

Economic evaluation of introduction of poplar as biomass crop in Italy

Riccardo Testa, Anna Maria Di Trapani, Mario Foderà, Filippo Sgroi*, Salvatore Tudisca

Department of Agricultural and Forestry Sciences, University of Palermo, Viale delle Scienze, Edificio 4 Ingr. H, 90128 Palermo, Italy



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ABSTRACT

Lignocellulosic biomass production deriving from agro forest species, as well as poplar (*Populus* spp.), has denoted an increase in last years in UE also thanks to a series of policies aimed at reducing emissions of greenhouse gases and promoting renewable sources. In Italy poplar represents the main agro forest species and it is cultivated according to two different methods: very Short Rotation Coppice (vSRC) and Short Rotation Coppice (SRC). The aim of this paper has been to evaluate the economic feasibility of poplar as energy crop in the southern Italy and specifically to consider its competitiveness with respect to conventional crops. In particular, an economic analysis in a representative case study located in the Sicilian hilly hinterland has been carried out, by comparing the direct costs and incomes of poplar (both vSRC and SRC) and durum wheat. Results showed that only introduction of SRC plantation could increase the farm competitiveness, while vSRC could be economically advantageous only with a substantial increase of biomass market price and/or CAP subsidy. However, the introduction of poplar should grant a better contribution to climate change mitigation with respect to annual crop, improving the greenhouse gases balance and diminishing the environmental impact of agricultural activity.

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1. Introduction

Since the seventies, environmental issues have reached a very important role in the international debate, leading to ever increasing number of studies about the problem of global warming. These last denoted that the increase of 2 ppm per year of greenhouse gases (GHG) over the last fifty years had no equal in history [1].

This has led in recent years to a series of policies aimed at reducing emissions of greenhouse gases and promoting electricity

producing plants by renewable sources rather than fossil fuels ones [2].

Renewable energy sources such as hydropower, biomass, geothermal, wind and solar represent a viable alternative to traditional fossil fuels both for the benefits in terms of reduced impact on the environment as well as established by the Kyoto Protocol, and for their ability to be renewable and not subject to depletion [3,4].

European Union defined a policy in support of renewable sources with the Directive 2009/28/EC (better known as the “20–20–20” targets) that set as objective for EU the achievement of a share of 20% from renewable sources in 2020 in the consumed energy mix [5].

Among renewable sources from which it is possible to generate electricity or heat, UE solid biomass (wood, wood waste, pellets and other green or animal waste) in 2012 reached a value of

Abbreviations: GHG, greenhouse gases; LCA, life cycle assessment; SPS, Single Payment Scheme; SRC, Short Rotation Coppice; vSRC, very Short Rotation Coppice

* Corresponding author. Tel.: +39 091 23896615; fax: +39 091 484035.

E-mail address: filippo.sgroi@unipa.it (F. Sgroi).

Table 1

Primary energy production of solid biomass in UE in 2012 [6].

Country	Production (Mtoe)
Germany	11,811
France	10,457
Sweden	9449
Finland	7919
Poland	6851
Spain	4833
Austria	4820
Italy	4060
Romania	3470
Portugal	2342
Others	16,329
Total UE	82,341

primary energy equal to 82.3 Mtep [6], increasing by 57.0% with respect to 2000 (Table 1).

This increase was due also to lignocellulosic biomass production deriving from agricultural activity, especially for several agro forest species, as well as poplar (*Populus spp.*), willow (*Salix spp.*), acacia (*Robinia pseudoacacia*) and eucalyptus (*Eucalyptus spp.*), that allow lower emissions compared to annual crops, leading to lower environmental impacts [7–12].

According to many studies, in fact, the use of lignocellulosic crops for energy purposes may contribute significantly to the reduction of global GHG emissions, if produced in a sustainable way with regard to costs and land-use change [13,14].

However, bioenergy is not necessarily carbon neutral because emissions of CO₂, N₂O and CH₄ during crop production may reduce or completely counterbalance CO₂ savings of the substituted fossil fuels.

The CO₂ balance of energy crops can be estimated by C stock changes in above and below ground biomass and in soils. This strongly depends on the previous land-use and former C stock levels, especially for the largest terrestrial C pool, the soil organic carbon (SOC) pool. Land-use types with high SOC stocks, such as grasslands on organic soils, are more susceptible to land-use change to conventional energy crops than low C systems, such as croplands [15]. On the other hand, perennial energy crops may help to recapture SOC that was previously lost by cultivation [16].

As regard N₂O emissions during crop production depend on the amount of N fertilizer, pedo-climate conditions, oxygen availability and soil microorganisms [17,18], while CH₄ field emissions, may only be significant in organic soils with high ground water tables and their sink strength depend mainly on their porosity [19,20].

In literature, the evaluation of environmental impacts and energy balances associated with biomass production and/or management usually has been performed by applying life cycle assessment (LCA) analysis. LCA is defined as a methodology for the comprehensive assessment of the impact that a product or service has on the environment throughout its life cycle [21–23].

In Italy, in recent years, lignocellulosic species have become very popular and inserted in the cultural plans of several farms, with over 5000 ha already planted [24]. Poplar represents the main agro forest species [25,26] and it is cultivated according to two different methods: very Short Rotation Coppice (vSRC) and Short Rotation Coppice (SRC). The first method is characterized by a high planting density (5500–14,000 plants ha⁻¹) with a harvest carried out every 1–4 years, while the second one is based on a lower planting density (1000–2000 plants ha⁻¹) with a harvest ranging from 5 to 7 years [27–29].

Most of the studies carried out until now in Italy have focused only in the Northern Italy, where poplar is more spread [30].

So the aim of this paper has been to evaluate the economic feasibility of poplar as an energy crop in the southern Italy and specifically to consider its competitiveness with respect to conventional crops. In particular, it has been carried out an economic analysis in a representative case study located in the Sicilian hilly hinterland, by comparing the direct costs and incomes of poplar (both vSRC and SRC) and durum wheat (*Triticum durum*) and analyzing if introduction of poplar for biomass production could increase the farm competitiveness, reducing the risk management. Besides, in order to evaluate also the environmental impacts of introduction of biomass plantation with respect to annual crop, it has been carried out a literature review of several studies regarding the LCA analysis, GHG emissions and carbon balance of poplar as energy crop.

2. Materials and methods

Since economic profitability is the most important factor for the adoption of poplar for biomass energy for a farmer, it has been evaluated the economic feasibility of the introduction of poplar in cultural plans for Sicilian farmers. In particular, it has been carried out an economic analysis in a representative case study located in the hilly hinterland, by comparing the direct costs and incomes of poplar (both vSRC and SRC) and durum wheat (*T. durum*).

For each cropping system the economic analysis referred both the yield and the cost items to the current prices of the last crop year (2012/2013) and it has been considered that farming operations were carried out exclusively through rental (soil tillage, fertilization, pesticide treatments, harvest, and transport).

As regard to the technical-economic data of durum wheat have been collected through a questionnaire by means of direct interviews to farmer [31–33].

Durum wheat represents the main traditional crop of this area, where it is cultivated especially as monoculture and the average production is equal to 40 q ha⁻¹ with a sale price of 20 € q⁻¹ [34].

The annual gross margin (or profit) of durum wheat has been obtained from the difference between the annual revenues, including gross production value and Single Payment Scheme (SPS) according to the Council Regulation (EC) no. 73/2009 [35] and direct costs.

For vSRC model it has been considered a total duration of 14 years, which includes seven rotations of two years each (harvest every two years). The planting density was equal to 6667 plants ha⁻¹ (3.00 × 0.50 m²) with an average production of 20 Mg ha⁻¹ D.M. year⁻¹ and a biomass market price of 80 € Mg⁻¹ D.M. [36].

With regard to SRC model it has been taken into consideration a 15-year cycle, which provides three rotations of five years each (harvest every five years). The planting density was 1111 plants ha⁻¹ (3.00 × 3.00 m²), the average biomass production equal to 15 Mg ha⁻¹ D.M. year⁻¹ and the wood chips market value of 100 € Mg⁻¹ D.M. [37].

As farmers usually consider the annual income to evaluate whether a certain cultivation is favorable, it has been applied the method of discounted cash flow (DCF) by comparing SRC and vSRC poplar plantation with an annual crop, as in other studies [38–41]. Therefore, the net present value (NPV) of the overall plantation was calculated according to the following formula:

$$NPV = \sum_{k=0}^n \frac{C_k}{(1+r)^k} \quad (1)$$

where NPV is discounted annual cash flows; C_k represents the annual cash flow, obtained from the difference between the annual inflows and the annual outflows; k is the time of the cash flow; n corresponds to the lifetime of investment (equal to 14 years for vSRC and 15 years for SRC); r is the discount rate

and it was assumed equal to Weighted Average Cost of Capital (WAAC) with a value of 5%.

The annual inflows included gross production value (in harvest years), SPS and energy bonus according to Council Regulation (EC) no. 1782/2003 [42].

The annual outflows included all monetary costs required for the productive cycle and were calculated on a net basis (without taxes). Among the annual outflows it has been calculated also the planting cost net of non-returnable public grant according to the Measure 121 of Sicilian Rural Development Plan [43].

Annual revenues and costs have been calculated considering that financial conditions over the whole period are constant.

Hence, in order to compare poplar plantations with durum wheat, from (1) it has been calculated the annual gross profit (or annuity), which divides all costs and incomes into average annual values:

$$a = NPV \frac{r(1+r)^k}{(1+r)^k - 1} \quad (2)$$

where a is the annuity of SRC and vSRC, NPV is discounted annual cash flows, r is the discount rate and k corresponds to the lifetime of investment.

So, the poplar biomass plantation will be convenient for farmer if annual gross margin will be higher than durum wheat one.

3. Results and discussion

The annual gross margin of durum wheat in the detected case study was equal to 380.00 € ha⁻¹ (Table 2). The revenues denoted a value of 1200.00 € ha⁻¹, while direct costs were equal to 820.00 € ha⁻¹. This value was due essentially to farming operations which represented the main cost item (465.00 € ha⁻¹), followed by fertilizers (100.00 € ha⁻¹).

Results showed a different economic feasibility of introduction of a poplar biomass plantation according to two considered typologies.

As regard vSRC poplar, as well as in other studies [44,45], results highlighted an annual gross margin of 143.00 € ha⁻¹, with a value lower both than traditional crop one and CAP subsidy payment granted to farmer by EU (equal to 445.00 € year⁻¹ ha⁻¹) (Table 3). In this condition farmers will hardly change to vSRC when expected annuities are so low, reducing farm competitiveness and increasing risk management [46,47].

SRC poplar, conversely, showed a higher value of annual gross margin which reached a value of 870.59 € ha⁻¹ (Table 4), denoting how this farming system could represent for farmer an entrepreneurial strategy aimed at increasing his income [48–50].

The better economic feasibility of SRC plantation with respect to vSRC was to be attributed at several reasons, as in other studies [51].

Table 2
Annual gross margin of durum wheat.

Items (€ ha ⁻¹)	Durum wheat
Revenues	1,200.00
Costs	820.00
Seeds	90.00
Fertilizers	100.00
Pesticides	45.00
Farming operations	465.00
Harvest	70.00
Transport	50.00
Annual gross margin	380.00

Firstly this difference was imputable to the starting investment that is higher in vSRC plantation (6667 plants ha⁻¹) with respect to SRC plantation (1111 plants ha⁻¹). In particular, the purchase of stems represented 69.1% of planting cost in vSRC and 32.2% in SRC.

Another reason was due to the fact that in vSRC plantation revenues obtained by farmer every two years (3645.00 € ha⁻¹) were lower with respect to SRC plantation in which harvest is carried out every five years (7945.00 € ha⁻¹). SRC plantation, in fact, offers wood chips of high quality with high fibers content (85–90%) deriving from trees that have not a small diameter (> 150 mm). This product, despite a lower biomass production (15 Mg ha⁻¹ D.M. year⁻¹), grants a higher market price (100.00 € Mg⁻¹ D.M.) with respect to vSRC wood chips [52,53].

Besides, vSRC plantation required higher costs with respect to SRC for irrigation water, pesticides and farming operations that were all closely correlated with the planting density, while the harvest assumed the highest cost item in both plantation typologies [54].

The harvesting costs also depended significantly on the productivity of the harvesting machine which was positively correlated with increasing amounts of biomass per hectare until technical

Table 3
Annual gross margin of vSRC poplar (14-year cycles).

Items (€ ha ⁻¹)	Years		
	Planting	Harvest	No harvest
Revenues	445.00	3645.00	445.00
Costs	9649.50	2100.00	900.00
Deep tillage	500.00		
Stems	6667.00		
Plant setting	500.00		
Irrigation equipment	500.00		
Fertilizers	300.00	400.00	
Pesticides	200.00		200.00
Irrigation water	350.00	300.00	300.00
Farming operations	632.50	400.00	400.00
Harvest and chipping		800.00	
Transport		200.00	
Costs net of non-returnable public grant	4824.75		
Cash flow		−4379.75	1545.00
NPV		1415.47	
Annual gross margin			143.00

Table 4
Annual gross margin of SRC poplar (15-year cycles).

Items (€ ha ⁻¹)	Years		
	Planting	Harvest	No Harvest
Revenues	445.00	7945.00	445.00
Costs	3453.50	1572.50	672.50
Deep tillage	500.00		
Stems	1111.00		
Plant setting	400.00		
Irrigation equipment	400.00		
Fertilizers	160.00	300.00	
Pesticides	100.00		100.00
Irrigation water	250.00	200.00	200.00
Farming operations	532.50	372.50	372.50
Harvest and chipping		500.00	
Transport		200.00	
Costs net of non-returnable public grant	1726.75		
Cash flow		−1281.75	6372.50
NPV		9036.45	
Annual gross margin			870.59

restrictions due to limitation in diameter are reached [55]. Furthermore, there should be a focus on a proper-sized transport system that reduces transport costs and thereby increases revenues [56].

As regard the environmental impacts of poplar biomass introduction, several studies showed a better contribution to climate change mitigation with respect to annual crops, improving the GHG balance [57,58], especially after the planting phase [59]. Firstly the introduction of a perennial energy crop after an annual cropland grants an increase of SOC stock, improving the carbon balance, soil fertility, erosion protection, water and nutrient retention in soils [60,61]. This is due to the fact that poplar do not require annual plowing and also to the frequent harvest of above ground biomass that leads to the die off of a major fraction of roots that contribute to SOC accumulation as well as accelerating fine root turnover [62]. In addition poplar has a lower N-fertilizer demand with respect to annual crops, because its higher nitrogen use efficiency, because in perennial crops the presence of plants during all year allows a better uptake of nitrogen, reducing N mineralization in the soil and N_2O emissions with regard to annual crop [63,64]. Finally, since Sicilian hilly soils do not have a high ground water tables, oxidize more CH_4 when poplar is cultivated with respect to annual crops [65].

These environmental benefits are supported also by several studies based on LCA analysis. Poplar for biomass production in fact show better environmental performance with respect to annual crop [66] despite the high diesel consumption for the harvest machine and the combustion derived emissions [67]. In fact, as showed in other studies, more than 6 Mg C ha^{-1} is sequestered in stumps [68], highlighting the key role that poplar could have in the future forest management for its carbon sequestration capacity [69], allowing a sustainable development in rural areas [70]. This is valid especially for Sicily where poplar is cultivated with lower amount of nitrogen with respect to Northern Europe [71,72] and for SRC plantation that, for its lower planting density respect to vSRC, requires lower inputs as well as irrigation water, pesticides and farming operations [73].

4. Sensitivity analysis

Results showed that only SRC plantation would have an higher economic convenience for farmer respect to durum wheat. Since in the Sicilian hilly hinterland it is very improbable to increase the biomass yield for pedo-climatic conditions [74–78], the introduction of vSRC plantation would grant a lower annual gross margin than annual crop, highlighting as a large biomass diffusion will be possible only with an increase of the market value or with economic sustain for its production [79,80].

So, a sensitivity analysis has been carried out by varying the value of wood chips market price of SRC plantation and the CAP subsidy payment granted to farmer by EU.

As regards the market value, sensitivity analysis denoted that vSRC market price should be equal to $92.15 \text{ € Mg}^{-1} \text{ D.M.}$ to obtain the same annual gross margin of durum wheat, increasing its value by 15.2% (Fig. 1).

Conversely, the vSRC market price should reach a value of $117.29 \text{ € Mg}^{-1} \text{ D.M.}$ to achieve the same SRC annual gross margin, with an increase of 46.6% with respect to the current price.

Regarding the CAP subsidy payment granted to farmers by the EU, sensitivity analysis showed that it should reach a value of $682.00 \text{ € year}^{-1} \text{ ha}^{-1}$ and $1172.50 \text{ € year}^{-1} \text{ ha}^{-1}$ to be competitive, respectively, with durum wheat and SRC plantation (Fig. 2).

Hence, sensitivity analysis highlighted that vSRC in Sicilian hilly hinterland could be economically advantageous only with a substantial increase of biomass market price and/or CAP subsidy, as well as in other studies [81,82].

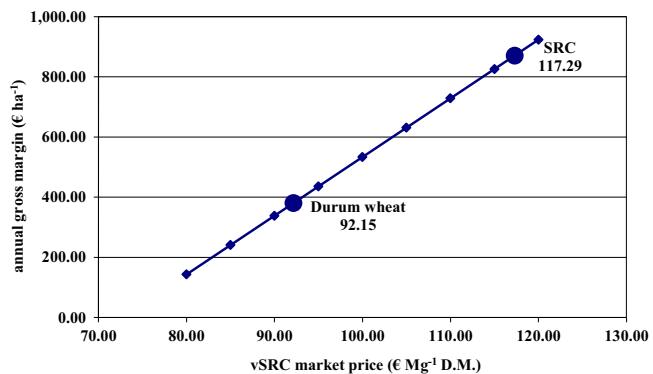


Fig. 1. vSRC market price to raise the annual gross margin of durum wheat and SRC plantation.

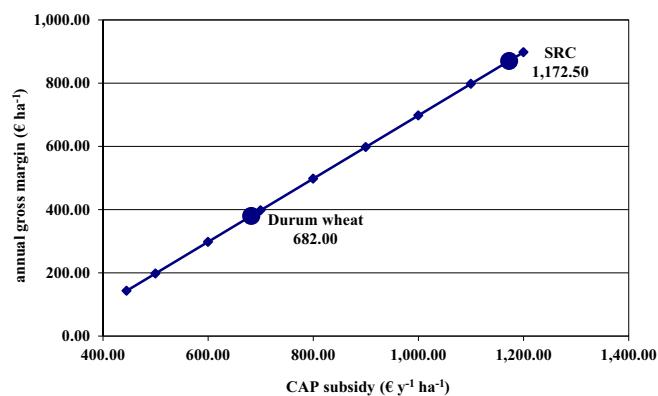


Fig. 2. CAP subsidy to raise the annual gross margin of durum wheat and SRC plantation.

5. Conclusions

Wood deriving from lignocellulosic agro forest species is a renewable energy source, which can be a viable alternative to traditional fossil sources also in terms of the environmental benefits. However, for farmer the biomass plantation can be advantageous only if the investment produces results at least comparable to traditional crops.

Economic analysis compared poplar biomass plantation with durum wheat in Sicilian hilly hinterland and results showed a different economic feasibility of its introduction in farm according to two considered typologies.

As regard vSRC plantation, economic analysis denoted an annual gross margin (143.00 € ha^{-1}) lower than durum wheat (380.00 € ha^{-1}), while SRC highlighted a clear economic convenience (870.59 € ha^{-1}). This difference between the two poplar biomass plantations was attributable essentially both to the higher revenues deriving from SRC plantation and the lower costs of planting phase and farming operations (related to the lower density of trees) that allowed to obtain a better economic convenience.

SRC plantation, in fact, offered wood chips of high quality that, despite a lower biomass production, granted a higher market price respect to vSRC wood chips.

Sensitivity analysis showed that vSRC should increase its biomass market price by 15.2% and 46.6% to obtain the same annual gross margin, respectively, of durum wheat and SRC or as an alternative the CAP subsidy payment granted to farmers by the EU should reach a value of $682.00 \text{ € year}^{-1} \text{ ha}^{-1}$ and $1172.50 \text{ € year}^{-1} \text{ ha}^{-1}$.

So, it is highlighted that a diffusion of vSRC plantation will be possible only with an increase of the market value or with higher

economic sustain for its production, while SRC cultivation could represent a viable alternative for farmers with respect to the traditional crops, improving the relations between agriculture and environment, reducing greenhouses emissions and environmental impacts.

Finally, it should be taken into account also the positive effects that the introduction of energy crop determines local employment. In fact, poplar requires a higher demand for labor than arable crops, creating new job opportunities both in the production phase and in the biomass plant for energy production, allowing a more sustainable development of rural areas.

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