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ORIGINAL PAPER

Profitability of timber plantations on agricultural land in the Po valley (northern Italy): a comparison between walnut, hybrid poplar and polycyclic plantations in the light of the European Union Rural Development Policy orientation

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Abstract
In the last decades, the Rural Development Policy of the European Union has been encouraging timber plantations on agricultural land with an increasing focus on supporting multifunctional forest investments, favouring a diversification of timber plantation investment possibilities. In this study, we estimated and analysed the potential financial returns from forest plantations on agricultural land in the context of the Po valley (northern Italy). We compared traditional monospecific walnut and hybrid poplar plantations with polycyclic plantations, an innovative model of mixed and multi-rotation plantation with much higher positive impact in terms of biodiversity. We defined different management models according to site fertility and investment costs and carried out a financial analysis using typical capital budgeting indicators, i.e. net present value, equivalent annual value and internal rate of return. Our results show that polycyclic plantations can reach on average the highest investment returns, although there are significant variations depending on site fertility and investment cost levels. The diversification of species, rotations and final assortments of polycyclic plantations appear to be potentially successful elements to cope with market risks. Hybrid poplar plantations are the most consolidated segment of investment but show the largest variability in terms of potential returns. For walnut plantations, the longer payback period can negatively influence the investment attractiveness. Results were analysed and discussed also considering the opportunity costs associated with the alternative agricultural land use (annual crops), and the effect of subsidies, land use costs and timber stumpage price variations. These proved to be determinant variables in influencing potential investments returns.

Keywords Productive forest plantations · Timber investments · Mixed plantations · Responsible management · Poplar · Rural Development Policy · Italy

Introduction

The expansion of forest plantations has reached, in the last decades, unprecedented levels, covering an area of 278 million hectares at global scale (FAO 2015; Payn et al. 2015). Of these, 76% have been estimated to be established and

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managed for productive purposes (Del Lungo et al. 2006), contributing to one-third of the global industrial timber supply (Jürgensen et al. 2014), a contribution that is expected to increase between 75 and 100% by 2050 driven by a globally increasing demand for wood and fibres (Carle and Holmgren 2008; Buongiorno et al. 2012). Provisioning services, in particular timber production, remain therefore the main driver for the expansion of forest plantations worldwide. However, in the last 20 years, there has been also a growing awareness of the potential of forest plantations to deliver other ecosystem services (Boyle 1999; Evans and Turnbull 2004; Carle and Holmgren 2008), in particular if plantations are compared to other forms of land uses as pastures or cropland (Pawson et al. 2013). In the case of timber-oriented investments, this awareness is reflected in the emergence of the so-called responsible investors, interested in combining their financial objectives with concerns about environmental and social impacts (UNECE/FAO 2014; Brotto et al. 2016). The trend towards responsible investments is observable also from the wide range of responsible management standards and guidelines that have been recently developed addressing specifically forest plantation concerns (Clark and Kozar 2011; Masiero et al. 2015).

Considering that the majority of forest plantations are established, either directly or indirectly, with public subsidies (Cossalter and Pye-Smith 2003; Bull et al. 2006; Duesberg et al. 2014), also public institutions have evidently a major role in influencing investments. In Europe, a growing role in supporting responsible investments in forest plantations is played by the European Union (EU) within its Rural Development Policy, the main policy instrument that the EU has to drive investment decisions in the agriculture and forestry sector within its Member States. This is reflected in the approach taken in the afforestation measures since the 1992 MacSharry reform (Regulation ECC No. 2080/1992) and the progressive shift from the primary idea of compensating land owners for taking agricultural land out of production ('set aside' approach) to the idea of incentivizing sustainable timber production from afforested areas, with an increasing attention to supporting new multifunctional forest plantations (Alliance Environment 2017). As such, the concept of these afforestation measures could be assimilated both to a subsidy given to land owners to produce timber and to a kind of payment for ecosystem services (PES) to increase the use of ecological and sustainability practices in new afforested areas, e.g. with the use of native and mix of species, as well as of voluntary forest certification schemes to guarantee responsible management practices (e.g. Harper 1993; Baldock and Beaufoy 1993; De Putter 1995; Weber 2005; OECD 2011; Szedlak 2017).

Among EU Member States, Italy represents a meaningful example of the impact of public subsidies on the investments in forest plantations, with subsidy policies that have been dynamically adapted to the changing social demands. Figure 1 presents synthetically the evolution of the predominant segments of productive forest plantation types and the main subsidy policies in recent history of the country.

Starting from the years just after the Second World War, industrial plantations with exotic species (e.g. *Eucalyptus* and *Pinus* spp.) were carried out in association with the need to support employment opportunities in rural and disadvantaged areas and to boost the industrial development, e.g. under the *Fund for the South* (L. 646/1950), the *First Law for Mountain Areas* (L. 951/1952) and the two '*Green Plans*' (L. 454/1961 and L. 910/1966) (Caruso 1977; Pettenella 1992). These types of plantations reached an extension of over 80 thousand hectares in the 1970s. However, in spite of what happened in other countries of southern Europe, where these types of plantations became consolidated and important segment of investments (e.g. Spain and Portugal) (Forest Europe 2015), in Italy the investments in new plantations with exotic species rapidly dropped as a consequence of two factors: the need for reducing public spending in the sector and a growing critical perception of the role of non-native species and monospecific plantations in rural landscapes. An important shift occurred at the beginning of the 1990s with a new phase of EU-based subsidy policies, firstly under the measures accompanying the Common Agricultural Policy (CAP) and later under the regional Rural Development Programs (RDPs) co-financed by the European Agricultural Fund for Rural Development (EAFRD). Under this new framework, in Italy a strong emphasis was given to the establishment of high-value hardwood plantations, using native species with medium–long rotations such as walnut (*Juglans regia*), cherry (*Prunus avium*) and oaks (*Quercus robur*; *Quercus petraea*), following the example of other EU Member States such as France. Between 1994 and 2006, under the afforestation measures of the Reg. EEC No. 2080/1992 and the RDPs 2000–2006 (Reg. EEC No. 1257/1999), out of the 144,714 hectares of plantations planted in Italy, over 75% were high-value hardwood plantations, mainly established on agricultural land by private small and medium holders for the production of industrial wood (Coletti 2001; Romano and Cilli 2009). However, after having reached the age of 20 years required by the contractual obligations associated with the afforestation measures as a minimum rotation age, most of these plantations appear to have been converted back to the previous agricultural uses, with a consequent rapid decline in the area covered with these species (not precisely quantifiable due to the lack of recent inventory data). The most consolidated segment of investments in plantations in Italy is represented by hybrid poplar plantations in the Po valley (northern Italy), traditionally grown on agricultural land and intensively managed in short rotation for the production of plywood and veneer logs. Historically, the dynamic of investments in

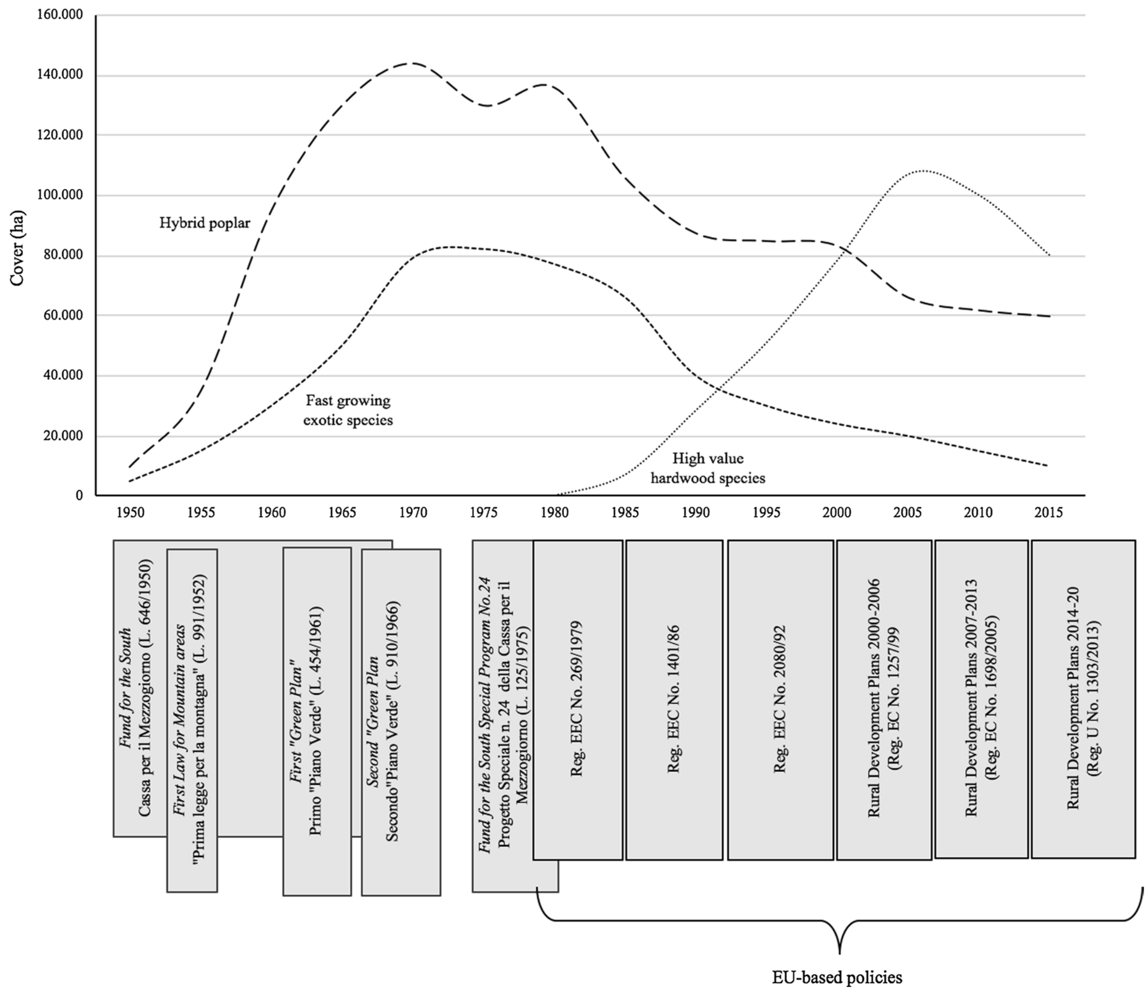


Fig. 1 Evolution of the main segments of timber plantations in Italy in respect of policy developments, 1950–2015. *Note* based on data from: IFN (1985), Gasparini and Tabacchi (2011), ISTAT (1970, 1980, 2000), Lapietra et al. (1995), Istituto Sperimentale per la Selvicoltura (1982), Boggia (1987), Coletti (2001), Romano and Cilli (2009). *Source*: own elaboration

poplar plantations has shown to be partially independent from the subsidy policies, mainly due to the key role that domestic poplar has for the plywood- and wood-based panels industries (Castro and Zanuttini 2008). However, after having reached the maximum expansion in the late 1960s (over 140 thousand hectares), also the area covered by poplar plantations has been then steadily decreasing (Coaloa 2008); according to the last National Forest Inventory data of 2005 (Gasparini and Tabacchi 2011), poplar plantations shrunk to an area of approximately 66,000 hectares. Being the opportunity cost of these investments (i.e. the missed income from cereals and rice productions) the most critical factor behind the declining of investments in poplar plantations in the Po valley, the RDPs' afforestation measures have been used to sustain poplar plantations. Although the use of RDPs' afforestation measures to set up this type of plantations is considered incoherent with the EU Rural Development Policy objectives, it has been possible thanks to the relatively high degree of national and regional competence in the technical definition of the forestry measures in the RDPs. As an example, between 2007 and 2013, under the measures 221 ('afforestation of agricultural land') and 223 ('afforestation of non-agricultural land') of the Reg. EC No. 1968/2005, out of the 18,654 hectares planted in Italy, 25.2% were planted with fast-growing species (mainly hybrid poplars), against the EU average of 1.71% (Table 1) (Alliance Environment 2017).

Initially, the use of RDPs to support productive forest plantations with fast-growing species was generally allowed, given that poplar plantations were considered to represent an environmental improvement compared to the alternative annual intensive agricultural crops, as demonstrated by several studies (Chiarabaglio et al. 2009, 2014). However, in more recent years, the intensive management and high pesticides and fertilizers inputs characterizing poplar plantation's management have led to growing reluctance

Table 1 Repartition by type of afforestation area supported under measures 221 and 223 Reg. EEC No. 1968/2005. *Source*: own elaboration based on data from Alliance Environment (2017)

	EU-27	Italy
Total planted area	287,490 ha	18,654 ha
Of which conifers species	23.6%	1.29%
Of which broadleaved species	49.9%	60.48%
Of which fast-growing species	1.71%	25.22%
Of which mixed stands	24.7%	13.02%

by public institutions, including the European Commission (EC), to support this type of investment. This resulted in stricter environmental restrictions and new rules in the RDPs afforestation measures eligibility criteria requiring the use of new and 'environmentally friendly' poplar clones more resistant to pest and insect attacks but not widely accepted by poplar growers and plywood and veneer industries (Castro and Giorcelli 2012). As a response to these issues, new examples of experimental mixed plantations have been tested in northern Italy since more than a decade: the so-called polycyclic plantations (Buresti Lattes et al. 2008a; Facciotto et al. 2014). These mixed plantations are defined as polycyclic because they include a mix of main and auxiliary species with different roles, objectives and rotations (Buresti Lattes et al. 2007; Pelleri et al. 2012); they are able to combine the production of different assortments, e.g. plywood and veneer logs from poplar clones with 10–14 years of rotation, sawn log from walnut or oaks with longer rotations (20–40 years) and biomass for energy from very fast growing species, such as willows and planes (Buresti Lattes and Mori 2006; Ravagni and Buresti Lattes 2007). The idea behind polycyclic plantation's concept is to integrate the positive environmental impacts associated with continuous tree cover and species admixture with firewood and timber production (Chiarabaglio et al. 2014; Londi et al. 2016). In addition, polycyclic plantations can potentially be a permanent use of former agricultural land, with a much higher positive impact in terms of ecosystem services provision (Buresti Lattes and Mori 2009). The area covered by experimental polycyclic plantations in Italy is estimated to be between 200 and 400 hectares mainly in Veneto, Lombardy and Piedmont. Although research and experimentation on dynamics and functioning of admixtures of species in forest stands is a topic of increasing relevance in Europe (Bravo-Oviedo et al. 2014; Del Río et al. 2015), similar experiences of mixed plantations of poplar and high-value hardwoods on agricultural land can be found only in France (Balandier and Dupraz 1999; Vidal and Becquey 2008a; Rivest et al. 2010).

In this paper we investigate the financial aspects of timber investments in the Po valley. Our focus is on productive forest plantations established on arable agricultural land mainly for the production of commercial timber (hereafter 'timber plantations'). These are sometimes found in the literature as 'tree farms' (e.g. Facciotto et al. 2014; Buresti Lattes et al. 2014). From a legal perspective, timber plantations are not considered a forestry activity and can be converted back to agricultural land use at any time according to Italian legislation (D.Leg. 34/2018 and previously D.Leg. 227/2001).

We compare two traditional monospecific plantation types, i.e. walnut and hybrid poplar plantations, with polycyclic plantation. These have been empirically found to be the main types of current timber plantation options in the context of the Po valley. The Po valley is a relatively homogenous context, and it is a particularly interesting case study at European level due to the historically significant level of investments in timber plantations (in particular hybrid poplars) on arable and very fertile agricultural land.

The application of financial analysis approach in forest economics can count on a rather consolidated body of literature (e.g. Price 1989; Klemperer 2003; Solberg 2010). In recent years, the specific topic of forest plantation investment's profitability has been investigated by several authors (Sedjo 2001; Zinkhan and Cubbage 2003; Cubbage et al. 2007, 2014), also focusing specifically on poplar plantations (Anderson and Luckert 2006; Tankersley 2006; Keča et al. 2011). However, in Italy timber plantations have rarely been analysed from a financial point of view. Only few studies have been published in Italian journals or technical magazines related to investments in hybrid poplar plantations (e.g. Borelli 1994; Borelli 1996; Borelli and Facciotto 1996) and high-value hardwood plantations (Berti and Mercurio 1992; Ragazzoni 1993; Cianciosi 1997), while no investigation has been carried out yet to assess whether polycyclic plantations can offer competitive financial returns to land owners. Our study objectives are therefore: (1) to estimate potential investment returns for walnut, hybrid poplar and polycyclic plantations in the Po valley; (2) to compare investment returns of timber plantations with alternative agricultural crops; and (3) to test the effect of subsidies, land use costs and timber stumpage price variations on the financial performances of timber plantations. A preliminary synthesis of this work has been published in an Italian technical forestry magazine (Pra et al. 2016), although without describing in detail the methodological aspects and the complete results and their discussion.

Methodology

The methodology consisted in the following steps: (1) definition of timber plantations and alternative agricultural crops models considered in the study; (2) collection and analysis of data on investment costs, timber stumpage prices and

Table 2 Description of timber plantations types, species and rotations considered in the study. *Source*: own elaboration

Types	Species	Number of trees at planting (trees ha^{-1})	Rotation (year) In high site fertility	Rotation (year) In average site fertility	Number of rotations in one polycyclic plantation cycle
Walnut	*Juglans regia*	110	20	27	
Hybrid poplar	*Populus × canadensis I*-214 clone	278	10	12	
Polycyclic plantations					
For plywood logs	*Platanus × acerifolia*	278	6	7	3
	Populus × canadensis I-214 clone	111	10	12	2
	Juglans regia	28	20	27	1
	Auxiliary trees/shrubs	264	10	12	1
	Total	681			
For energy	*Platanus × acerifolia*	552	6	7	3
	Populus × canadensis I-214 clone	46	10	12	2
	Juglans regia	46	20	27	1
	Auxiliary trees/shrubs	161	10	12	1
	Total	805			
For sawn logs	*Platanus × acerifolia*	278	6	7	3
	Populus × canadensis I-214 clone	69	10	12	2
	Juglans regia	69	20	27	1
	Auxiliary trees/shrubs	243	10	12	1
	Total	659			

productivity data; (3) financial analysis; and (4) sensitivity analysis. Each step is further described below.

Definition of timber plantations and alternative agricultural crops models considered in the study

The analysis compared three types of timber plantations (Table 2):

(a) walnut plantations, the most widespread investment model among high-value hardwood plantations;
(b) traditional hybrid poplar plantations (clone *Populus × canadensis* 'I-214');
(c) polycyclic plantations, where we distinguished three different sub-categories:

- polycyclic plantations for plywood logs, with higher component of poplar clones for plywood and veneer production;
- polycyclic plantations for energy, with higher component of species for firewood production;
- polycyclic plantations for sawn logs, with higher component of high-value hardwoods for sawn logs production.

Planting schemes for polycyclic plantations are presented in Annex 1 of the supplementary material. Management regimes normally adopted for walnut and hybrid poplar plantations are described in Buresti Lattes et al. (2008b), Allegro et al. (2014), Chiarabaglio et al. (2014) and Mori (2015). Polycyclic plantation management regimes are derived from experimental sites of the Association of Tree Farming for Economy and the Environment (AALSEA)[1] described in Buresti Lattes and Mori (2006). We defined management models and detailed them according to site fertility (average and high fertility) and investment costs (minimum or maximum). We defined the length of the rotation periods according to site fertility: high fertility corresponds to better growing conditions thus allowing shorter rotation periods (i.e. 10 years for poplar and 20 years for walnut and polycyclic plantations) than average fertility conditions (i.e. 12 years for poplar and 27 years for walnut and polycyclic plantations).

We also identified three alternative agricultural crops: maize silage, maize grain and soy (Trestini and Bolzonella 2015), and defined six models based on site fertility and production costs.

Table 3 presents the twenty models of timber plantations and the six models of agricultural crops used in the study.

[1] Website: www.aalsea.it/.

Table 3 Definition of the representative management models of timber plantations and agricultural crops defined according to site fertility and investment costs assumptions. *Source*: own elaboration

Type*	Site fertility		Investment costs		Models	Source
	High	Average	Minimum	Maximum		
Maize silage	X		X		MHMIN	De Carli (2015)
	X			X	MHMAX	Trestini and Bolzonella (2015)
		X		X	MAMAX	
Maize grain	X			X	GHMAX	
		X	X		GAMIN	
Soy	X		X		SHMIN	
Hybrid poplar	X		X		PHMIN	Ravagni and Buresti Lattes (2007)
	X			X	PHMAX	
		X	X		PAMIN	
		X		X	PAMAX	
Walnut	X		X		WHMIN	
	X			X	WHMAX	
		X	X		WAMIN	
		X		X	WAMAX	
Polycyclic plantations						
For plywood logs	X		X		PlyHMIN	
	X			X	PlyHMAX	
		X	X		PlyAMIN	
		X		X	PlyAMAX	
For energy	X		X		EneHMIN	
	X			X	EneHMAX	
		X	X		EneAMIN	
		X		X	EneAMAX	
For sawn logs	X		X		SawnHMIN	
	X			X	SawnHMAX	
		X	X		SawnAMIN	
		X		X	SawnAMAX	

*The combinations have been selected based on the availability of data

Collection and analysis of investment costs, timber stumpage prices and productivity data

We included as investment costs all the expenditures involved in the preparation, planting and maintenance of the selected types of plantations: site preparation (ploughing and harrowing), fertilization, seedlings purchase and transport, planting operations (marking, digging and planting), irrigation, disc harrowing, weeding, phytosanitary treatments, pruning and, finally, removal of residues and stumps after harvesting. We did not include harvesting costs because trees are normally sold as standing trees. Unitary costs have been provided by AALSEA and are reported in Annex 2 of the supplementary material, and Annex 3 presents management regime and annual costs for all timber plantation models.

Species growth rates and yield in the context of the Po valley are based on a mean annual increment (MAI) basis with data derived from AALSEA and from the LIFE + InBioWood experimental sites in Mantua (San Matteo delle Chiaviche, Ponte sull'Oglio, Viadana) and Verona (Gazzo Veronese, Villa Bartolomea) provinces (Castro et al. 2013; Pelleri et al. 2013; Olivotto 2016; Buresti Lattes et al. 2015; Mori and Buresti Lattes 2017, other AALSEA studies not yet published). Investment costs and yields for the agricultural crops are derived from Trestini and Bolzonella (2015) and De Carli (2015).

Average timber stumpage prices based on main assortments (firewood, woodchip, pulpwood, plywood, veneer and sawn logs) have been identified for the Italian market through literature (Pasini and Pividori 2014, 2015) and a market analysis (Table 4). Both cost values and timber stumpage prices include the value-added tax (VAT). Input data on productivity for different assortments are reported in Annex 4 of the supplementary material, and Annex 5 presents the yield and timber revenue calculation.

Table 4 Prices for different species, products and assortments used in the study. *Source*: own elaboration

Product/assortment	Unit	Value	Note	Reference year	Source
Maize silage	EUR t^{-1}	40	–	2015	Trestini and Bolzonella (2015)
Maize grain		163	–		
Soy		350	–		
Walnut sawn logs	EUR m^{-3}	300	–	June 2014	Pasini and Pividori (2014, 2015)
Poplar plywood and veneer logs	EUR m^{-3}	55	Given a price of 90 EUR t^{-1} of fresh biomass for processing trunk up to 20 cm DBH (diameter at breast height)	June 2014	
Poplar pulpwood	EUR t^{-1}	25	–	December 2014	
Chipwood	EUR t^{-1}	10	–	December 2014	
Plane tree firewood	EUR t^{-1}	35	Given a price of 55 EUR t^{-1} for harvesting, sizing and extraction and a final consumer price of 90 EUR t^{-1} of fresh biomass	December 2014	

Financial analysis

Cash flow tables were elaborated for all the 20 plantation models, which are presented in Table 5. We considered cost and revenues in terms of market prices and assuming constancy through time.

We carried out a financial analysis using three capital budgeting indicators to estimate financial returns and compare alternative investments: net present value (NPV), equivalent annual value (EAV) and internal rate of return (IRR). The NPV represents the present value of future cash flows, and it is generally considered as a preferable indicator to be used when analysing short-term forestry investments (Klemperer 2003; Wagner 2012). However, the NPV, reported as euros per hectare (EUR ha^{-1}) over the rotation period, does not allow the comparison between models with different rotations. Therefore, we decided to use the EAV[2] as our primary indicator, which is based on the idea of equal yearly distribution of the NPV along the rotation period, and it is useful to equally compare investments that have different rotations, including annual rotations such as agricultural crops, e.g. as done by Cubbage et al. (2007). The EAV is equivalent to the Faustmann ground rent (Faustmann 1849) and therefore is based on the assumption that the investment can be repeated ad infinitum. We decided to include also the IRR in order to be able to compare our results with those of other studies, being de facto the IRR the most commonly used indicator in financial literature. References for the calculation and interpretation of these indicators can be found in forest economics manuals and textbooks (e.g. Zinkhan and Cubbage 2003; Klemperer 2003; Solberg 2010; Bullard et al. 2011; Wagner 2012). These indicators were calculated as follows:

[2] The EAV can sometimes be found in the literature as equivalent annual annuity or net present annuity.

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{R_n - C_n}{(1+i)^n}$$

$$\mathrm{EAV} = \frac{\mathrm{NPV} * i}{1 - (1+i)^{-N}}$$

$$\mathrm{IRR} = i : \sum_{n=0}^{N} \frac{R_n}{(1+i)^n} = \sum_{n=0}^{N} \frac{C_n}{(1+i)^n}$$

where n = year number, R = revenues (cash inflow), C = costs (cash outflow), i = annual discount rate, and N = rotation length.

We calculated also the discounted payback period (PBP) as an additional indicator providing information on financial exposure risk associated with the investment. The discounted PBP determines the length of time (number of years) required to recover the costs of the investment, making the NPV equal to zero or positive. This was calculated as follows:

$$\text{Discounted PBP} = n : \sum_{0}^{N} \frac{R_n}{(1+i)^n} = \sum_{0}^{N} \frac{C_n}{(1+i)^n}$$

where $0 \leq n \leq N$.

The choice of the discount rate, which represents a land owner's opportunity cost for the investment capital, is controversial; discount rates cited in the literature for timberland investments vary from 3 to up 12%. We decided to use a discount rate of 3.5%, as suggested by HM Treasury 'Green Book' (2003). The analysis was carried out also testing alternative discount rates, which are 2%, as the closest value to long-term bond interest rate of EU Member States provided by the European Central Bank (EBC 2016); 5%, as suggested by the European Commission for European investments in the forestry and agriculture sectors (Snowdon and Harou

Table 5 Cash flows for the 20 timber plantation models (expressed in current values and not discounted). *Source*: own elaboration

Model	Flow	Year												
		0	1	2	3	4	5	6	7	8	9	10	11	12
Walnut														
WAMIN	Outflow	−906	−129	−192	−162	−139	−169	−116	−66	−66	−33	−33	−33	−33
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	0
WAMAX	Outflow	−1413	−219	−322	−277	−229	−274	−186	−116	−116	−58	−58	−58	−58
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	0
WAHMIN	Outflow	−906	−129	−192	−162	−139	−169	−116	−66	−66	−33	−33	−33	−33
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	0
WAHMAX	Outflow	−1413	−219	−322	−277	−229	−274	−186	−116	−116	−58	−58	−58	−58
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	0
Hybrid poplar														
PAMIN	Outflow	−1547	−441	−524	−621	−621	−677	−421	−388	−355	−183	−293		
	Inflow	0	0	0	0	0	0	0	0	0	0	12,931		
PAMAX	Outflow	−2314	−644	−769	−977	−977	−1033	−713	−655	−613	−277	−373		
	Inflow	0	0	0	0	0	0	0	0	0	0	12,931		
PHMIN	Outflow	−1547	−441	−524	−621	−621	−677	−421	−388	−355	−183	−183	−183	−293
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	12,931
PHMAX	Outflow	−2314	−644	−769	−977	−977	−1033	−713	−655	−613	−277	−277	−277	−373
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	12,931
Polycyclic plantations														
For plywood logs														
PlyAMIN	Outflow	−1993	−319	−226	−174	−144	−132	−7	0	0	0	−704	−97	−147
	Inflow	0	0	0	0	0	0	651	0	0	0	8451	0	1302
PlyAMAX	Outflow	−3202	−498	−347	−275	−220	−183	−10	0	0	0	−1021	−132	−199
	Inflow	0	0	0	0	0	0	651	0	0	0	8451	0	1302
PlyHMIN	Outflow	−1993	−319	−226	−174	−144	−132	−7	0	0	0	0	0	−704
	Inflow	0	0	0	0	0	0	0	651	0	0	0	0	8515
PlyHMAX	Outflow	−3202	−498	−347	−275	−220	−183	−10	0	0	0	0	0	−1021
	Inflow	0	0	0	0	0	0	0	651	0	0	0	0	8515
For energy														
EneAMIN	Outflow	−1993	−212	−173	−141	−112	−86	−12	0	0	0	−437	−40	−61
	Inflow	0	0	0	0	0	0	1085	0	0	0	3533	0	217
EneAMAX	Outflow	−3,27	−340	−277	−232	−179	−127	−16	0	0	0	−613	−55	−83
	Inflow	0	0	0	0	0	0	1085	0	0	0	3533	0	217
EneHMIN	Outflow	−1993	−212	−173	−141	−112	−86	−12	0	0	0	0	0	−437
	Inflow	0	0	0	0	0	0	0	1085	0	0	0	0	3577
EneHMAX	Outflow	−3,27	−340	−277	−232	−179	−127	−16	0	0	0	0	0	−613
	Inflow	0	0	0	0	0	0	0	1085	0	0	0	0	3577
For sawn logs														
SawnAMIN	Outflow	−1980	−268	−209	−161	−135	−113	−17	0	0	0	−532	−60	−92
	Inflow	0	0	0	0	0	0	649	0	0	0	5296	0	1298
SawnAMAX	Outflow	−3206	−423	−329	−261	−210	−162	−24	0	0	0	−758	−83	−124
	Inflow	0	0	0	0	0	0	649	0	0	0	5296	0	1298
SawnHMIN	Outflow	−1980	−268	−209	−161	−135	−113	−17	0	0	0	0	0	−532
	Inflow	0	0	0	0	0	0	0	649	0	0	0	0	5361
SawnHMAX	Outflow	−3206	−423	−329	−261	−210	−162	−24	0	0	0	0	0	−758
	Inflow	0	0	0	0	0	0	0	649	0	0	0	0	5361

Table 5 (continued)

Model	Flow	Year 13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Walnut																
WAMIN	Outflow	−33	−33	−33	0	0	0	0	−293							
	Inflow	0	0	0	0	0	0	0	11,734							
WAMAX	Outflow	−58	−58	−58	0	0	0	0	−373							
	Inflow	0	0	0	0	0	0	0	11,734							
WAHMIN	Outflow	−33	−33	−33	0	0	0	0	0	0	0	0	0	0	0	−293
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,734
WAHMAX	Outflow	−58	−58	−58	0	0	0	0	0	0	0	0	0	0	0	−373
	Inflow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,734
Hybrid poplar																
PAMIN	Outflow															
	Inflow															
PAMAX	Outflow															
	Inflow															
PHMIN	Outflow															
	Inflow															
PHMAX	Outflow															
	Inflow															
Polycyclic plantations																
For plywood logs																
PlyAMIN	Outflow	−67	−67	−89	−7	0	0	0	−247							
	Inflow	0	0	0	0	0	1302	0	10,473							
PlyAMAX	Outflow	−89	−89	−111	−10	0	0	0	−321							
	Inflow	0	0	0	0	0	1302	0	10,473							
PlyHMIN	Outflow	−97	−147	−67	−67	−89	−7	0	0	0	0	0	0	0	0	−247
	Inflow	0	1302	0	0	0	0	0	0	1302	0	0	8409	0	0	4819
PlyHMAX	Outflow	−132	−199	−89	−89	−111	−10	0	0	0	0	0	0	0	0	−321
	Inflow	0	1302	0	0	0	0	0	0	1302	0	0	8409	0	0	4819
For energy																
EneAMIN	Outflow	−28	−28	−37	−12	0	0	0	−247							
	Inflow	0	0	0	0	0	2,17	0	6944							
EneAMAX	Outflow	−37	−37	−46	−16	0	0	0	−321							
	Inflow	0	0	0	0	0	2,17	0	6944							
EneHMIN	Outflow	−40	−61	−28	−28	−37	−12	0	0	0	0	0	0	0	0	−247
	Inflow	0	2,17	0	0	0	0	0	0	2,17	0	0	3504	0	0	5403
EneHMAX	Outflow	−55	−83	−37	−37	−46	−16	0	0	0	0	0	0	0	0	−321
	Inflow	0	2,17	0	0	0	0	0	0	2,17	0	0	3504	0	0	5403
For sawn logs																
SawnAMIN	Outflow	−42	−42	−56	−17	0	0	0	−247							
	Inflow	0	0	0	0	0	1298	0	9759							
SawnAMAX	Outflow	−56	−56	−69	−24	0	0	0	−321							
	Inflow	0	0	0	0	0	1298	0	9759							
SawnHMIN	Outflow	−60	−92	−42	−42	−56	−17	0	0	0	0	0	0	0	0	−247
	Inflow	0	1298	0	0	0	0	0	0	1298	0	0	5253	0	0	6500
SawnHMAX	Outflow	−83	−124	−56	−56	−69	−24	0	0	0	0	0	0	0	0	−321
	Inflow	0	1298	0	0	0	0	0	0	1298	0	0	5253	0	0	6500

Table 6 Inputs used in the sensitivity analyses. *Source*: own elaboration

Hypothesis	Types			
	Polycyclic plantations	Walnut	Hybrid poplar	Agricultural crops
Subsidies*				
CAP direct payment	–	–	–	317 EUR ha^{-1} y^{-1}
RDP average contribution	See Table 7		See Table 7	–
RDP Emilia-Romagna	See Table 7		See Table 7	–
RDP Friuli-Venezia Giulia	See Table 7		See Table 7	–
RDP Lombardy	See Table 7		See Table 7	–
RDP Piedmont	See Table 7		See Table 7	–
Land use cost				
Annual land rent cost	462 EUR ha^{-1} y^{-1}			
Timber stumpage price variations				
Poplar plywood logs				
+ 20%	66 EUR t^{-1}			
− 20%	44 EUR t^{-1}			
Walnut sawn logs				
+ 30%	390 EUR m^{-3}			
− 30%	210 EUR m^{-3}			
Firewood				
+ 10%	38.50 EUR m^{-3}			
− 10%	31.50 EUR m^{-3}			

*We did not consider the Veneto RDP because at the time this paper was written no budget was yet allocated to the Measure 8.1

2013); and 8%, as selected by Cubbage et al. (2014) for the comparison of timber investments returns at global level.

We firstly considered a baseline scenario, where land costs and subsidies have not been included.

The financial analysis does not consider land value tax and income tax. This choice is motivated by the fact that the Italian tax regime varies substantially depending on the legal status and the business model of the investors.

Sensitivity analysis

Besides the discount rate, we completed other sensitivity analyses on many key variables, testing the effects of different hypothesis on subsidies, land use costs and timber price variations. The inputs used for the sensitivity analyses are reported in Table 6.

Concerning subsidies, we considered the uniform CAP direct payment and the project-based grants of the afforestation Measure 8.1 defined by the RDPs 2014–2020 in the northern Italian regions (Emilia-Romagna, Friuli-Venezia Giulia, Lombardy, Piedmont and Veneto). CAP direct payment is applicable only to agricultural crops (EC 2016). Timber plantations included in this study cannot benefit from the direct payment because, according to the Ministerial Decree 6513/2014, only very short rotation plantations with rotations below 8 years are eligible. RDP project-based grants break down into three components: reimbursement of a percentage of planting costs, compensation for income losses, and a premium for the stand maintenance. Eligibility criteria and contribution level differ among the five northern Italian regions (Table 7). Hence, we simulated regional scenarios as well as the average contribution level for the three components of subsidies across the five regions.

In the second sensitivity analysis, we included the land rent cost. This was calculated as the average land rent value of agricultural land suitable for timber plantations in the Po valley as reported by the Agricultural Annual Review of CREA (2016). We assumed that, given the active market for farmland renting in northern Italy, the average value of rents can be considered a good indicator of the real land use costs. This simulation was also performed in combination with the hypothesis of average subsidies contribution.

Finally, we simulated the hypothesis of timber stumpage price variations: ± 20% variation in the stumpage price of plywood logs (poplar); ± 30% in the stumpage price of sawn logs (walnut); and ± 10% variation in the price of firewood. It was assumed that these ranges reflect the average variation rates in the Italian domestic market for standing trees in recent years.

Table 7 Subsidy contribution provided with the 2014–2020 Rural Development Plans (Measure 8.1) of the northern Italian regions. *Source*: own elaboration

Type	Region	Site preparation and planting costs reimbursement (%)	Income loss compensation		Maintenance premium	
			Amount (EUR ha^{-1} y^{-1})	Duration (years)	Amount (EUR ha^{-1} y^{-1})	Duration (years)
Short-rotation plantation, 8–12 years (hybrid poplar)	Emilia-Romagna	40%*	–	–	–	–
	Friuli-Venezia Giulia	80%	–	–	–	–
	Lombardy	60%*	–	–	–	–
	Piedmont	60%*	–	–	–	–
	Veneto	80%	–	–	–	–
Average		65%	–	–	–	–
Medium–long-rotation plantations > 12 years (polycyclic plantations and walnut)	Emilia-Romagna	100%	–	–	400	12
	Friuli-Venezia Giulia	100%	885	12	852 (1st year) 668 (2nd and 7th years) 239 (3rd to 6th years)	7
	Lombardy	70%**	395	12	495	5
	Piedmont	80%	600	10	600	5
	Veneto	80%	250 (non-professional farmer) – 1000 (professional farmer)	12	1000 (1st to 5th years) 500 (6th to 12th years)	12
Average		85%	450	9	530	8

These are grant-based contributions subject to eligibility criteria. For a more detailed overview it is recommended to make reference to the official websites: Emilia-Romagna: http://agricoltura.regione.emilia-romagna.it/psr-2014–2020; Friuli-Venezia Giulia: https://www.sviluppoorurale.fvg.it/home/; Lombardy: http://www.psr.regione.lombardia.it; Piedmont: http://www.regione.piemonte.it/agri/psr2014_20/; Veneto: http://www.avepa.it/psr-2014–2020

*Percentages are higher (70% in Emilia-Romagna, 80–100% in Lombardy, 80% in Piedmont) if using poplar 'environmentally friendly clones' (Facciotto et al. 2014) or holding FSC® or PEFC™ forest management certification

**90% if holding FSC® or PEFC™ forest management certification

Results

The results of the study are presented in the following order: (1) investment costs, yields and timber revenues, (2) potential investment returns and (3) influence of subsidies, land use costs and timber stumpage price variations on profitability indicators.

Investment costs, yields and timber revenues

Table 8 summarizes the main data on investment costs, yield and timber revenues (i.e. the values of standing tree sales at different rotation ages) of the cash flows.

Total investment costs include site preparation, planting and maintenance costs. The total investment costs of timber plantations range from 2469 EUR ha^{-1} for walnut plantation models with minimum costs (WHMIN and WAMIN) to 9898 EUR ha^{-1} for poplar model PAMAX. Polycyclic plantations have investment costs ranging between 3618 EUR ha^{-1} (polycyclic plantations for plywood with minimum costs—PlyHMIN and PlyAMIN) and 6707 EUR ha^{-1} (polycyclic plantations for sawn logs with maximum costs—SawnHMAX and SawnAMAX). The mean total investment cost of the simulated timber plantation models is 5274 EUR ha^{-1}. If we split investment costs into their three components it results that maintenance is the most important one, followed by planting and site preparation. Site preparation costs are rather homogenous and range from 463 to 679 EUR ha^{-1}. Planting costs have a higher variability, ranging from 443 EUR ha^{-1} for walnut plantations with minimum costs to 2591 EUR ha^{-1} for the polycyclic plantations for energy with maximum costs (EneAMAX and SawnHMAX). The mean planting cost corresponds to 1611 EUR ha^{-1} with a standard deviation of 730 EUR ha^{-1}. The high standard deviation for planting cost is explained by the great variability in the number of planted trees among models: walnut plantations have the lowest density (110 tree ha^{-1}), while the polycyclic plantations for energy plantations reach the maximum (805 tree ha^{-1}). Maintenance costs show also a high variability, ranging from 1563 EUR ha^{-1} for walnut plantations with minimum cost to 7584 EUR ha^{-1} for poplar model PAMAX. The mean maintenance cost is 3092 EUR ha^{-1} with a standard deviation of 1707 EUR ha^{-1}. In this case, the high standard deviation is related to the variability on the intensity of management interventions:

Table 8 Summary of input data on investment costs, productivity and timber revenues. *Source*: own elaboration

Model code	Rotation (years)	Investment costs (EUR ha^{-1})				Volume per ha		Timber revenues (EUR ha^{-1})
		Site preparation	Planting	Maintenance	Total	MAI (m^3 ha^{-1} y^{-1})	Total yield (m^3)	
Walnut								
WHMIN	20	463	443	1563	2469	1.9	38	11,734
WHMAX	20	679	734	2518	3931	1.9	38	11,734
WAMIN	27	463	443	1563	2469	1.4	38	11,734
WAMAX	27	679	734	2518	3931	1.4	38	11,734
Hybrid poplar								
PHMIN	10	463	1084	4524	6071	26.9	269	12,931
PHMAX	10	679	1635	7030	9344	26.9	269	12,931
PAMIN	12	463	1084	4890	6437	22.4	269	12,931
PAMAX	12	679	1635	7584	9898	22.4	269	12,931
Polycyclic plantations								
For plywood logs								
PlyHMIN	20	463	1530	2424	3618	23.0	460	22,179
PlyHMAX	20	679	2523	3505	5650	23.0	460	22,179
PlyAMIN	27	463	1530	2424	3618	17.0	460	24,998
PlyAMAX	27	679	2523	3505	5650	17.0	460	24,998
For energy								
EneHMIN	20	463	1530	1625	3972	20.5	410	15,903
EneHMAX	20	679	2591	2380	6106	20.5	410	15,903
EneAMIN	27	463	1530	1625	3972	15.2	410	17,910
EneAMAX	27	679	2591	2380	6106	15.2	410	17,910
For sawn logs								
SawnHMIN	20	463	1517	1992	4417	26.6	531	18,302
SawnHMAX	20	679	2527	2900	6707	26.6	531	18,302
SawnAMIN	27	463	1517	1992	4417	19.7	531	20,360
SawnAMAX	27	679	2527	2900	6707	19.7	531	20,360
Mean		571	1611	3092	5274			20,084
SD		111	730	1707	1992			6203

poplar plantations require more intensive irrigation and phytosanitary treatments compared to polycyclic plantations and walnut.

Productivity is expressed as MAI (m^3 ha^{-1} y^{-1}) and as total yield over the rotation period (m^3 ha^{-1}). Chipwood obtained from branches, residues or auxiliary species in polycyclic plantations are excluded from the calculation. The MAI ranges from 1.4 m^3 ha^{-1} y^{-1} for walnut plantations in average fertility sites (WAMIN and WAMAX) up to 26.9 m^3 ha^{-1} y^{-1} in poplar (PHMIN and PHMAX) and polycyclic plantations for plywood logs in high fertility sites (PlyHMIN and PlyHMAX). The maximum total yield reaches a value of 269 m^3 ha^{-1} for poplar plantations in 10-year rotation and 531 m^3 ha^{-1} for the polycyclic plantations for sawn logs in a 20-year cycle.

Concerning timber revenues, the range varies from a minimum of 11,734 EUR ha^{-1} for walnut plantations in a 27-year rotation up to a maximum of 12,931 EUR ha^{-1} for poplar plantations in a 10-year rotation.

Potential investment returns

Table 9 summarizes the investment returns for timber plantations estimated for the baseline scenario using NPV, EAV, IRR and discounted PBP. EAV is used as primary indicator in order to compare models with different rotations. The mean EAV for the simulated timber plantation models is 329 EUR ha^{-1}. For walnut plantations the EAV ranges from 74 EUR ha^{-1} (WAMAX) to 266 EUR ha^{-1} (WHMIN). The NPV for walnut plantations ranges between 1282 EUR ha^{-1} (WAMAX, 27-year rotation) and 3781 EUR ha^{-1} (WHMIN, 20-year rotation), and IRR values vary from 5.0% to 10.0%. Poplar plantations show a greater variability, with the EAV ranging from −10 EUR ha^{-1} (PAMAX) to 454 EUR ha^{-1} (PHMIN). In this case, NPV ranges between −94 EUR ha^{-1}

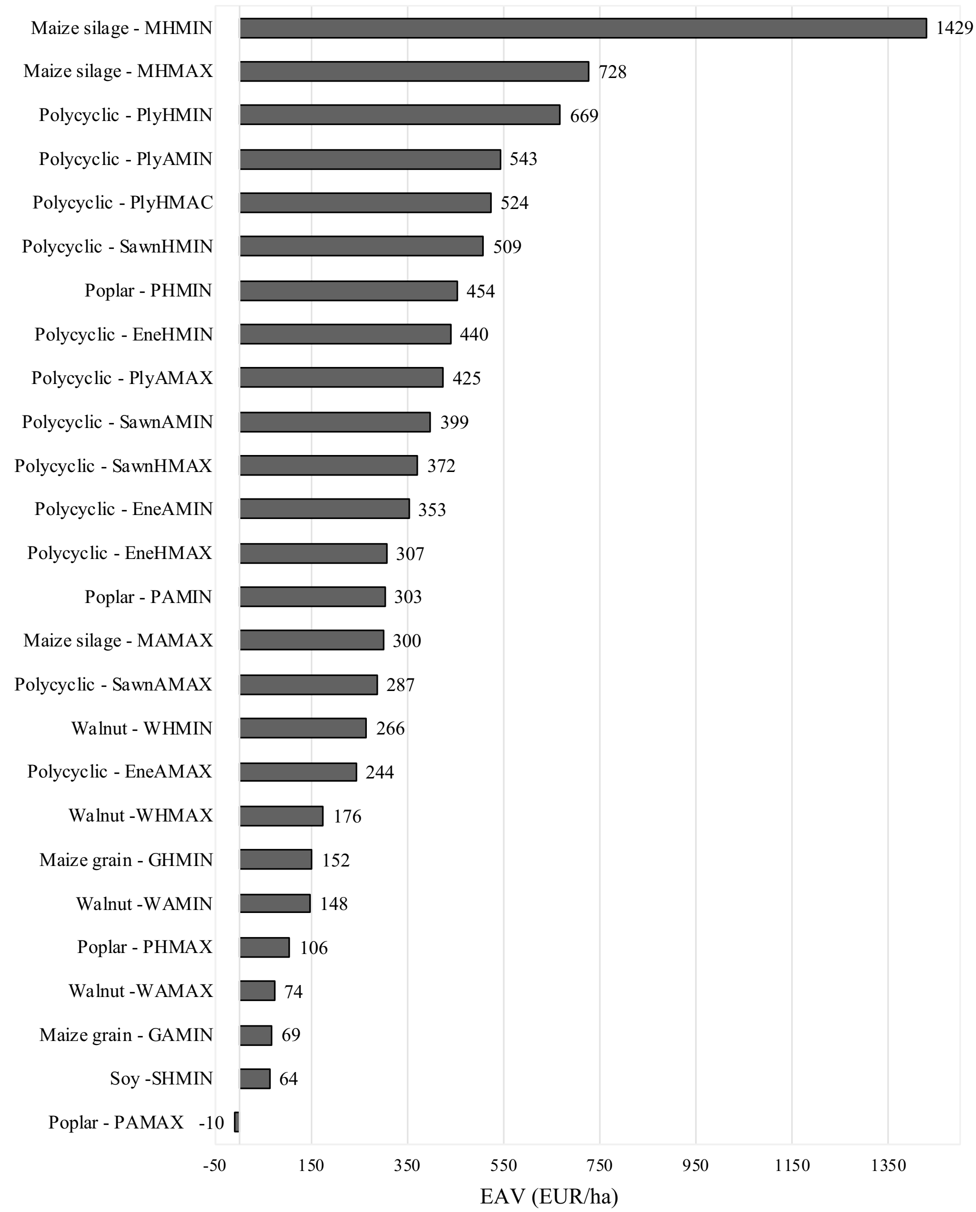
Table 9 Results of the financial analysis by capital budgeting indicators with a 3.5% discount rate. *Source*: own elaboration

Models	Rotation (years)	NPV (EUR ha^{-1})	EAV (EUR ha^{-1})	IRR	Discounted PBP (year)
Walnut					
WHMIN	20	3781	266	10.0%	20
WHMAX	20	2504	176	7.0%	20
WAMIN	27	2550	148	7.0%	27
WAMAX	27	1282	74	5.0%	27
Mean walnut		2529	166		
Hybrid poplar					
PHMIN	10	3774	454	12.0%	10
PHMAX	10	884	106	5.0%	10
PAMIN	12	2923	303	9.0%	12
PAMAX	12	−94	−10	n.d.	12
Mean hybrid poplar		1871	213		
Polycyclic plantations					
For plywood logs					
PlyHMIN	20	9510	669	16.4%	10
PlyHMAX	20	9386	524	11.5%	10
PlyAMIN	27	9386	543	13.5%	12
PlyAMAX	27	7343	425	10.0%	12
Mean for plywood		8806	540		
For energy					
EneHMIN	20	6351	440	13.7%	10
EneHMAX	20	4368	307	9.0%	10
EneAMIN	27	6094	353	11.0%	12
EneAMAX	27	4225	244	8.0%	12
Mean for energy		5259	336		
For sawn logs					
SawnHMIN	20	7240	509	13.9%	10
SawnHMAX	20	5287	372	9.5%	10
SawnAMIN	27	6899	399	11.0%	12
SawnAMAX	27	4962	287	8.0%	12
Mean for sawn logs		6097	391		
Mean polycyclic plantations		6721	423		
Overall mean			329		
SD			174		

(PAMAX, 12-year rotation) and 3774 EUR ha^{-1} (PHMIN, 10-year rotation), with IRR values up to 12.0% for the best model. Among polycyclic plantations, EAV varies from 244 EUR ha^{-1} (EneAMAX) to 669 EUR ha^{-1} (PlyHMIN). The NPV varies between 7343 EUR ha^{-1} (PlyAMAX, 27-year cycle) and 9510 EUR ha^{-1} (PlyHMIN, 20-year cycle) for polycyclic plantations for plywood logs; between 4225 EUR ha^{-1} (EneAMAX, 27-year cycle) and 6351 EUR ha^{-1} (EneHMIN, 20-year cycle) for polycyclic plantations for energy; and between 4962 EUR ha^{-1} (SawnAMAX, 27-year cycle) and 7240 EUR ha^{-1} (SawnHMIN, 20-year cycle) for polycyclic plantations for sawn logs. IRR values of polycyclic plantations range from 8.0% to 16.4%.

Table 9 provides also the means by type of plantation (walnut, poplar, polycyclic plantations for plywood logs, for energy, and for sawn logs). Polycyclic plantation models have on average better financial performances (mean EAV = 423 EUR ha^{-1}) than agricultural crops models (mean EAV = 457 EUR ha^{-1}). Agricultural crops show the greatest variability depending on the site fertility and production costs. Poplar plantations show a mean EAV of 213 EUR ha^{-1}. Walnut plantations show the lower mean EAV(166 EUR ha^{-1}). Financial analysis results for agricultural crops are detailed separately in Annex 6 of the supplementary material.

Fig. 2 Profitability ranking of the 26 models of timber plantations and agricultural crops by EAV (EUR ha^{-1}) with a 3.5% discount rate. *Source*: own elaboration



The discounted PBP represents the number of years that it takes to recover the investment costs: for walnut plantations in high fertility sites it is 20 years and for those in average fertility sites it is 27 years, while it is 10 or 12 years, again depending on our assumption on site fertility, for poplar and polycyclic plantations.

Figure 2 ranks the financial performances of both timber plantations and alternative agricultural crops. The rank is expressed in terms of EAV ha^{-1} to allow a comparison between investment horizons of different lengths. Maize silage models MHMIN and MHMAX have the best financial performances as they provide an EAV of, respectively, 1429 and 728 EUR ha^{-1}. Polycyclic plantations for plywood models result as the best ones among timber plantations. PlyHMIN model ranks third with an EAV of 669 EUR ha^{-1}, followed by PlyAMIN (543 EUR ha^{-1}) and PlyHMAX (524 EUR ha^{-1}). The best poplar plantation model ranks seventh with an EAV of 454 EUR ha^{-1}, while the lower among the poplar plantation models ranks last and is the only model showing a negative NPV among the 20 models considered for timber plantations. Walnut plantation models are found between the 17th and 23rd positions. The remaining agricultural models rank far below in terms of financial performances reaching only the 15th, 20th and 24th and 25th positions.

Figure 3 summarizes the results according to alternative discount rates for the three types of timber plantations, presented using EAV as dependent variable. If we apply an

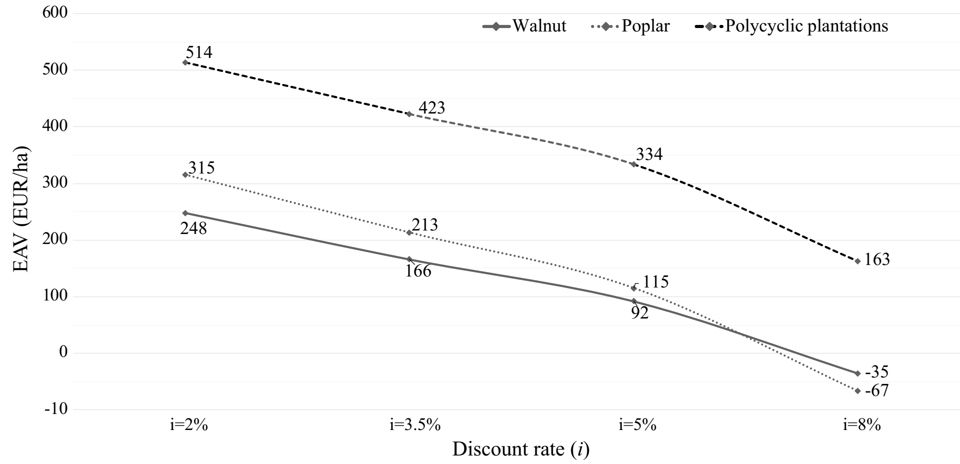


Fig. 3 Changes in the EAV (EUR ha^{-1}) in relation to alternative discount rates (2%, 3.5%, 5% and 8%). *Source*: own elaboration

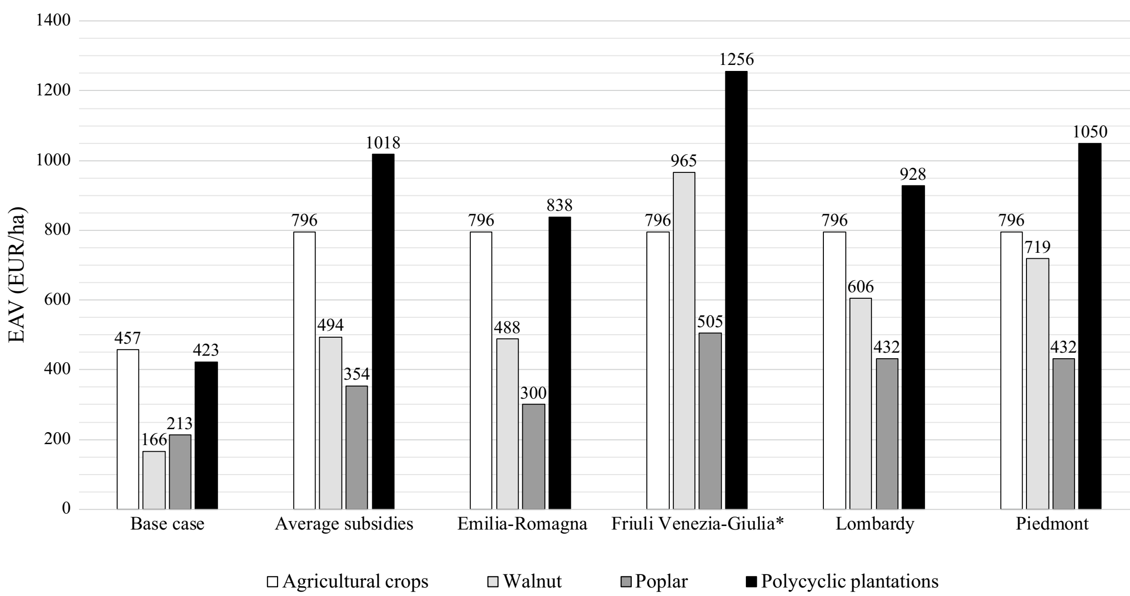


Fig. 4 Results of the sensitivity analyses on subsidies by EAV (EUR ha^{-1}) with a 3.5% discount rate. *In the case of Friuli-Venezia Giulia the model 'polycyclic plantation for plywood logs' has not been taken into consideration because of limitation in the number of poplar clones accepted set in the measure (< 10% of the total amount of plants per hectare). *Source*: own elaboration

8% discount rate, EAV for timber plantation models results positive only in the case of polycyclic plantations (163 EUR ha^{-1}), while walnut and poplar plantations present a negative one, respectively, − 35 EUR ha^{-1} and − 68 EUR ha^{-1}. In the case of a 2% discount rate, the EAV results 248 EUR ha^{-1} for walnut plantations, 316EUR ha^{-1} for poplar and 514 EUR ha^{-1} for polycyclic plantations. Finally, if we apply a 5% discount rate, walnut plantations present an EAV of 92 EUR ha^{-1}, poplar plantations 115 EUR ha^{-1} and polycyclic plantations 334 EUR ha^{-1}.

Influence of subsidies, land use cost and timber stumpage prices

The results of the sensitivity analysis of different assumptions of subsidies on the mean EAV of timber plantations and agricultural crops are presented in Fig. 4. The results show that these have a relevant effect on the financial performances of timber plantations and agricultural crops. The CAP direct payment of 317 EUR ha^{-1} y^{-1} is applicable only to agricultural crops, and it has the effect of increasing the average EAV of agricultural crops to 796 EUR ha^{-1}. In the case of timber plantations, we simulated the average contribution level based on RDP project-based

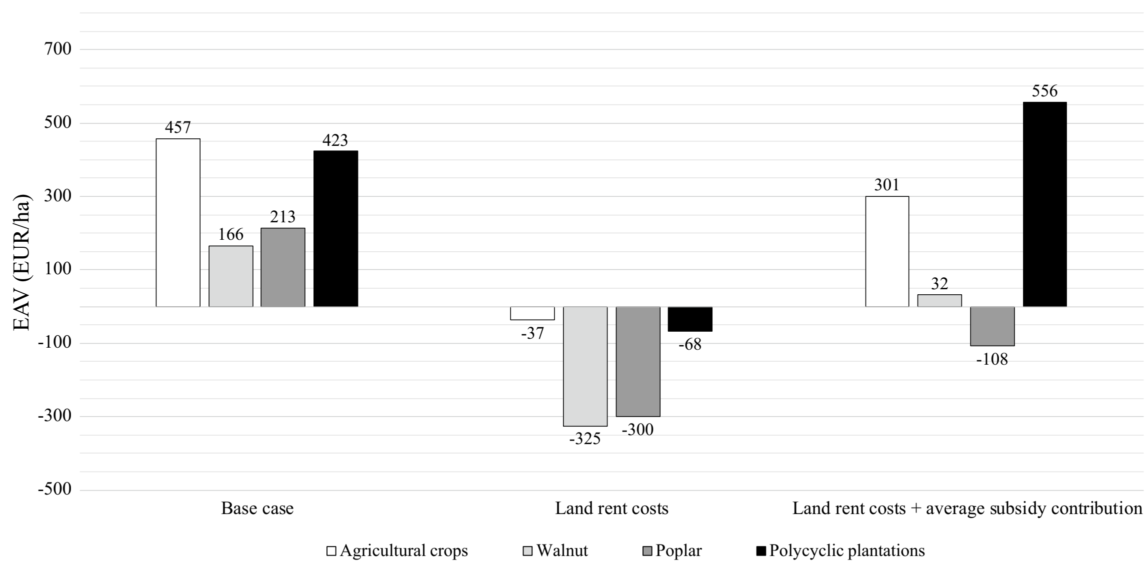


Fig. 5 Results of the sensitivity analyses on land use cost by EAV (EUR ha^{-1}) with a 3.5%

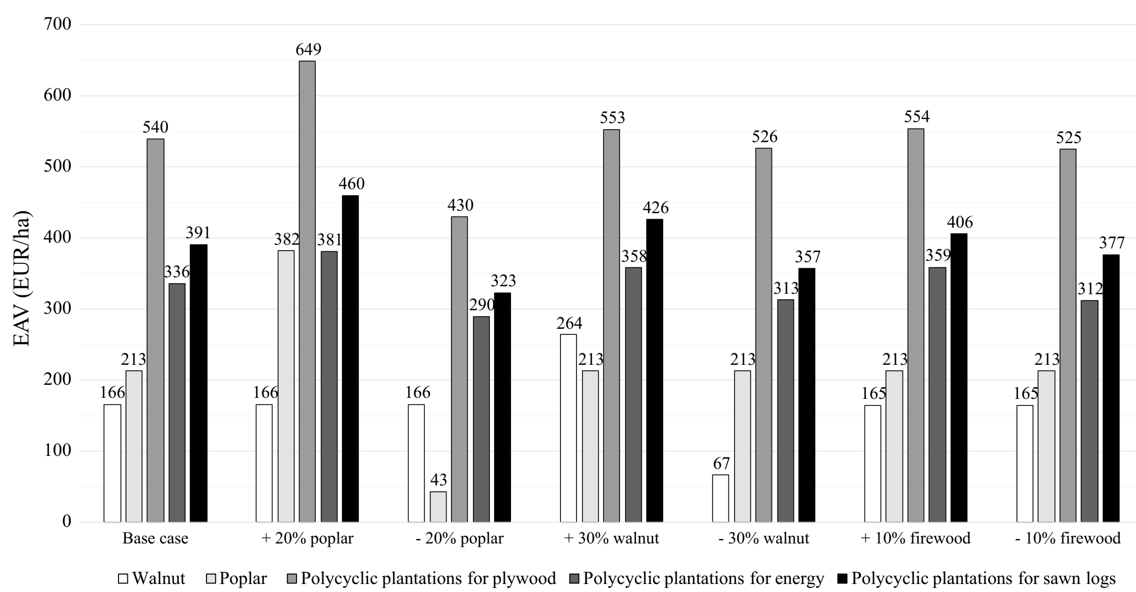


Fig. 6 Results of the sensitivity analyses on timber stumpage price variations by EAV (EUR ha^{-1}) with a 3.5% discount rate. *Source*: own elaboration

grants and four regional-specific scenarios (input data in Tables 6, 7). In the hypothesis of average subsidy contribution, EAV of polycyclic plantations reaches 1081 EUR ha^{-1}, while walnut 494 EUR ha^{-1} and poplar 354 EUR ha^{-1}. In the best hypothesis (Friuli-Venezia Giulia), EAV of polycyclic plantations can increase to 1256 EUR ha^{-1}, walnut to 965 EUR ha^{-1} and poplar to 505 EUR ha^{-1}, while in the minimum hypothesis (Emilia-Romagna) polycyclic plantations presents an average EAV of 838 EUR ha^{-1}, walnut 488 EUR ha^{-1} and poplar 300 EUR ha^{-1}.

When we include an annual land rent cost in the simulation (Fig. 5), calculated as the average land rent value of arable land suitable for plantations in the Po valley, none of the models present a positive EAV, if not supported by subsidies. EAV for agricultural crops is −37 EUR ha^{-1}, for polycyclic plantations −69 EUR ha^{-1}, and for poplar and walnut, respectively, −300 EUR ha^{-1} and −326 EUR ha^{-1}. When adding an average subsidy contribution (including CAP direct payment for agricultural crops), EAV increases to 301 EUR ha^{-1} for agricultural crops, to

556 EUR ha^{-1} for polycyclic plantations, and to 32 EUR ha^{-1} for walnut, and it remains negative (− 108 EUR ha^{-1}) for poplar.

The results of the sensitivity analysis of the effects of timber stumpage price variations on investment profitability are presented in Fig. 6. Poplar stumpage prices have varied on average by ± 20% if we consider the prices registered by Chambers of Commerce in Italy (varying from 44 EUR/t to 66 EUR/t). A +20% in poplar stumpage price increases substantially the mean EAV of poplar plantations (382 EUR ha^{-1}). However, polycyclic plantation models remain in line or more competitive given that all models have, although in different percentages, a poplar component. Polycyclic plantations for plywood are shown to be the most profitable plantation model under this assumption (650 EUR ha^{-1}). A − 20% in the stumpage price of poplar has the effects of reducing the EAV of poplar plantation models (44 EUR ha^{-1}), while polycyclic plantation models maintain the best mean performances. A ± 30% assumption in prices of walnut has been used to simulate the real variations that can happen in the market. With a +30% in walnut stumpage price, walnut monospecific plantation models reach an EAV of 264 EUR ha^{-1}, slightly higher than poplar plantations but substantially lower than polycyclic plantations. Under a − 30% in stumpage price assumption, EAV of walnut decreases to 67 EUR ha^{-1}.

Firewood prices can be considered stable in the domestic market, and the results show that a ± 10% variation does not chance significantly the EAV of timber plantation models, including polycyclic plantations for energy models.

The results of the sensitivity analyses are reported in the supplementary material (Annex 7 and Annex 8).

Discussion

Investment in timber plantations in the Po valley were analysed assuming representative forest management regimes and defining different models according to investment costs and site fertility. All inputs used in the study refer to the context of the Po valley and are derived from literature and market analysis and from the experimental sites of AALSEA and LIFE + InBioWood project. These have been selected and analysed assuming appropriate management conditions; therefore, our estimates cannot represent all the situations and it has to be considered that different assumptions related to site characteristics and management regimes could led to significantly different results.

The average investment cost of establishing and managing a timber plantation, including site preparation, planting and maintenance costs, is 5274 EUR ha^{-1}. The range of investment costs among plantation models is rather high and varies from 2469 EUR ha^{-1} for walnut plantations to 9898 EUR ha^{-1} for poplar plantations, depending on the number of trees to plant and the management intensity. Polycyclic plantations are based on the highest number of trees to plant, between 659 and 805 trees per hectare, while walnut plantations the lowest, 110 trees per hectare. Poplar plantations present the highest number of management interventions, in particular related to irrigation and phytosanitary treatments. On the other hand, polycyclic plantations need less management interventions, thanks to the species diversification and positive ecological interaction among them. According to a recent study by Pelleri et al. (2013), the capacity of polycyclic plantations to be more resistant to external disturbances has been quantified in a potential reduction of 61% of the use fertilizers, irrigation and pesticides compared to monospecific hybrid poplar plantations. In general, the hypothesis of a greater resistance of mixed plantations compared to monospecific ones has received an increasing evidence in the literature, i.e. Jactel and Brockerhoff (2007), Stojanovic et al. (2015), Jactel et al. (2016). The growth rates of timber plantation species in the Po valley, expressed as MAI ha^{-1} y^{-1}, range between 1.4 m^3 ha^{-1} y^{-1} for walnut and 26.9 m^3 ha^{-1} y^{-1} for poplar plantations. If compared with MAI of fast-growing species at global level (e.g. Sedjo 2001; Cossalter and Pye-Smith 2003), hybrid poplar in the Po valley is among the species with the highest MAI in the temperate zones, as confirmed also by other studies, i.e. Spinelli et al. (2011).

We carried out the financial analysis using NPV, EAV, IRR and discounted PBP as indicators. When interpreting the results, it has to be considered that the results are presented 'before tax', not including thus land value tax and income tax, which depend on legal status and the business model of the investor. We compared timber plantations with alternative agricultural crops by ranking all the models based on their EAV and assuming a fixed 3.5% discount rate. We used the EAV as primary indicator in order to equally compare investment with different rotations, but it has to be considered that the EAVs can be compared only under the assumption that the investments can be repeated ad infinitum. Although agricultural crops models have in general the greatest variability, maize silage models in high-fertility sites dominate the rank, with EAV values of, respectively, 1429 EUR ha^{-1} and 728 EUR ha^{-1}, depending on the management costs. Maize grain and soy financial results ranked far below, especially for those cultivation models associated with average fertility conditions. Polycyclic plantation models result on average the best ones among timber plantations, with EAV ranging from 244 to 669 EUR ha^{-1}. The best results in the rank are provided by polycyclic plantation models with a high component of hybrid poplar for plywood logs. Poplar plantation models have the greatest variability among timber plantations, with EAV varying from − 10 to 454 EUR ha^{-1}. Walnut plantation models result all in the lower half of the rank, with EAV ranging from 74 to 266 EUR ha^{-1}. Obviously, the choice of the discount rate affects substantially the EAV of a multi-year investment in timber plantations; we addressed this issue providing analyses based on alternative discount rates suggested in the literature.

Discussing the results of the sensitivity analyses to test the effect of subsidies, land use costs and timber stumpage price variations, our analyses indicate that these factors affect significantly timber plantation investment returns. In the average subsidy scenario, based on the current RDP Measure 8.1 project-based grants for northern Italian region, the mean EAV values of polycyclic, poplar and walnut plantations increase, respectively, up to 1018 EUR ha^{-1}, 494 EUR ha^{-1} and 354 EUR ha^{-1}. The results reflect the current approach of the RDPs derived from the Reg. EEC No. 1305/2013 that tends to incentivize more medium–long rotation with multifunctional role rather than short-rotation plantations (with the objective of 'support for sustainable and climate friendly land use'). The uniform CAP direct payment of 317 EUR ha^{-1} y^{-1} has also strong effect on profitability levels of agricultural crops (Bolzonella et al. 2014); this is not applicable to the timber plantation types considered in this study. It has been debated that in this type of contexts with high opportunity costs related to alternative agricultural land use, even if these forest plantations are profitable, land owners would not be attracted to invest in plantations that require high capital advances and produce an income only at the end of the rotation (Alliance Environment 2017). An additional indicator for exposure risk of the investment that we estimated in this study is the discounted PBP; this has resulted to be shorter for poplar and polycyclic plantations, 10 or 12 years, according to site fertility, while for walnut it is 20 or 27 years. Therefore, we can presume that subsidies can have a determining role in incentivizing land owners to establish plantations in this context. In addition, polycyclic plantations have also the advantage of producing a first income already at the seventh year (firewood from plane tree) and have cost of the investment recovered with the first poplar rotation completed (10 or 12 years). The need to rent land appears to have great negative effects on the investments, if not supported by subsidies. The inclusion of a land rent cost without subsidies decreases mean NPV to negative values for all timber plantations as well as for agricultural crops models. Timber stumpage prices are also a key factor to determine the profitability levels of timber plantations. We simulated several variations of poplar, walnut and firewood stumpage prices. This analysis is particularly relevant given that the Italian domestic timber market is far from being stable and the variations chosen for the analysis reflect the average real variations rates in recent years. Poplar timber market can be considered the most secure and fairly stable market. However, our results show that a 20% variation in poplar stumpage price affects significantly the EAV of an investment in this sector, that can increase up to 382 EUR ha^{-1} (+20% in poplar stumpage price) or drop to 44 EUR ha^{-1} (−20%). Walnut timber market is historically the less stable, and consequently, the profitability of the investment can radically change. Moreover, it has to be considered that walnut timber has the most floating price in the domestic market and the stumpage price used in the analysis is the most uncertain due to the lack of market information. Financial performances of poplar and walnut plantations are shown to be very sensitive to timber stumpage price variations, being these plantations monospecific. On the contrary, the diversification of species, rotations and final assortments of polycyclic plantations appear to be a successful key element to manage the risk of variations in timber prices.

We used the IRR to be able to compare our results with those of other studies where this has been used as primary indicator. Based on our estimations, timber plantations on agricultural land in the Po valley can potentially reach IRR values above the average 5% reported by Sedjo (2001) for forest plantations in Europe. For what concerns hybrid poplars and walnut plantations, our estimates appear to be in line with the values derived by other authors in the same context: Borelli and Facciotto (1996) estimated IRR of poplar plantation in the range 2–8%, while Cianciosi (1997) estimated IRR of walnut plantation between 9.1 and 9.6%. In the case of hybrid poplar plantations, various studies have been carried out by several authors in other contexts; the values of IRR in their analysis vary between 4.3% in the context of Canada (Anderson and Luckert 2006), 6.4% and 9.1% in southern USA (Tankersley 2006), 4.3% and 6.9% in Serbia (Keča et al. 2011, and 3.9% and 8% in the Ebro valley in Spain (Aunos et al. 2002). In the case of polycyclic plantation, financial aspects have never been investigated in Italy. However, a term of comparison is provided by Vidal and Becquey (2008b), who carried out a financial analysis of an experimental mixed plantation of hybrid poplar and walnut in agricultural land in France, where the IRR values estimated ranged between 6.9 and 7.6%, against a 5.5% of monospecific walnut and a 7.5% of monospecific poplar in the same context.

Our estimations allow us to hypothesize the investment trends for these plantations in the upcoming future. Investments in poplar plantations are likely to be rather stable in the near future, driven mainly by a constant demand for timber to feed the plywood and veneer industries. In addition, current research on the development of new more environmentally friendly poplar clones, more resistant to pest and insect attacks and more adapted to specific soil characteristics (Vietto et al. 2011; Facciotto et al. 2014) could lead to a reduction in management costs and consequently higher investment returns. On the contrary, investments in high-value hardwood plantations are likely to continue to fall despite the current framework of higher subsidies for medium–long-term plantations provided by the RDPs. The instability of the high-value hardwood market for sawn logs, together with longer discounted PBP, is likely to determine this trend. Investments in polycyclic plantations are likely to grow in the near future, also boosted by the favourable subsidy policy framework. This trend will be probably driven by the encouraging results on poplar growth rates in polycyclic plantations (e.g. Castro et al. 2013; Buresti Lattes et al. 2015; Mori and Buresti Lattes 2017) and the growing attention towards their better environmental impact compared to monospecific plantations (Buresti Lattes and Mori 2009; Motta et al. 2014; Chiarabaglio et al. 2014; Londi et al. 2016). On the other hand, polycyclic plantations present also limitations connected to the higher complexity for the land owners in terms management practices and for forest enterprises for harvesting operations (Pelleri 2016), that will need to be addressed by practitioners.

Conclusions

We estimated and discussed potential investment returns from timber plantations established on agricultural land, focusing specifically in the context of the Po valley, considering the opportunity costs associated with the alternative agricultural land use and the effects of factors such as subsidies, land use costs and timber stumpage prices. We compared two monospecific plantation types, i.e. walnut and hybrid poplar plantations, with polycyclic plantations. Walnut is the most widespread species among medium–long-rotation high-value hardwoods and has a significant expansion with the subsidies provided under the afforestation measures of the Reg. EEC No. 2080/1992 and Reg. EEC No. 1257/1999. Poplar plantations have been historically the most consolidated segment of investment in timber plantations in Italy; they are cultivated in intensive short rotations using hybrid clones, mainly clone 'I-214', for the production of plywood and veneer logs. Polycyclic plantations are an emerging example of mixed and multi-rotation plantations, with medium–long cycles or even potentially a permanent, producing much higher positive impacts in terms of biodiversity and environmental services provision. Timber plantations were compared as well with the main alternative agricultural crops: maize silage, maize grain and soy.

When considering the baseline scenario, where no land use costs nor subsidies have been included, our results show that polycyclic plantations present on average the best financial performances and poplar plantations are on average more profitable than walnut plantations, although there are significant differences among the single models depending on site fertility and investment cost levels. If we consider also the sensitivity analyses performed in the study, the potential financial performances of polycyclic plantations demonstrate that mixed and multifunctional plantations can be competitive, and in some cases even more interesting, in financial terms than monospecific plantations. In addition, the capacity of polycyclic plantations to better deal with market risks compared to monospecific plantation, thanks to the diversification of species and final assortments, emerged as an important management solution. However, it has to be considered that polycyclic plantations require more technical knowledge and management competencies by land owners and the problem of technology transfer should not be underestimated.

In the context of the Po valley, for investors without explicit land use costs to sustain, timber plantations can offer interesting investments opportunities. However, the opportunity costs for alternative land uses can be extremely high and market risk appears to be a crucial element in investment decisions. Longer payback periods might make annual agricultural crops more attractive for land owners. For non-land owners, investments in timber plantations in the Po valley are rather risky.

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