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**REVIEW**

# Miscanthus giganteus – an overview about sustainable energy resource for household and small farms heating systems

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## Abstract

*In the last decade, the local Romanian farmers are facing more and more new challenges from the competition with the big farming systems. The temperamental changing weather of recent years has left arable farmers looking very seriously at new and secure profit opportunities for the future. For a sustainable, profitable and reliable long-term investment, Miscanthus giganteus represent one of the most important energy crops. Energy plants provide many years of gains that are 4 times as much as they were with normal woods or coppice rotation plants, so one hectare of energy plant replaces 4,000 to 7,000 litters of oil per year. Moreover Miscanthus giganteus is a phytoexcluder plant, which have a specific property not extracting contaminants from the soil, being suitable for field restoration.*

*The use of bioenergy crops for rural progress may differ in various regions depending on farmers` perception and acceptance, supported by programmes established at national and local level for bio-renewable energy resources. It is proven that many economic benefits of bioenergy production by cultivation of Miscanthus giganteus may contribute to a multifunctional agriculture, especially for polluted or marginal land, by developing the rural areas.*

*The most important technology to make available Miscanthus feedstock easily on the market is briquetting or pelleting the biomass in mixing with other agriculture waste.*

**Keywords:** *Miscanthus giganteus crops, cultivation technology, field restoration, briquetting, pelleting, heating systems, combustion;*

## 1. Introduction

The strive to reduce the dependency upon fossil fuels has switch the attention on biofuels which have as main advantages to be a renewable energy source, that is very easily available and which also benefits upon a low environmental fingerprint (ATKINS [1]). Biomass exploitation contributes to the boost of rural areas development through the agricultural activities. One of the most promising sources of biomass are lignocellulosic crops (*Miscanthus giganteus*, *Arundo donax,* sorghum, reed grass) that can be used in addition with other agriculture waste for production of heat and electricity by means of direct combustion or by production of biofuel and biogas (JURIŠIĆ et al. [2]).

In Europe the advisors are estimating a maximum of 30% of potentially available biomass which can be used for energy production (TOMIĆ et al. [3]). Recent research made in Romania shows that, in average, natural and anthropic ecosystems can offer yearly about 190 million tons extractable, renewable biomass, without causing ecosystems disorders (DOBRINOIU et al. [4]). In the last ten years, different technologies and equipments were developed for manufacturing and efficient burning of briquettes from sawdust, straw, Miscanthus, energy grasses and other biomass sources.

Miscanthus (*Miscanthus×giganteus*) is one of the best options for low input bioenergy production in Europe and USA. *Miscanthus×giganteus* is a perennial tall C4 grass (3-4 m), with long productive life-span (15-20 years) that is harvested each year (DŽELETOVIĆ et al. 2013 [5]). This plant is a *Miscanthus sinensis* hybrid and it is characterized by a very high potential yield and resistance to environmental conditions species, suitable for economic bioenergy production growth. Due to an efficient production of biomass, this energy plant may have an important role in sustainable agricultural production of fuel biomass in the near future, especially recovering marginal lands [3]. *Miscanthus giganteus* (Miscanthus) is a valuable energy plant, which can be successfully cultivated in Romania, on polluted soils with Pb and Cd (BARBU [6].

In Romania the plant cultivation have been tested on an area larger than 600 ha in different areas of the country (Arad, Bihor, Dobrogea etc.) and with various soils characteristics, which are producing tonnes of biomass (SABĂU [7]). Therefore, future perspectives may be developed at profitable level, because actually the lack of investments for sustainable and valuable end uses of Miscanthus production (densification and combustion technologies, solutions for insulation materials in construction or biomaterials etc.) make the plant cultivation for Romanian farmers not so challenging.

Miscanthus biomass has a very good quality for combustion (similar as a light coal or wood), thermic value of Miscanthus biomass amounts to 9.2-17.7 $MJ \cdot kg^{-1}$[3]. It has also a positive ecological impact for marginal land that makes this crop suitable as a bioenergy resource for sustainable feedstock in household and small farms heating system uses. Efficient Miscanthus cultivation and biomass combustion creates perspectives to reduce greenhouse gas emissions by fixing into crop more quantities of $CO_2$ than those liberated during combustion, cultivation and preparing technologies. A quantity of 20 tonnes of Miscanthus biomass represent as energy value equivalent of 8 tonnes of coal and comparing with coal, burning Miscanthus emits $CO_2$ emissions are 90% less to produce the same amount of energy [1], (DEFRA [8], CASLIN et al. [9]).

By enzymatic hydrolysis of pretreated biomass of Miscanthus, over 400 mg/g biomass of reducing sugars can be released (VINTILA et al. [10]). This yield is higher than the yields achieved with other types of agricultural biomass, Miscanthus can provide more fermentable sugars than corn stover for instance. Among other aspects, from the same area of land 2 to 4 x times more ethanol can be produced from Miscanthus perennial crop than from annually corn crops and thereby, energy demand can be supplied cheapest from Miscanthus as bioenergy source (HEATON & al. [11]).

The most important technology to make available Miscanthus feedstock easily on the market is briquetting or pelleting the biomass. Biomass pelleting is still expensive for several reasons: high share of labour in biomass preparation, substantial biomass losses, increased labour costs, increased electric and fuel energy costs, expensive maintenance of the equipment for pellet production [3]. Hence, Miscanthus briquette production is easily available and compares favourably with wood pellet and coal production (MURPHY et al. [12]).

The present review will represent briefly the prospects of Miscanthus biomass suitability for bioenergy production in Romania, taking into consideration the current situation in the domain of bio-renewable energy potential (wood exploitation from natural areas, politics to promote rural development and renewable energy), as well as some results from the research in this field.

## 2. Romanian potential for Miscanthus giganteus crops

*Agro-ecological aspects for Miscanthus giganteus cultivation in Romania*

In the last decade more farmers have experienced the cultivation of Miscanthus within the agro-climatic condition of Romania, some of them being successful and others less, because of local conditions and technical aspects related with the planting processes and market availability. In Balkans (Croatia, Bulgaria and Serbia) there are similar climatic conditions as in our country, and the results of positive experimental Miscanthus productions depends mostly on local agro-ecological conditions [2], [3], [5]. Miscanthus planting in Romania was conducted in different areas of the country, on different soils including contaminated areas: Timiș, Copșa Mică and Rovinari.

Miscanthus is recognized as a cold-tolerant C4 plant. However, the main limitative factor for a prolonged vegetation season is late spring frosts, which can destroy early spring leaves and efficiently shorten the growing season duration. The influence of latitude on the yield is evident in the north Europe, where the yields are lower than in the south Europe, regardless of the irrigation [3], [5]. Sufficient water supply is necessary to ensure good rates of establishing and satisfactory biomass production. Miscanthus is highly productive in moist environment, and resistant for prolonged wet seasons, but it is very susceptible to insufficient moisture (SCHWARZ [13]) considers the precipitation quantity of 800 mm sufficient for obtaining high Miscanthus yields in moderate climate. It had been shown that minimal annual precipitation quantity of 600 mm may be insufficient for Miscanthus growth.

Irrigation during the first year generally improves the establishing rates of the crop and annual yield differences are observed depending on climate (drought stress, sunlight exposure and soil conditions). Considering that *Miscanthus giganteus* is sterile, the propagation of the plants is substantial vegetative, either by rhizome cuttings or by micro-propagation [5].

In Romania more than 10,000 ha are covered by mining and power plant residues (mining sterile, ash and slag deposits) and this surface is not available for food agriculture. Considering the fact that Miscanthus crops are suitable on heavy metals contaminated soil, it is expected that more and more degraded land will be used for this purpose. In order to stimulate the process of vegetative grow from the first year, especially on marginal land, it is important to use fertilisers as sewage sludge, manure or mineral supplements such as N,P,K. The best results are obtained in case of the tests fertilized with sewage sludge, which can be a positive factor regarding the opportunity of sustainable valorisation of the wastewater sludge (LIXANDRU et al. [14]).

Moreover, Romania is facing flooding difficulties because of intensive cuttings in forestry areas and low investment in flood management. As Miscanthus is water friendly plant, farmers have an optimal alternative to grow this crop for multiple uses: bioenergy, water management and road protection during winter, bio-based materials. Another positive impact of cultivating Miscanthus could be determined in those areas where fertilizers as nitrogen and phosphorus put stringent problems around drinking water reservoirs or wells.

The incidence of Miscanthus crops in different regions of Romania is relevant, as shown in figure 1 on a vegetation map considering the suitability for growing this bioenergy plant. It is estimated that biomass comprises 63% of total renewable energy sources in Romania [7].

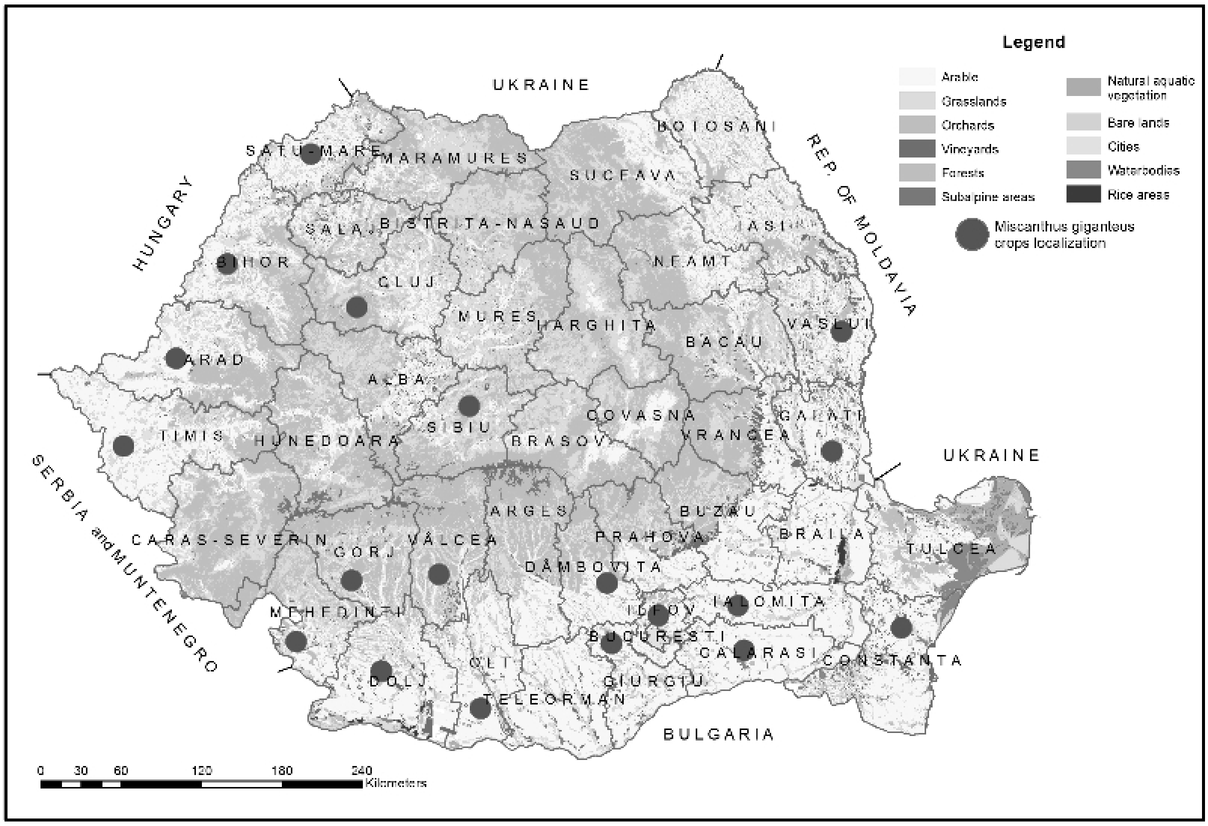


**Fig.1** - Regions of Romania where Miscanthus was cultivated between 2008 and 2014 (source: I.Sabău, 2014 [7])

No statistical data are available on biomass utilization in Romania (most frequently this is omitted in the reports on energy balance, but biomass is nevertheless traditionally used for thermal energy production in industrial small scale or household heating systems).

*Technical aspects for optimal harvesting*

Miscanthus crops has similar requirements as corn, so it needs good agricultural soils with a sufficient water supply. On well water-bearing soil layers an average annually harvest of 17 to 20 tonnes/ha over 18 years can be expected (KRISTÖFEL [15])

Research in Europe and Illinois shows a 30 to 50 percent yield reduction when harvest is delayed from autumn to late winter. Mowing during the growing season harms plant growth and regeneration by depleting root stock. Dry matter yield of Miscanthus in the establishment year is generally low, 2-5 tonnes per hectare, which is insufficient to merit harvest [5], [12].

Miscanthus harvested from 1 hectare corresponds to 155 loose cubic meters (bulk density of $60kg.m^{-3}$) [15]. Miscanthus biomass is harvested at the end of the growing season, for European case studies in late winter and spring harvests result in higher quality feedstock for combustion, but lower yields due to field losses. After the second year of crop establishment, Miscanthus can be harvested annually in April with a moisture content of about 12 - 14 wt.-% [1], [15]. Usually a corn chopper can be used for harvest. Because of the low water content there are no problems with Miscanthus harvest and storage. Delivery of Miscanthus biomass may be done with a specially designed conveyor belt wagon, so that the charging can be done without major construction efforts from the farmers [5], [15].

## 3. Miscanthus biomass pretreatment and combustion properties

After harvesting Miscanthus, there are two options to preserve the feedstock biomass. One is to ensure a large stock unit for bulk density of 50-130 $kg \cdot m^{-3}$ and another one is to briquetting (pelleting) the biomass to a density of briquettes of 750-850 $kg \cdot m^{-3}$(LOGISTEC [16]). Miscanthus has good pressing properties and represents one of the most compressible energy crop, (PLÍŠTIL [17]). Miscanthus briquette production compares favourably with wood pellet, kerosene, and coal production, rather than with Miscanthus pelleting more environmentally damaging are revealed [12].

*Miscanthus* is a good biomass when using a hydraulic commercial briquetting press or mechanical press at moisture contents of approximately 10-12%, the harvest`s humidity, that is suitable for pressing processes. The densities of Miscanthus briquettes are 750 – 850 $kg \cdot m^{-3}$[16]. By densification, the Miscanthus biomass is easily and more efficient to provide the feedstock to consumers.

Experimental results made by BAXTER [18] show that Miscanthus stems have better fuel quality than leaves, with much lower ash, N and S contents, and slightly higher C concentrations and higher estimated calorific value. Crop treatment without any Nitrogen addition into fertiliser provide a better fuel quality, resulting in a fuel with lower N emissions, ash content, and a lower propensity to fouling and higher C concentrations for an higher combustion efficiency. In general, the late harvested Miscanthus samples have better fuel quality, with lower N, Cl, ash contents, alkali index and slightly higher C contents. [18]

Compared to wood, perennial crops typically contain significantly higher concentrations of ash. This is partly due to their fast growing metabolism (accumulation of nutrients) and different organic structure ($SiO_2$- phytoliths) but can also be significantly influenced by the harvesting period and by the mechanical harvesting technique used. High concentrations of Cl and S in combination with high concentrations of K and Na imply that high aerosol emissions, as well as considerable deposit formation on boiler tubes, can be expected from these volatile elements. During combustion these elements vaporise and condense in the flue gas (forming fine particulates) as well as on heat exchanger surfaces with decreasing flue gas temperatures. Moreover, high concentrations of K and Si can result in the formation of ashes with low melting temperatures and thereby can cause slagging on the grate as well as in the combustion chamber [18], (DAHL [19]).

The main elemental compositions of combustion properties in an electrically heated furnace (max. temperature 1,100°C), the gross calorific values (GCV) and the bulk density of perennial grass fuels, including the reference for wood pellets fuel, are revealed in Table 1 [19], (VOICEA [20]).

Dahl [19] revealed that combustion of perennial crops - as Miscanthus and other energy plants, is challenging and can only be performed if special adjustments are taken regarding the combustion and process control technology used in comparison with wood burning. Moreover, significantly higher emissions of particulates as well as of gaseous emissions of HCl, $SO_2$ and NOx, Dahl observed from the tests he ran compared to wood pellets test. These problems are related to the composition of these kind of biomass comprising high ash contents with increased concentrations of Si, K and Ca (forming low temperature melting ash), as well as high concentrations of Cl, S and N in the gaseous emissions.

**Table 1. Analyses results of fuel samples for SG (switchgrass), GR (giant reed), MI (Mischantus), CA (cardoon), WP (wood pellets) [19], [20]** *(d.m - dry matter, wt – weight, a.f - ash free, GCV - gross calorific value)*

| Biomass | SG | GR | *MI* | CA | WP |
|---|---|---|---|---|---|
| wt% d.m. | | | | | |
| Ash | 8.3 | 6.1 | ***2.3*** | 17.4 | 0.50 |
| N | 0.67 | 0.71 | ***0.16*** | 1.1 | 0.08 |
| Mg/kg d.m. | | | | | |
| Si | 14,991 | 13,920 | ***7,305*** | 21,142 | < 400 |
| Ca | 6,555 | 3,253 | ***1,776*** | 19,025 | 938 |
| K | 12,756 | 6,497 | ***1,446*** | 21,546 | 484 |
| Na | 924 | 331 | ***58*** | 10,330 | 30 |
| Mg | 2,223 | 1,627 | ***644*** | 3,936 | 152 |
| Al | 763 | 919. | ***82*** | 4,445 | n.a |
| S | 735 | 2,160 | ***390*** | 1,566 | 73 |
| Cl | 1,511 | 2,245 | ***880*** | 17,780 | 53 |
| MJ/kg (d.m., a.f.) | | | | | |
| GCV | 17.8 | 19.8 | ***17.7[1] - 19.6*** | 20.3 | 20.3 |
| kg d.m./m³ | | | | | |
| Bulk density | 585 | 116 | ***117*** | 561 | 644 |

[1]GCV – results obtained by Voicea [20]

The new combustion systems for Miscanthus burning are designed with operational measurement to reduce the tendency of slag formation by decreasing combustion temperature using cooled grates and for furnace special walls in the combustion chamber. Another approach is to upgrade the fuels aspects by either separating problematic elements (egg. leaching) or trying to neutralise their effects by additives (e.g. addition of lime to increase the slag melting point), that option is important to be analysed if it is economically efficient.

Further tests have demonstrated that blends of Miscanthus biomass with wood fuels in small scale combustion, reduce the HCl, $SO_2$, NOx and particles emissions due to the dilution effects achieved and due to special combustion chamber improvement [19]. This approach is probably the optimal way to introduce these new crops into the new markets, but comprehensive test runs with different biomass blends are necessary in order to optimise the blending ratios for future biofuels.

According to SIMS et al. [21], Miscanthus has the highest energy yield per hectare: 204 GJ $ha^{-1}$, higher than other bioenergy crops as dense short rotation coppices of willow and poplar (168 GJ $ha^{-1}$), biodiesel from oil seed plants (27 GJ $ha^{-1}$) or ethanol from starch or sugar biomass (14-114 GJ $ha^{-1}$).

## 4. Small scale heating systems based on miscanthus biomass

The most common heating systems for Romanian small communities are individual farm and household small burning installations using wood and coal as solid fuels or gas, and only occasionally energy crops or other biomass residues. To ensure that the solid fuels are available for the small scale heating systems, there are turning to develop new approaches how to burn efficiently biomass from energy crops as Miscanthus, willow, local wood rotation crops or agricultural residues that can represent a sustainable resources.

Now, the Romanian market for solid biofuels is doing the first steps for acceptance of alternative crops for energy plants and new energy supply chain for biomass appear, creating opportunities to grow local businesses for rural development. The farmers have alternative options to use the agricultural residues and energy crops biomass for their heating needs and to provide the feedstock with biomass (bales, briquettes and pellets) for other household and farms requirements.

The Danish, German and Austrian heating systems became the most efficient burning installations in terms of calorific value, emissions, ash content and automatic charge. The economic and technical efficiency for small scale heating systems is raising up, starting 50 to 200 kWh or more (800kWh), installations being adapted for household and local institutions energy needs, [16], (www.mispower.fr, [22]).

In figure 2 there are represented some compact heating systems [22] and a combined systems with solar panels. The burning installations are using as solid biofuels Miscanthus biomass, straw, wood chips and sawdust, other agriculture and forestry residues, in form of bale, briquettes, pellets and bulk biomass.

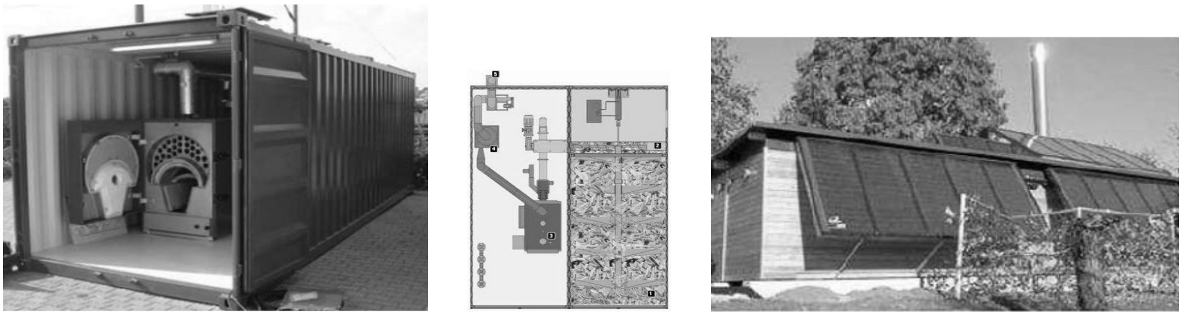

**Fig.2 – Compacted heating boilers using Miscanthus and different other biomass [22]**

Some combustion properties of Miscanthus briquettes is represented in table 3, and the results are specific for an Austrian heating systems (200 kW) [14], (BRUNNER [23]) and Romanian tests for mixing Miscanthus with other available biomass resources (sawdust and straw).

**Tabel 2. Combustion properties of Miscanthus briquettes [14][1] and from Romanian tests[2] [20]**

| Net calorific value MJ/kg dm | Ash content wt.-% dm | Water content wt.-% | Softening temperature of ash °C | Nitrogen wt.-% dm | Sulphur wt.-% dm | Chlorine wt.-% dm |
|---|---|---|---|---|---|---|
| 17.7[1] | 3.1[1] | 7.5[1] | 1,010[1] | 0.24[1] | 0.035[1] | 0.025[1] |
| 15.8[2] | 2.89[2] | 7.1[2] | - | 1.01[2] | 0.17[2] | - |
| dm…dry matter, wt.-%...weight % | | | | | | |

To supply an increasing demand on biomass for heating systems at small scale level the most important alternative is to blend Miscanthus with other biomass available (including wood residues) by briquetting - that is less expensive than the pelleting processes, even if the market demand is higher for pellets because they are more efficient in order to automatize the charging system.

## 5. Logistics, sustainability and economical aspects

In Romania the energy obtained from biomass is traditionally in use from wood, processes running in an old-fashioned and unorganized way, which is technically and environmentally outdated. Thus, it is necessary to accept that the investments in biomass energy supply chains are currently the most attractive opportunities for investors, considering that quite moderate funds are sufficient and financial support for renewable energy resources are available (egg. Romania offer an amount of 134 €/MWh for projects up to 1 MWh/year energy installations). The intensive use of existing biomass (agriculture and forest residues) and new energy crops may create a multi-functional agriculture, as well as comparative cost/benefit stability for rural development. (DŽELETOVIĆ, 2010 [24]). Logistic and market availability control, also dissemination of successful cases are important in order to open the receptivity of consumers for bioenergy (CRES [25]).

However, biomass utilization has certain drawbacks: only periodical availability of the biomass, scattered distribution, difficult gathering, packing and storage, which is caused by low density, low thermal value expressed per volume unit and high moisture content, while investments for construction of biomass combusting plants are higher than those for combustion of conventional fuels [5].

This problems may be optimally solved if the Miscanthus biomass is compressed in the form of pellets of briquettes. In Romania Miscanthus crops are cultivated in small plots and only a few farmers have large areas that ensure feedstock supply for heating installations, therefore the biomass is not efficient harvested and valorised. From other countries` experiences (France, UK, Austria) an effective solution is to install heating systems with energy capacity higher than 50kW, [22], (ERICSSON et al., [26]).

Figure 3 shows the heat supply costs in €/MWh including costs for harvesting, transport (up to 50 km), drying and pelletizing/briquetting [14]. The fuel costs amount to 24-56 €/MWh, depending on the used raw material and the pelletizing plant. Straw pellets and Reed canary grass briquettes are the most efficient biofuels in costs presented for an installation of 200 kWh and for Miscanthus heating costs are 45 €/MWh, [22]. There are options to blends different cheap biomass locally available and tests are needed to be runs to prove the efficiency of biomass supply for small scale heating systems.

The costs for pelletizing and briquetting amount to 11 - 32 % of the whole fuel costs. An exception are the digestate pellets, because it is assumed that digestate can only be used for combustion if it is no longer needed as fertilizer and therefore no raw material costs incur. For this reason only costs for transport and drying have to be taken into account and consequently the pelletizing costs amount to 55 % of the fuel costs. Certainly, the costs for pelletizing and briquetting strongly depend on the pelletizing/briquetting plant. Therefore, an optimal operation of the plant, especially with regard to the production of mixed raw material pellets, is a large cost advantage (ZENG et al., [27]). If the raw materials are mixed, an optimal plant operation must be ensured in order to keep the production costs low.

Miscanthus has high energy balance, calculations published by British Department of Trade and Industry (publication URN 01/797) put the Miscanthus carbon ratio at 53:1. This means that, of the carbon contained in the fuel, for every one part of man-made carbon inputs needed to grow and harvest it, 53 parts are absorbed by the crop from the environment. Miscanthus biomass contains 47% carbon (fixed in lignocellulosic parts), therefore a crop of 15 tonnes dry matter per hectare would fix in a single year 7 tonnes of carbon - equivalent to 25.7 tonnes of $CO_2$, (HARVEY [28], NEWMANN [29]).

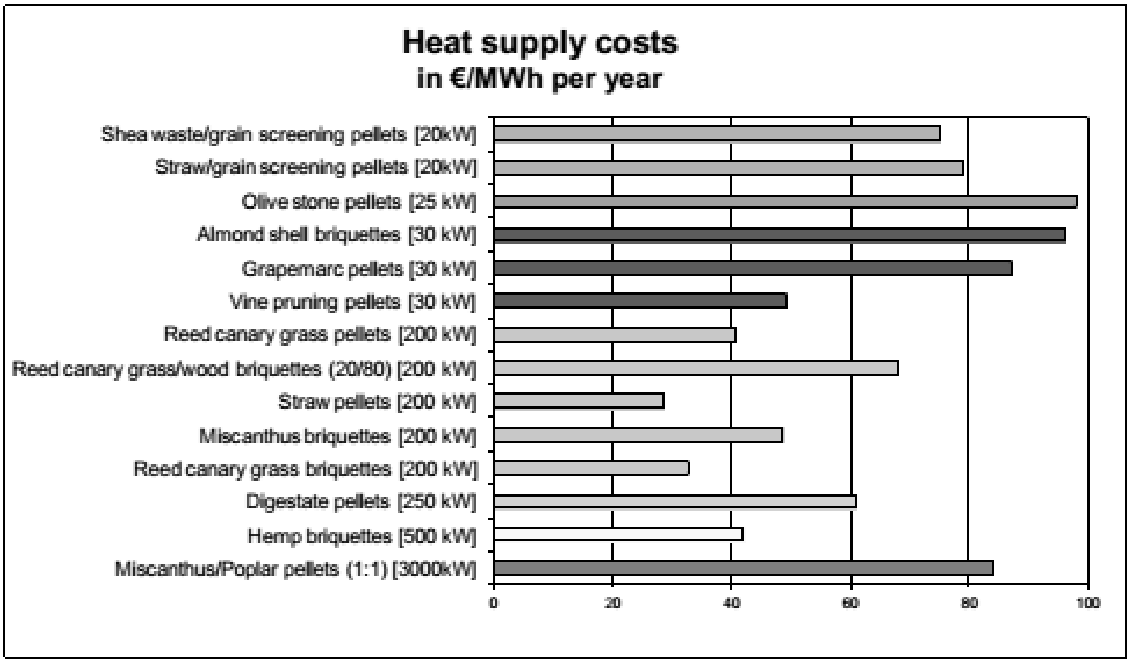


**Fig.3 -** Comparison of heat supply costs for different heating systems of the case studies [15]

To prove the sustainability of each bioenergy system, as well as for Miscanthus energy feedstock supply, the International Sustainability and Carbon Certification (ISCC) proposed a standard that comprise six principles that may be adapted by countries within a life-cycle assessment of every value chain production (MATTHEWS [30], EIBI [31], and GREVÉ et al. [32]):

- Biomass shall not be produced on land with high biodiversity value or high carbon stock;
- Biomass shall be produced in an environmentally responsible way;
- Safe working conditions through training and education and proper equipments;
- Biomass production shall not violate human rights or land rights; costs and benefits should be distributed in equitable way;
- Biomass production shall takes place in compliance with all applicable national and regional laws and follow international treaties;
- Good management practices shall be implemented.

One of the most challenging objective for Romanian study case is to connect the developers of bioenergy strategy and policy with the wider bioenergy sector and to inform about economic support for opportunities that increase biomass resources availability. Open dialogues between investors, researchers, biomass producers and heating systems providers, farmers and consumers of solid biofuels as Miscanthus crops and other available biomass must be created and supported through national policy in this area of interest. (WELFLE [33], STERN [34]). Prominent examples of energy transitions are evident today (ARAÚJO [35]), and Miscanthus as energy crop may offer advantages for emerging fields of technologies based on biomass resources.

## 6. CONCLUSIONS

Miscanthus biomass production is of best quality for energy production (moisture, N, contents, etc.) if is harvested towards the end March or in April (based on Romanian case studies) depending on season' characteristics. Investigations indicate that the actual potential for energy production from renewable sources in Romania are good, and the energy produced from biomass is recognized as a renewable energy source of first importance.

Utilization of Miscanthus as bioenergy crops in Romania was initially stimulated by research programs funded by the national research projects. Nowadays there are projects aiming to expand the areas cultivated with Miscanthus. Though promising results are evident, the market stimulation to increase the interest for this energy crop is very low, only sequential investments being made by private owners. The lack of a national strategy on biomass for Romanian potential lowers the perspectives to speed up the bioenergy sectors development.

Despite of that, young farmers, researchers and open-minded investors may find optimistic solutions for boosting the bioenergy sector, especially on sustainable use of available biomass and suitable energy crops. Having this approach, Miscanthus is an optimal selection to marginal land recovery and for agro-ecological development of rural areas.

By intensive utilization of the existing and convenient energy crops as Miscanthus, their high potential could be realized and thus contribute to comparative price stability of agricultural products, stimulating eventually a long-term rural progress in countries like Romania. It is expected that the use of energy crops for rural development will probably differ in various regions depending on multiple factors related with the agro-climatic conditions, land availability, people awareness for bioenergy and funding opportunities. Along with profitability, it is estimated that the energy production based on Miscanthus cultivation will also contribute to the agriculture`s multi-functionality.

This represents a great potential for Miscanthus crops to be integrated and accepted as biomass feedstock for household and small farm heating systems as well as for large combustion and power plants (CHP).

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