SHORT ROTATION COPPICE IN NORTHERN ITALY: COMPREHENSIVE SUSTAINABILITY

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ABSTRACT: Short Rotation Coppice (SRC), subdivided into SRF – plantation with a short cutting frequency (1 or 2 yrs) and in MRF – plantation with a medium cutting time (5 yrs), takes up about 7,000 hectares, mainly in Lombardy and Veneto Regions; over the years the development of specific poplar clones for biomass and the improvement of cultivation technique have made it possible to obtain remarkable increases in yield. Nevertheless, in bibliography the information concerning this crop is not always clear and unanimous.
On the basis of the cultivation technique carried out in Northern Italy, an economic, energetic and Environmental (EEE) evaluation of the poplar MRF field-chain phase has been carried out. Data on a poplar plantation growth in Po Valley area have been considered; mainly: duration 10 years; cutting time 5-years; biomass yield 40 t_{WB}/ha·year (at 55% of moisture content w.b.).
In these conditions a ratio between output and input energy of 30 and between GHG absorption and GHG emission of 56 with a production cost of 60 €/t_{DM} was pointed out. Besides the positive energy and environmental balances, even the economical sustainability of MRF, with a gain of 820 €/ha·year, appears interesting.
Keywords: Short Rotation Forestry (SRF), Poplar, Energy Crops, Energy balance, Sustainability, CO_2 balance.

1 INTRODUCTION

In Italy the contribution of agro-energy to national energy demand is still moderate; nevertheless, even if slowly, its relevance has increased in recent years. Agro-energy seems like a possible and, theoretically, interesting alternative to traditional crops allowing a diversification of income sources. Compared with other energy sources, the dedicated crops offer the advantage of extremely intense field management that ensures the highest yield, as well as, the shortest wait time. Cultivation of biomass crop on arable lands allows for increased energy production and should be quite profitable for the environment (groundwater protection, ecological planning, phyto-remediation, green house gases adsorption, etc). This is especially the case for woody crops, including Short Rotation Coppice (SRC).

Over the last 20 years, in Italy, supported by favourable public grant programs, SRC has grown to comprise about 6,500 ha, mainly in the Po Valley area. The Regions Lombardy and Veneto have been the first to give subsidies for SRC and now account for almost all the Italian land area dedicated to this energy crop, 4,000 and 1,300 ha respectively.

In Italy the woody species suitable for SRC are *Populus* spp, *Salix* spp, black locust and eucalyptus, however most plantations consist of specific poplar clones; this arboreus specie is historically well-known by Italian farmers and has proven the most adaptable for bio-fuel production. Over the years the development of new specific clones for biomass production (at the moment the most important are: AF2, Monviso and Pegaso) and improvement in cultivation techniques have made it possible to obtain remarkable yield increases. Regarding the crop management, several systems with different cutting times have been used: first, 1-year and, later, 2-years and 5-6 years. Different cutting times require different plant densities and different lane width. SRC can thus be subdivided into SRF – plantation with short cutting frequency (1 or 2 years) and in MRF – plantation with medium cutting frequency of (> 5 years) (Figures 1 and 2).

Planting systems are different too, with highly variable plant density: 10,000-14,000 plants/ha (annual plantation with twin rows), 5,000 - 6,000 plants/ha (biennial plantation with single rows) and 1,000 - 1,800 plants/ha (in MRF).

Figure 1: Two-years poplar plantation

Figure 2: Five-years poplar plantation

In plantations with medium cutting time the distance between stumps in the row is quite similar to the width of lanes. Figure 3 shows the most widespread planting systems adopted in Italy for SRF and MRF. In either, the lane allows for use of conventional tractors.

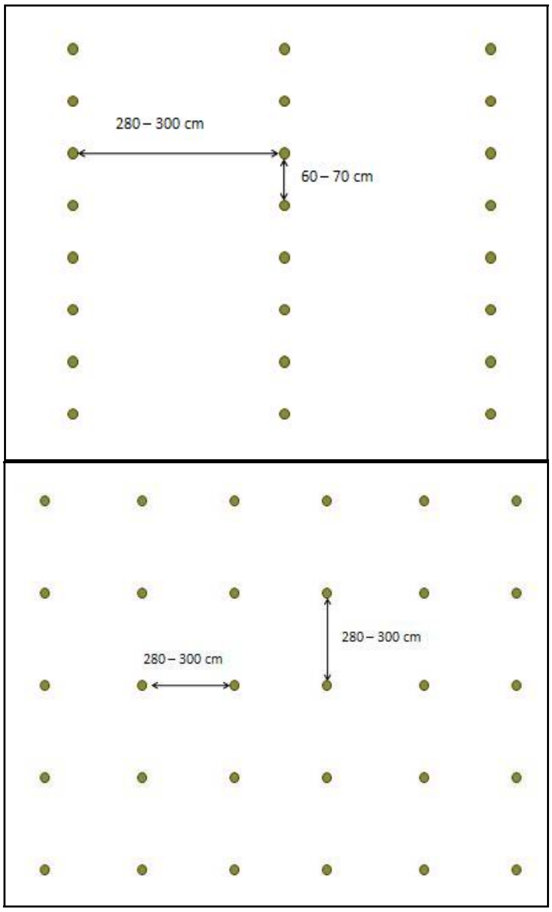

Figure 3: Most widespread planting systems for biannual SRF (up) and MRF (below)

At present, even if the best quality bio-fuel comes from 5-year plantations, the larger part of Italian SRC is based 2-years cuts. In the near future MRF plantations will be more widespread because of the better quality of chips (due mainly to lower ash content) [10].

2 SRC: ECONOMIC, ENERGETIC AND ENVIRONMENTAL EVALUATION

Wood chip produced from SRC is a raw material with a low market value (sale prices range from 60 to 110 €/t_{dm}): the economic sustainability of this crop is highly dependent on reduction of production costs. This aim can be reached through high yields as well as the complete mechanization of all field operations. Among these, the harvest is the most tricky because of new, sophisticated equipments with high operating costs [20] [22] [23] [24] [26]. The need for high yields requires high inputs during the crop cycle that can lessen both energetic and environmental sustainability.

Thus besides economic sustainability there are also energetic and environmental aspects that must be considered. Taking into account the considerable public grants given to the main agro-energy chains, it is appropriate to evaluate not only economic sustainability (often achieved by means of public subsidies), but also energetic and environmental sustainability. In this way a Comprehensive Sustainability could be estimated. Nevertheless, though the literature provides information about this wood-crop [2] [3] [7] [8] [19] it is not always clear and unanimous. Regarding SRC energy performance, several values of woody biomass production are reported (Table I).

Discrepancies in results can be attributed mainly to differences in following factors:

- species cultivated,
- calculation methodology,
- cultivation techniques (i.e. field operations, type and rate of fertilizers/herbicides, etc.),
- biomass yield,
- selection of agro-energy chain phases/operations (i.e. storage, transport, drying, conversion process, etc).

Few studies have been conducted to investigating the environmental aspects of energy-crop cultivations; but a number of software tools to assess economic and energy performance of bio-energy production have been recently developed.

Nevertheless, most of these tools lack flexibility; their analysis is often restricted to a single type of bio-energy chain only the main operations of a chain. This makes it difficult to apply them to the several agro-energy chains actually in use.

Moreover, in the future it will become more and more important to be able to evaluate the energy-environmental sustainability of each bio-energy chain. Already, before allowing public subsidies, a couple of Italian regions are calling for energy and environmental evaluations of some bio-energy chains.

The aim of this job, 20 years after SRC introduction in Italy, is to clarify the economic, energy and environmental sustainability of these plantations and, specifically, of MRF poplar biomass plantations in northern Italy. For this purpose a specific software tool has been developed; capable of providing unbiased information on these three aspects of "Comprehensive Sustainability" of this bio-energy chain.

Input required by the software are details of: (i) farm (area, agricultural machinery fleet, crop system, etc.), (ii) cultivation technique (mechanization operations and sequence; input rate and market prices, energetic and carbon equivalent) and (iii) the characteristics of products and byproducts (yields, market prices, lower heating value, moisture content).

For the economic evaluation the method of fixed and variable costs [9] [16] is used while for energy balance computation the software uses Gross Energy Requirement (GER) methodology [25], also considering manpower an input [21]. The environmental analysis takes into account the same inputs as energy balance evaluating them by a specific carbon equivalent (CE, kg CO_2 equivalent/kg) [15] or by an average emission factor (0.575 kg CO_2 eq/kWh) [4].

To calculate economic net income the software considers chip-wood selling as well as public subsidies coming from the Rural Development Program (RDP) and Common Agricultural Policy (CAP). Lower Heating Value (LHV) of biomass harvested is taken into account for energy aspects while for environmental output above and below-ground biomass (estimated as a fraction of above-ground) are computed in addition to the biomass released into the soil.

On the bases of carbon percentage of each biomass and considering the molecular weight of carbon and carbon dioxide, the amount of absorbed CO_2 is calculated.

Table I : Poplar and willow SRF: estimated energy ratio (EROEI: Energy Returned On Energy Invested) reported in literature

SPECIES	CUTTING TIME [years]	DURATION [years]	YIELD [t_{dm}/he·yr]	EROEI	AUTHORS
Poplar, Willow	6	18	14-22	14-19	Turhollow and Perlack [27]
Poplar, Willow	3	16	8-12	29	Matthews [18]
Poplar	4	23	10-15	22-26	Dubuisson and Sintzoff [6]
Willow	4	24	9	25	Borjesson [5]
Poplar, Willow	3	16	12	2-5	Matthews [18]
Poplar	2	8	20	13	Manzone [17]
Willow	3	9-21	10-15	17-53	Keolaian [13]
Willow, Poplar	4	20	3,5-5,9	1,4-8,8	Walle et al. [28]
Willow	3-4	23	10	40-58	Heller et al. [11]

3 A CASE STUDY

In this paper, with respect to the operating conditions of the Po Valley area, results concerning the conversion from cereals (maize) to poplar MRF (5-years cutting time, duration 10 years) of 40 ha (50% of total farm AUA – Agricultural Used Area) are reported.

The cultivation technique has been described by Rinnova Green Energy in a recent publication. Transplanting, by contractors in early spring (Figure 4), is based on plant rods put into soil previously fertilized with manure (50 t/ha), ploughed and tilled.

Figure 4: Planter machine for MRF plantations coupled with tractors, plant rods are loaded on the platform near to the operators.

Mechanical weed control consists of harrowing in the first 3 years of every cutting time. Chemical weed control is limited to the following treatments: 2 after transplanting, 2 during the growing season after harvest and 1 in the second and sixth years. Nitrogen fertilization is applied, after the cut, using 300 kg/ha of urea

Pest and disease management requires 1 treatment with pesticide against harmful insects during the first 2 years after transplanting and after harvest. In the same years 2 irrigations (400 m^3/ha each) are scheduled. The harvest (downing of trees - Figure 5, stacking, chipping and transport of chips to farm temporary storage) as well as final restoring of the soil, are done by contractors.

Table II shows the operations required during the entire MRF poplar cultivation-cycle; Table III shows rate, market prices and energy and environmental equivalents for the various production factors.

Inputs for which specific economic, energy and environmental costs are not available, have been replaced with similar ones.

Figure 5: Feller for MRF. After 5-years the shoots basal diameter can reach 25 cm.

In the study case, the software tool considers:

- a biomass yield of 40 t_{wb}/ha·yr (moisture content = 55%, LHV = 18,5 GJ/t_{dm}, carbon in above and below-ground biomass = 50%, ratio root/stem = 0,2);
- a chip-wood sale price of 35 €/t_{wb};

and, about public grants:

- the decoupling cap (400 €/ha·yr);
- the planting subsidy provided by Lombardy Region (1000 €/ha).

Table II : Machines and mechanization planning on surface intended for SRC and for traditional crops

OPERATION	MACHINE		COOPLING TYPE, MACHINE SIZE	WORKING YEARS [TIMES PER YEAR]	
				On AUA_{MRF}	On AUA_{MAIZE}
Pre-planting Fertilization	Manure Spreader	Agricultural Machinery Fleet	TP, 10 t, 10 m^3	1 [1]	From 1 to 10 [1]
Primary soil cultivation	Plough	Agricultural Machinery Fleet	P, double-shovel	1 [1]	From 1 to 10 [1]
Secondary soil cultivation	Rotary harrow	Agricultural Machinery Fleet	PP, 2,40 m	1 [1]	From 1 to 10 [1]
Transplanting	Planting Machine	Contractor	T, bifilar	1[1]	-
Chemical Weed Control	Spraying machine	Agricultural Machinery Fleet	PP, 15 m, 1000 dm^3	1-6 [2] 2-7 [1]	From 1 to 10 [1]
Pests and Diseases Management	Spraying machine	Agricultural Machinery Fleet	PP, 15 m, 1000 dm^3	1-2-6-7 [1]	
Cover Fertilization	Fertilizer Spreader	Agricultural Machinery Fleet	PP, 1500 dm^3	6 [1]	From 1 to 10 [1]
Mechanical Weed Control	Rotary harrow	Agricultural Machinery Fleet	PP, 2,40 m	1-2-6-7 [2] 3-8 [1]	-
Harvest Operations	Harvester, Chipper, Trailer	Contractor	SPM, T, PP	5-10 [1]	-
Soil Final Restoration	Hoeing machine	Contractor	P, 1,2 m	10 [1]	-

Notes: PP = coupling with pto; P = coupling without pto; T = trailed coupling; SPM = self-propelled machine

Table III : Production factors utilized within simulation: rate, market price, energy (EE) and carbon (CE) equivalents

PRODUCTION FACTORS	QUANTITY		COST		ENERGY EQUIVALENT		CARBON EQUIVALENT	
	Unit	Rate	Unit	Price	Unit	Energy content	Unit	CE
Planting material	Plant rod/he	1650	€/plant rod	1,1	MJ/kg	37,00 [12]	kg CO_2eq/MJ	0,575 [4]
Organic Manure	t/he	50	€/t	2,25	MJ/t	100,00 [12]	kg CO_2eq/kg	0
N fertilizer (covering)	kg/he	200	€/kg	0,3	MJ/kg	74,00 [12]	kg CO_2eq/kg_{IA}	1,3 [1]
Herbicide	kg/he	12	€/kg	21	MJ/kg	201,80 [1]	kg CO_2eq/kg_{IA}	9,1 [1]
Pesticide (pyrethroid)	kg/he	4	€/kg	89	MJ/kg	603,00 [1]	kg CO_2eq/kg_{IA}	11,7 [1] [15]
Water	m^3/he	1600	€/m^3	0,07	MJ/m^3	0	kg CO_2eq/kg	0
Diesel Fuel	-	-	€/kg	0,79	MJ/kg	51,50 [12]	kg CO_2eq/kg	3,14 [15]
Lubricant	-	-	€/kg	4,00	MJ/kg	83,70 [12]	kg CO_2eq/kg	2,94 [15]
Manpower	-	-	€/h	15,00	MJ/h	2,30 [21]	kg CO_2eq/MJ	0,575 [4]
Tractors	-	-	-	-	MJ/kg	92,00 [12]	kg CO_2eq/MJ	0,575 [4]
Ag-machines	-	-	-	-	MJ/kg	69,00 [12]	kg CO_2eq/MJ	0,575 [4]

Notes: Infra square brackets the Reference number

4 RESULTS

Results show that, cultivating 50% of the farm area with MRF, the production cost of chip-wood reaches 1070 €/ha·yr (59.5 €/t_{dm}). This cost makes possible a net income of 820 €/he·yr (46.1 €/t_{dm}) and a revenue/cost ratio of 1.8.

The energy input is 5,4 GJ/ha·yr (0.30 GJ/t_{dm}) while the energy gain is highly positive (272 GJ/ha·yr - 15,1 GJ/t_{dm}).

The specific GHG emission is 40 kg CO_2 eq/t_{dm} (0.7 t CO_2 eq/ha·yr) with a positive net balance of 2.16 t CO_2 eq/t_{dm} (39 t CO_2 eq/ha·yr).

Comprehensive Sustainability is expressed by all 3 results obtained by the simulation (**Figure 6**). The smaller the area of the triangle identified by the three costs (economic, energetic, environmental) the higher the energy-crop sustainability.

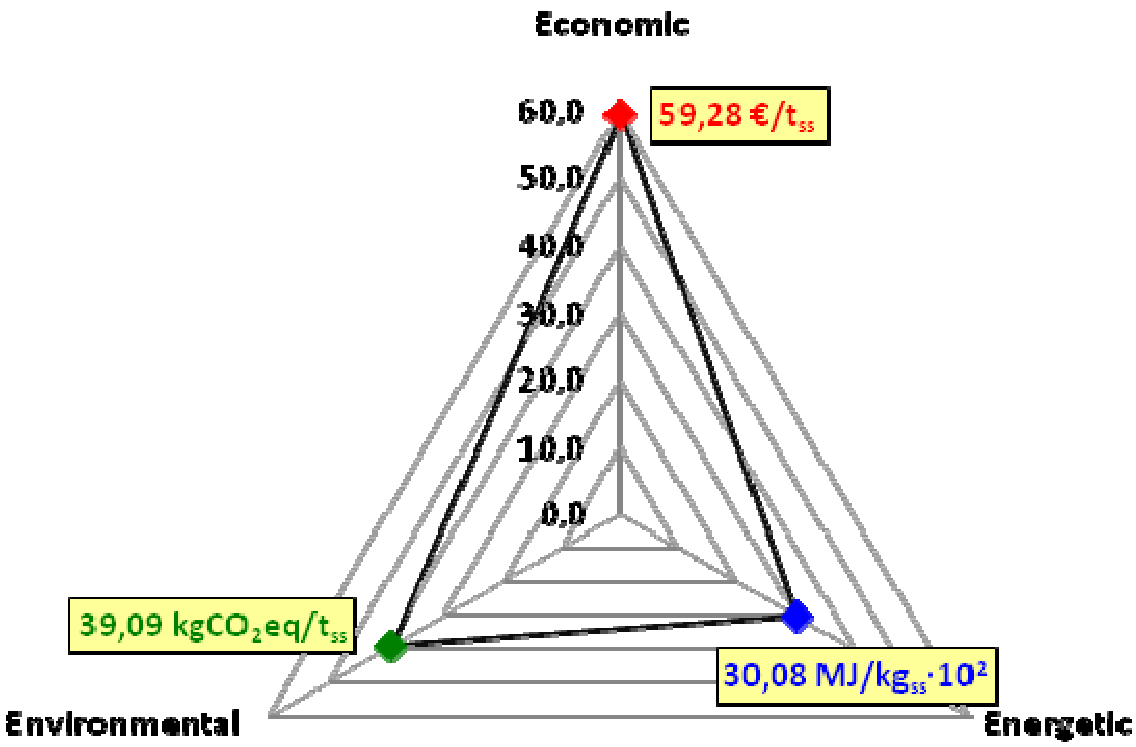

Figure 6: The Comprehensive Sustainability triangle; on vertices: economical cost (red), energy input (blue) and GHGs emission (green).

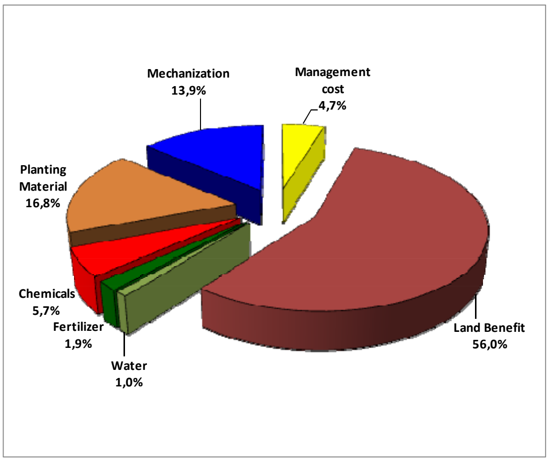

Figure 7: Economic costs allocation, land is the most important items

Output/Input energy ratio (EROEI) is equal to 40 and is strongly favourable as is as the ratio of absorbed to emitted GHG, at 56.

Figures 7, 8 and 9 show economic costs, energy inputs and CO_2 emissions.

Concerning economic aspects, the most relevant expense is for the benefit land (56.0%) followed by the planting material purchase (16.8%) and expense for mechanization (13.9%).

Regarding energy and environmental issues of MRF cultivation the benefit land is not considered; the most important items are: the use of N-fertilizer and field operations mechanization involving an high oil consumption. Fertilizers account for 41.0% of total energy inputs and for 50.5% of CO_2 emissions while for mechanization these proportions are 43.3% and 30.1% respectively. Concerning mechanization, the basic way to reduce oil consumption is to optimize tractor-machine coupling [14].

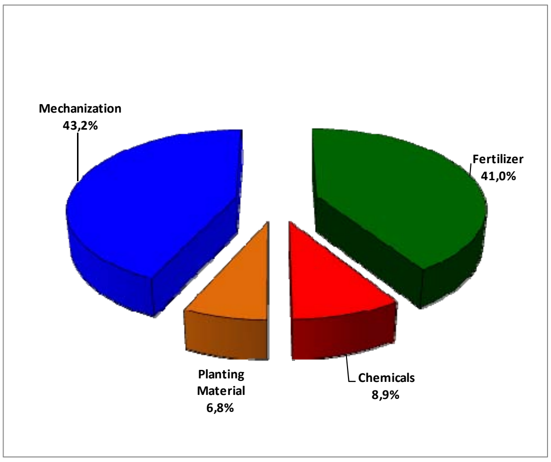

Figure 8: Energy input allocation

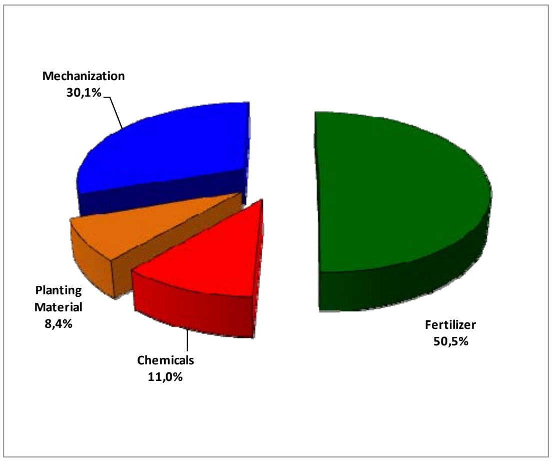

Figure 9: GHG emission allocation

5 CONCLUSIONS

Regarding the field phase of the energy-chain, the poplar MRF plantation, in the conditions considered (10 years rotations with harvested every 5-years, yield of 40 t_{WB}/ha·year, moisture content of 55%), appears very interesting from an energy and environmental point of view. EROEI are greater than 40 and the ratio of GHG absorptions/emission reaches 56. Direct energy inputs account for 57% of the total energy requirement while indirect input account for 43%.

Poplar MRF is also profitable in economic terms with the greatest gains in respect to traditional crops. These results concern a high yield polar-MRF, using specific biomass clones, planted in fertile soil, irrigated and well managed.

In regard to SRC results reported in recent publications, MRF load better outcomes: it requires fewer field operations and lower levels of production factors while reaching higher yields.

Even though in Italy the largest SRF area is actually cultivated with 2-years plantations, in the near future the larger part of new plantations will be run with the 5-years system.

A large SRC diffusion are possible only if economic results will be advantageous for farmers. Considering the drop in agricultural subsidies, this will be possible only with high biomass yields and an increase in chip-wood market value.

Finally, MRF can contribute to solving the problem of traditional cultivation surplus and to improving the relations between agriculture and the environment.
The availability of public subsidies for this bio-energy crop seem justified by its good energy and environmental performance.

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