"AN APPLIED RESEARCH TO SUPPLY ENERGY COMING FROM EXPLOITATION OF BIOMASS SCRAPS TO "LITTLE AND MIDDLE ENTERPRISE (LME)" (PART ONE)

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Abstract

The research was funded by "Operative National Plan - European Capital for Regional Development" (PON-FERS 2007-2013, Industry 2015). Authors considered the Sicilian LME producing wastes from operational processes as like woody chips, wood shavings, shells of hazelnut or almond and so on. A previous survey carried out on a consistent sample of Sicilian LME showed that electrical power required by operational processes ranges substantially around three main values (250, 500 and 635 kW_e) and research was addressed to obtain previous values of electrical power. People takes in consideration the exploitation of biomass through pyrolysis process since it produces syngas usable as fuel in gas-turbine of CHP plant, bio-oil and bio-char too, both of them able to supply thermal energy to many section of plant.

The whole paper describes the general plane of research and guidelines for:

- calculus of sizes of biomass stockpile storage (storage and drying - first section)
- design of equipments of pyrolysis process and exhausts treatment (pyrolysis process – second section)
- design of cogeneration system (**CHP** techniques – third section).

The result of research specifies too the economical decreasing of operational costs of LME and the remarkable environmental benefits arose by exploitation of biomass.

For room reason the part one of paper describes the generalized characteristics of research and results of calculations to design drying and storage section.

Keywords: Biomass, Pyrolysis, Energy, CHP, Enterprise

Research

Aim of research is production of syngas through a “pyrolysis process” fed by residual biomass from manufacturing of LME. Syngas supplies a gas turbine of a CHP system to produce electrical power required by operational cycles of LME (250, 500, 600 kW_e).

Steam at low pressure obtained through heat exchanges with exhaust of turbine feeds pyrolysis reactor.

Steam is utilized too, trough heat exchange with external air, to produce hot air to remove moisture content in biomass.

Fig.1 shows a schematic flow-diagram of all operational paths of process.

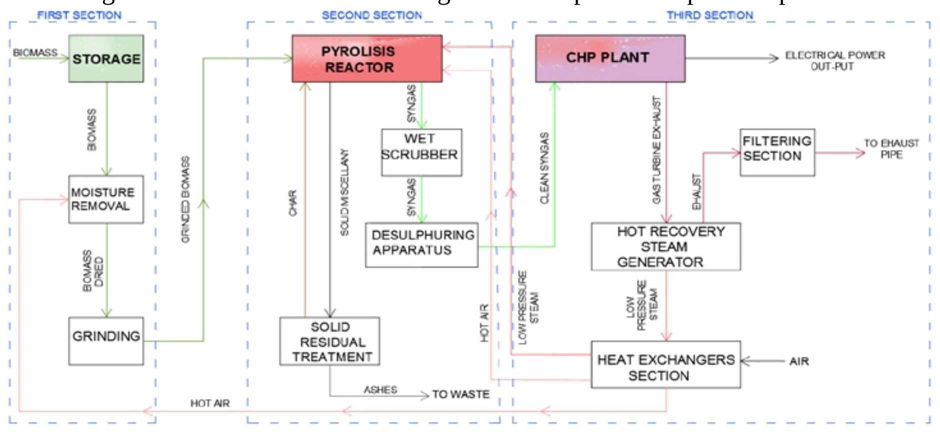

Fig.1

Types of chosen biomass and influencing parameters

Nowadays exploitation of biomass to produce biofuel through various processes (Tab.1) provides to about 15% of world energy request.

	PROCESS	***PRODUCTS***
THERMOCHEMICAL PROCESSES	COMBUSTION	THERMAL ENERGY
	GASIFICATION	SYNGAS
	PYROLISIS	SYNGAS BIO-OIL BIO-CHAR
BIOLOGICAL AND CHEMICAL/PHYSICAL PROCESSES	FERMENTATION	BIOETHANOL
	TRANS-ESTERIFICATION	BIODISEL
	SQUEEZING AND FILTATION	VEGETAL GAS
	ANAEROBIC DIGESTION	BIOGAS

Tab.1: Synthetic table of main biomass conversion : processes and products

Speaking about biomass, people may refer to any substance including carbon in its chemical structure derived, in direct or indirect manner, by photosynthesis process.

The substances in fossil form are kept out since out of purpose of research.

The biomass scraps from investigated LME suitable for research are coming from:

- Agro-industrial:

The resulting of wasted matter from manufacturing of olive oil, wine, almond, hazelnut and walnut (olive pits, shells, etc., etc.);

- Manufacturing of woody objects as furniture etc., etc. (woody shavings, scraps and remnants).

Fig.2 shows the main paths to obtain biofuel from biomass.

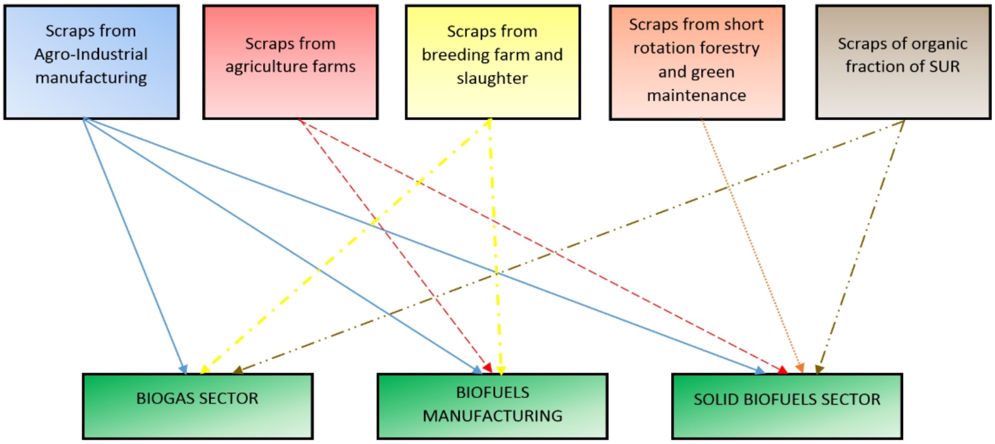

Fig.2: spinneret of biomass

Even if characteristics of biomass are very variable due to large number of substances so called, there are some parameters quite important for our purposes as like content of moisture (**R_M**) and lower heating power (**LHP**) of each biomass.

As regard moisture of biomass, naming **m_w** the mass of water contained in the whole and **m_d** the mass of dry substance, the moisture content (**u**) on wet basis is given by formula (1).

(1) $u = m_w / (m_w + m_d)$ (theoretically $0 \le u \le 1$)

Formula (2) instead gives the moisture content on dry basis (**u_0**)

(2) $u_0 = m_w / m_d$ (theoretically $0 \le u_0 \le \infty$)

Ratio $R_M = (m_w + m_d) / m_d = 1 + u = 1 / (1 - u)$ is important as regard the evaluation of cost of operations since it is representative to know the increased quantities of biomass as such to collect, transport and store per unit of dry matter.

In function of humidity content, practically R_M ranges between value 2 (u=50÷55 %) and value 5 (u= 75÷80 %).

As regard low heating power (**LHP**), taking in account that usable energy relative whole mass of substance as such (dry + water) is given by chemical energy of dry matter decreased the heat of vaporization of water, it is possible to write formula (3)

(3) $$(m_w + m_d) \cdot LHP = m_d \cdot LHP_0 - m_w \cdot r$$

where:

- LHP_0 = Low heating power of dry substance
- r = heat of vaporization of water

From a practical point of view, being the quantity of water in substance as such equal to “x time” the quantity of hydrogen (H) present in substance, the formula (4) gives

(4) $$LHP = LHP_0 - x \cdot H \cdot r$$

Fig.3 is an exemplum of variation of LHP in function of moisture content and kind of biomass in gasification process:

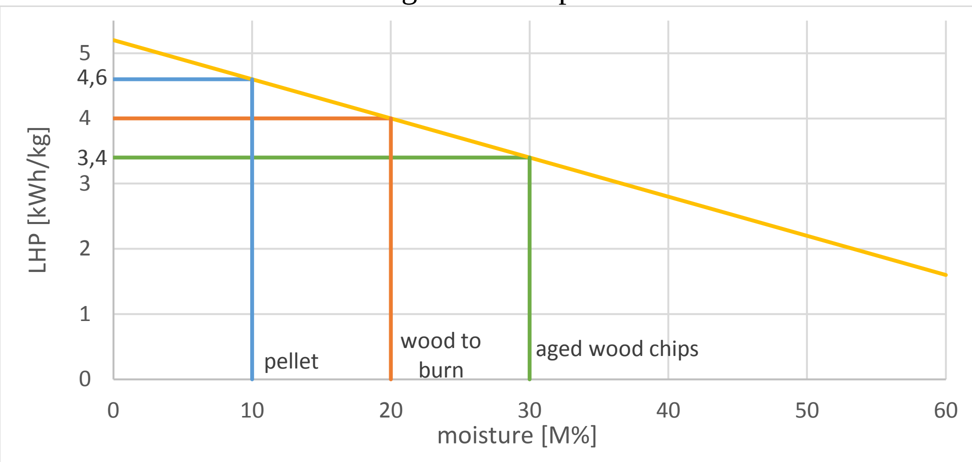

Fig. 3: Trend of LHP of woody matters in function of contents [1]

The process of Pyrolysis

Pyrolysis is a thermodynamics break-down of organic matter at temperatures variable in function of many parameters and in function of pyrolysis the chose.

Tab.2 shows for each kind of pyrolysis characterizing parameters and products of process.

The ranging of parameters depends on type of feedstock and kind of reactor.

PYROLYSIS	***AVERAGE RANGING OF OPERATIVE TEMPERATURES [°C]***	***STAYING TIME [s]***	***HEATING RATE [k/s]***	***PRODUCTS % RANGE***
SLOW	250÷300	1500÷1800	0.1÷1.0	Bio-char 80÷85 Bio oil <4 Gas 05÷15
INTERMEDIATE	400÷500	10÷30	5÷80	Bio-char 20÷30 Bio oil 45÷50 Gas 20÷30
FAST	400÷500	0.5÷2.0	10÷200	Bio-char 10÷15 Bio oil 65÷75 Gas 10÷15
FLASH	400÷500	0.2÷0.5	500÷1000	Bio-char 15÷25 Bio oil 60÷70 Gas 10÷15
GASIFICATION	900÷1200	0.1	>1000	Bio-char 05÷10 Bio oil - Gas 85÷90

Tab.2 [2]

During pyrolysis process the big chains of carbon (**C**), hydrogen (**H**) and oxygen (**O_2**) of biomass due to temperature are transformed into smaller gaseous molecules (**syngas**), considerable vapors (**tar and oil**) and solid carcoil (**bio-char**).

Fig.4 shows relative proportion of final products in function of temperature of process.

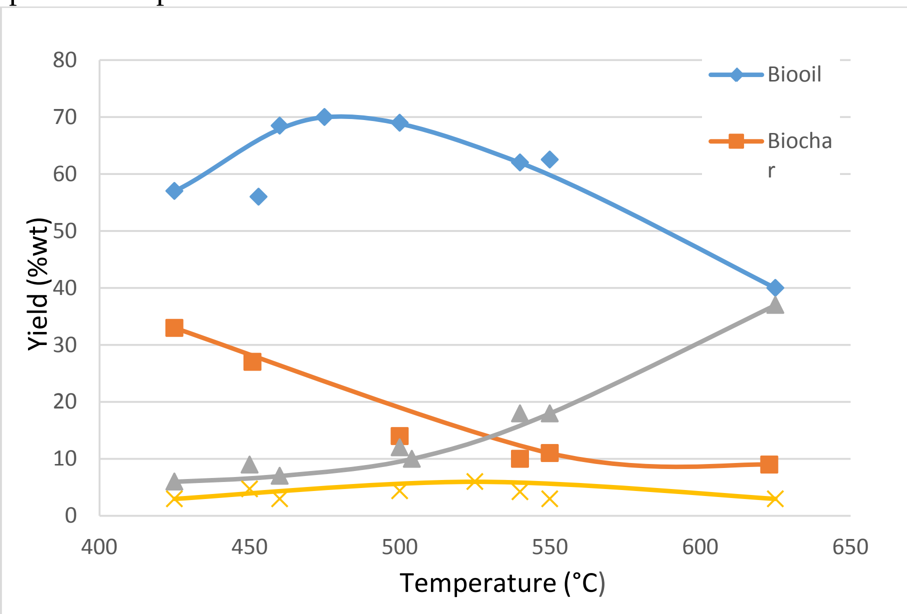

Fig.4 [3]

As regard syngas, aim of research is that it must be used as fuel to supply gas turbine. [4]

Heating power of syngas depends on oxidant agent (Tab.3).

LOW HETING POWER [kJ/Nm^3]	***OXIDANT AGENT***
LOW 4-6	AIR-AIR/STEAM
MEDIUM 12-18	O2-O2/STEAM
HIGH 40	H2

Tab.3

It is true that syngas used as fuel produce about 30% less of engine out-put in comparison with petrol [5] but it owns positive features for LME as saving of coasts of wasted matter removal and lower amount of polluting emission like unburnt hydrocarbons (**HC**) and carbon monoxide (**CO**).

As regard bio-char, it is solid matter highly flammable in presence of air so that many precautions have to be taken during its utilization.

Positive feature of bio-char produced is that it owns energy enough to supply heating break-down of biomass up to required temperatures so that pyrolysis process could be “thermally self-sufficient” (Bridgewater 2012).

4 – One Method to calculate stockpile storage

An experimental plant [6] fed by olive pits, through a syngas turbine produces an average electrical power of 90 ÷ 100 kW.

Fig.5 shows experimental plant.

Fig.5 [6]

Syngas supplying turbine comes from pyrolysis process of plant.

Experimental data of operation of plant point out following results:

- Average flow-mass of olive pits $\dot{m}_{op}$ = 484.0 kg/h
- Lower heating power (LHP) of olive pits LHP_{op} = 4500 kcal/kg
- Average flow-rate of produced syngas $\dot{m}_{sy}$ = 370 Nm^3/h
- Average of syngas LHP LHP_{sy} = 1480 $kcal/Nm^3$

From previous experimental data, formula (5) gives the average specific value of consumption (**Cs_{op}**) of olive pits to produce 1.0 Nm^3/h of syngas:

(5) $$Cs_{op} = \dot{m}_{op} / \dot{m}_{sy} = 1.31\ [kg/Nm^3]$$

Through (5) and value of LHP_{op}, formula (6) gives amount of Thermal Rate (**TR**) to produce 1.0 Nm^3/h of syngas through olive pits:

(6) $$TR = Cs_{op} \cdot LHP_{op} = 5{,}895.0\ [kcal/ Nm^3]$$

Tab.4 shows average LHP_i adopted for each considered biomass:

Dry Biomass	***Average LHP_i [kcal/kg]***
Olive pits	4,500
Wood shavings	3,200
Woody scraps	3,600
Shells of almonds, walnut and hazelnut	4,200
Marc	4,300

Tab.4

Formula (7) gives Cs_i for investigated biomass and results are showed in Tab.5:

(7) $$Cs_i = TR / LHP_i$$

Dry biomass	***Abbreviation***	***Specific Consumption***	***[kg/Nm³]***
Olive pits	op	Cs_{op}	1.31
Wood shavings	ws	Cs_{ws}	1.85
Woody scraps	wc	Cs_{wc}	1.64
Shells	sh	Cs_{sh}	1.41
Marc	ma	Cs_{ma}	1.37

Tab.5

Technical bibliography of some companies (PV Power System, ABB, Capstone, etc. etc.) making gas turbines able to produce electrical out-put as required by LME, give the average value of efficiency (**η_t**) showed in Tab.6.

Formula (8) gives thermal power (**P_T**) theoretically required to produce electrical power need of LME and Tab.6 shows the results for each required power in function of η_{ti} :

(8) $$P_{Ti}\ [kW_T] = P_{Ei}\ [kW_E] / \eta_{ti}$$

P_{Ei} $[kW_E]$	η_{ti}	P_{Ti} $[kW_T]$	P_{Ti} [Kcal/h]
250	0.30	834	717,240
500	0.33	1,564	1,345,040
635	0.35	1,815	1,560,900

Tab.6

Formula (9) gives for each electrical power the amount of required biomass ($\dot{\mathbf{M}}_{\mathbf{i}}$) and results are showed in Tab.7 :

(9) $$\dot{M}_i = (P_{Ti} / LHP_{sy}) \cdot Cs_i$$

P_{Ei} $[kW_E]$	P_{Ti} [Kcal/h]	Biomass	LHP_i [kcal/kg]	Cs_i $[kg/Nm^3]$	$\dot{M}_i$ [kg/h]
250	717,240	Op	4,500	1.31	635
		Ws	3,200	1.85	897
		Wc	3,600	1.64	795
		Sh	4,200	1.41	683
		Ma	4,300	1.37	664
500	1,345,040	Op	4,500	1.31	1,191
		Ws	3,200	1.85	1,681
		Wc	3,600	1.64	1,490
		Sh	4,200	1.41	1,281
		Ma	4,300	1.37	1,245
635	1,560,900	Op	4,500	1.31	1,382
		Ws	3,200	1.85	1,951
		Wc	3,600	1.64	1,730
		Sh	4,200	1.41	1,487
		Ma	4,300	1.37	1,445

Tab.7

The volume of stockpile storage depends on the geometrical shape and size of biomass : in fact one cubic meter of storage volume contents greater quantity of "olive pits" compared to "wood shavings" due to more compact shape of "olive pits" that causes smaller empty portion (co-volumes) in whole storage volumes.

To take in account of this factor, people devised the "shape efficiency" ($\boldsymbol{\eta_f}$) that takes in account geometrical shape and size of investigated biomass.

The methodology of devising is originated from a geometrically compared processing coming from so named "**mass steri**" of European Norm (EN 14961-5).

The EN 14961-5 prescribes in fact the acronyms to give to various types of woody mass also in function of the volume of biomass that one empty cubic meter can include and in function of average specific volume too.

Tab.8 gives values of η_f devised :

Biomass	η_{fi} ***[m_i^3/m^3]***	***ρ_i [kg_i/m^3]***
Olive pits	0.70	1,100
Wood shavings	0.45	220
Woody scraps	0.55	430
Shells	0.60	600
Marc	0.65	1,060

Tab.8

Taking in account of $\dot{M}_i$ (Tab.7), η_{fi} and ρ_i (Tab.8) , formula (10) permits the calculus of minimum essential daily volume of storage (**v_d**) for each electrical power required and for each types of wasted biomass investigated.

Results are showed in Tab.9.

$$v_d = (\rho_i / \dot{M}_i)^{-1} \cdot \eta_{fi} \cdot 24 \tag{10}$$

Power [kW_E]	***Biomass***	$\dot{M}_i$ ***[kg/h]***	η_{fi} ***[m_i^3/m^3]***	v_d ***[m^3/day]***
250	Olive pits	635	0.70	9.7
	Wood shavings	897	0.45	44.03
	Woody scraps	795	0.55	24.40
	Shells	683	0.60	16.39
	Marc	664	0.65	9.77
500	Olive pits	1,191	0.70	18.19
	Wood shavings	1,681	0.45	85.52
	Woody scraps	1,490	0.55	45.74
	Shells	1,281	0.60	30.74
	Marc	1,245	0.65	18.32
635	Olive pits	1,382	0.70	21.11
	Wood shavings	1,951	0.45	95.78
	Woody scraps	1,730	0.55	53.11
	Shells	1,487	0.60	35.69
	Marc	1,445	0.65	21.27

Tab.9

Fig. 6 shows the trend of daily volume for each biomass in function of required electrical power

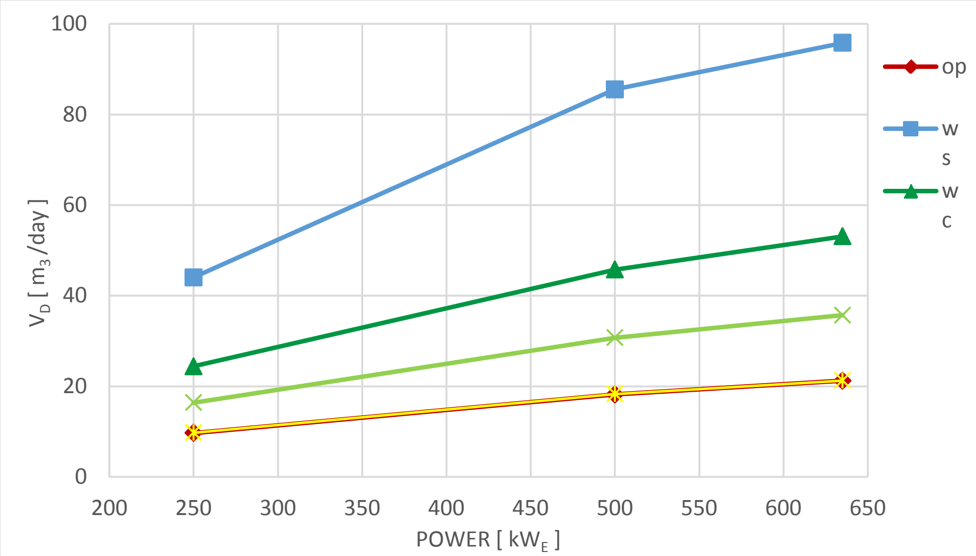

Fig.6

The pattern of Fig.6 allows a rough valuation of v_d also for powers not strictly corresponding to that ones investigated.

Removal of moisture from biomass

The removal takes place by almost convective heat exchange between hot air coming from CHP section and biomass.

Heat power of hot air must provokes the evaporation of moisture contained in biomass.

Formula (11) gives thermal power exchanged by air :

(11) $$\dot{Q}_{Tar} = c_p \cdot \dot{M}_{ar} \cdot \Delta T$$

where:

- ΔT is the difference of temperature between hot air and biomass.

From a practical point of view values of ΔT can range between 20°C (minimum value - ΔT_{min}) and 60°C (maximum value - ΔT_{max})

- In the range of thermal exchange the specific heat at constant pressure of air is $c_p = 0.24$ kcal/kg °C pretty well constant.
- $\dot{M}_{ar}$ is the flow-rate of hot air.

The percentage of moisture contained in investigated biomass range between 20% and 60% so that people obtain the minimum of mass of moisture ($\dot{M}_{H2Omin}$) and the maximum ($\dot{M}_{H2Omax}$) through

$\dot{M}_{H2Omin} = 0.20 \cdot \dot{M}_{imin}$ and

$\dot{M}_{H2Omax} = 0.60 \cdot \dot{M}_{imax}$.

Using the relative numerical values of mass-flow of Tab.7, people obtain tab.10.

P_{Ei} [kW_E]	$\dot{M}_{H2Omin}$ [kg_{H20} /h]	$\dot{M}_{H2Omax}$ [kg_{H20} /h]
250	127	538
500	238.2	1,009
635	276.40	1,171

Tab.10

Formula (12) shows thermal power need to cause evaporation of moisture:

(12) $\dot{Q}_{ev} = r \cdot \dot{M}_{H2O}$

Where r is the latent heat of evaporation.

In range of temperature of thermal power exchange (20°C ÷ 60°C), the value of latent heat of evaporation can be pretty well constant as the average value r = 575 kcal/kg

The almost convective heat of exchange must be such that $\dot{Q}_{Tar}$ can supply $\dot{Q}_{ev}$ and trough the formulas (11) and (12) is possible to write formula (13) :

(13) $\dot{M}_{ar} = (r / c_p \Delta T) \cdot \dot{M}_{H2O} \cdot (1/\eta_{st})$

Where η_{st} = efficiency of thermal exchanger.

Efficiency of thermal exchanger nowadays can reach up the value of 0.85 adopted.

Placing in (13) the values of Tab.10 people find the hot air flow-rate to removal moisture as showed in Tab.11.

P_{Ei} [kW_E]	$\dot{M}_{armin}$ [kg_{ar} /h]	$\dot{M}_{armax}$ [kg_{ar} /h]
250	19,907	25,286
500	33.586	47,423
635	38,972	55,037

Tab.11

First conclusion

All previous referred permits to LME to have guide lines for :

- Calculus of stockpile daily volume of storage v_d.

Of course each LME can calculate the volume of storage necessary for stockpile in function of times of operational cycle of its manufacturing and relative biomass wasted.

- LME can calculate hot air flow-rate to draw out moisture by data of stockpile in function of heat exchanging temperatures of air included between 20°C and 60°C.

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Symbolism:

LME	:	Little and Middle Enterprises
CHP	:	Combined Heating and Power
R_M	:	Moisture
LHP	:	Lower heating power
LHP_0	:	Low heating power of dry substance
u	:	Moisture content on wet basis
u_0	:	Moisture content on dry basis
r	:	Heat of vaporization of water
m	:	Mass
$\dot{m}_{op}$	:	Average flow-mass of olive pits
$\dot{m}_{sy}$	:	Average flow-rate of produced syngas
Cs	:	Specific value consumption
TR	:	Thermal Rate
w (subscript)	:	Water
d (subscript)	:	Dry substance
sy (subscript)	:	Syngas
op (subscript)	:	Olive pits
ws (subscript)	:	Wood shavings
wc (subscript)	:	Woody scraps
sh (subscript)	:	Shells
ma (subscript)	:	Marc
i (subscript)	:	Generic
E (subscript)	:	Electrical
T (subscript)	:	Thermal
air (subscript)	:	Air
H_2O (subscript)	:	Water
P	:	Power
$\dot{M}$	:	Mass rate
η_t	:	Turbine efficiency
η_{ec}	:	Efficiency of energy conversion
η_{st}	:	Efficiency of thermal exchanger
η_f	:	Shape efficiency
v_d	:	Volume of storage
$\dot{Q}_{Tar}$	:	Thermal power
$\dot{Q}_{ev}$	:	Thermal power required for the evaporation of moisture