Alfonso-Solar, D.; Perpiñá, C.; Pérez-Navarro, A.; Peñalvo-López, E.; Vargas-Salgado, C.; Cárdenas, R. (2009). Methodology for optimization of distributed biomass resources evaluation, management and final energy use. Biomass and Bioenergy. 33(8):1070-1079. https://doi.org/10.1016/j.biombioe.2009.04.002

Methodology for optimization of distributed biomass resources evaluation, management and final energy use

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Abstract

A methodology has been developed to assess optimal management and energy use of distributed biomass resources, where logistics is a main factor but other features must be also considered: biomass resources properties (quantity, quality, seasonality & availability), plant size effect, available technologies for power, heat and solid biofuels generation, CO_2 emissions balance and quantification of potential biofuel consumers.

This methodology provides a quantification and characterization of biomass resources, a list of optimal locations from logistic point of view and the necessary data to perform detailed technical, economic and environmental analysis of the different biomass energy use options. It has been applied to three districts of the Valencian region in Spain and main results and conclusions are also included in this paper.

Keywords

Biomass resources, optimization methodology, biomass transport, distributed energy resources.

1. Introduction

The massive implementation of distributed energy resources is a key element for the strategy to increase energy efficiency and reliability of supply. Biomass is a renewable energy source which implies large savings in harmful emissions to the atmosphere taking advantage of local energy resources in a sustainable way. Nowadays the energy use of biomass in Spain is very limited but climate and intense agricultural activities should provide a higher contribution of this renewable source in the total needs of primary energy. The planned rapid deployment of biomass installations requires the development of a general methodology to identify the best biomass applications for each geographical area that guarantee its technical, economical, environmental viability, and reliability of supply to the final consumers of processed biofuels, electricity or heat . This methodology should provide detailed evaluation of biomass resources, potential biofuel (pellets, wood chips) demand for thermal or cogeneration applications, optimization of biomass management (collecting and transport) costs and emissions, and best available energy valorisation technologies (pre-treatment technologies as pellet production, and generations technologies for combined heat and power generation)

2. Methodology

The methodology can analyse wide geographic areas by making subdivision and considering a potential biomass plant in each subdivision. Subdivision size can obey to administrative boundaries (default option), customer defined groups of municipalities or other specific criteria (i.e.: upper limit for transport distance).

The developed methodology has been structured in six different modules as described in Figure 1. In the next paragraphs the global approach and the different modules are described.

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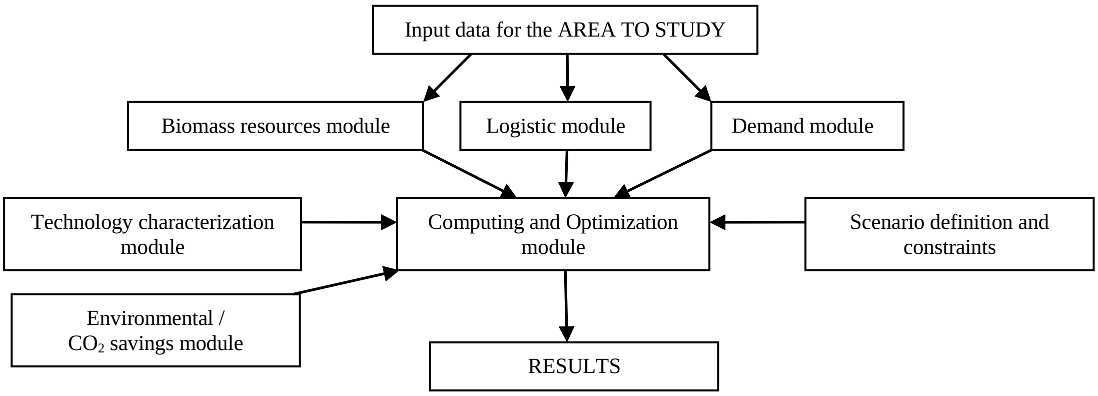

Figure 1: Scheme of methodology to assess the optimal energy valorisation of biomass resources

Specially for biomass resources module and logistic module using geographic information systems (GIS) is an adequate tool [1,2]. GIS can be employed as an strategic planning tool or as an operational tool, in this last case, where it is requested finer spatial resolution (i.e. transport distance or time calculations), GIS becomes an indispensable tool.

The application of the methodology will provide an accurate knowledge of biomass resources and will optimize:

- Locations of the biomass plant from the point of view of logistics (minimum transport times).
- Energy application. In these centres biomass can be converted into electricity, heat and /or standardized biofuels (pellets), according to local energy demand, biomass resources characterization and other possible additional constraints (i.e. legislation), which favour possible applications. Methodology should clarify which application to address.
- Employed technology. Selected energy application (i.e. power plant, cogeneration plant...) can be performed using different technologies (boiler + steam turbine, gasifier + internal combustion engine,...), but biomass properties and plant size combine with technology restrictions (maximum or minimum size, maximum ash content, ...) will provide which technologies to use.

Final application and technology selection will be given by the optimization criteria, which can obey to economic or environmental issues (CO_2 balance), and the imposed restrictions of the possible scenario.

2.1 Biomass resources module

Biomass sources considered in the analysis are those derived from forestry, agricultural crops (woody crops as olives, grapes, oranges, almonds, apples,...; and herbaceous crops as rice, wheat, barley, maize...) and agro-industries (olive oil industries, wine production industries, dry fruits peeling plants, rice mills,...). Quantification of biomass resources is performed using generation ratios as those described in Table 1. These generation ratios and characterization of produced waste biomass (higher heating value, moisture and ash content) have been obtained from bibliography [3 – 8] and direct field analysis during BIOVAL project (BIOVAL is a project titled "Optimization of the Energy Use of Biomass Resources in the Valencian Region", 2005 – 2006, funded by the regional government of the Valencian region – IMPIVA, Generalitat Valenciana- and the European Fund of Regional Development). Regarding the generation ratios, in most cases standard deviations were in the range 20 – 50%.

Table 1.

Biomass resources quantification. Generation ratios for agricultural residues

Code	**Biomass resource** (type of crop)	**Description**	**Waste biomass generation ratio** (referred to wet biomass)	**HHV** ($MJ\cdot kg^{-1}$ dry)	**Moisture** (%wet basis, fresh)	**Ash** (%dry basis)
AG_{Ai}	Agricultural residues from woody crops	Annual tree prunings	1.8-4.1 ($t\cdot year^{-1}\cdot hm^{-2}$ of cropland)	17.2-18.4	30 – 40 %	1.8-3.4 %
AG_{Bi}	Agricultural residues from herbaceous crops	Cereal straw, maize cobs and stalks	1.5-7.8 ($t\cdot year^{-1}\cdot hm^{-2}$ of cropland)	16.8-18.1	20 – 30 %[a]	4.2-7.5%[b]

FR_i	Forestry residues	Silviculture waste	1.0 – 1.9(t·year^{-1}· hm^{-2} of woodland)	18 – 20%	29 – 45%	1.2 – 3.4%
AI_i	Agro-industrial residues	Fruit peels and pulp, cereal husk, dry fruit shells	0.16 - 3.6 (t·t^{-1} of product)	16 – 22.0%	50 – 65%[c]	2 – 6%[d]

[a] fresh Maize cobs and stalks have a moisture content of 55-65%
[b] rice straw has an ash content (in %dry basis) of around 18%
[c] dry fruits shells and rice husk have low moisture content in the range 8-12% (in % wet basis)
[d] rice husk has an ash content (in %dry basis) of around 17%

Geographic location of biomass residues can be performed using GIS with a resolution of 1-km^2 pixel or using municipalities as minimum area units.

Seasonality is also an important factor for logistics, specially for agricultural residues where it can be very severe. It can be evaluated in a monthly basis according to typical labour operations during year for each crop (for agricultural wastes) and typical production cycles for industries. In Figure 2 (a) it has been included typical seasonality functions for several agricultural crops (tree prunings and cereal straw), these functions are applicable when it is considered more than one cultivation plot of each representative crop, because they can be considered as statistical functions so it is required a minimum sample size to be meaningful. In Figure 2 (b) it has been included the aggregated seasonality analysis of a district, obtained as the addition of mass of each type of agricultural waste biomass every month.

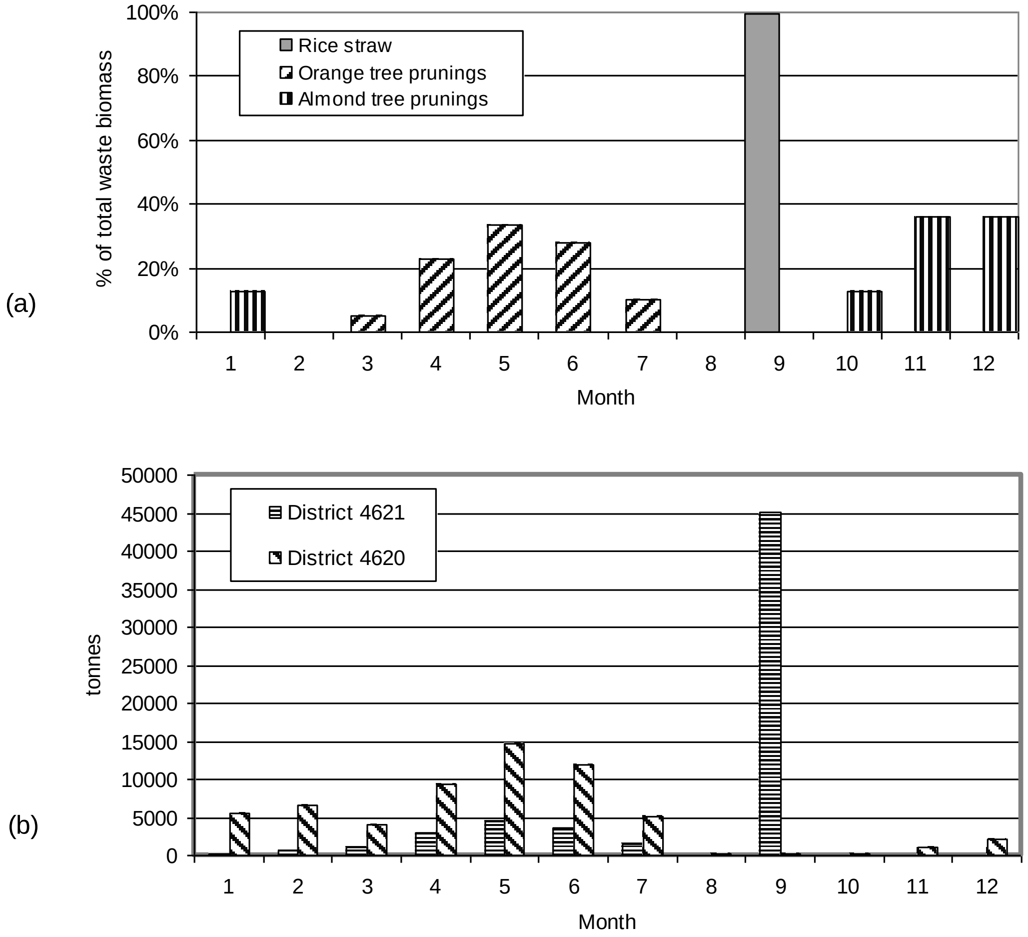

Figure 2: Seasonality graphics of agricultural waste biomass. (a) Single crops, (b) Aggregated seasonality for districts

In this module the availability for energy use of each type of agricultural waste biomass (availability coefficients) is defined according to bibliography [5,6] and additional surveys performed by the authors, being important to take into account other uses of biomass (i.e. animal feeding, domestic fuel), and size of agricultural plots. In Table 2 in has been included a summary of availability considerations. For agricultural waste biomass global availability was in the range 20 – 40% referred to the total theoretical biomass production.

Table 2.
Biomass resources availability for energy use.

Biomass resource	Availability for energy use	Additional considerations
Tree prunings (AG_{Ai})	60 – 80%	It was considered that biomass from plots smaller than a minimum value (0.6 – 0.8 hm^2) would not be collected due to difficult accessibility and logistics (for the same total area, many small plots instead of few big ones provide higher management complexity)
Cereal straw & similar (AG_{Bi})	15 – 30% (rice straw & corn stalks 50 -60%)	
Forestry (FR_i)	20 – 40%	This percentage represents the waste biomass produced due to silviculture treatments really performed in Spain compared with the theoretical potential value computed according to woodland surface.

2.2 Demand module

Suitable demand segments or typical customers for thermal or cogeneration applications with biomass must be identified (hospitals, schools, residential homes, industries,…) and, according to statistical and cartographic data, these demand points or areas are located in the map (mainly urban areas and industrial areas) and quantified in terms of energy needs (kWh·year^{-1}). Three different demand sectors: residential (R), commercial (C) and industrial (I) have been considered.

Suitable demand segments of commercial and residential sector are, mainly, those included in the European directive about energy performance of buildings [9], focused on increasing energy use efficiency and renewables (solar, biomass,…). In these segments main energy needs can be potentially covered by a central boiler for hot water, space heating and cooling (with absorption systems). They are included in Table 3.

In the industrial sector the suitable demand segments have been identified using reports from EUBIONET [6,7] and project Pellets for Europe [10]. In these segments the energy needs are steam, hot water or hot air for drying.

Average thermal energy needs for each demand segment has been estimated using Spanish national statistics and official sectorial reports from the Spanish administration and defining a thermal energy indicator which employs statistical data available for each demand segment (n. of beds, total area, n. of students, turnover,…) as detailed in Table 3.

Table 3.
Estimation of potential demand for local consumption of biofuels

Sector	Demand Segments	Thermal energy consumption indicator (for hot water, steam or other suitable thermal process)
C	School	400 – 500 kWh·student^{-1}· year^{-1}
	Sport activities	400 – 500 kWh·user^{-1} · year^{-1}
	Hospital	25 - 35 MWh·bed^{-1} · year^{-1}
	Care centres	40 – 110 kWh·m^{-2} · year^{-1}
	Hotels	25 - 35 MWh·room^{-1} · year^{-1}
R	Residential homes	40 – 110 kWh/m^2 · year, considering 5 climatic zones in Spain for houses of 80 – 130 m^2 and 3 – 4 people.
I	Industry	200 – 1700 kWh· (k€_turnover)$^{-1}$ · year^{-1} 40 – 480 MWh · employee^{-1} · year^{-1} Different values according to specific industrial activity based on NACE[a] code.

[a] NACE Code is a pan-European classification system which groups organisations according to their business activities. It assigns a unique 5 or 6 digit code to each industry sector. Examples of these codes are NACE code DA.15.50 (Manufacture of dairy products) or DB.17.30 (Finishing of textiles)

After considering the total thermal energy demand of each sector it must be considered the fraction of available market for biomass applications, given the fact that a percentage of the customers will employ other fuels or electricity to cover their thermal needs. It has been considered, as default values, that the available market for biomass applications is 10% for the residential sector, 30 % for commercial sector, and 30% for industrial sector.

Grouping of these segments can be made according to administrative boundaries (municipalities or districts). Typically, small/medium customers (school, small hospitals, houses…) require high quality biofuels (low ash, sodium, chlorine and sulphur content) for thermal applications (central boilers), and large customers (i.e. industries) can use lower quality biofuels for both thermal or cogeneration applications, as they are usually able to deal with ash disposal, gas cleaning and maintenance requirements.

2.3 Logistic module

Based on road network characteristics and accessibility to biomass sources, this module allows computing transport time and distances between two generic points ***x*** (origin) and ***y*** (destination) in the area of study, these functions are called Time(x,y) and Distance(x,y). Sources or origins of biomass are fixed and destination can be either fixed by the restrictions of the considered scenario (i.e. presence of power plants, hospitals, industrial customer, etc.) or by applying an algorithm of minimization of transport costs (according to transport time or distance), which is the most usual approach to define optimum location of the biomass plant for a considered area. This module provides the biomass transport including specific considerations about logistic structure (maximum weight of transport unit and previous densifications in bales, if any). Typically, a biomass transport cost function [2], is composed by fixed costs and distance dependent costs. The evaluation of average biomass transport cost, ABTC ($€\cdot t^{-1}$), of a specific potential location ($y=y_B$) for a biomass plant is given by the following equations:

$$\mathrm{BTC(x,y)}=\frac{\mathrm{FC + DC\cdot Distance(x,y)}}{\mathrm{TUC}} \tag{1}$$

$$\mathrm{FC=FC1 + FC2} \tag{2}$$

$$\mathrm{DC=DC1 + DC2} \tag{3}$$

$$\mathrm{ABTC}(x_i,y_B)=\frac{\mathrm{FC\cdot NR + DC}\cdot\sum_i \mathrm{Distance}(x_i,y_B)}{\mathrm{TUC\cdot NR}} \tag{4}$$

where:

BTC(x,y) = the specific cost of a single run transporting biomass from point x to point y ($€\cdot t^{-1}$)

FC = the fixed cost due to loading/unloading (FC1),and compaction (FC2) operations

Distance(x,y) = one-way distance between point x and point y.

NR = the total number of runs

DC = distance dependent costs duel to fuel consumption and operation and maintenance ($€\cdot km^{-1}$) of the transport unit (DC1, i.e. truck) and the baling system unit (DC2). This coefficient includes also time dependent cost (hours of personnel) by considering an average transport speed of 30 – 50 $km\cdot h^{-1}$.

TUC = transport unit or truck capacity (in tonne)

Two logistic structures are available in the logistic module of the methodology at the moment which are called BLS1 and BLS2. In BLS1 biomass is transported in medium size truck (truckload of 8 – 12 t, 25 - 30 m^3) with previous compaction of biomass (bales of around 1 m^3, 300 – 400 kg) . In BLS2 biomass is transported also in the same medium size truck but without compaction, in this case truckload is fixed on

3 tonne. A summary of main considerations made in order to obtain the transport cost function for logistic structure BLS1 can be found in Table 4. These considerations are based on real experience of enterprises dealing with biomass collecting and transport in Spain, and machinery specifications from manufacturers.

Table 4.
Considered parameters and values for transport cost computing of logistic structure BLS1

Distance dependent costs for logistic structure BLS1

Parameter	**DC1**[a]	**DC2**[a]
Speed ($km \cdot h^{-1}$)	30 - 50	30 - 50
Fuel consumption (l/100km)	30	30
Maintenance ($€ \cdot km^{-1}$)	0.1	0.1
Personnel (people)	1	2
DC - distance dependent cost ($€ \cdot km^{-1}$)	**1.5**	**0.525**

Fixed cost estimation for logistic structure BLS1

Parameters	**FC1**[b]	**FC2**[b]
Bales production capacity ($t \cdot h^{-1}$)	-	4
Fuel consumption for full load of transport unit (l)	5	25
Transport unit capacity (tonne)	10	10
Required time for full load of transport unit (hours)	3	2.5
Personnel (number of workers))	1	2
Fixed cost (€ per run)	**41.0**	**85.0**

Reference cost indicator	**Value**
Fuel ($€ \cdot l^{-1}$)	1
Personnel ($€ \cdot h^{-1}$)	12
Operation & Maintenance of vehicles ($€ \cdot km^{-1}$)	0.1

[a] DC1 – Distance dependent cost of the transport unit (truck), DC2 – Distance dependent cost of the baling system unit.

[b] FC1 – Loading/unloading cost of the transport unit (truck), FC2 – Baling cost.

Finally, Eq. (5) and Eq.(6) represent average biomass transport cost functions, ABTC, for logistic structure BLS1 and BLS2 respectivelly. It can be deduced that previous compaction provides a lower specific transport cost (in $€ \cdot t^{-1}$), even for short transport distances.

$$\mathrm{ABTC\_1}(x_i,y_B) = 12.6 + \frac{0.2025}{\mathrm{NR}} \cdot \sum_i \mathrm{Distance}(x_i,y_B) \quad \text{, for BLS1} \tag{5}$$

$$\mathrm{ABTC\_2}(x_i,y_B) = 13.7 + \frac{0.5}{\mathrm{NR}} \cdot \sum_i \mathrm{Distance}(x_i,y_B) \quad \text{, for BLS2} \tag{6}$$

In a real biomass plant it is usual to partially or totally subcontract the transport activities, specially when biomass resources present severe seasonality. In this case it can be useful to estimate, separately, the cost of previous compaction ($€ \cdot t^{-1}$) which will be present anyway. This cost function is given by Eq. (7):

$$\mathrm{CPC}(x,y) = 8.5 + 0.0525 \cdot \mathrm{Distance}(x,y) \tag{7}$$

where:

CPC(x,y) = the specific cost of compacting biomass ($€ \cdot t^{-1}$) of point x for posterior transport to point y. It depends also on distance because compaction machine must move to the collecting point.

There are additional costs associated to transport activities which are those derived from required investment to buy the necessary trucks and compaction machines. The cost and basic operation parameters of these vehicles are summarized in Table 5.

Table 5.
Cost and basic operation parameters for biomass transport and compaction vehicles.

Vehicle	Cost, k€/unit	Lifetime, years	Typical Operation	Capacity
Compaction truck	420	7	8 h/day, 230 d·year^{-1}	4 t·h^{-1} of bales
Transport truck	170	7	10 h/day, 230 d·year^{-1}	3 – 4 runs per day BLS1: 10 t/compacted load BLS2: 3 t/uncompacted load

In order to quantify the impact of logistic structure investment in the biomass transport process it can be obtained an additional transport cost derived from logistic structure (ATCLS, in € per tonne of biomass) considering the lifetime of the vehicles. For a biomass plant of 25000 t·year^{-1} (wet) and an average transport distance of 20 km results are shown in Table 6

Table 6.
Impact of logistic structure investment on biomass transport cost transport cost

Logistic structure	Compaction truck		Transport Truck		Biomass plant size	ATCLS
	Units	Total cost (k€)	Units	Total cost (k€)	t·year^{-1} (wet)	€·t^{-1}
BLS1	4	1.680	5	850	25000	14.5
BLS2	-	-	15	2550	25000	14.6

It is observed that ATCLS is similar for both logistic structures so it can be concluded that BLS1 (transport with previous compaction) should be selected as average biomass transport cost, already showed in Eq. (5), is lower. It is also interesting to note that for a defined biomass plant with an average transport distance of around 20 km, the average biomass transport cost (ABTC) and additional transport cost derived from logistic structure (ATCLS) are similar for BLS1 (in the range 14 – 17 €·t^{-1}). When using BLS2 the ATCLS remains in the range 14 – 15 €·t^{-1} but the average biomass transport cost is higher (23 – 25 €·t^{-1}).

2.4 Technology characterisation module

Technologies for energy use of biomass are characterized in the methodology in terms of conversion efficiencies, cost and specific restrictions (i.e. minimum size, maximum ash content,…), and influence of plant size, defined through biomass consumption B (t·h^{-1} of raw biomass), in these parameters.

This module also includes the characterization of pre-treatment plants (pellet production plants) and generation/cogenerations plants included in Table 7. These plants are characterized from an economic and efficiency point of view according to bibliography [3,4] and manufacturers by several functions: Installation cost, IC(B) (in € per t·h^{-1}), specific Operation and Maintenance costs of the whole plant, OMC(B), Electric and Thermal efficiency,$EFF_E(B)$ and $EFF_{TH}(B)$, respectively in MWh·t^{-1}.

Table 7.
General description of bioenergy plants included in the technology characterization module

Bionergy plant		Efficiency (%HHV)		Restrictions	
Code	**Description**	**Electric**	**Thermal**	**Application range, R_AP**	**Max. ash content %dry basis, R_ASH**
BP1	Biomass pelletization plant (Dryer + grinder + pelletizer)	-	80-90%	> 10 kt·year^{-1} of pellets	1 - 6%
BP2	Biomass gasification power plant. Fluid	24 – 27%	31 – 37%	>0.5 MW$_e$	<5%

	bed gasifier with internal combustion engine. Thermal output can be hot water or low pressure steam (< 10 bar)				
BP3	Similar to BP2 but with downdraft fixed bed gasifier.	16 – 21%	25 – 30%	0.05 – 0.8 MW_e	not specified
BP4	Biomass power plant based on ORC (organic rankine cycle) turbine. Thermal output is hot water at 80-90ºC	15 - 17%	65 -72%	0.2 - 2 MW_e	not specified
BP5	Biomass power plant based on condensing steam turbine.	15 -22%	-	> 2 MW_e	not specified

In figure 3 it is shown IC and OMC functions for a pellet production plant (BP1), and IC for a biomass gasification power plant based on fluid bed gasifier and internal combustion engine (BP2). For BP2 it is usually employed a constant value of OMC of around 0.02 $€\cdot kWh^{-1}$ referred to generated electricity, equivalent to 11 – 15 $€\cdot t^{-1}$ of wet biomass. In this example plant size is referred to wet biomass with a 40% of moisture. Regarding specific restrictions for the plant types BP1 and BP2 it must be taken into account that ash content should be lower than 3% and 5% respectively, to assure technical viability.

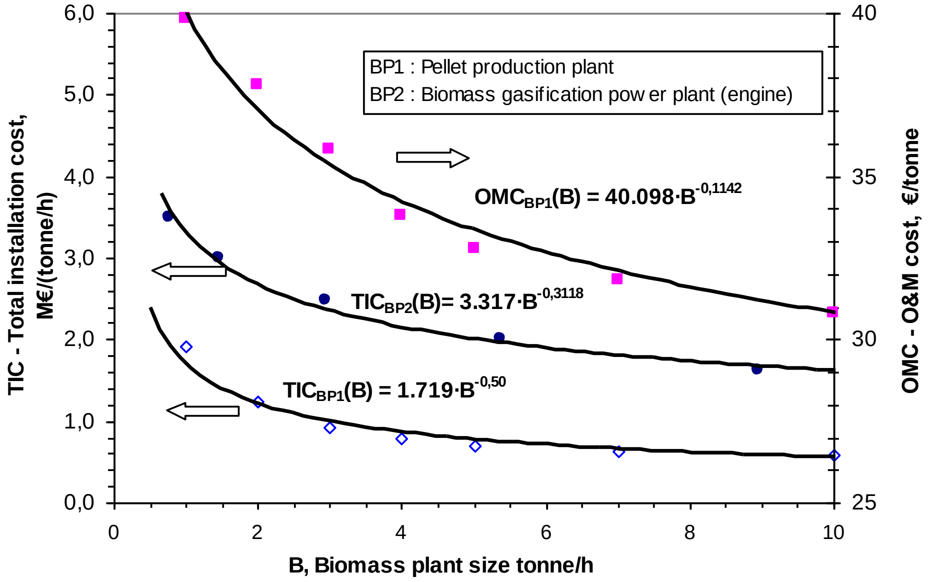

Figure 3: Biomass plant specific installation and O&M costs as a function of the plant size

2.5 *Environmental / CO_2 savings module*

In this module the CO_2 saving due to substitution of electricity produced in conventional power plants and/or thermal energy produced by consumption of fossil fuels are computed. In the global CO_2 emissions balance it must be taken into account the use of fossil fuels in transport and collection (directly related to transport distances and compactation requirements), and biofuel productions process (pelletization). In order to compute CO_2 savings and effective emission, CO_2 emission factors from IPPC[1] European Directive and bibliography [13,14] have been used, Table 8 summarizes some of them.

Table 8.
CO_2 emission factors of several energy carriers

	Emission factor	
Fuel or Electricity	**Code**	**$kgCO_2 \cdot kWh^{-1}$ (HHV)**

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[1] Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. Oficial. Journal L 257 , 10/10/1996 P. 0026 – 0040

Electricity – NG (combined cycle, 55% efficiency) power plants	CO2E01	0.33
Electricity - Oil power plants (38% efficiency)	CO2E02	0.68
Electricity - Coal power plants (38% efficiency)	CO2E03	0.87
Electricity - European power plants mix [a] (40% coal, 30% gas, 30% non fossil)	CO2E04	0.43
NG - fuel	CO2F01	0.18
Oil – fuel [b]	CO2F02	0.26
Coal - fuel	CO2F03	0.33
Fuel mix for thermal applications [c] (50% gas, 40% oil, 10%coal)	CO2TH01	0.23

[a] Electricity distribution losses have not been included.

[b] Emission factor for Oil can be expressed as 2.8 $kgCO_2 \cdot l^{-1}$

[c] To evaluate CO_2 savings due to thermal power from cogeneration applications it is included the HHV efficiency of the boiler (≈ 80%HHV), or other thermal system, which will be substituted by the heat recovery system of the cogeneration plant. The energy units are referred to kWh of net thermal energy.

In a biomass power or cogeneration plants the CO_2 savings are due to the electricity and thermal energy produced in the plant, which substitutes electricity from the grid (CO_2 savings of 0.43 $kgCO_2 \cdot kWh^{-1}$) and thermal energy from boilers (0.28 $kgCO_2 \cdot kWh^{-1}$).

The production process of a pellet plant requires electricity (mainly for milling and pelletization) and heat (for drying) as showed in Table 9, and these energy needs produce CO_2 emissions. In a typical medium size pellet production plant [12,15] with a capacity of 2.86 $t \cdot h^{-1}$ of pellets (with 10% of moisture content in wet basis), corresponding to 4.76 $t \cdot h^{-1}$ of raw biomass, the emission factor, considering Electricity from European power plants mix, is 0.02 $kgCO_2 \cdot kWh^{-1}$ of produced pellets (HHV basis).

Table 9.
Energy requirements of conventional pellet production plant on hourly basis.

Energy input, MW (HHV basis)			**Energy output, MW (HHV basis)**		
Raw Biomass	Electricity	Fuel [a]	Biomass pellets	Electricity	Heat
13,22	0,51	2,05	11,17	-	-

[a] Assuming biomass pellets as fuel for drying purposes.

Raw biomass management (loading/unloading, compaction and transport) produces CO_2 emissions due to fuel consumption. Based on considerations made in the logistic module for cost estimation, it can be obtained average specific CO_2 emissions functions (ACO2) for biomass logistic structures BLS1 and BLS2 as described in Eq.(8) and Eq.(9) respectively. In these equations CO_2 emissions due to loading/unloading, compaction and transport operation are included (compaction only for BLS1).

$$\mathrm{ACO2\_1}(x_i, y_B) = 8.4 + \frac{0.17}{\mathrm{NR}} \cdot \sum_i \mathrm{Distance}(x_i, y_B) \qquad \text{, for BLS1} \tag{8}$$

$$\mathrm{ACO2\_2}(x_i, y_B) = 4.7 + \frac{0.56}{\mathrm{NR}} \cdot \sum_i \mathrm{Distance}(x_i, y_B) \qquad \text{, for BLS2} \tag{9}$$

Looking at function **ACO2(x_i,y_B)** it is obtained that, for more than 7-9 km of average transport distance, BLS1 (transport with previous compaction) produces lower CO_2 emissions than BLS2 (without previous compaction).

2.7 Computing and optimization module

This module interacts with the other modules to apply defined scenario constraints and optimization criteria which must be fulfilled in the optimization process. As showed in Table 5**¡Error! No se encuentra el origen de la referencia.**, scenario constraints can limit the type biomass to be taken into account, biomass collection and transport structure, specific type or types of bioenergy plant to be analysed, or the possible plant locations. Table 10 describes the applied constraints considered for the BIOPTION scenario applied to the Valencian region in the BIOVAL project, selected biomass resources, biomass logistic structure, type of bioenergy plants to be analyzed and additional constraints were fixed by the Valencian government according to regional short term objectives regarding biomass energy resources use.

Table 5.
Description of applicable constraints for a generic scenario in the methodology

Applicable constraint	Description	Considered values in scenario BIOPTION
Biomass resources	It defines the sources of biomass that will be considered (AG_{Ai}, AG_{Bi}, FR_i,...). Some scenarios can require analysing specific sources of biomass because of enviromental implications, legislation, high availability or other reasons.	Agricultural biomass, forestry and agro-industrial residues from olive oil industry: AG_{Ai}, AG_{Bi}, FR_i, AIi (only residues from olive oil industry)
Biomass logistic structure	It defines the selected logistic structure (BLS1, BLS2) to be analysed.	Transport with previous compaction: BLS1
Bioenergy plants	It defines the types of bioenergy plants to be analysed (BP1, BP2, ...).	Pellet plant and generarion/cogeneration plants: BP1 & BP2 & BP5
Technology restrictions	It defines the technology restrictions to be applied as described in Table 7. These restrictions can be ignored in case it is considered future situations in which economic or technical features of a selected technology could change.	Regarding application range and maximum ash content of the raw biomass: R_AP, R_ASH
Additional constraints:	It allows additional constraints that are usually used in viability studies for biomass plants. Typical examples are: - To limit biomass transport distance by district boundaries and/or with a maximum transport distance (i.e. 25 km). - To define the number of possible locations (5, 10, 20, ...), ordered and selected according to minimum transport costs, showed in the results.	Additional constraints: transport distance limited to district boundaries, minimum transport costs define 20 possible locations.

Methodology application to the most employed scenarios includes an optimization in two steps: the first one provides the list of the best locations according to minimum transport costs and biomass resources distribution, and the second step is based on user criteria taking into account provided results about potential local biomass consumers, average biomass properties and potential biomass plant characteristics (size, costs, efficiency and CO_2 savings).

The optimization process can be performed based on different criteria. In Table 6 it is included description and assumptions for two optimization criteria.

Table 6.
Optimization criteria. Description and assumptions.

Optimization criteria	Description & assumptions
Economic suitability	Minimum Simple Payback period of the installation (years) - Energy prices: Electricity = 0.11 €·kWh^{-1}, heat =0.025 €·kWh^{-1}, pellet =150 €·t^{-1}. - Biomass logistic structure costs: 170 k€ per truck, 420 k€ percompaction machine - 40% of subcontracted transport & 130 € per subcontracted run - For BP2 it is considered an O&M cost of 0.02 €·kWh^{-1} of produced electricity and additional costs of personnel for general purposes of 2 people with an hourly cost of 20 €·h^{-1}.
Maximum CO_2 savings	Minimum CO_2 emission of the global process (kg of CO_2 per t of processed biomass) BP1 = Pellet production for substitution of fossil fuels in thermal applications

BP2, BP3, BP4 = Cogeneration and electricity only applications
BP5 = only electricity applications
CO_2 savings reference:

- Electricity - European power plants mix 0.43 $kgCO_2 \cdot kWh^{-1}$
- Cogeneration heat - 0.28 $kgCO_2 \cdot kWh^{-1}$ (referred to thermal energy)
- Fuel - Fuel mix for thermal applications 0.23 $kgCO_2 \cdot kWh^{-1}$ (HHV)

3. Results and discussion

Figure 4 and Table 7. include main results of the methodology application to three districts of the Valencian region (C.V) under the scenario BIOPTION described in **¡Error! No se encuentra el origen de la referencia.**. Figure 4 shows an example of the 20 best locations for one district and Table 12 describes quantity and main properties of biomass resources, potential local demand (biomass consumers), basic characteristics of potential biomass plants for the three districts, and economic and CO_2 savings analysis.

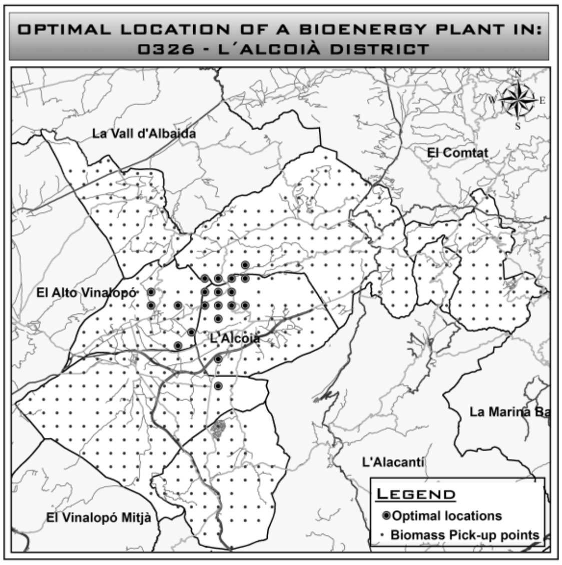

Figure 4. Optimal biomass plant locations for district 0326 -El Comtat.

Table 7.
Main results of methodology application for three districts of C.V.

Identification and general results at district level			
District code - name	0326 - El Comtat	0327 - L'Alcoià	4623 - La Costera
District total area, km^2	377,8	539,7	528,3
Biomass, $kt \cdot year^{-1}$	19.38	25.36	24.00
Biomass, $t \cdot h^{-1}$ - 5000 $h \cdot year^{-1}$	3,9	5,1	4,8
Average LHV, $kWh \cdot kg^{-1}$	2,82	2,98	2,97
Ash content, % dry basis	1,5%	2,6%	2,1%
Mean transport distance, km	11,5	16,7	23,3
Transport cost, $€ \cdot t^{-1}$	16,9	17,2	18,5
Local demand, % of self-consumed biomass	74%	68%	14%
Potential cogeneration sites	11	7	-
Application BP1. Pellet production plant			
Pellet production, $kt \cdot year^{-1}$	11.5	15.09	14.28
Specific investment, $k€ \cdot t^{-1} \cdot h^{-1}$	873	763	785

Simple payback period_BP1, year	7,2	6,5	7,0
CO_2 savings_BP1, kg $CO_2 \cdot t^{-1}$ of biomass	525	524	513
Application BP2. Power plant – Fluid bed biomass gasifier with IC engine			
Rated power, MW - 5000 $h \cdot year^{-1}$	3,10	4,20	4,1
Electric efficiency, %LHV	30,8%	31,7%	31,5%
Specific investment, $k€ \cdot kW^{-1}$	2.28	2.02	2.07
Specific investment, $M€ \cdot t^{-1} \cdot h^{-1}$	1.82	1.67	1.71
Simple payback period_BP2, year	9,9	8,5	8,9
CO_2 savings_BP2, kg $CO_2 \cdot t^{-1}$ of biomass	334	345	346
Simple payback period_BP2 (+CHP), year	7,0	6,1	6,4
CO_2 savings_BP2 (+CHP), kg $CO_2 \cdot t^{-1}$ of biomass	602	623	612

In these three districts both applications, pellet or power plant, could be possible but in district 4623 low potential local demand of biomass (only 14% of self-consumption) would provide higher distribution costs, so it will be advisable to install a power plant. In this district potential cogeneration sites have not been detected so it should be a power only plant.

In district 0326 and 0327 high number of potential cogeneration sites (11 and 7 respectivelly) makes this application highly promising. It is interesting to notice that, however the main part of benefits comes from electricity sold to the grid, cogeneration applications reduce payback period from 8.5 - 10 years (for power only application) to 6 - 7 years. As expected according to technology characterization, higher plant size increases economic feasibility.

For district 0326 and 0327, low average ash content (<3%) and high potential for self consumption of biomass (74% and 68% respectively) make advisable the installation of a pellet plant. Specific investment in district 0327 would be 13-15% lower than 0326 due to higher biomass plant size, and expected payback period would be almost 10% shorter.

For biomass plants in the range 19 – 25 $kt \cdot year^{-1}$ and transport distances of 13.5-23.3 km, it is observed that, from an economic point of view, cogeneration plant payback period is the shorter one (around 6.1 – 7 year), followed by pellet plants (6.5 – 7.2 years) and, in last position, the power-only plant with an expected payback period of around 8 – 10 years (for power plants in the range 3 – 5 MW).

Regarding CO_2 savings the magnitude is the same and it can be concluded that for cogenerations plants the CO_2 savings are 600 – 625 kg $CO_2 \cdot t^{-1}$ of biomass (with 35 – 40% moisture), a 15 – 20 % higher than for pellet plant application and almost two times the CO_2 saving provided by a power-only power plant.

4. Conclusions

A methodology to optimize distributed biomass resources management and energy use has been developed, where logistics is a main factor but other features are also analyzed: biomass resources properties , plant size effect, CO_2 savings, economic feasibility, technologies costs, efficiency and restrictions, and potential biofuel consumers. This methodology provides quantification and characterization of biomass resources, a list of optimal locations from transport cost point of view, and basic economic, technical and CO_2 savings analysis of the different energy use options. The methodology is structured in different modules, and inside these modules there are many functions and constants that can be easily identified, modified or extended.

It has been observed that biomass compaction previous to transport reduces specific cost and CO_2 emissions of this operation, even for short distances. An analysis performed in Spain, for three districts of the Valencian community showed that biomass plant size and heat recovery, in cogeneration applications, increase the economic feasibility reducing payback periods in a 25 – 30%. Suitability for cogeneration applications can present big differences between areas under study because for these applications it is necessary to find a potential site for heat recovery (i.e. industry with high thermal needs). Cogeneration applications are, usually, optimal solutions from both CO_2 savings and economic feasibility point of view.

Pellet plant production becomes more feasible when most of the pellet production can be self-consumed in the area under study, in this case quantification of potential demand for pellets becomes an important parameter for final decision. In the analysis performed in the Valencian community the potential pellet self-consumption can also vary very much from less than 20% to 100% according to local conditions.

Acknowledgements

This work was completed in the framework of the activities of the biomass research group of the the IIE (Instituto de Ingeniería Energética) in regional, national and international. The authors deeply thank all the organizations involved in these projects for their support and, specially, IMPIVA-Generalitat Valenciana , the Spanish Ministry of Science and Technology and the European Commission for the projects BIOVAL, BIODER and EU-DEEP respectively, for the provided funding that made this work possible.

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