VALORISATION OF MISCANTHUS GIGANTEUS BIOMASS AND AGRICULTURAL RESIDUES FOR SUSTAINABLE SUPLLY OF THERMAL ENERGY IN RURAL AREAS

Ana Elisabeta DARABAN (OROS)[1], Stefana JURCOANE[1]

e-mail: anadaraban@ispam.ro

Abstract

New trends regarding thermal conversion of different type of solid biomass to provide renewable bioenergy for rural communities include the use of energy crops and agricultural residues in an efficient way. Romanian policy for bioenergy asks for considering alternative options to demonstrate sustainability of biomass supply chain (logistics by available quantities, transport, processing equipments, customers' needs) and facilitating the development and competitiveness of market availability for biomass including pressed products (pellets, briquettes) to create optimal conversion of biomass in local heating systems. In this perspective the actual study shows the potential of C4 perennial grass Miscanthus giganteus and some indigenous resources as cereal straw, wood biomass (orchard trees pruning, saw dust, wood chips) or other agricultural residues (home grown biomass) to ensure the local requirements for heating by promoting low-carbon technologies and to achieve European and national target for renewable energy by 2020. *Miscanthus giganteus* biomass harvest from the scientific farm Moara Domneasca was tested, by varying mass percentage (20%, 60% or 80%), for pressing capacity in briquetting installations, in combination with different kind of vegetable biomass, in order to identify optimal blends by ensuring improved energy efficiency and cost-effective production. Lower calorific power (net calorific value - NCV) of different Miscanthus blends with agricultural vegetable residues have presented values varying from 15.8 MJ/kg up to 18.1 MJ/kg depending on elemental contents (C, H, N, S) and lignin concentration, respectively the type of biomass burned. The study pointed out a great potential of using solid biofuels, available in rural areas and therefore the opportunity of developing energy plants for local heating systems using sustainable biomass resources.

Key words: bioenergy, Miscanthus giganteus, agri-residues, energy efficiency

INTRODUCTION

In the last period Romania has developed national strategies regarding renewable energy, but only recently various biomass was included as alternative option for fossil fuel and has special approach in order to sustain its market growth in Eastern European region. New projects and laws have been advanced by some dedicated association of investors and researches by increasing the interest for energy crops as *Miscanthus giganteus*, energy willow and also for available residual biomass (cereal straw, wood chips, sawdust, orchard prunings).

Using energy crops, there are avoided greenhouse gas (GHG) emissions ranged from 7.7 to 35.2 t CO2 eq/ha annualy (Style D., Jones M. 2015).

Miscanthus (*Miscanthus×giganteus*) is a perennial tall C4 grass (3-4 m), with long productive life-span (15-20 years) and high production (15-25 tones). By harvesting each year, Miscanthus represents one of the best options for low input bioenergy production in Europe and USA (Dželetović *et al*., 2013).

In the scientific farm Moara Domneasca, Ilfov has been tested agricultural technologies for cultivation and harvesting the sustainable energy crop *Miscanthus giganteus.* In this research, the main objective was to demonstrate that all available biomass from a farm, energy plants and agricultural residues can provide solid biofuels for on-site use as thermal energy supply in local heating systems. Optimal conversion of solid biomass in thermal systems requires advanced technologies for pressed products as pellets and briquettes, to create sustainable market availability.

Energy efficiency assessment of technologies and processes used at international level were studied for selecting the optimal alternatives to enhance pressed biomass potential for thermal energy. In this field of interest, countries as Denmark, Germany, Austria, and France may offer high valuable experienced solutions (Daraban Oros A.E. *et al.*, 2015).

[1] University of Agronomic Sciences and Veterinary Medicine, Bucharest Romania

Still, there are not many options for mixed biomass (lignocellulosic plants, straw or wood) pressing process by varying the materials types, water content and specific technologies (hydraulic or mechanical press).

Though blends of different type of biomass are easily to transform in pellets, the hydraulic process is less energy efficient, especially for small and medium projects due to high costs for biomass preparation, labour cost, energy fuel needs and equipment maintenance (Tomic F. *et al.*, 2011).

Pelleting Miscanthus biomass is more expensive and has higher environmental impacts then briquettes production, thus briquetting represents an easily available process as low investment in rural areas and can be compared favourably with wood pellets and coal production.

Greenhouse gas emissions associated with Miscanthus briquettes production are comparable to coal and kerosene production, 12.28 kg CO_2 and respectively 11.69 kg CO_2 per 1 GJ of bioenergy produced (Murphy F. *et al.*, 2013).

Considering the environmental aspects, the energy crop biomass is assumed to emit only the carbon it had accumulated from the atmosphere during its growing cycle, therefore biomass combustion is carbon neutral, in comparison with fossil fuels, which have positive carbon footprint. When Miscanthus is replaced with agri-residues for briquettes production all environmental impacts are lower, and the present research highlighted this by the experimental obtained results.

MATERIALS AND METHODS

Pelletizing and briquetting technologies were conducted for pressing the biomass harvest from the Moara Domneasca farm in order to demonstrate the potential of Miscanthus biomass to be mixed with other vegetable residues that are not valorised such as cereal straw, sawdust and woodchips from orchard pruning.

Different experiments already presented in other research, studied the potential of Miscanthus biomass by mixing with saw dust for briquettes production and with blends of straw and other agricultural biomass for pellets production. The experimental tests made in different stages, showed that energy crops are suitable to be mixed with other biomass (wood or agricultural residues), in order to provide locally sustainable products (briquettes and pellets) as solid biofuel for small scale heating systems (Daraban Oros A.E.[i] *et al.*, 2015). The main advantages of briquetting energy crops and agricultural residues for thermal energy applications are: uniform combustion comparable with coal, reduced particulate emissions, transport, storage and feeding, facts that demonstrate more efficiency use for pressed products then for loose biomass or normal bales (Tumuluru J.S. *et al.*, 2011).

Because pelleting process is more expensive, we tested in our experiments the briquetting process with a double mechanical press (capacity: 140 kg/h, power consumption: 12.5 kWh) by varying the particles size, humidity and Miscanthus mass percentage (table 1, figure 1). In particular, other test parameters from Miscanthus blends with wood briquettes production (Daraban Oros A.E.[i] *et al.,* 2015), are compared with actual data obtained from the tests run with blends with straw and with content of 100% Miscanthus.

In the case of high concentrations of Miscanthus, water addition was necessary 0.2 L/kg of Miscanthus biomass.

The combustion properties were studied using a calorimetric bomb IKA C200 and a CHNS-O elemental analyser with assistance from the Faculty of Energetics from Politehnica University Bucharest, (*figure 2*).

Tabelul 1

Specific properties of *Miscanthus giganteus* blends with other vegetable biomass

Samples	Biomass specific content (*Miscanthus* % of volume)	Particle sizes (mm)	Humidity of raw materials (wt %)
B1	M20% + Straw 80%	0.2 – 20	10.4
B2	M60% + Straw 40%	0.2 – 20	10.1
B3	M80% + Straw 20%	0.2 – 20	9.5
B	M100%	0.2 – 10	9.8
P[i]	*M100%*	*0.2 – 10*	*11.2*
Ba[i]	*M30% + W 70%*	*0.2 – 10*	*15.4*
Bb[i]	*M50% + W 50%*	*0.2 – 10*	*13.2*
Bci[2]	*M70% + W 30%*	*0.2 – 10*	*12.4*

[1]M- Miscanthus, Straw from cereals, W - wood (sawdust and wood chips)
[i]Results presented in other article accepted for publishing (Daraban Oros A.E.[i] *et al.*, 2015)

Figure 1 **Briquettes samples of Miscanthus (M) percentage blends with straw**

Figure 2 **Bomb calorimeter IKA C200 for combustion characterisation of solid biomass with Miscanthus blends**

An environmental assessment was conducted for the Moara Domneasca biomass obtained in 2015 by evaluating the potential of actual available biomass to supply the farm requirements for thermal energy. Miscanthus production involves: land preparation, crop cultivation and harvesting, processing and transport to users. Specific attention is paid to production of Miscanthus not using any fertilisers (field operations), assessing the briquetting process technology (including size reduction) and on-site biomass transport for a minimal distance of 5-10 km.

Energy efficiency and GHGs emissions balance were calculated on the life cycle assessment (LCA) basis compering with other biofuels or fossil fuels using literature data. The LCA was conducted in Simapro 8.0 using primary and secondary data from various sources, machinery producers, providers and ecoinvent database. The assessed impacts consist in calculation of acidification potential (AP) - expressed in kg SO_2^- equivalent, eutrophication potential (EP) – in kg PO_4^-equivalents, global warming potential (GWP) – in kg CO_2^- equivalents and the cumulative energy demand (CED) – in MJ, expressed as energy ratio (ER), (Murphy F. *et al.*, 2013).

$$ER = Eo/Ei,$$

where, Eo- energy output
Ei- energy input.

Comparing with Miscanthus pelletizing or briquetting production LCA, described by Murphy F., in this research, the briquetting production tests involve reduced operations for field technical processes: no fertilization and pesticides addition, no drying (raw biomass has water contents of 9-15 wt %) and short distance (5-10 km) to deliver final products for users. Consequently, the LCA of Miscanthus use in blends with straw and other agri-residues for briquettes should have lower environmental impacts (Kristöfel C., Wopienka E., 2012).

RESULTS AND DISCUSSIONS

Specific combustion properties of Miscanthus blends with other vegetal biomass

For efficient combustion, blends of pressed biomass (briquettes) were studied in order to provide optimal solid biofuels. Research works were focused for Moara Domnească farm, which intends to develop an alternative heating systems based on locally available solid biomass.

Lower calorific power (net calorific value - NCV) of different Miscanthus blends with agricultural residues have presented values varying from 15.8 MJ/kg up to 18.1 MJ/kg depending on elemental contents (C, H, N, S) and lignin concentration, respectively according with the type of biomass burned.

Combustion properties (*table 2*) pointed out that Miscanthus blends with wood have increased net calorific values value up to 18.1 MJ/kg (dm - dry matter) then those with straw, respectively up to 16.5 MJ/kg (dm), due to lignin contents. NCV of Miscanthus blends depends on the percentage mixing with wood or straw analysed (20%, 30%, 60%, 50%, 70%, 80%). The results indicate an average of 50-60% of Miscanthus blends with agri-residues (straw or wood sawdust) can offer effective and sustainable utilisation of on-site farm available biomass for its heating requirements.

The 100% Miscanthus briquettes or pellets have better combustion properties than those with straw blends and less than with wood blends, hence this energy plant may replace wood or other common fuels for heating supply, depending on local climate and farming suitability.

The environmental impact assessment presents the 15 years case scenario; production of Miscanthus briquettes using low operational processes (only cultivation, harvesting, maintenance, pressing) and transporting of products for 10 km to the direct users.

Table 2

Combustion specific properties of Miscanthus giganteus blends with other vegetal biomass

Probe number/ Percentage of Miscanthus (M)	*Ash content wt.[1] % dm[2]*	*Water content W_t^i (Total humidy) wt.-%*	*Carbon wt.% dm*	*Hidrogen wt.% dm*	*Nitrogen wt.% dm*	*Sulphur wt.% dm*	*Q_i MJ/kg dm*
B1 –M 20%	*5.82*	*8.73*	*42.44*	*5.27*	*1.26*	*ND[3]*	***15.8***
B2 – M 60%	*4.25*	*9.12*	*45.53*	*6.34*	*1.14*	*ND*	***15.9***
B3 – M 80%	*4.54*	*7.95*	*46.18*	*6.17*	*1.05*	*ND*	***16.25***
B – M100%	*2.95*	*7.62*	*45.29*	*6.03*	*1.15*	*0.1*	***16.5***
P[i] – M100%	*2.78*	*9.51*	*43.66*	*5.4*	*1.05*	*0.15*	***17.0***
B1[i] –M 30%	*2.44*	*3.88*	*47.5*	*5.65*	*0.283*	*0.17*	***18.1***
B2[i] – M 50%	*3.3*	*4.2*	*48.4*	*4.9*	*0.292*	*ND[3]*	***17.7***
B3[i] – M 70%	*2.3*	*3.92*	*48.36*	*5.66*	*0.301*	*0.2*	***17.8***

[i]Results by Daraban Oros A.E.[i] *et al.*, 2015, [1]wt. = weight, [2]dm = dry matter basis, [3]ND = not detectable

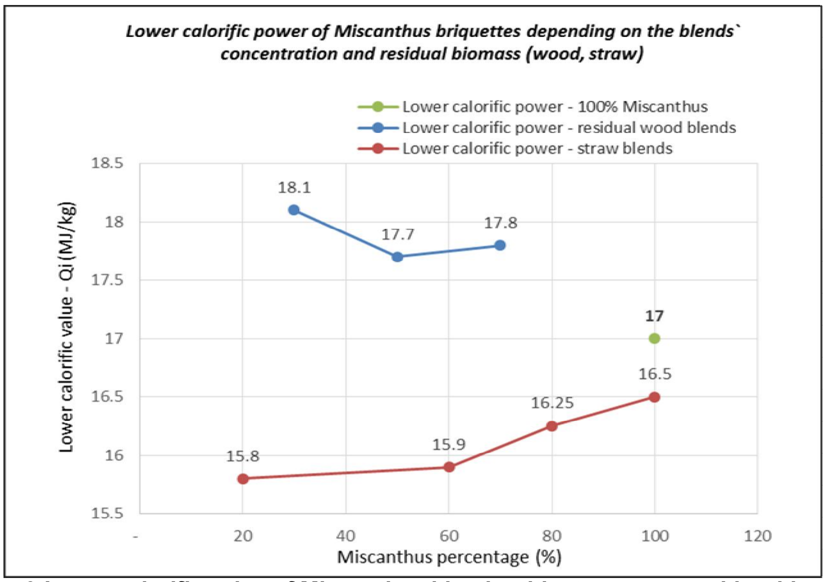

Figure *3* ***Lower calorific value of Miscanthus blends with straw comparable with wood blends***

For one Gigajoule (GJ) energy contained in the briquettes (for an average of NCV - 17 MJ/kg for Miscanthus blends) the AD, EP CED, GWP

Environmental aspects of Miscanthus use for mixed biomass briquettes

The LCA calculations for briquettes production have been done by assuming blends of Miscanthus percentage (by mass) of 60% with straw and respectively 50% with residual wood blends (orchard trees pruning).

Briquettes manufacturing of 1 GJ energy content from Miscanthus in blends with agri-residues requires 177.85 MJ of energy and results the emission of 15.12 kg CO_2^- eq. In addition to this, 0.0604 kg SO_2^-eq and 0.0119 kg PO_4^- eq are released in the surrounding environment.

The processes of cultivating Miscanthus and using this biomass by mixing with some agri-

impacts are presented (*table 3*) over each stage of the Miscanthus crop life cycle (Nemecek *et al.*, 2007).

residues, in the form of briquettes, contribute to the environment impacts expressed as acidification potential, eutrophication potential, global warming potential and energy demand, identified during the life cycle stages. Environmental assessment shows high impacts especially during the pressing activity (*figure 4*), but still the carbon emissions 15.12 kg CO_2^-eq. is lower than for pellets production 20.3 kg CO_2^-eq, by Murphy F.

The LCA results for using the briquettes of Miscanthus blends with agri-residues as energy source can be compared with other studies presenting different biomass variations and products made for bioenergy in other western European countries (UK, France, Austria and Germany). (Heller M.C. *et al.*, 2003, Zeng T. *et al.*, 2012, Murphy F. *et al., 2013*).

Table 3

Environmental impacts of *Miscanthus* blends with agri-residues for briquettes of 1 GJ energy production

Impact	Land preparation and cultivation	Harvest and maintenance	Briquetting	Crop removal	Transport	Total
AP (kg SO_2-eq)	0.0011	0.0025	0.0561	0.00038	0.0003	0.06038
EP (kg PO_4-eq)	0.0007	0.0011	0.0048	0.0002	0.0001	0.0119
GWP (kg CO_2- eq)	0.18	2.5	12.32	0.05	0.07	15.12
CED (MJ)	8.9	8.5	158.3	0.85	1.3	177.85

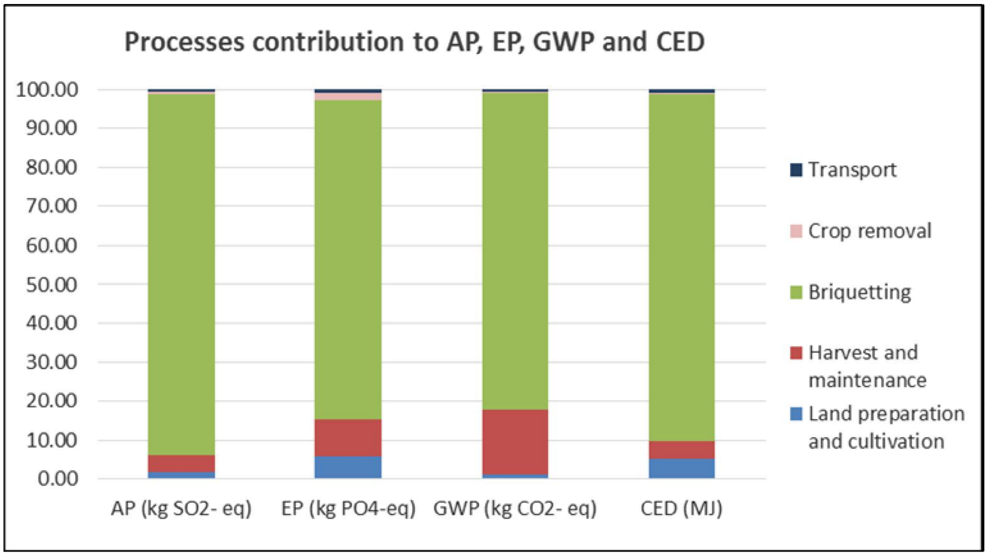

Figure 4 **Environmental impacts of Miscanthus blends briquettes production**

CONCLUSIONS

Miscanthus biomass and agricultural residues represent solid biofuels, which can replace in a sustainable manner the wood or natural gas supply for thermal energy in efficient heating systems, especially in rural areas. This study results identify the main issues considered in the Miscanthus processing chain, which may enable the development of optimal management choices and assist further progress in an enlarging of biomass industry in rural areas in Romania.

There are lots of technologies and installations available to burn ligno-cellulosic plants as Miscanthus, straw, wood residues (orchard or forest), corn stover and others, but different blends of energy crops and agri-residues must be assessed in order to obtain high energy efficiency.

The potential for scaling up Miscanthus cultivation is currently restricted by the planting and harvesting capacity, grower acceptance and technology compatibility. There is also social resistance for energy crops that needs to be sensitively approached, especially where perennial energy crops are proposed on long-term land use change. (Aylott M., McDermott F., 2012).

The benefits of energy crops include not only their use for biomass heat and electricity but also their ability to store carbon, benefit industrial landscapes, prevent erosion, improve biodiversity in the right location and ensure fuel independence.

The great advantage of biofuels is that they are considered to be 'carbon neutral' as they use up as much carbon dioxide during growth, as they expel as a fuel. (Tumuluru et al., 2011)

The use of Miscanthus together with agricultural residues for energy production in an efficient and optimal operational farm strategy offers many environmental benefits including; less climate impact, soil fertility, increasing local biodiversity and bioremediation reducing organic pollutants, where is necessarily.

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