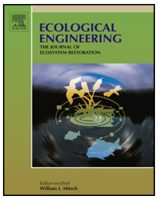
Ecological Engineering 106 (2017) 496–506

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Biomass residues revaluation with energy production in a nursery company

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ARTICLE INFO

Article history:
Received 13 February 2017
Received in revised form 27 April 2017
Accepted 5 May 2017

Keywords:
Nursery waste
Biomass chipper
Greenhouse heater
Biomass heater
ORC (Organic rankine cycle)
Residues revaluation

ABSTRACT

In the Tuscany region, Italy, nurseries produce a large amount of biomass residual and treat it as waste product from working activity, usually. The aim of this study is to evaluate a different way to use residuals for the nursery company *Vannucci Piante* (Pistoia), from the availability of residuals to the thermal demand of the company. The possibility of internally treating the biomass in order to transform it into solid fuel has also been taken into account. The thermal demand derives from the heating of greenhouses and offices during the winter period. The thermal energy requirement and the solid biomass fuel availability are studied in order to be conciliated. Three different solutions have been evaluated, considering co-generation and incentive bonus for the production of thermal and electric energy, as provided by the Italian law. The feasibility of the solutions has been analysed and the results have been compared, in order to describe the best solution in economic terms. As emerged in this study, policies for renewable energy in Italy are not up to the task of supporting those type of investment, in particular for agricultural waste revaluation.

1. Introduction

The nursery sector in Europe involves 90,000 ha of cultivated land and 120,000 ha for nurseries. Production reached 19.8 billion Euros in 2011, mainly concentrated in the Netherlands (33%), Italy (13%), France (12%), Germany (12%) and Spain (11%). As for Italy, up to 13,000 ha concern potted flowers and plants. Despite the large area taken by nurseries and the sector's economic relevance, most Italian companies are characterized by their limited size: 64% of nurseries have less than 1 ha of extension (Sarri et al., 2013).

Agricultural greenhouses areas have greatly risen worldwide over the last few decades. A large amount of energy input is required, in order to maintain an appropriate temperature for crop growth during the winter and summer seasons. Energy demand prediction needs to enhance energy management and energy savings of the agricultural greenhouses.

The demand for energy in agriculture has increased considerably with the introduction of high-yielding varieties and mechanized crop-production practices. Therefore, it is necessary to implement a switch from conventional to alternative energy sources. Generally, studies have been concentrated on worldwide production of field crops such as wheat, rice, soybean, cotton, maize, mustard, cluster bean, green gram, pearl millet, sugarcane, etc. in order to improve the energy output–input analyses and to investigate their relationships (Unmole et al., 1987; Satpathy et al., 1991; Singh et al., 1999; Singh et al., 2000; Saha et al., 2002). At the same time, agricultural companies' residuals are mainly composed by biomass, and smaller percentages by plastic, paper and iron.

Even if Italian nurseries' area is only 1.2% of the utilized agriculture area (ISTAT, 2013(istituto nazionale di statistica), 2013), nurseries represent the most considerable working activity for some Italian districts.

Over the last few years, several machine manufacturers have been offering dedicated implements for collecting pruning residue. These machines generally derive from conventional mulchers, equipped with a storage bin or with a blower, the latter designed to direct the flow of comminuted residues to a conveyor belt (Daou et al., 2009). In order to separate biomass from soil part, many authors propose to use innovative shaker machine for optimizing the process (Boncinelli et al., 2015).

The input energy (and its cost) of a farm is studied in many paper. Mohammadi and Omid (2010) determined the energy use efficiency for the production of cucumber and compared input energy use with input costs in the Tehran province, Iran. They

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http://dx.doi.org/10.1016/j.ecoleng.2017.05.006
0925-8574/

Nomenclature

C_i	Thermal energy valorisation coefficient (from italian law “Conto termico”) [€/kWh]
C_e	Emission valorisation coefficient (from italian law “Conto termico”) [−]
E	Annual energy [MJ/y]
$flow_{bio}$	Flow rate of drum machine
i	Interest rate [−]
Ia	Annual incentive for biomass boiler (from italian law “Conto termico”)
Mo	Moisture on dry basis [%]
M	Mass [kg]
M_{bio}	Quantity of green residues processed;
LHV	Lower heating values [MJ/kg – MJ/Sm^3]
n	Year of investment [y]
NPV_n	Net present value at year n [€]
P_n	Nominal thermal power (from italian law “Conto termico”) [kW]
Pow_{drum}	Mechanical power supply by drum machine
PI	Profitability index [−]
PBP	Pay back period [y]
Q	Thermal power [kW]
r	Latent heat of vaporization [MJ/kg]
S_0	Initial costs [€]
S_{diesel}	Cost of diesel used by drum machine
S_k	Annual cash flow [€]
t	Time of estimated annual work of boilers [h] (from italian law “Conto termico”)
t_{work}	Time of working machine to process a certain quantity of biomass [h]

Greek symbols

η	Efficiency

Subscripts

bio	Biomass
d	Diesel fuel
dry	Dry
ng	Natural gas
w	Water
wet	Wet

Acronyms

LHV	Lower Heating Values
NPV	Net Present Value
ORC	Organic Rankine Cycle
PBP	Pay Back Period
PI	Profitability Index

also introduced a mathematical model based on greenhouse farms. Hamedani et al. (2011) examined the energy use patterns and the relationship between energy input and yield for grape production in Malayer region of Hamadan Province, Iran. Other researchers Rafiee et al., (2013) examined energy use patterns and the relationship between energy inputs and yield for prune production in the Tehran province of Iran and they presented a comprehensive picture of the current status of energy consumption and some energy indices.

Other studies focused on energy consumption of greenhouses. (B. Ozkan C. F., 2007) examined the energy use patterns and cost of production in a greenhouse and open-field grape production. Canakci and Akinci (2006) investigated the energy use patterns in greenhouse vegetable production, in order to determine the energy output–input ratio and their relationships. Kuswardhani et al. (2013) estimated energy consumption per unit floor area of greenhouse and open field for tomato, chili and lettuce production in Indonesia. A model-optimized prediction (MOP) methodology is proposed (Yang et al., 2016), in order to predict the energy demand of greenhouses with a better performance of accuracy and cost. (B. Ozkan A. K., 2004) examined the energy equivalents of inputs and output in greenhouse vegetable production in the Antalya province, Turkey, for the production of four greenhouse crops (tomato, cucumber, eggplant and pepper).

Many other researchers studied the use of pruning. Pruning can be treated in order to recover major quantities of organic materials, in particular wood-chip and substrate. Wood-chip can be used as a bio-filter or as a bio-fuel depending on the efficiency of separation and the quality in terms of type, heat value, moisture and size. Substrate can be reintroduced in field, in order to maintain ground level or mix it with virgin substrate (Sarri et al., 2013). Some researchers studied pruning harvesters (Picchi and Spinelli, 2010; Croce et al., 2013) or production of compost and biogas from green residues (Chilosi et al., 2015; Baldi et al., 2016). Other researchers proposed a prune recycling. In fact, (Z. González, A. Rosal, A. Requejo, A. Rodríguez, 2011) characterized chemically orange tree pruning and use it in pulping and combustion processes. Moreover, they proposed it as a suitable cheap energy source by combustion. Energetic and economic analysis of a tri-generation system fueled only with tree pruning residues are proposed (Dentice d’Accadia et al., 2016; Clodoveo et al., 2016).

Pistoia (43°54′N, 10°41′E. 30 a.s.l.), is a city located in the Tuscany region, in the center-north of Italy, and it has the greatest plant nursery district in the country. This area is characterized by an average rainfall of 1300 mm per year, average winter temperature around 5/7 °C with minimum peaks of −10 °C and summer temperature around 21/23 °C with maximum peaks of 40 °C. The soil consists of alluvial deposits which are fertile and rich in sand and silt. The above-mentioned conditions are ideal for cultivating outdoor ornamental plants. This is the reason why Pistoia has become the most important nursery district in Italy and a major one in Europe all over the years (Lucchetti et al., 2016).

Currently, this district has about 4100 ha of field-grown plants, 1000 ha of pot-grown plants, and about 100 ha for greenhouse cultivations. The companies operating in this sector are more than 1500, with 5500 workers. Half of them are employees, while the others are entrepreneurs and independent small farmers. The estimated gross saleable production is around 500 million euros, with 300 million euros of export. Pistoia’s nursery production represents about 25% of the national production and more than half of it is exported (Lucchetti et al., 2016).

Green residues in the Pistoia district are generally treated like wastes by nurseries, even if the Italian law could acknowledge this type of residues as a by-product of nursery activity.

Reusing biomass as energy supply for the nursery can reduce CO_2 emission, but is it an economically competitive alternative to fossil fuel?

The aim of the present study is to analyze the benefits of different treatments of biomass, in terms of waste recycling, revaluation of biomass waste and energy saving, as well as the possibility to use different energy sources. Thermal and electric energies can be produced starting from the wood-chip source: their quantities are evaluated in order to cover the energy needs of the company. Biomass production system and energy generation plants are determined in terms of technical data and economic costs.

This study is referred to *Vannucci Piante*, one of the largest nurseries located in Pistoia. Even if the study is referred to a single company, the proposed solutions can be applied also to other nurs-

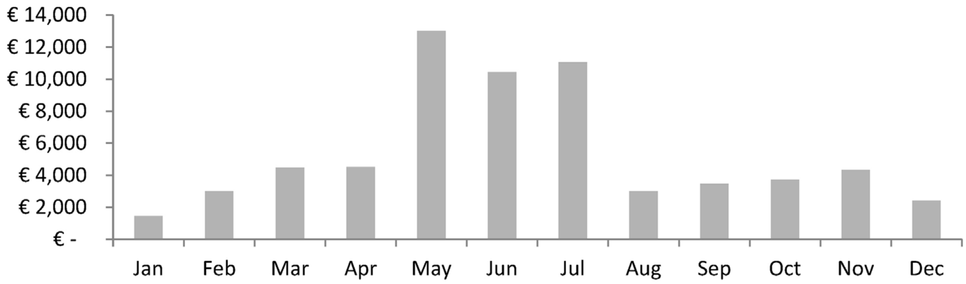

Fig. 1. – Costs for disposing of biomass waste products in 2014 for Vannucci Piante.

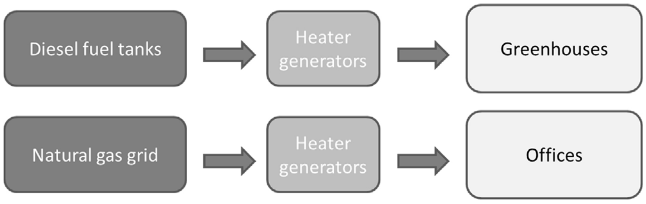

Fig. 2. – Thermal energy plant at present.

Table 1
–Installed thermal power.

Site	Power [kW]
Greenhouses site A	2300
Greenhouses site B	3900
Offices	200
TOTAL	6400

ery companies. In the specific case of Pistoia, benefits can involve the entire nursery district and the local economy.

2. Current situation

Data used in this research like disposal cost, waste volume production and fuel consumption have been provided by *Vannucci Piante* and they are referred to the year 2014 (Fig. 1).

Biomass residual is currently being treated as a waste product, so it is disposed by an external company. The part of soil present in the waste is separated from the biomass part and it is brought back to *Vannucci Piante*. This service represents a cost for the company: the service costs 12 €/t. Annual biomass disposal costs are more relevant in the summer season when the plants are pruned (Fig. 2).

On the other side, thermal energy production is necessary during the winter season (Fig. 3), mainly in order 160 to:

- Serve greenhouses in order to preserve and improve the growth of some varieties of plants;
- Heat company offices and indoor working build.

Greenhouses are heated by a number of diesel fuel heaters (90% efficiency) evenly distributed in each greenhouse and supplied by pipe plants that start from external storage tanks. Offices are served by natural gas boilers (95% efficiency). Fig. 4 shows the annual energy costs, limited to cold months. These costs are more relevant from November to February, when the ambient temperature is low.

2.1. Biomass production

Biomass residuals production is due to different working and maintenance operations in nursery company:

- Pruning and felling;
- Unsold plants which cannot be sold during next season;
- Plants damaged by chemical, biologic or weather agents compromising their appearance.

Biomass physical features depend on the production period of the year (Fig. 5). Most plants are sold to foreign and Italian buyers during the winter and spring seasons. At the end of this period, a large part of unsold plants cannot be cultivated a second time, and this is why pruning production increases from May to July. In 2014 *Vannucci Piante* has produced 5407 t of waste linked to biomass and soil.

The moisture level is a fundamental parameter, in order to evaluate wood-chip quality. Moisture on a dry basis is defined as ((Associazione Italiana Energie Agroforestali), 2009):

$M_0 = \frac{m_w}{m_{bio}} \left[kg_w/kg_{bio,dry}\right](1)$

The average annual medium value of moisture of new biomass residuals is about 70% (Francescato, 2009 (Associazione Italiana Energie Agroforestali), 2009). Wood-chip produced with nursery's residues is considered of B1 category in wood-chip market ((Associazione Italiana Energie Agroforestali), 2009).

Moisture level determines the heat value of this type of wood-chip and the selling and buying price (Fig. 6) (Franceschi, 2015). Its value depends on the time of production and the variety of plant residuals. The lower heating value for dry biomass is assumed $\mathrm{LHV_{bio,dry}}$=17 MJ/kg$_{\mathrm{dry}}$ (Francescato, 2009(Associazione Italiana Energie Agroforestali), 2009). The LHV of wet biomass is obtained by energy balance, taking the latent heat of vaporization into account.

$\mathrm{LHV_{wet}} = \frac{\mathrm{LHV_{dry}} + \mathrm{Mo} \cdot \mathrm{r}}{1 + \mathrm{Mo}}(2)$

The buying price is given by wood-chip market. The selling price is considered the 2/3 of buying price (Franceschi, 2015).

Moisture values change during storage time: the rate of change depends on the place and time of storage, weather conditions during the storage period and the size of wood-chip. Moisture reduction determines a mass decrease during the drying period ((Associazione Italiana Energie Agroforestali), 2009) (Simpson, 1998).

2.2. Thermal energy demand

There are two different greenhouses sites. They are 450 m far from each other and they cover 11,230 m^2 and 21,270 m^2 of area respectively. At present, each greenhouse has 4/5 heaters (using diesel fuel) of 100 kW and 140 kW size for a total of 20 x 100 kW and 30 x 140 kW. Thermal power of generators is 2300 kW for the first site and 3900 kW for the second site. Offices are located in a two floor building and have a total area of 2170 m^2. They are served by two natural gas boilers of 100 kW. The entire installed thermal power is 6400 kW (Table 1).

The annual consumption of natural gas and diesel fuels is determined using invoices of the energy provider. The amount of heating

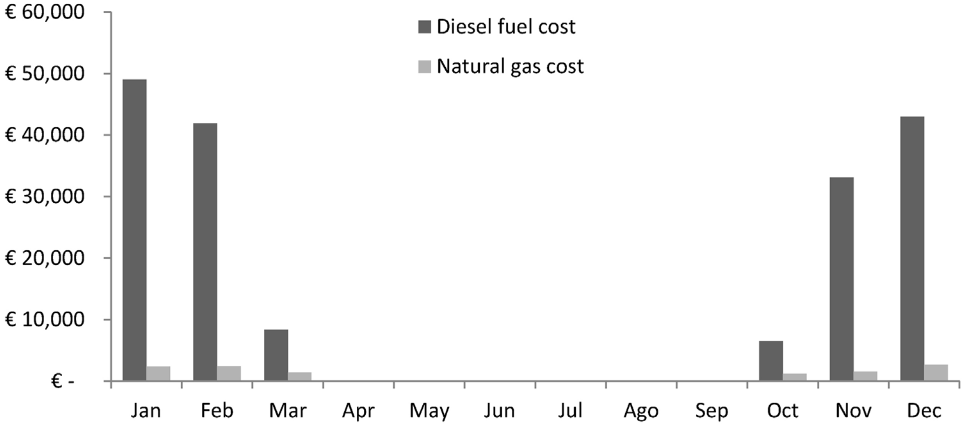

Fig. 3. – Thermal energy costs in 2014 for *Vannucci Piante*.

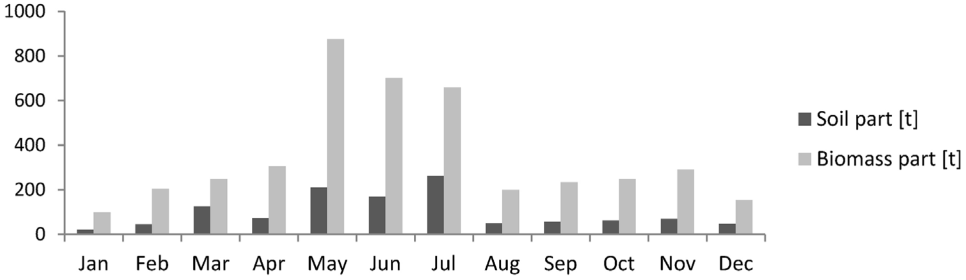

Fig. 4. – Annual biomass waste and soil fraction production in 2014 for Vannucci Piante.

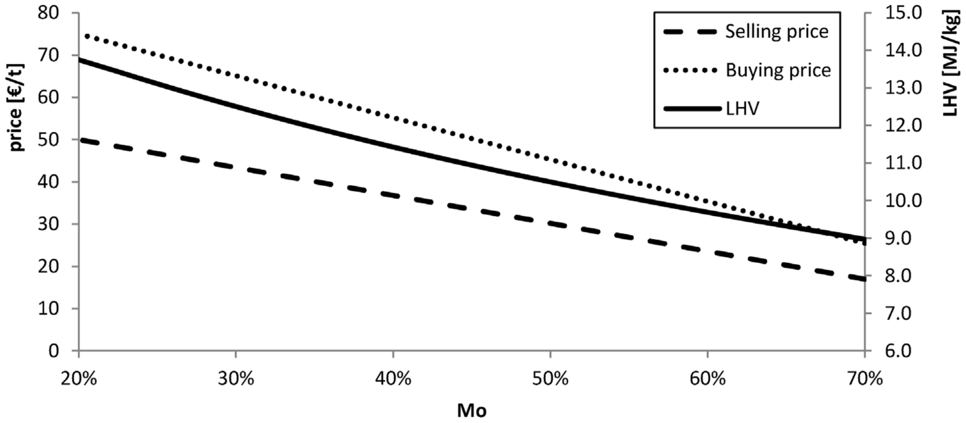

Fig. 5. – Low Heating Value, Selling and Buying Prices of B1 category woodchip varying moisture (Franceschi, 2015), ((Associazione Italiana Energie Agroforestali), 2009).

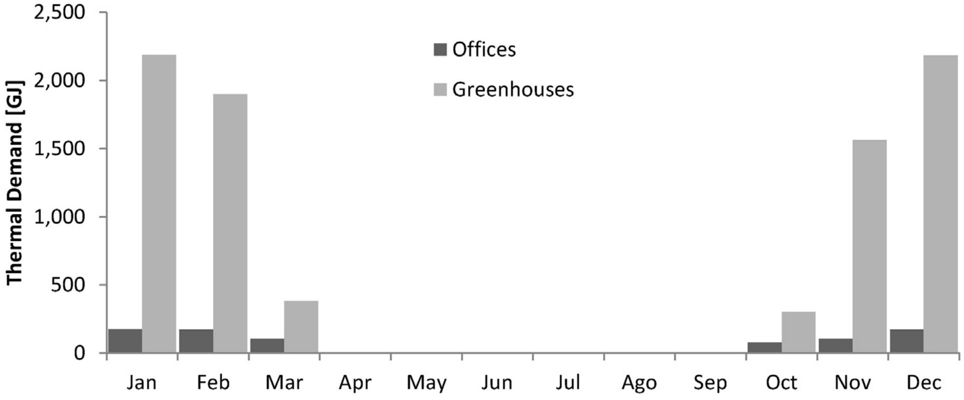

Fig. 6. – Annual thermal demand in 2014 for Vannucci Piante.

Table 2
–Technical data and costs of Biomass treatment machines.

	Drum screener Pezzolato L3000 mini	Drum chipper Pezzolato PZ 250
Working power [kW]	15	60
Biomass flow [t/h]	6	8
Price [€]	30,400.	30,000.
Annual fuel cost [€/year]	5290.	13,750.
Annual labor cost [€/year]	27,030.	17,580.

energy is determined using the annual consumptions of diesel fuel and natural gas fuel, their lower heating values (LHV – for diesel fuel is 43 MJ/kg and 35 MJ/Sm^3 for natural gas fuel) and the boilers thermal efficiencies:

$$E_H = LHV_d \cdot m_d \cdot \eta_d + LHV_{ng} \cdot m_{ng} \cdot \eta_{ng} \tag{3}$$

3. Alternative solutions

Biomass nursery residuals can be treated and revalued in different ways. Italian laws allow the use of biomass residual as a by-product of the nursery. Therefore, residuals are not considered waste materials and the company does not need to dispose of the biomass as waste. In order to reevaluate biomass and different heating supplies, the identified possibilities are:

1. Production of wood-chip used to supply wood-chip boilers. Biomass processing takes place within the company and it produces substrate which is fed back to fields and wood-chip. Wood-chip is stored into an open-sides specifically dedicated warehouse. Diesel fuel heaters are replaced by wood-chip boilers, positioned into boilers sites, and the heating supply is performed by hot water pipes plants.
2. Production of wood-chip, which is entire sold to wood-chip traders and providers. Thermal energy for greenhouses is generated by natural gas heaters that replace actual heaters.
3. Production of wood-chip used to feed an Organic Rankine Cycle (ORC) plant in order to cogenerate electric power and thermal power.

Each solution is optimized in terms of investment returns, following three indicators (especially warehouse's size):

$$NPV_n = -S_0 + \sum_{k=1}^{n} \frac{S_k}{(i+1)^k} \tag{4}$$

$$PI = \frac{NPV_{20}}{S_0} \tag{5}$$

$$PBP = n_0 : NPV_{n_0} = 0 \tag{6}$$

where NPV$_n$ is *Net Present Value* indicator related to n years of investment, S$_0$ is initial costs, S$_k$ is annual cash flow, PI is *Profit Index* indicator and PBP is *Pay Back Period* indicator.

3.1. Biomass processing

In order to obtain useful and saleable products, biomass is processed with two sequentially treatments:

- Separation of wood parts from the substrate: the treatment is performed by a separating machine, which has a rotating drum screener. For this purpose, the drum screener "Pezzolato L3000 mini" has been chosen (Table 2).
- Wood parts are chipped in order to obtain little parts of wood-chip. Size reduction ensures a better drying and a better use of the warehouse. Actually, wood-chip has a higher density than pre-chipped wood and it takes less space. Drum chipper "Pezzolato PZ 250" has been chosen for chipping treatment (Table 2).

In order to estimate annual diesel and labor costs for these operations, cost of labor per hour $s_{labor} = 25$€/h has been considered. Then, the medium cost of diesel fuel, which is s_{diesel}=0.827 €/l. The following equations have been applied with these values:

$$t_{work} = \frac{M_{bio}}{flow_{bio}}$$

$$S_{diesel} = \frac{t_{work} \cdot Pow_{drum}}{\eta \cdot LHV_{diesel}}$$

$$S_{labor} = t_{work} \cdot s_{labor}$$

Where:

- t_{work} is the time the drum machine takes to process a certain quantity of biomass/residues
- M_{bio} is the quantity of biomass/residues processed
- $flow_{bio}$ is the flow rate of the drum machine
- S_{diesel} is the cost of diesel used by the machine for t_{work} of time
- η is the efficiency of machine, assumed to be 25% for both machines
- LHV_{diesel} is the lower heating value of diesel fuel
- Pow_{drum} is the mechanical power outcome of drum machine

Separation process with drum screener handles a greater quantity of mass than drum chipper because at this stage, biomass contains an important part of soil (Fig. 5).

3.2. Solution 1–Heating plant of greenhouses powered by produced wood-chip and sale of surplus of latter

In order to supply thermal energy to greenhouses and offices there are two reference configurations: centralized and decentralized. A heating plant implemented by wood-chip boilers requires additional components, for example wood-chip tanks and automatic systems for fuel supply, water thermal storages, ash removal systems, and many others. For this reason, the centralized configuration is normally chosen. Considering the location of greenhouses and offices, two thermal centrals are needed: one for a greenhouses group and one for the offices. The considered power boilers have a size of 500 kW. This is the best compromise between machine cost and incentives provided by Italian law. In particular, for reference model, the "Turbomat TM 500" (Table 3), produced by Froling, has been chosen. Then, Centralized configuration is necessary for transporting the heat from the centrals to greenhouses and offices using hot water as heat transfer fluid (Figs. 7 and 8, Table 4).

The cost of such a plant is 580,000 €, estimated by the company TIESSEI S.R.L. (Pistoia, IT).

Italian Economic and Industry Ministry promotes energy saving, introducing "Conto Termico" decree (DM 28/12/12) which provides an incentive bonus I$_a$ for the first 5 years of operation. This incentive is aimed at biomass heaters. The amount of the incentive for each year is:

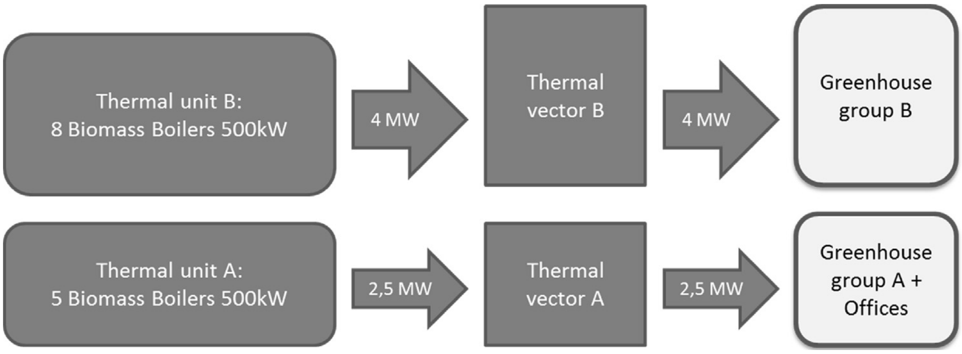

Fig. 7. –Biomass-fed thermal energy plant.

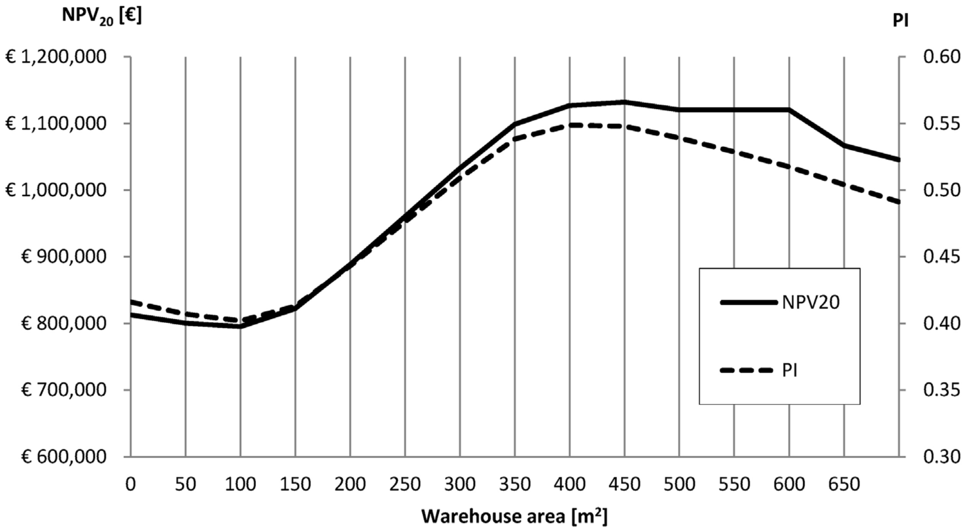

Fig. 8. – Variation of NPV_{20} and PI by varying the size of warehouse.

Table 3
–Technical data of Turbomat TM 500.

Turbomat TM 500 SPS4000 – Froling	
Nominal Power (KW)	500
Efficiency (Mo ≤ 50%)	94%
Temperature of exhaust gas at nominal condition [°C]	140
Max Pressure [bar]	6
Min Temperature return [°C]	65
Max waterTemperature [°C]	90
Total weight [Kg]	8400

$I_a = P_n \cdot t \cdot C_i \cdot C_e$

C_i [€/kWh] is a coefficient about thermal energy valorization, which depends on the thermal power of each boiler. In the present case C_i=0.020 €/kWh (P_n=35.÷500.kW).

t is the operation time (hours per year) and it depends on the plant location's climatic zone. t=1400 h because Pistoia is in the "D" climatic zone (each district of Italy is classified on climatic zone from "A" to "F").

C_e is a coefficient about emission of primary particulate per Sm^3 of air. In this analysis C_e=1.2 because the boiler emissions are between 15 mg/Sm^3 and 20 mg/Sm^3.

Table 5
–Technical data of natural gas heaters.

Nominal power [kW]	85.0
Heater natural gas consumption [Sm^3/h]	8.767
Efficiency	95%

Table 6
– Comparison of NPV_{20} and PI in open field solution storage and 350 m² warehouse storage.

	Open field storage	Warehouse 350 m² storage
NPV_{20}	€ 1,064,537	€ 732,187
PI	3.23	1.75

The wood-chip produced by transformation of biomass is stored in a warehouse, implemented by a farm building opened on three sides with useful height of 5.m, specific capacity estimated of 2. t/m² and a specific cost of 250. €/m² (Agenzia delle Entrate -Ufficio Provinciale, 2015). It is assumed that wood-chip is stored monthly and that the moisture of wood-chip decreases by 10% per month ((Associazione Italiana Energie Agroforestali), 2009). If it is not used

Table 4
– Thermal power requirement.

	Thermal unit A	Thermal unit B
Users	Greenhouses group A + Offices	Greenhouses group B
Thermal power requirement (kW)	2300+200=2500	3900

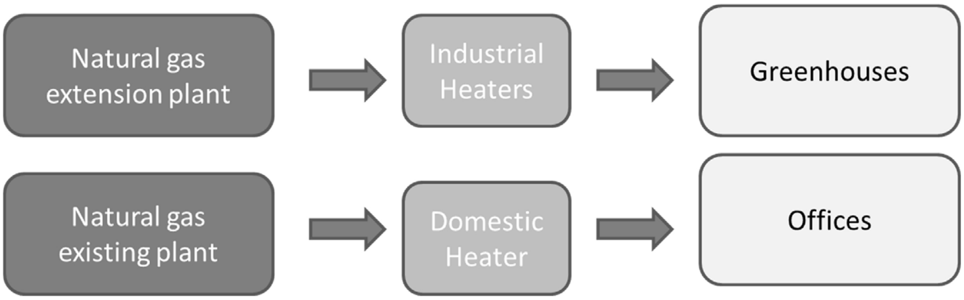

Fig. 9. – Natural gas feeding a thermal energy plant.

Table 7
– Thermal power requirement in ORC solution.

	Thermal unit A	Thermal unit B + ORC
Users	Greenhouses group A + Offices	Greenhouses group B
Power requirement (kW)	2300 + 200 = 2500	3900

Table 8
–Technical data of ORC module.

ORC Turboden 3 CHP Mode	
Thermal power IN [kW]	1971
Electric power generated [kW]	300
Electric efficiency	15.5%
Thermal power for cogeneration[kW]	1636
Thermal efficiency COG	83%
Water to users temperature [°C]	75
Water return temperature [°C]	55
Operating Time [hours]	4661

Table 9
– NPV_{20} and PI of ORC solution.

ORC	
NPV_{20}	€ 1,085,558
PI	0.24

or sold beforehand, the moisture reaches at least a 20% stabilization (Simpson, 1998). If the woodchip stocked in the warehouse has $Mo \leq 50\%$, it is utilized for satisfying the thermal requirement. Otherwise the necessary woodchip is purchased at Mo=20%. The warehouse has a maximum capacity that depends on its size. This limit can be overcome by selling the surplus of the driest wood-chip available in stock. The profitability of investment in this solution is studied varying the size of warehouse to identify the optimal size (Fig. 9); a maximum of NPV_{20} for the size 450 m^2 and a maximum of PI for the size 400 m^2 are present. The configuration of “0 m^2” represents a virtual situation in which the wood-chip, produced during the month, is entirely sold and the thermal requirement is satisfied purchasing dry wood-chip (Mo=20%).

In this configuration PI assumes the absolute maximum value. It is reasonable that building new warehouses is not economically profitable. Moreover, the best configuration for this solution is assumed to be a 450 m^2 warehouse.

3.3. Solution 2–Selling of all produced woodchip and supplying thermal demand by natural gas heat generators

A different solution is proposed in order to reduce initial costs and simplify the plant. In this solution, all woodchip is stored in a warehouse and sold when woodchip reaches Mo=20% or when the warehouse is full. Thermal energy for greenhouses is produced by the combustion of natural gas. The feasibility of a natural gas heating system depends on the natural gas grid and the location of greenhouses. Natural gas heaters are placed into greenhouses as replacement of diesel fuel heaters: they directly transfer heat to air, without needing a hot water distribution system. By doing so, heating plant results cheaper than the previous solution and there is no lost heat due to heat transportation. The natural gas supply is performed by a pipe system that links every greenhouse to main gas pipe (Fig. 10).

In comparison with the previous plant, there is no labor requirement for woodchip supply and heating boilers cleaning, and no labor for biomass storage place and systems either. Moreover, biomass treatment is completely separated from thermal energy production. There is no possibility to benefit of incentives in this case, and natural gas is more expensive than woodchip. As for the thermal energy demand, 73 heaters of 85 kW each have been taken into account (Tables 4 and 5).

As in Solution 1, Fig. 11 shows the profitability of the investment, varying the size of the warehouse.

Fig. 11 shows that the best solution in terms of NPV_{20} has a warehouse of 350–400 m^2.

Biomass storage warehouse is a considerable cost of the investment. Its feasibility also depends on the availability of areas necessary to realize it. A different solution is proposed in order to reduce initial costs and simplify the plant. Biomass residuals are stored in an open field area across the year, during production time. Natural dehumidification occurs during the storage period, in particular during spring and summer months. Treatment of biomass is carried out during summer months, when average moisture level is at its lowest. In this case biomass is subject to weather agents and is directly in contact with the ground, even if in most of the year it preserves its original size and it is less decomposable than woodchip. Produced woodchip is immediately sold to traders. Considering the amount of biomass produced by *Vannucci Piante*, biomass could be worked in July, August and September, hypothetically. The average moisture level is considered 50% and the estimated mass reduction due to decomposition is of 20% (Simpson, 1998). Sold woodchip is priced 30 €/ton (Franceschi, 2015). Considering mass reduction due to dehumidification and decomposition, woodchip production is about 2978 ton/year. Woodchip sale proceeds stands at 89,949€/year. NPV_{20} and PI are reported in Table.

3.4. Solution 3–ORC in cogeneration with boiler powered by wood-chip byproduct

In this solution, electric energy is produced in order to extract the highest economic value from the biomass. Thermal and electric energies are produced in a co-generative plant. Two thermal energy units and one ORC (Organic-fluid Rankine Cycle) system are assumed to be necessary (Fig. 12, Table 6). The heat generated by ORC can be used to satisfy a thermal demand when it is requested, or can be dissipated by a dry cooling tower.

As for the choice of thermal boilers, the same considerations of Solution 1 are assumed: “Froling Torbomat TM 500” and the same

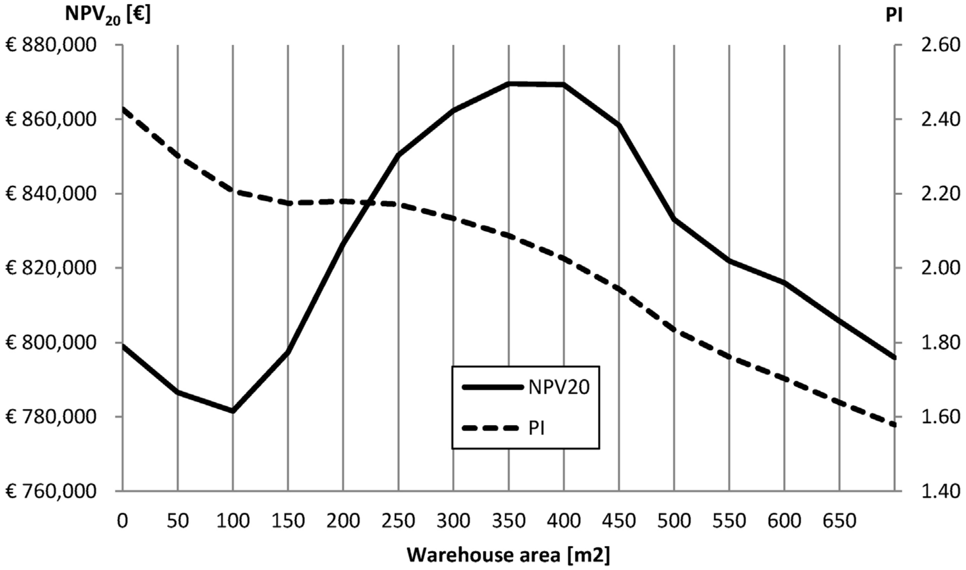

Fig. 10. – Variation of NPV_{20} and PI varying the size of warehouse.

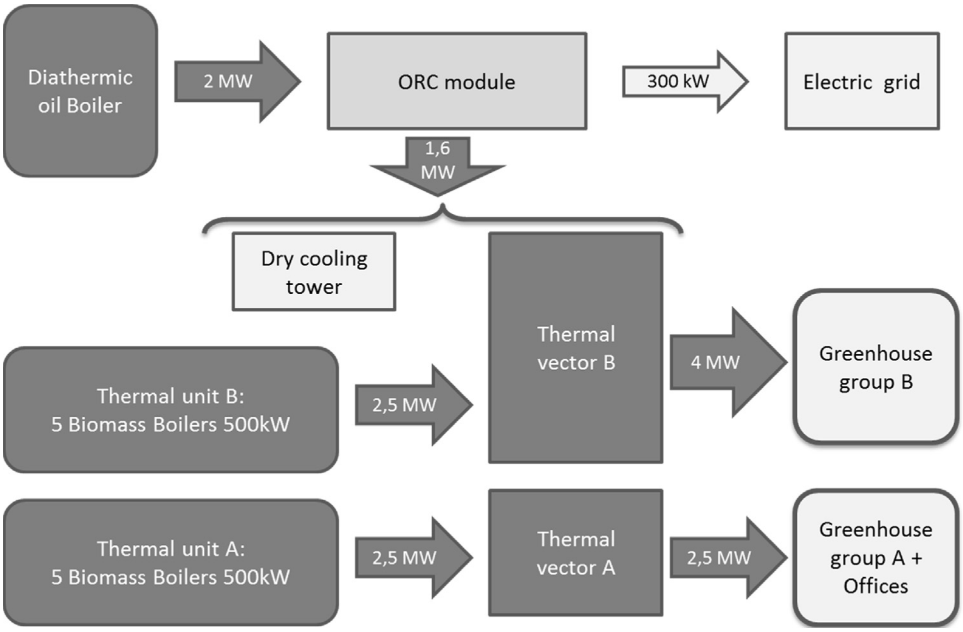

Fig. 11. – Thermal and electric energy production plant with ORC.

heat pipe plant described in Solution 1 have been used. Considering the quantity of woodchip produced in a year and in order to maximize the working time, the electric power size of ORC co-generator is of 300·kW_{el} (Table 6). The annual quantity of produced woodchip permits the ORC module to work only 4661 h per year (Tables 7 and 8).

Woodchip produced by transforming of biomass is stored in a warehouse, that in this case is designed to maximize its use. Boilers of thermal centrals guarantee the right to receive an incentive bonus, as mentioned for Solution 1. The ministerial decree DM 23/6/2016 gives the right to receive a basic incentive rate for electric energy produced for 20 years, in order to realize an electric energy plant generator powered by woodchip. The rate that the *Vannucci Piante* company pays for the electric energy is lower than the rate provided by incentives. Therefore, the analysis of productivity of this solution can be obtained from the electricity consumption of company.

4. Results

All proposed solutions are compared in terms of economic returns with three indicators of equations 1,2,3.

The economic valuation of the solutions has been reported in Fig. 13 and Table 9.

Initial costs are extremely different. Natural gas solution has the lowest cost and this is mostly due to the low cost of natural gas heaters. ORC solution is the most expensive one: initial costs amount to € 4,500,000. This is due to the high cost of ORC module respect to other initial costs of the solution. Such a solution could be favourable only if cash flow is good during the investment years. The woodchip boilers solution, without electric energy production,

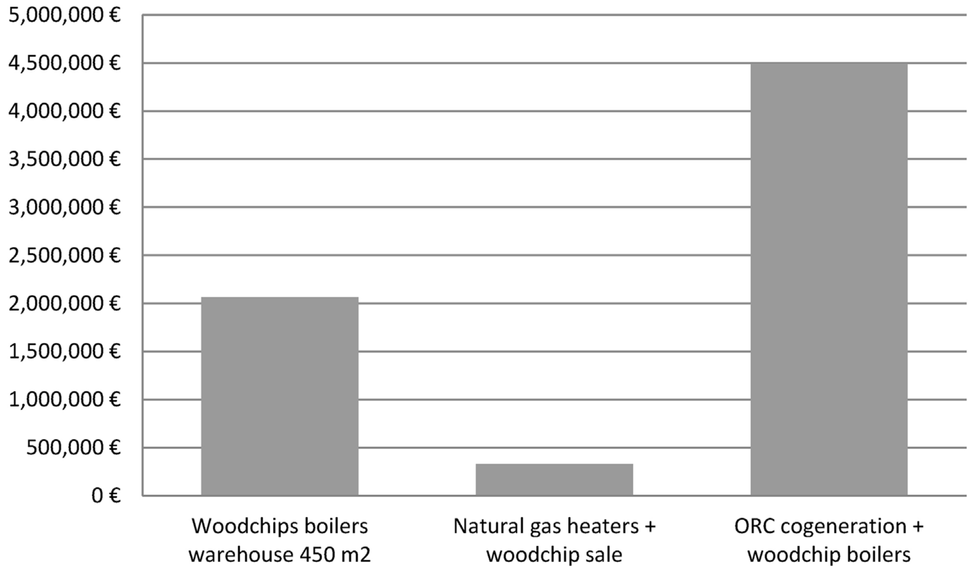

Fig. 12. – Initial costs of the proposed solutions.

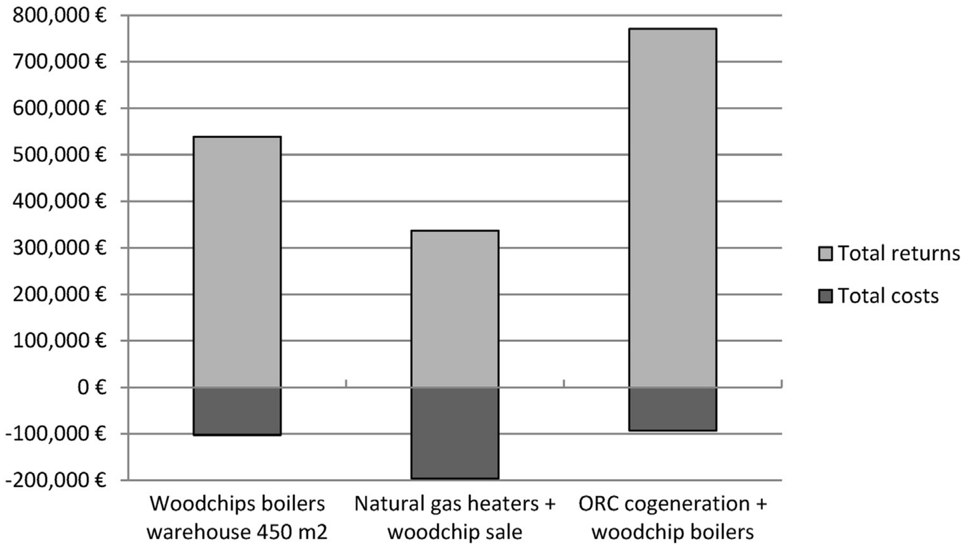

Fig. 13. – Annual cash flow for each proposed solution.

has an intermediate initial cost: in this case the most relevant cost derives from the woodchip boilers. The biomass treatment machinery cost is not so significant, in comparison with the other costs of investments. In this way, the wood chip production can be easily performed in economic terms.

Annual cash flows are reported in Fig. 14, and details in Table 10.

Although the Natural gas heaters solution has the lowest initial costs, annual costs are higher than in the other two solutions. This is due to the natural gas purchase cost. The annual costs for the other two solutions are comparable.

The solution with ORC has highest annual returns. The best annual return for this solution is the sale of electric energy produced, which amounts to about € 344,000. Another significant return in the first and the third solutions is given by bonus incentives. Moreover, saving fuel currently used by the company is another important return in all three solutions. Less considerable returns are the wood chip selling and the saving on biomass waste disposal.

As shown in Fig. 14 and Table 11, NPV_{20} of the solutions are similar. Natural gas has the best one, the others have significantly different trends. The trend of ORC solution NPV has the best rise during the given period, because this solution has the highest annual return. Despite of NPV_{20}, the PBPs of the solutions are very different. Natural gas solution has the lowest value (2 years). The woodchip boilers solution's PBP is 7 years and the ORC solution is the worst one with 13 years of PBP. As Table 11 shows, the best PI is the one for the natural gas solution.

5. Conclusions

The results of this study show that natural gas solution is the best one in economic terms, considering the three indicators in Table 11. Even if the NPV_{20} of woodchip boilers solution is the highest, the PBP and PI are considerably better in natural gas solution (Table 12).

The others two solutions, wood chip boilers and ORC, exploit the biomass by-product source, representing two ways to implement renewable energy production. This type of solutions has high initial costs. Even if the Italian Economic Ministry guarantees incentives bonus for renewable energies, they are basically not enough

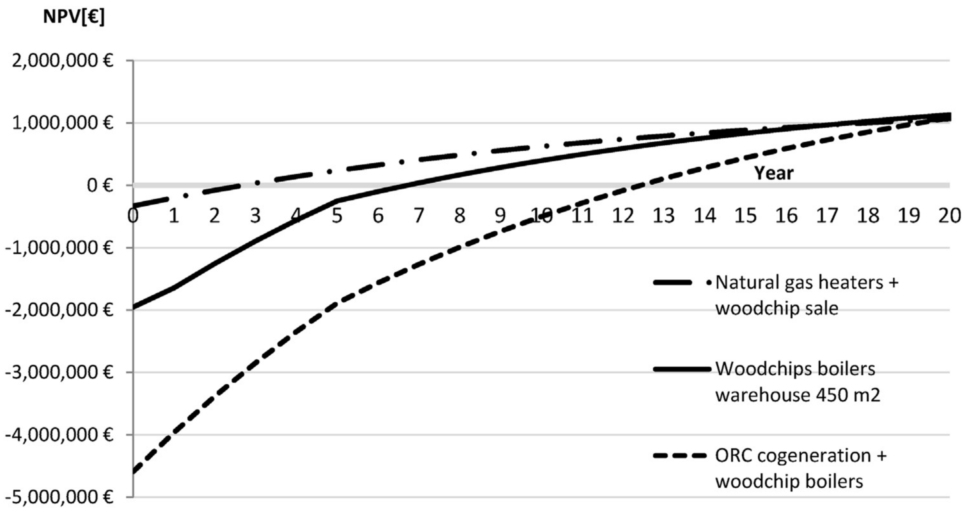

Fig. 14. – NPV trend in 20 years-long investment for each proposed solution.

Table 10
– Details of initial costs for each proposed solution.

	Woodchips boilers warehouse 450 m^2	Natural gas heaters + woodchip sale	ORC cogeneration + woodchip boilers
Thermal units	€ 1,312,000	€ 208,780	€ 1,010,000
Heat pipe system	€ 580,000	€ 0	€ 580,000
Biomass treatment machinery	€ 60,400	€ 60,400	€ 60,400
Wood-chip warehouse	€ 112,500	€ 0	€ 343,750
Natural gas distribution plant	€ 0	€ 60,000	€ 0
ORC Plant	€ 0	€ 0	€ 2,500,000
Total	€ 2,064,900	€ 329,180	€ 4,494,150

Table 11
– Details of annual cash flow for each proposed solution.

		Woodchips boilers warehouse 450 m^2	Natural gas heaters + woodchip sale	ORC cogeneration + woodchip boilers
Annual Costs	Biomass treatment	-€ 71,400	-€ 63,345	-€ 63,345
	Wood-chip purchase	-€ 10,985	€ 0	€ 0
	Natural gas purchase	€ 0	-€ 123,160	€ 0
	Plant maintenance	-€ 20,000	-€ 10,000	-€ 30,000
	Total costs	-€ 102,385	-€ 196,505	-€ 93,345
Annual Returns	Saving on waste disposal	€ 64,880	€ 64,880	€ 64,880
	Saving on actual fuel purchase	€ 194,038	€ 181,940	€ 194,038
	Wood-chip selling	€ 61,619	€ 89,949	€ 0
	Bonus incentives	€ 218,400	€ 0	€ 168,000
	Electric energy selling	€ 0	€ 0	€ 343,957
	Total returns	€ 538,937	€ 336,769	€ 770,875
Annual cash flow		€ 436,552	€ 140,264	€ 677,530

Table 12
– Economic indicator used for profitability analysis of investments for each proposed scenario.

	Woodchips boilers warehouse 450 m^2	Natural gas heaters + woodchip sale	ORC cogeneration + woodchip boilers
NPV_{20}	€ 1,131,932	€ 1,064,537	€ 1,085,558
PI_{20}	0.55	3.23	0.24
PBP	7 years	2 years	13 years

to make these solutions compete with conventional fossil fuels alternatives.

This study highlights that selling wood chip produced with biomass by-product is more reasonable than using it internally in a nursery company.

According to the results of this work, policies on renewable energies incentives should be strengthen in Italy. Not surprisingly, companies like *Vannucci Piante* treat biomass by-product as a waste.

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