mainly preventive, by reducing greenhouse gas emissions; however, carbon sequestration is a complementary measure. Although short-term carbon sequestration can be somewhat effective, it is really interesting when it is permanent. Sequestration calculates the carbon removed from the atmosphere over a period, while the stock expresses the cumulative carbon of a forest. Sequestration and stock are closely related, but ecosystem service valuation often focuses on the former, which can discourage forest maintenance. This study analyzes carbon sequestration and storage in four pine forests located in central Spain, comparing its valuation for different equivalence times, a period considered sufficient to compensate for the emission of one ton of CO_2 into the atmosphere. Equilibrium equivalence times were calculated for each forest, defined as the period in which carbon sequestration and stock payments are equal; values ranged from 33 to 101 years, with significant correlations with commercial volume and carbon stock. Equivalence times of 30–50 years are reasonable in Mediterranean forest stands with moderate growth and density, while in dense mature stands this time should increase to 50–100 years. Valuing carbon stocks and paying for them in a sustained manner over time promotes sustainable forest management, while the sale of sequestration credits may generate a speculative "greenwashing" market. In addition, payments for stocks can be applied to any forest stand and not only to new plantations. Carbon stock valuation is a win–win strategy for climate change mitigation, sustainable forest management, and rural development.

Keywords: carbon sequestration; carbon stock; climate change; climate change mitigation; forestry

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1. Introduction

Climate change requires significant mitigation actions. The main strategy must be preventive, limiting greenhouse gas (GHG) emissions [1]. According to the latest Spanish national inventory, GHG emissions in 2020 were 274,743 kt $CO_{2\,eq}$, a reduction of 12.5% compared to 2019, 37.9% compared to 2005, and 5.3% compared to 1990 [2]. However, the advanced results for 2021 point to an increase of 5.1% [3]. The sharp reduction in 2020 was probably due in part to the COVID-19 pandemic, and not only to the mitigation measures adopted. Consequently, further efforts are needed to reduce emissions. There are complementary mitigation actions, such as conserving and enhancing GHG sinks and reservoirs, including forests [4].

Plants have an important role in climate change mitigation, as they are able to take atmospheric carbon from CO_2 through photosynthesis and fix it for a period of time that depends on their lifetime. Carbon fixation is especially important in trees, due to their size and longevity, which allows them to hold it for a long time [5]. Even when trees are felled, carbon remains sequestered in the wood [6,7]; carbon persists in centuries-old wooden constructions and objects.

An essential criterion for carbon sequestration in forests to be effective in mitigating climate change is permanence [8]; if sequestration by plants is intense, but its release to the atmosphere is also intense, the final influence on atmospheric GHG concentrations is negligible or even negative. Depending on management and conservation actions, forests can be carbon sinks or carbon sources [9]. Therefore, it is essential to know how much carbon is sequestered in a forest, and how long it remains sequestered. The dependence of sequestration on its permanence makes some authors prefer to refer to it as carbon rental [10,11]. Valuation of carbon sequestration in forestry requires equating the marginal costs of energy reduction and carbon sequestration, which depends on permanence; the longer the sequestration, the higher its cost [11].

Sequestration calculates the carbon removed from the atmosphere over a period of time, while the stock expresses the amount of carbon in the vegetation at a given time. The stock is the result of the carbon sequestered and maintained over time, i.e., the cumulative carbon, considered the most appropriate method for quantifying carbon sequestration in forests [12]. Sequestration and stock are closely related. However, the valuation of ecosystem services (ES) often focuses on sequestration, without considering the stock. Hence, the current activity of vegetation in mitigating climate change is valued, but not the ES of maintaining the carbon sequestered.

Valuing sequestration, but not permanence, may have undesirable effects: planting new forests to sell carbon credits is encouraged, but the maintenance of existing forests may be abandoned as no remuneration is received. This may jeopardize the permanence of sequestration. There is a particular risk in regions such as the Mediterranean, where the low production of market-price goods means that forests are often financially deficient, as the investments required exceed the returns obtained [13]. As a result, short-term speculation may be encouraged by selling carbon credits for greenwashing, rather than promoting long-term sustainable forest management. In addition, carbon payments promote the increase in carbon density in forests [14]. This can be detrimental in Mediterranean forests, which are subject to a high fire risk that is also increasing as a consequence of climate change. Increasing carbon density implies increasing fuel density, which may be contrary to prevention policies. However, payment for the accumulated stock, while also favoring carbon accumulation, to increase rents, does not rely exclusively on sequestration to generate income.

The aim of this study is to analyze the ES of carbon sequestration and storage in four pine forests located in central Spain, valuing and comparing it both in terms of carbon stock and sequestration, for different periods.

2. Materials and Methods

2.1. Calculation of Carbon Stock and Sequestration

The IPCC 2006 guidance [15] was followed to calculate the carbon stock (C_{ST}), also including soil litter (L) in the calculation. Calculations refer to the area unit, hectares (ha), to allow comparison between forest stands. Carbon accumulated in deeper soil layers, which cannot be established by species, was not taken into account, as it is highly site dependent. Therefore, although carbon is known to exist in the soil, it was excluded from the calculation model. C_{ST} is calculated for each species by multiplying its commercial volume (V_C) in m3/ha, by the biomass conversion and expansion factor (BCEF), the ratio of belowground biomass to aboveground biomass (R) and the carbon fraction of dry matter in the trees ($c_{f\text{-}t}$) and adding the product of soil litter biomass (L) multiplied by its carbon fraction ($c_{f\text{-}l}$). The results are expressed in Mg C, but the most commonly used unit is Mg $CO_{2\,eq}$; for conversion, the ratio between the weight of the CO_2 molecule and the weight of the C atom is considered, with an equivalence factor of 44/12 [15].

$$C_{ST} = \{(V_C \cdot BCEF \cdot (1 + R) \cdot c_{f\text{-}t}) + (L \cdot c_{f\text{-}l})\} \cdot (44/12) \quad (1)$$

C_{ST} at the end of a year is the stock at the end of the previous year, adding the annual increment due to sequestration (C_{SQ}) and new plantings (C_F) and subtracting losses due to mortality and decomposition, removals, or fires (C_L).

$$C_{ST(n)} = C_{ST(n\text{-}1)} + C_{SQ(n)} + C_{F(n)} - C_{L(n)} \quad (2)$$

Sequestration (C_{SQ}) is the amount of CO_2 removed from the atmosphere by vegetation through photosynthesis and fixed as carbon in plant tissues. Hence, forest stand growth reflects CO_2 sequestration. It can be calculated using the annual volume increment (I_V), calculated using growth equations. In this study it was considered that the commercial volume growth is similar for above- and belowground fractions; although there are temporal variations, for the purpose of this study this assumption is considered acceptable. The calculation of C_{SQ} is similar to Equation (1), substituting V_C for I_V, and eliminating soil litter (L), since this is an average value for the stands of each species:

$$C_{SQ} = \{I_V \cdot BCEF \cdot (1 + R) \cdot c_{f\text{-}t}\} \cdot (44/12) \quad (3)$$

Plantations incorporate new carbon into the forest (C_P). However, plantations often use young trees, with negligible biomass and carbon for calculation purposes ($C_P \approx 0$). Once these specimens have developed, they will be included in forest inventory revisions and quantified as part of the stock.

Stock losses (C_L) may be caused by tree mortality, natural or as a result of outbreak caused by diseases or pests (C_M), by harvesting and pruning (C_H) or by forest fires (C_F). Carbon losses due to tree mortality occur when plant biomass decomposes and carbon is released into the atmosphere. The death of a tree does not imply the immediate release of the accumulated carbon, as some of it passes into the soil litter and some remains in the dead wood, sometimes for years in dry climates, such as the Mediterranean. For this reason, mortality was not included in this study:

$$C_L = C_H + C_F \quad (4)$$

Timber harvesting eliminates commercial and non-commercial aboveground biomass, but not belowground biomass and ground litter. In Mediterranean Spain non-commercial aboveground biomass cannot be left in the forests due to the high risk of fire, since its degradation is very slow, remaining for years as dry fuel; it is frequently eliminated by controlled burning, outside the fire risk period. Once the harvested volume (V_H) is known, it is possible to establish the carbon harvested (C_H):

$$C_H = \{V_H \cdot BCEF \cdot c_{f\text{-}t}\} \cdot (44/12) \quad (5)$$

In the event of a forest fire, a portion of the stand will be affected. Post-fire reports usually determine the volume of timber affected by fire (V_F). It can be considered that during a fire all aboveground biomass of the affected trees and soil litter is burned, while the belowground biomass is not affected. A fraction of the commercial biomass is completely burned while another, although damaged, is recoverable (r_t) [16]. The values of these fractions are specific to each fire, but at least in Spain there are annual figures of timber recovered by species [17]. The carbon lost in a fire will be the total stock affected, discounting the fraction of commercial biomass recovered. To convert the volume recovered into biomass, instead of using the expansion factor (since in this case the aerial part would not be included), the wood density (D) is applied:

$$C_F = \{(V_F \cdot BCEF \cdot c_{f\text{-}t}) - (r_t \cdot V_F \cdot D \cdot c_{f\text{-}t}) + (L \cdot c_{f\text{-}l})\} \cdot (44/12) \quad (6)$$

2.2. Valuation of Carbon Stock and Sequestration

The value of carbon sequestration in forests should be at least equal to the cost of achieving the same emission reduction by another method [18]. The most objective valuation method is to use a market price, such as EU emission allowances (EUA). EUA prices are available from 2005 to 2021 [19]. In addition, for this study, the current market value in 2022 was used. The expected value of EUAs for 2030 ranges from 85 to 129 EUR/t CO_2, depending on the sources [20–25]; according to the references consulted, an average value of 107 EUR/t CO_2 was assumed (Figure 1).

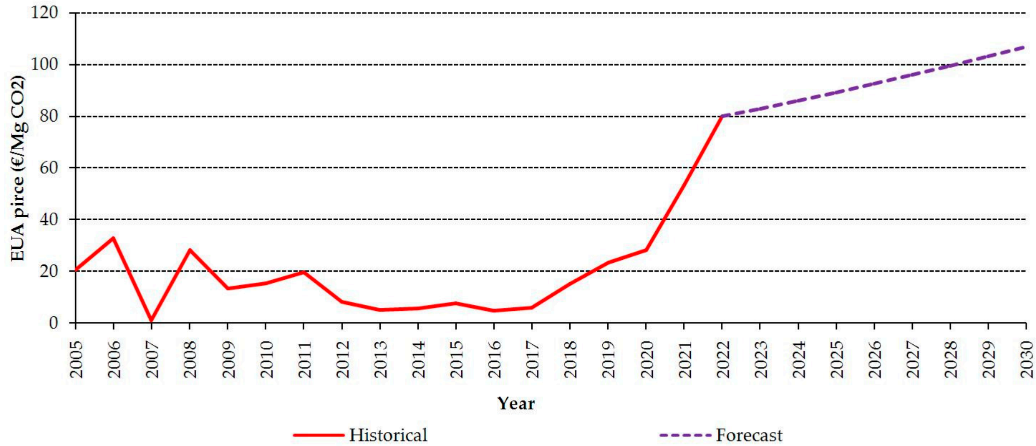

Figure 1. European Union Allowance (EUA) prices 2005–2030.

The EUA price refers to the emission of one ton of carbon into the atmosphere, so it could equally apply to the removal of one ton of carbon from the atmosphere. If the emission is permanent, then the removal should be also permanent. Applied to carbon sequestration in forests, one ton of carbon removed from the atmosphere should be permanently sequestered in trees. Actually, the concept of permanence is relative: neither the lifetime of CO_2 in the atmosphere is permanent nor should sequestration be permanent.

The period of time considered sufficient to compensate for the emission of one ton of CO_2 into the atmosphere is called the equivalence time (T_E). Several studies have determined this period, obtaining values ranging from 46 to 60 years [12,26–29], although they reach up to 150 years [30]. Other authors, after considering the previous studies, propose a reference value of 100 years [31], a figure also used in some forest compensation schemes [32,33]. Currently, the Spanish government requires a permanence period between 30 and 50 years for CO_2 absorption projects included in the carbon footprint and offset registry [34].

Three equivalence times were analyzed in this study: 100 years, a conservative figure from the scientific point of view; 50 years, the maximum permanence established in Spain (considering the uncertainty associated with longer periods) and a figure with broad scientific support; and 30 years, the minimum permanence time accepted in Spain.

The annual price of the carbon ton that remains sequestered, that is, of the carbon stock (P_{CST}/year), will be the annual market price of the ton of CO_2 (EUA value) divided by the equivalence time (T_E), in this study: 30, 50, or 100 years.

$$P_{C_{ST}/year} = EUA/T_E \tag{7}$$

2.3. Case Studies

As noted above, it was considered preferable to value the carbon stock as opposed to sequestration, because this promotes sustainable forest management and avoids speculative processes. The aim was to analyze the relationship between payments for carbon sequestration and carbon stock, considering different equivalence times (30, 50, and 100 years). To analyze this, four pine forests located in the Mediterranean region, in central Spain, were studied. The forests are dominated by *Pinus sylvestris* L., *P. pinaster* Aiton, *P. pinea* L., and/or *P. nigra* J.F. Arnold. All of them had management plans and forest inventories, with commercial timber volume values and annual harvest forecasts (Table 1).

Table 1. Basic data of the studied forests.

Property Name	Area (ha)		Main Species	Coordinates
	Total	Pine Forest		
Cuerda Herrera	207	144	*Pinus pinea*	4°01′17.28″ W, 40°30′12.52″ N
Jurisdicción	848	458	*Pinus sylvestris*, *P. pinaster*, *P. nigra*	4°09′05.77″ W, 40°36′09.34″ N
Monte Agudillo	1212	543	*Pinus pinea*, *P. pinaster*	4°18′04.40″ W, 40°26′31.11″ N
Ventilla-Vinatea	610	370	*Pinus pinea*	3°57′40.51″ W, 40°31′26.97″ N

The period analyzed was from 2010 to 2026, which encompasses the implementation period of all management plans. For each forest, annual sequestration and stocks were first calculated, and then valued, based on equivalence time. The calculation data for the species studied were adopted from the literature.

Four values were obtained for each forest: annual carbon sequestration value (C_{SQ}) and annual carbon stock value with equivalence times of 30 years ($C_{ST\text{-}30Y}$), 50 years ($C_{ST\text{-}50Y}$), and 100 years ($C_{ST\text{-}100Y}$). Subsequently, the equilibrium equivalence time (T_{Eq}) was calculated, defined as the time that equals the payments for sequestration and carbon stock.

Statistical regressions were performed between T_E and different parameters of the studied forest stands: stand density (N), diameter at breast height (D_{bh}), total height (H_t), commercial volume (V_C), carbon stock (C_{ST}), and carbon sequestration (C_{SQ}). For each regression an ANOVA was performed, calculating the *p*-value to determine if the regression was significant, and R^2 to determine to what extent the parameter explains T_E.

3. Results

The carbon stocks of the dominant tree species in the studied forests were calculated according to Equation (1) (Table 2).

Table 2. Carbon stock equations and calculation data.

Species	BCEF (Mg/m^3)	R	L (Mg/ha)	$c_{f\text{-}t}$	$c_{f\text{-}l}$	C_{ST} ($Mg\ CO_2/ha$)
Pinus nigra	0.640	0.244	15.100	0.509	0.401	$1.486\ V_C + 22.202$
Pinus pinaster	0.550	0.284	13.200	0.511	0.394	$1.323\ V_C + 19.070$
Pinus pinea	0.730	0.183	8.500	0.508	0.413	$1.609\ V_C + 12.872$
Pinus sylvestris	0.620	0.272	48.200	0.509	0.401	$1.472\ V_C + 70.870$

BCEF—biomass conversion and expansion factor [35]; R—ratio of belowground biomass to aboveground biomass [36]; L—soil litter [37]; $c_{f\text{-}t}$—tree carbon proportion [36]; $c_{f\text{-}l}$—soil litter carbon proportion [37]; C_{ST}—carbon stock [Equation (1)]; V_C—commercial volume (m^3/ha).

C_{SQ} was calculated according to Equation (3) (Table 3). The annual increase in commercial volume (I_V) was obtained using specific equations for each species and for the area studied [38].

Table 3. Carbon sequestration equations.

Species	I_V (m^3/ha Year)	C_{SQ} ($Mg\ CO_2$/ha Year)
Pinus nigra	$5.840 + 0.0147345 \cdot V_C - 0.0000011 \cdot {V_C}^2$	$1.486\ I_V$
Pinus pinaster	$4.500 + 0.0137175 \cdot V_C + 0.0000002 \cdot {V_C}^2$	$1.323\ I_V$
Pinus pinea	$4.010 + 0.0079149 \cdot V_C + 0.0000024 \cdot {V_C}^2$	$1.609\ I_V$
Pinus sylvestris	$3.500 + 0.0114846 \cdot V_C - 0.0000037 \cdot {V_C}^2$	$1.472\ I_V$

V_C—commercial volume (m^3/ha); I_V—annual increase in commercial volume (m^3/ha).

C_H was calculated according to Equation (5) (Table 4). All forests were sustainably managed, with plans regulating annual timber harvesting (V_H). C_F was calculated according to Equation (6) (Table 4). The average value of recovered timber (r_t) was calculated by averaging the values per species over the last decade, collected from the Spanish national forest fire statistics [17].

Table 4. Carbon loss equations (Mg CO_2/ha yr) and calculation data.

Species	C_H (Mg CO_2/ha Year)	r_t	D (Mg/m^3)	C_F (Mg CO_2/ha Year)
Pinus nigra	1.194 V_H	0.725	0.576	0.415 V_F + 22.202
Pinus pinaster	1.031 V_H	0.769	0.455	0.375 V_F + 19.070
Pinus pinea	1.360 V_H	0.569	0.596	0.728 V_F + 12.872
Pinus sylvestris	1.157 V_H	0.751	0.502	0.453 V_F + 70.870

C_H—carbon loss due to harvesting; V_H—commercial volume harvested; r_t—proportion of recovered timber [17]; D—timber density [39]; C_F—carbon loss due to forest fires; V_F—commercial volume damaged by fire.

Taking into account commercial volumes, expected harvesting, and annual growth, and considering the price per ton of carbon (EUA) in each year, the potential income per hectare in each forest derived from sequestration and stock for the three equivalence time scenarios (30, 50, and 100 years) was calculated (Figure 2).

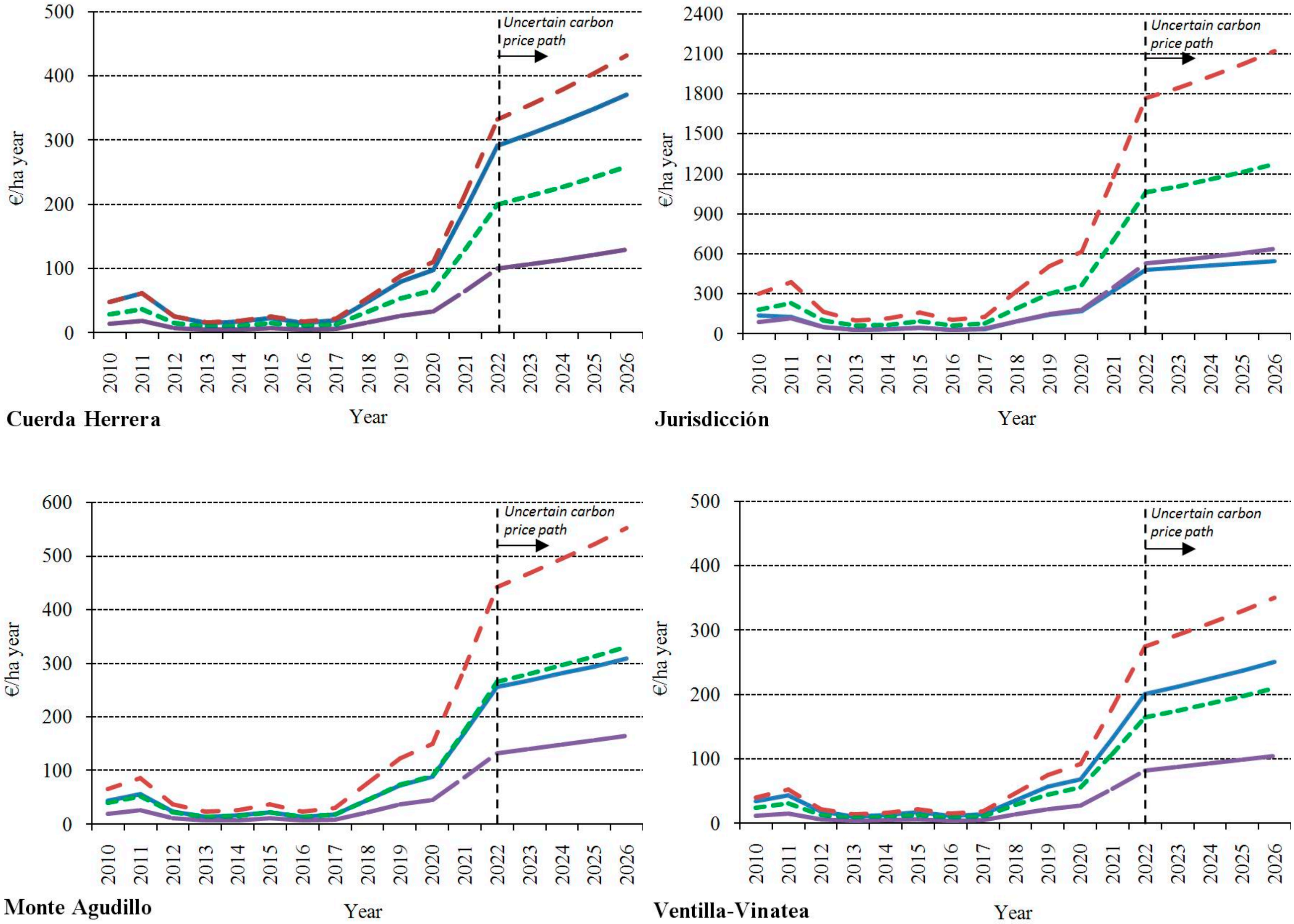

Figure 2. Carbon stock and sequestration valuation. C_{SQ}—valuation of carbon sequestration; $C_{ST\text{-}30Y}$—valuation of carbon stock with equivalence time of 30 years; $C_{ST\text{-}50Y}$—valuation of carbon stock with equivalence time of 50 years; $C_{ST\text{-}100Y}$—valuation of carbon stock with equivalence time of 100 years.

Equalizing the values of sequestration and stock payments in each forest, equilibrium equivalence times (T_{Eq}) were calculated. Values ranged from 33 to 101 years (Table 5). T_{Eq} only showed significant correlations with V_C and C_{ST}.

Table 5. Basic data, equivalence time, and correlations in 2022.

Property Name	T_{Eq}	N (Tree/ha)	D_{bh} (cm)	H_t (m)	V_C (m^3/ha)	C_{ST} (t CO_2/ha)	C_{SQ} (t CO_2/ha)
Cuerda Herrera	32.9	381	22.6	6.0	67.17	124.59	3.64
Jurisdicción	101.1	531	35.0	15.9	431.18	662.99	6.01
Monte Agudillo	49.6	211	30.5	11.8	95.65	165.91	3.20
Ventilla-Vinatea	39.3	324	18.1	6.1	54.54	103.14	2.51
p-value	-	0.2910	0.1702	0.0785	0.0131 *	0.0135 *	0.0893
R^2	-	50.26%	68.86%	84.92%	97.40%	97.32%	82.94%

T_{Eq}—equivalence equilibrium time that equals carbon sequestration and stock payments. N—number of trees per hectare; D_{bh}—diameter at breast height; H_t—total height; V_C—commercial volume; C_{ST}—carbon stock; C_{SQ}—carbon sequestration; * significant *p*-values.

Equations were sought to relate the significant variables to the equilibrium equivalence time. The equations that most accurately expressed these relationships were:

$$T_{Eq} = 4.5605\ V_C^{0.5105} \tag{8}$$

$$T_{Eq} = 2.5693\ C_{ST}^{0.5653} \tag{9}$$

These equations make it possible to estimate the equilibrium equivalence time in a forest stand using V_C or C_{ST}. The greater the volume and carbon stock of the forest stands, the longer the equivalence equilibrium time.

The adoption of equivalence times of 30–50 years (similar to the time of permanence established in Spain for forestry carbon offsetting) is reasonable in Mediterranean forest stands of moderate growth and density, while in mature and dense stands the equivalence time should increase to 50–100 years. There is no single equivalence time for the valuation of carbon stocks in all the forest stands studied.

4. Discussion

Climate change mitigation requires a drastic reduction of GHG emissions. Carbon sequestration in forestry is a complementary mitigation strategy but is not a substitute for steep emission reductions [40].

Carbon sequestration in forestry produces potentially marketable carbon credits [41], which has enabled the development of carbon markets. Additionality in carbon sequestration is clear in new plantations, but more complex to demonstrate in forest management. In conservation, additionality is only considered to exist when forests are at risk of disappearing (avoided deforestation), which is limited to developing countries [42]. Consequently, in developed countries, such as Spain, additionality is mainly focused on forest carbon sequestration.

There is a broad consensus that biodiversity or landscape protection are ecosystem services (ES), and likewise the protection of carbon stocks should be considered as such [43]. Sequestration considers current CO_2 capture, but forests have stored carbon over time, giving rise to a stock, which should also be valued as an ES. Maintaining the carbon stored in forests, instead of using the land for other activities, is an ES that should be rewarded. Moreover, the disappearance of forest would imply the release of the carbon stock, thus, losing this ES and contributing to climate change through emissions and future loss of sequestration due to the disappearance of the sink [16]. Consequently, it is important to promote forest conservation, not just carbon sequestration.

Trees store carbon from germination to death and decomposition. Throughout this period, the carbon stock accumulated in a forest varies, increasing as a result of tree growth or new plantations, and decreasing as a result of tree death and decomposition, timber harvesting, or exceptional events such as windstorms, or outbreak caused by diseases, pests, or fire. Therefore, valuation of carbon stocks, i.e., cumulative carbon [12], rather than sequestration, allows for a much broader and holistic view of forest management. An accounting framework that includes carbon stocks and flows allows for improved policy decision making for climate change mitigation [43]. In addition, annual payments for the annual value of carbon stored encourage continued efforts to safeguard the carbon stocks [44].

Carbon sequestration is subject to carbon price fluctuations. For example, the ton of carbon had very low values in the 2010s, growing very rapidly in the 2020s. This may induce changes in forest management strategies, depending on the evolution of the carbon price [14]. Although at least in the next decade the carbon price seems to continue to increase, the long-term trajectory is uncertain. For example, carbon capture and storage may offer cheaper carbon credits than sequestration in the future. Market fluctuations do not fit well with long-term sustainable forest management, which requires stability in forecasting. Carbon stock valuation provides greater stability than sequestration valuation, which is more sensitive to market fluctuations.

Basing the forest economy entirely on carbon sequestration is not desirable, and a diversified forest economy is preferable. For example, part of the sequestration may be devoted to increasing the carbon stock, but another part may be devoted to timber production or biomass production for energy, activities that rather than being mutually exclusive can be a win–win strategy and promote sustained mitigation [45–47]. Paying for sequestration is problematic in the case of logging. However, paying for stock allows rewarding the part of the sequestration that increases the stock, while the part used to produce timber is rewarded by the value of the wood products created. Valuing carbon stocks and paying for them on a sustained basis over time rewards good forest management [43].

Excessive emphasis on carbon sequestration can lead to inappropriate forest management decisions, or even encourage mismanagement [48], a risk that is reduced by valuing the stock. Promoting high densities is useful to increase the carbon stock [14], but in regions such as the Mediterranean it means assuming a higher risk of forest fires: in the case of fire, the stock is lost, and with it the ES provided and the potential income. Preventive fire treatments reduce carbon stocks and sequestration, but also the vulnerability of stands to forest fires. Thinning implies a reduction of stocks and sequestration in the short term, but is essential to achieve forest management objectives, and can stimulate stand growth and regeneration in the medium term [49,50]. The valuation of carbon stocks also makes it possible to remunerate forest regeneration, with a high potential for carbon sequestration [51], which is complex to introduce in traditional carbon markets due to the difficulty of demonstrating its additionality.

Remuneration for carbon sequestration is actually a rental, for a more or less extended period of time. The ton of CO_2 sequestered can be objectively valued through a market price such as the EUA. However, this value is useless if permanence is not established. The valuation of the carbon stock by dividing the price per ton of carbon by the equivalence time is more objective than the valuation of sequestration, since it implicitly takes permanence into account.

The timing of carbon payments also has implications. Payments in the early years tend to favor reforestation [52]. However, early payment of carbon credits in anticipation of future sequestration promotes reforestation as a short-term business, when in fact it is a long-term investment. There is great uncertainty about the actual effectiveness of carbon sequestration [53]. A forest fire, drought, or pests may affect a forest or plantation [54], whose carbon sequestration for the coming decades may have been paid for in advance. Underestimation of tree losses due to human and climatic disturbances leads to significant errors in carbon accounting [49]. Carbon stock payments allow real-time changes to be taken into account, instead of forecasts.

New afforestations and reforestations will not generate carbon revenues in the first years (or even decades), as the stock will be small [55]. However, if properly managed, it is a source of income in the medium and long term, often much more stable than timber harvesting [56]. Thus, there is a conflict between a short-term opportunistic market and a more stable long-term market, with a progressive increase in revenues until the forest reaches maturity, where growth may be reduced, but not the accumulated stock. Ignoring the time required for trees to reach their sequestration potential has been identified as cause of major errors in carbon accounting [49].

Paying for carbon stocks is paying for something measurable; if forest management is adequate, it will be maintained and income will continue to be received, but if the biomass decreases or is burned, it will no longer be remunerated. Moreover, payments for stocks can be applied to any forest, not just new plantations, allowing multiple use of forests and promoting sustainable management and rural development.

In the area studied, the equivalence times for carbon stock payments to be competitive should be from 30 to 100 years, depending on the density and age of the forest; an average value of 50 years can be considered. The first value, 30 years, is precisely the lowest period of permanence currently accepted in Spain for carbon offset projects. Although it is a low equivalence time, in practice it is realistic for Mediterranean stands of moderate or low growth. The period defining the carbon rental price varies over time, from 179 years in 2010 to 28 years in 2100 [11]. In each region, it will be necessary to evaluate which periods are the most realistic for calculating annual stock payments.

5. Conclusions

Carbon sequestration in forestry is a complementary climate change mitigation strategy. However, it carries some risks and uncertainties, such as carbon permanence, volatility of carbon markets, risk of promoting inadequate forest management and not promoting forest conservation or creating short-term speculative bubbles.

Carbon sequestration and stock maintenance are closely interrelated, and both are ES that should be remunerated. Carbon stock maintenance is currently only remunerated when there is a significant risk of disappearance, which is very unfair.

Remuneration of forest carbon stocks, rather than only sequestration, has great advantages in promoting both sustainable forest management and more effective climate change mitigation by internalizing the permanence of sequestration. To remunerate the carbon stock, it is enough to divide the price per ton of carbon by the permanence time, which in Mediterranean Spain would be from 30 to 100 years.

Carbon stock valuation is a win–win strategy for climate change mitigation, sustainable forest management and rural development.

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