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Wood Biomass as Sustainable Energy for Greenhouses Heating in Italy

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Abstract

The Italian greenhouse vegetable industry is an important sector that requires thermal energy as much as 0.74 Mtoe, derived mostly from fossil fuels, which corresponds to 2 $MtCO_2$ emissions. The Energy Strategy 2020 of the European Commission calls for increased use of renewable resources in the energy system, thus pushing the technology of wood biomass system for space heating of the greenhouses, since this resource is considered as 'greenhouse gas' (GHG) neutral when converted to heat, excluding the GHG generation during harvesting, transportation, and pre-processing of raw materials.
Taking into account the different climatic areas in the Italian peninsula, power energy load was estimated to be between 30 Wm^{-2} (in southern regions) and more than 175 Wm^{-2} (in northern regions), while the energy consumption was estimated in the range from 21 to 546 $kWh_{th}m^{-2}year^{-1}$ according to different internal air temperatures. Moreover, the CO_2 enrichment in greenhouses from the exhaust gas of a biomass heating system can bring benefits for greenhouse plant production, along with optimal management strategies to reduce fuel consumption.
Unfortunately, CO_2 enrichment from the exhaust gas of biomass boilers is still challenging and expensive, considering that wood biomass boilers generate a higher volume of particulate matters (PM) and ash emissions than other fossil fuels. However, wet scrubbers and other recent flue gas conditioning devices could help to reduce costs and make this process more feasible.
Thus, a techno-economic assessment is highly recommended to ascertain the economic feasibility of wood biomass boilers for the greenhouse industry.
Finally, some economic considerations are provided to make cost-effective use of the solid biomass in relation to the economic

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incentives by the National Decree of 28 December 2012, so-called “White Certifies”.

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Keywords: Wood Biomass; greenhouses heating system; CO_2 enrichment

1. Introduction

The agro-food industry is the leading manufacturing sector in Europe, in terms of turnover, value added, employment and number of companies. In Europe, its turnover was around 950 billion Euros in 2010 and it employed nearly four million people. In general, the agro-food industry is composed by transformation companies, using products from agriculture (primary production) to supply the agro-food industry. As general figure, the Italian added gross value of the agro-food system, in its wider meaning of agriculture and food industry, has reached in 2011 a global economic value of 250 billions €, which correspondents to about 16% of the added gross value of Italian economic in 2010. About 12.9 million hectares is agricultural land in Italy.

According to Campiotti et al. (2011), the national agri-food system amounted to a total final energy consumption of 16.43 Mtoe (tonne of oil equivalent) (Tab. 1).

Table 1. Agriculture and energy consumption of productive sectors in Italy.

Productive sectors in the agro-food system	Energy consumption (Mtoe)
Direct consumption (irrigation, processing land, air heating, utilities)	3,03
Food industry	2,90
Indirect consumption (phytosanitary, fertilizers, plastics), transport, preparation, storage, distribution, storage, sales	10,50
Total	16,43

2. Greenhouse energy consumption in Europe

The EU greenhouse farming sector is facing a trend that responds to the changing consumer demands in a society that, globally, is increasingly affluent, and generate concerns and negative consequences, i.e.: high fossil energy-demand, energy consumption, environmental impacts, Carbon dioxide (CO_2) emissions. Greenhouses are used to control or modify the many environmental factors affecting plant growth, mainly temperature and relative humidity, rain, wind, hail and snow. As general statement, the most important climatic factors which influence the quality of the indoor microclimate are the quality of solar radiation and the temperature. Solar radiation is the main source of photosynthetic energy for plant growth and production. On the other hand, temperature is the most critical climatic factor for the greenhouse functionality. Therefore, the greenhouse design must follow regulations related to the local climate as well as the greenhouse heating technologies in order to maintain an optimal microclimate, especially as solar radiation and temperature, for the cultivated plants. Thus, the covering materials with their mechanical and radiometric properties determine the transmittance and the good insulation performance.

The greenhouse sector, with about 150,000 hectares of covered surface in Europe, represents one of the most intensive energy sector in the agro-food industry. In South Europe, about 5 ÷ 6 $kg.yr^{-1}.m^{-2}$ fossil fuel are required for keeping the inside air at around 15°C÷20°C; on the other side, in Central-North Europe, from 60 to 80 $kg.yr^{-1}.m^{-2}$ heating oil are required for maintaining optimal air temperature inside the greenhouse area. Estimation made in Spain, Italy, The Netherlands and Greece reported for these countries a greenhouse fossil energy consumption of about 4 Mtoe, with 11.3 Mt_{CO2} emissions, and a total yearly economy value in products and structures in the range of 12.5 billions € (Table 2).

Table 2. Greenhouse agriculture in Europe

Country	Greenhouse surface (ha)	Economic turnover (billions €)	Heating (MWh_{th})	Electricity (MWh_{el})
Italy	30,000	3	8,432,500	112,866
Netherland	10,311	6.8-7.7	29,510,800	3,723,000
Spain	43,964	1.5	989,627	33,623
Greece	5,646	0.5	87,644	1,700
Total	**89,921**	**About 12.50**	**39,020,571**	**3,871,189**
			3.35 Mtoe	0.77 Mtoe
			9.4 Mt_{CO2}	2.1 Mt_{CO2}

0.0860 toe = 1 MWh_{th} ; 0.201 toe = 1 MWh_{el} ; 1 toe equals to 2.81 t of CO_2 emissions.
(*Source:* Estimation of authors from data available on national data-bases, internet and EUROSTAT, 2008 and 2009.)

More in details, the Italian greenhouse is characterized with not less than 6,000 ha as permanent greenhouse structures, and equipped with fossil acclimatization systems, which accounts for a total energy consumption of about 0.74 Mtoe, predominantly coming from fossil fuel (Table 3).

Table 3 - Electrical and thermal energy consumption in greenhouse sector in Italy

Country	Greenhouse[a] surface (ha)	Heating[b] (toe)	Electricity[c] (toe)
Italy	6,000	706,786	24,830

a. plastic-greenhouses and glass-greenhouses;
b. yearly energy consumption;
c. yearly electricity demand of greenhouse users (ventilation, opening, pumping);
Source: The Regulatory Authority for Electricity and Gas of Italy, 2009.
Elaboration from national data and EUROSTAT 2008 and 2009.

The greenhouses are widespread all over the Italian peninsula with a greater concentration (about 60% of the total) in southern regions, where most of the greenhouses consist of low-cost structures covered with plastic films. They are usually provided with simple heating systems, while greenhouse acclimatization is mainly used in the northern areas of Italy, with most of the greenhouse structures covered with glass.

The Sankey diagram (Fig. 1) shows the direct energy inputs of Italian agriculture, with the greenhouse agriculture as one of the most intensive sub-sector in terms of direct energy consumption, mostly due to greenhouse acclimatization.

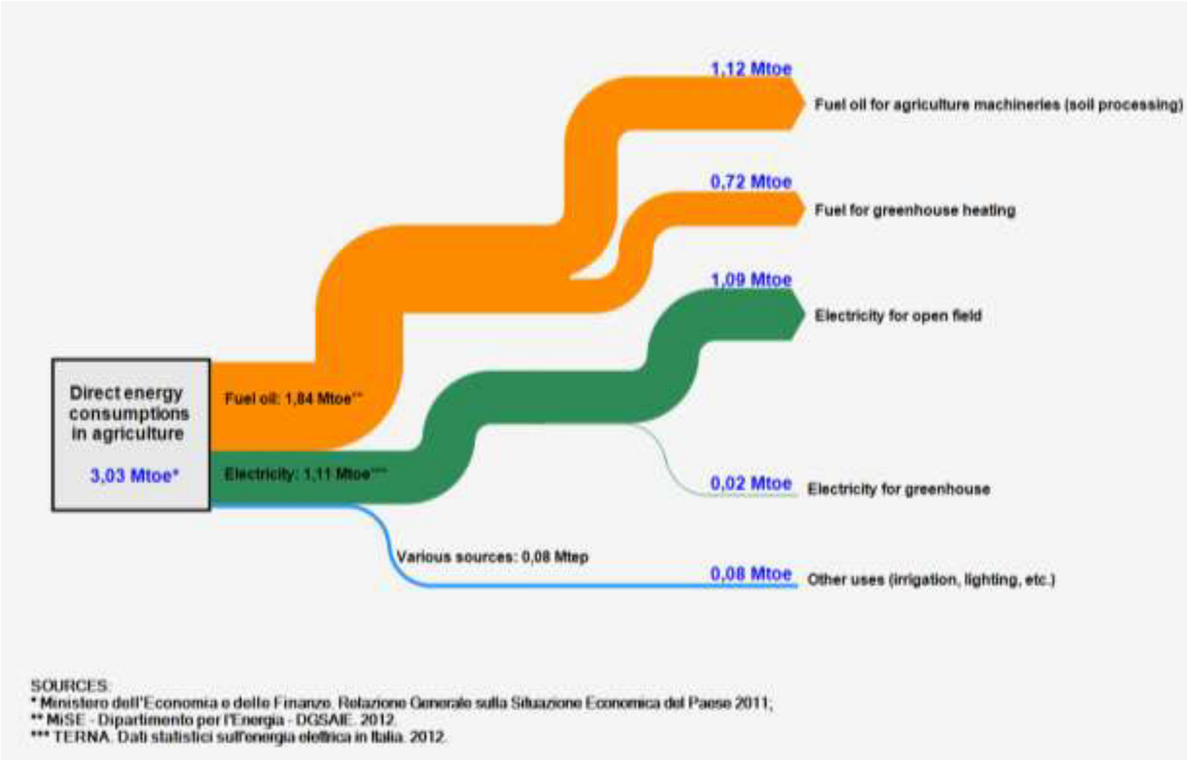

Fig. 1. Direct energy consumption in Italian agriculture .

Recently, in Italy which is one of the European countries most vulnerable to the impacts of high energy cost, the renewable energies come along as the most promising energy resource for application in greenhouse acclimatization to face the present concern on fuel costs, that has posed a serious threat to the viability of the agricultural companies in the field of greenhouses. Particularly, the photovoltaic and the solid biomass for heating and cooling purposes have attracted a lot of attention in substitution of conventional fuels, since it is general conviction that the increasing of oil energy price is a trend which doubtless will continue for the coming years in Europe, and this will increase risks and lower profit for agricultural companies and growers.

Nevertheless, biomass energy production (such as energy crops) can compete with food production for agricultural land and raw materials, as the recent experience in Italy brought to light when a large number of biogas plants were built during the last 5 years, or in early 2007 when the demand for maize increased due to ethanol production in the USA. (Mathiesen et al., 2011). However, the carbon balance should be carefully evaluated.

Besides, there is some concern over their usage in residential heating due to the emissions of various pollutants, such as polycyclic aromatic hydrocarbons, NOx, CO, SOx, and particulate matter (PM).

3. Classification of Biomass Sources

The classification of solid biofuels is based on their origin and source. The fuel production chain of fuels shall be unambiguously traceable back over the whole chain. Both EN 14961 (2010) and EN 15234 (2010) have been divided into 6 parts, where part 1 gives the general requirements, and parts 2-6 are specific for fuels to be used by relatively small-scale users and non-industrial applications. In the standards, the limit is drawn at boilers with a capacity of 500 kW. All boilers above that size are considered 'industrial', those under that limit are 'non-industrial'

The solid biofuels are divided into the following sub-categories (EN 14961-1, 2010):

- woody biomass;
- herbaceous biomass;
- fruit biomass;
- blends and mixtures.

The purpose of classification is to allow the possibility to differentiate and specify raw material based on origin with as much detail as needed.

Taking into account the energy content, table 4 shows the following Net calorific value (CV) or Lower Heating Value (LHV) (this means that the latent heat of vaporization of the water vapour created by combustion is not recovered by condensation):

Table 4. Greenhouse agriculture in Europe

Fuel	Net Calorific Value (CV) by mass GJ.tonne^{-1}	Net Calorific Value (CV) by mass kWh.kg^{-1}	Bulk density Kg.m^{-3}	Energy density by volume MJ.m^{-3}	Energy density by volume kWh.m^{-3}
Biomass Fuel					
Wood chips (30% MC)	12.5	3.5	250	3,100	870
Log wood (stacked - air dry: 20% MC)	14.7	4.1	350-500	5,200-7,400	1,400-2,000
Wood (solid - oven dry)	19	5.3	400-600	7,600-11,400	2,100-3,200
Wood pellets and wood briquettes	17	4.8	650	11,000	3,100
Miscanthus (bale - 25% MC)	13	3.6	140-180	1,800-2,300	500-650
Fossil Fuels					
House coal	27-31	7.5-8.6	850	23,000-26,000	6,400-7,300
Anthracite	33	9.2	1,100	36,300	10,100
Heating oil	42.5	11.8	845	36,000	10,000
Natural gas (NTP)	38.1	10.6	0.9	35.2	9.8
LPG	46.3	12.9	510	23,600	6,600

(From http://www.biomassenergycentre.org.uk)

4. Biomass heating systems

Biomass with low moisture content, provided in its raw form or processed as pellets, chips, briquettes, etc., can be converted in both heat and CO_2 to a greenhouse via combustion or other thermo-chemical processes such as gasification or pyrolysis (McKendry, 2002).

Several different types of biomass boilers can be supplied with wood chips, pellets, or briquettes: their sizes range from small (10÷20 kW), to medium (50 kW and above), and to power-station (100 MW and more).

Biomass fuel is fed to the grate mechanically where it undergoes the four-stage combustion process to produce energy:

- Warming and drying Temperature $T< 150$ °C
- Pyrolysis $150< T<500$ °C

- Gasification 500< T<800 °C
- Combustion of gases 800< T<1600 °C

The biomass boilers systems should provide a drying of the first load of fuel on the grate and then its heating towards the spontaneous ignition temperature of 400 °C, accomplished by automatic ignition systems, most notably hot air.

Warming and drying requires hot combustion chamber above and around where the fuel enters the grate. Thus, boilers contain some refractory material, and the greater this quantity of refractory walls, the less responsive the boiler to changes in heat demand, the longer the time taken to reach ignition temperature and the greater the residual heat that will need to be dissipated when the boiler is switched off.

To prevent the formation of slag on the grate, the combustible gases (mainly CO and H_2) are burned some distance away from the grate at a high temperature, while maintaining the temperature range on the grate itself.

Incomplete gasification and oxidation can occur, and black smoke can be produced, if for some reasons wet fuel is not dried sufficiently by the boiler. Moreover, the tars released during the 'Pyrolysis stage' will gradually coat the heat exchanger surfaces resulting in reduced heat exchange efficiency and the eventual failure of the boiler (Palmer et al., 2011).

Automatic feed burner main types are:

- Stoker burner boilers
- Stoker boiler using an underfed combustion system

Both boilers can burn wood pellets and wood chips up to 30% moisture content (MC). For wood chip with a MC of between 30% and 50%, moving grate boilers, also known as stepped grate or inclined grate boilers, have been designed.

Since the last decade, the gasification technology has been gaining a great importance when coupled with syngas combustion for heat and power, due to its high efficiency; moreover, it makes the thermo-chemical conversion of biomass cleaner and easier to control, compared to direct combustion of solid fuels (Reed and Das, 1988; Quaak et al., 1999; Whitty et al., 2008; Caputo et al., 2005; Dion et al., 2013).

Biomass boilers are not normally sized to meet the peak heat load but rather to provide a large percentage of the heat requirement, thus needing a buffer vessel: heat produced by the boiler that exceeds the immediate heat requirement of the greenhouse is stored to meet subsequent heating requirements.

Biomass consumption as fuel for greenhouse heating is related to both the greenhouse surface and the specific energy needs of crops. Considering a thermal power of the greenhouse surface to be heated equivalent to 100 $W.m^{-2}$, a conversion yield of 85%, biomass producing 3.9 $kWh.kg^{-1}$, the annual average biomass consumption is about 45÷90 $kg.m^{-2}$ with 1,500÷3,000 running hours.

The capacity of the heat store places a limit on the amount of heat that can be stored. The size of heat store, tipically 15÷20 x $10^{-3}.m^3$ per unit greenhouse area, depends on the control strategies and on the CO_2 enrichment in the greenhouse, if any (Chalabi et al., 2002; Nederhoff , 2004).

5. Clean CO_2 enrichment

The enrichment of greenhouse air with CO_2 leads to better plant growth, shorter cropping times, and higher quality. Therefore, low-cost CO_2 sources may result in the most profitable choice for crop growth in greenhouses, combining control of ventilation and CO_2 enrichment.

Carbon dioxide gas for enrichment can be derived either from pure gas and the combustion gases from a hydrocarbon fuel such as low sulphur paraffin, propane, butane or natural gas, or from the combustion of biomass fuel. In Canada, the fuel cost for providing heat and CO_2 represents about 28% of the operating cost of a greenhouse, and in the recent past years, a detailed economic study has been completed by Caputo et al. (2005) on utilizing wood residue for producing electricity using combustion in comparison with gasification technologies in Europe. The optimal CO_2 concentration for growth and yield seems to be 700÷900 vpm (volume parts per million). The CO_2 concentration should be kept to at least the outside level, but CO_2 enrichment is not a current practice in mild climates up to now (von Zabeltitz, 2011).

A number of studies have been carried out to determine the most economically profitable CO_2 enrichment strategy for greenhouse using CO_2 from the exhaust gases of natural gas boilers (Houter et al., 1989; Nederhoff, 1990; Rijsdijk & Houter, 1993; Ioslovich et al. 1995; Aikman et al., 1997; Stanghellini et al., 2008; Vanthoor et al., 2012). The EUPHOROS project, within the 7th Framework Programme of RTD, dealt with the efficient use of inputs in protected horticulture, and investigated the optimum ventilation, thermal storage and CO_2 management for different climates and available sustainable energy sources, giving valuable information on costs and technologies (See Deliverable 14).

Exhaust gases from gas burners can be led directly into the greenhouse. Gas will be burned, and the CO_2 is blown with the circulating air into the greenhouse. Special control systems are necessary, and care must be taken to avoid carbon monoxide production. Thus, it seems convenient to mix the exhaust gas with fresh air (von Zabeltitz, 2011), in order to condense water vapour, dilute the concentrations of the emissions, and permit distribution in the greenhouse.

On the contrary, biomass combustion is not as clean as natural gas combustion. While it produces CO_2 and water vapour as well, it also leads to higher emissions of NOx, SOx, CO, Particulate Matter, and VOCs.

In terms of enrichment applications, combustion of dry and clean wood biomass can produce two times more useful CO_2 than natural gas for the same energy unit (Chau et al., 2009). Exact flue gas composition depends on furnace technology and efficiency: a comprehensive review of exhaust gas composition and toxicity, and of CO_2 recovery methods from the exhaust gas of biomass heating systems for safe enrichment in greenhouses, has been carried on by Dion et al. (2011).

Most of the pollutants mentioned previously are due to incomplete combustion. VOCs and large organic pollutants can be significantly reduced controlling residence time, temperature and turbulence (Reed and Das, 1988).

Scrubbing system with particular catalysts can transform nitrogen oxides NOx and sulphur oxides SOx found in exhaust gases into valuable byproducts , but the economical feasibility and the overall sustainability of developed methods should be assessed.

Cyclones, scrubbers, electrostatic precipitators (ESP) and fabric filters can typically stop PM, up to aerodynamic diameter size as large as 0.1 μm, but care should be taken to control PM concentrations, as well (Dion et al., 2011).

Membrane based CO_2 separation process seems to be the most promising technology due to its energy-saving, space-saving and ease for scale up, as reviewed by Yang et al. (2008), but currently no application to CO_2 enrichment in greenhouses have been reported.

6. Economic assessment

A techno-economic assessment, combining the technical and economical parameters which could affect the economics of a project, is highly recommended before taking the final decision (Chau et al., 2009).

From this point of view, in Italy the National Decree 28 December 2012 introduced large economic incentives, called “White Certifies”, in order to shift boilers to wood biomass types, if addressed to greenhouses heating. The technical Datasheet n. 40E - Installation of wood biomass boilers in the greenhouse industry – sets up some requirements of the whole system to be installed.

Boilers must undergo to standards EN 303-05 (2012), EN 12809 (2001), and Italian UNI 10683 (2005), dealing with technical parameters and maximum power (500 kW), and :

- efficiency not less than 85 %;
- respect of emissions as required in class 5, EN 303-05 (2012).

Biomass must fulfill the quality classes provided by EN standards , in particular:

- wood pellets: class A1/A2, EN 14961-2 (2010);
- wood briquettes: class A1/A2 and B, EN 14961-3 (2010);
- wood chips: class A1/A2 and B, EN 14961-4 (2010).

The cost of the boiler varies considerably, in relation to the technological level of the boiler itself. In Italy, the cost of a modern wood chips/pellets boiler is about 100÷250 €.kW^{-1}, depending on its size. The cost of the boiler is to be added to other device costs that complete the system: loading system, accumulator, control system and safety, installation, etc.: in practice, the total cost (excluding building works) is more than twice the one above. In general, the specific cost can be considered in the order of 300÷400 €.kW^{-1} for systems of lesser power (up to approximately 80 ÷ 100 kW) and in the order of 200 ÷ 300 €.kW^{-1} for boilers of greater power (over 100 kW).

Despite these fact, the economic incentives called “White Certifies” cover all the above mentioned costs, thus making profitable even the conversion of the existing heating plants. In fact, incentives provided in the time span of 5 years may vary between 5 and 100 €.m^{-2}, related to the area of the greenhouse floor surface, in relation to cladding materials and shape ratio of the greenhouse, and to 6 climatic zones as defined by the degree-day method.

As the power energy load was estimated to be between 30 W.m^{-2} (in southern regions) and more than 175 W.m^{-2} (in northern regions), the overall cost for the biomass heating system may vary between 6 and 70 €.m^{-2}, thus resulting in most cases lower than the incentives themselves.

In North Italy, the price for wood chips and wood pellets are 0.032 and 0.06 €.kWh$_{th}^{-1}$, respectively. Compared to heating oil price, they result in 2÷3 times lower price, making greenhouses management more profitable.

7. Conclusions

The present work deals with wood biomass systems for space heating of the greenhouses. In Italy, greenhouses heating energy load was estimated to be between 30 W.m^{-2} (in southern regions) and more than 175 W.m^{-2} (in northern regions). Besides a techno-economic analysis of wood biomass boiler systems, it is worth noting that the flue gas contains a large amount of CO_2, and that this resource can be exploited to increase the production. Since some decades ago, carbon dioxide enrichment has been established in northern Europe greenhouses, recycling the exhaust gas coming from gas heating systems, due to benefits brought to plant production: anyway it needs optimal management strategies to reduce fuel consumption.

Unfortunately, biomass boilers generate a higher volume of NOx, SOx, VOCs, particulate matters (PM), and ash emissions than other fossil fuels, thus making CO_2 enrichment still challenging and expensive. Recently, flue gas conditioning devices proved themselves able to reduce costs and make this process more feasible.

All this standing, in relation to the economic incentives by the Italian National Decree of 28 December 2012, varying between 5 and 100 €.m^{-2}, related to the floor area of the greenhouse, it is worth converting boilers to wood biomass boilers and even to consider the installation of some flue gas conditioning devices.

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