METHODOLOGY TO EVALUATE THE FEASIBILITY OF LOCAL BIOMASS RESOURCES AS A FUEL FOR BUILDING BOILERS. APPLICATION TO A MEDITERRANEAN AREA

David Alfonso-Solar[1], Carlos Vargas-Salgado[2], Elías Hurtado-Pérez[2], Paula Bastida-Molina[1]

[1]Instituto de Ingeniería Energética, Universitat Politècnica de València, Camino de Vera, s/n, edificio 8E, acceso F, 2ª planta. 46022 Valencia (España), paubasmo@etsid.upv.es

[2]Department of Electrical Engineering, Universitat Politècnica de València, Spain. carvarsa@upvnet.upv.es

ABSTRACT

The massive implementation of distributed energy resources based on biofuels requires a complex methodology to assess the optimal energy valorization options and economic feasibility. This paper has focused on producing pellets for boilers. The work focuses on the residential and commercial sectors. To consume local biomass, it must be considered the availability of potential customers, biomass availability, properties, and dispersion to evaluate transport cost. The developed methodology was applied to three different counties of the Valencian Community (typical of Mediterranean areas). Biomass resources for different counties have been quantified and characterized regarding key issues as heating value and ash content. Considering every evaluated area (the typical total area in the range 600 to 1800 km2) as a biomass management unit, the impact of pellet production plant size and biomass transport costs for three different counties was evaluated. However, different balances between biomass resources availability and self-consumption potentials are obtained, the economic feasibility of pellet plants was acceptable in the three cases with payback periods from 5 to 6 years.

Keywords: Renewable energy, Biomass, Pellet, Cogeneration, Distributed Energy Resources.

INTRODUCTION

The massive implementation of distributed energy resources is a key strategy to increase energy efficiency and reliability of supply. Biomass applications imply large savings in harmful emissions to the atmosphere taking advantage of local resources, sustainably, with competitive costs. The rapid deployment of biomass installations requires the development of a general methodology to:

- Evaluate the quantity, quality, and availability of these residues in the area of interest.
- Determine demand segmentation and identification of segments with high potential to use biofuels (pellets, wood chips)
- Develop an optimal logistic strategy to minimize the harvesting, collecting, and distribution costs and environmental impact.
- Analyze available technologies for biomass pretreatment (drying, grinding, and densification) and combined heat and power generation.

This methodology is based on the figure of the transfer centers. These installations are located in strategic points to optimize the logistic process and present different morphologies; they include storage areas and have a pretreatment system and/or a cogeneration system. In these centers, biomass can be converted into electricity, heat and /or standardized biofuels (pellets).

Cogeneration systems can cover the biomass pretreatment process's thermal and electrical needs (drying, grinding, pelletization) (Zailan, *et al*., 2021) When installed in the transfer center, there are several advantages because biomass is a heterogeneous resource. There are many types with different properties; it is possible to produce standard biofuels with higher quality biomass (i.e., low ash content) and consume low-quality biomass in the cogeneration system to produce valuable energy products as heat and electricity with competitive costs.

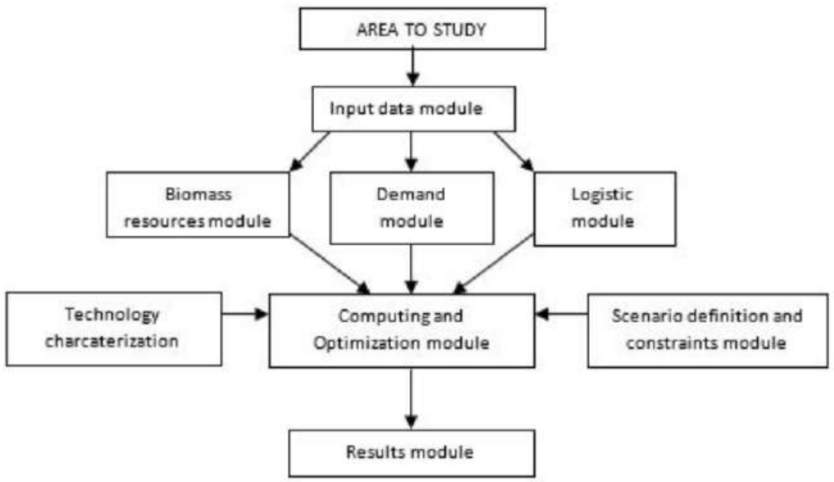

Figure 1: Scheme of methodology to assess the optimal energy valorization of biomass resources.

Technology, energy and environment in construction

METHODOLOGY

The methodology is being implemented using Geographic Information Systems software and is structured in eight modules, as described in Fig 1. In the next paragraphs, the global approach and the different modules are described.

Input data module

This module must introduce the cartographic data regarding urban areas, agricultural areas and crops, forest areas, industrial activities areas, municipalities divisions, and road networks. Statistical data for each municipality regarding population, type of dwelling, services, and industrial activities will also be employed and represented geographically. Standard data formats for this module are fixed due to current data availability, format, and accuracy.

Biomass resources module

Biomass sources initially considered in the analysis are forestry, agricultural crops, and some related industries' wastes. Quantification of Biomass resources is performed by generation ratios (tonne residues per Ha, tonne residues per tonne of product, or tonne residues per k€ of turnover) and represented in the map using cartographic and statistical data. Characterization of Biomass (i.e., Higher heating value, composition, moisture, and ash content) is assessed using European databases (TNO 2021., Reisinger,1995) from previous projects, sectorial studies, and additional laboratory analysis. The geographic location of biomass residues is performed using a resolution of 1-km2 pixel (for superficial generation), and seasonality is evaluated monthly according to typical labor operations during the year for each crop (for agricultural wastes) and typical production cycles for each crop industry.

This module defines the availability of each type of biomass, being important to consider that some biomass types as cereal straw can present low availability (Passalacqua *et al*., 2004) (20 45% from total waste production) because it is being used for animal feeding and bedding.

Demand module

Potential demand segments or typical customers must be defined (hospitals, individual houses, blocks of apartments, industries, etc.). According to statistical and cartographic data of municipalities, these demand points are fixed on the map (mainly urban areas and industrial areas). These points will be used to compute biofuel distribution distances to final users. Further grouping of these segments is considered according to the size of installable thermal or cogeneration applications because it can be related to biomass quality. Typically, small customers (residential and small commercial) segments require high-quality biofuels (low ash, sodium, chlorine, and sulfur content). Large customers can also use lower-quality biofuels to deal with ash disposal, gas cleaning, and maintenance requirements. According to several manufacturer's catalogs, boilers for thermal or cogeneration applications can be classified in the ranges summarized in Table 1.

Demand calculations are based on statistics of consumptions per household and the type of energy to supply (electricity or fuel) of the boiler (Alfonso *et al*.,2009; Perpiñá *et al*.,2008; Roni, 2019; Graham *et al*.,2001; Sun *et al*., 2020).

Boiler size (kW)	Segments	Biofuel quality needs (pellets)
<100	Residential and small commercial customers	High Quality (i.e ash content < 1% in dry basis)
100 to 2,000	Medium/Large commercial segments and small industrial customers	Medium quality (i.e. ash content 1 – 3 %)
>2,000	Medium/large industrial customers and district heating plants.	Low quality (i.e. ash content 3 – 6 %)

Table 1. Relation between boiler size, typical demand segment, and biofuel quality needs

Logistic module

According to 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 fixed by the restrictions of the scenario (i.e., present power plants, hospitals, industrial customers, etc.) by applying an algorithm of minimization of transport costs (according to transport time and distances) to define the optimum destination for a covered area. Typically, biomass transport cost function boiler (Alfonso *et al*.,2009; Perpiñá *et al*.,2008; Graham *et al*., 2001) BTC (€/tonne), is composed of fixed costs, FC (€/tonne), distance-dependent costs, DC (€/tonne-km), and time-dependent costs, TC (€/tonne-hour), as defined by equation 1:

$$BTC\ (x,y) = FC + DC \cdot Distance\ (x,y) + TC \cdot Time\ (x,y) \qquad (1)$$

Technology, energy and environment in construction

Technology characterization module

Pretreatment technologies. Pellet plant

The pretreatment plants can produce pellets in a general approach and be composed of drying, grinding, pelleting and cooling systems, peripheral equipment, storage facilities, and other general facilities. These pelleting plants are characterized according to bibliography from an economic and energy needs point of view, by several functions (Zailan ,2021) for each technology as Installation cost, IC1(B) (€ per tonne/h), specific Energy consumption, EElectricity and Efuel (kWh/tonne) and specific Operation and Maintenance costs of the whole plant, OMC1(B) (€/tonne). These functions can be constants or considered a function of the plant capacity, B, measured in terms of the hourly amount of managed raw biomass (tonne/h). In Fig 2 it has been represented the function IC1(B) for the different systems and the total pelleting plant installation cost TIC1(B), and function OMC1(B) considering biomass with 40% moisture, continuous operation, and 3,200 h/year of operation.

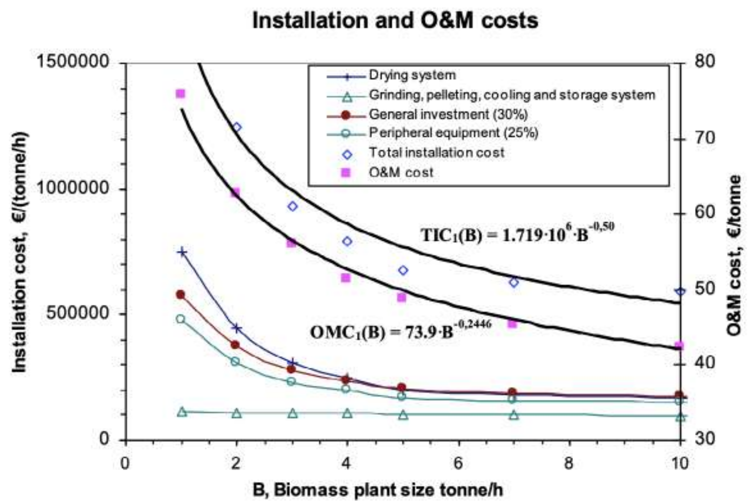

Figure 1: Biomass pelleting plant-specific Installation and O&M costs as a function of the plant size (Alfonso *et al*.,2009; Perpiñá *et al*.,2008)

Scenario definition and constraints module

The scenario definition is represented by a set of constraints to be considered in the optimization process. Inside this module, there is a complete list of possible scenarios to be analyzed but, before simulating the selected scenario, a basic pre-selection of suitable scenarios is made automatically. Both pre-selection and detailed simulations of the selected scenarios are performed in the computing and optimization module, so there is an initial interaction between these two modules. Table 2 describes two scenarios of the methodology.

Scenario	Description and constraints
AGRIPELLET	Only biomass from agricultural crops. Transport distance<25km and optimum destinations. Pellets as the unique energy product
BIOCOMBI	Biomass from agricultural crops, forestry, and related industries. Transport distance<30 km and optimum destinations.

Table 2. Description and constraints of main scenarios of the methodology
For specific feasibility analysis in the following points, it was selected the BIOCOMBI scenario.

Computing and Optimization module

The main optimization computing can be performed based on economic suitability or efficiency and CO2 savings; the first is described below.

Economic optimization is an iterative process based on computing the payback period of the transfer center for each y possible location (as a general approach, it is considered one iteration per 1-km2 pixel of the analyzed area). The payback period is computed, as described in Equations 2 to 4, with the total installation costs of the transfer center, generally TIC1 and TIC2 (€), total O&M cost, TOMC (k€/year), total raw biomass cost, TRBC (k€/year), total biomass transport cost, TBTC (k€/year) and energy products revenues, EPROD (k€/year).

$$\text{PAYBACK PERIOD}_y = \frac{\text{TIC}_1(B) + \text{TIC}_2(B)}{\text{EPROD - TRBC - TBTC - TOMC}(B)} \tag{2}$$

$$\text{TBTC}_y = \sum_x \text{BTC(x,y)} \tag{3}$$

$$\text{TOMC}(B) = \text{B}\cdot 3200\,\frac{\text{hours}}{\text{year}}\,[\text{OMC}_1(B) + \text{OMC}_2(B)] \tag{4}$$

It can be observed that the main variable for the economic optimizations is the size of the plant, B (tonne/h of raw biomass). It is important to notice that usually, B is a function of distance concerning the destination point. So length has two opposite effects: on the one hand, a higher radius provides higher B, so specific installation costs are lower, but on the other hand, a higher radius provide higher biomass transport costs so that the methodology will provide a unique optimum solution for a certain B and maximum transport distance.

Technology, energy and environment in construction

RESULTS MODULE

This module shows the results for the selected scenarios; typically, the main results are:

- Plant localization and size (tonne of biomass per year)
- Main biomass types and properties (average and specific for each type).
- Selected Technologies: Installation costs and O&M costs, pellet production
- Economic feasibility

IDENTIFICATION AND GENERAL RESULTS AT THE DISTRICT LEVEL			
County code	4600G01	4617	4620
County name	L´Horta	La Plana de Utiel-Requena	La Ribera Alta
County total area, km^2	620	1721	970
Biomass, kt·year^{-1}	51,667	77,088	64,574
Biomass, t·h^{-1}- 5000 h·year^{-1}	16.1	24.1	20.2
Average LHV, kWh·kg^{-1}	2.90	3.10	2.96
Ash content, % dry basis	6.9%	2.9%	1.9%
Mean transport distance, km	16.79	23.1	16.99
Transport cost, €·t^{-1}	20.53	24.3	20.40
Local demand, % of self-consumed biomass	304%	3%	63%
APPLICATION BP1. PELLET PRODUCTION PLANT			
Pellet production, kt·year-1	3,3225.90	49,075.43	40,125.56
Specific investment, k€·t-1·h-1	394.7	326.4	360.0
Simple payback period_BP1, year	5.8	5.1	5.3
CO2 savings_BP1, kg CO2 ·kWh^{-1} of raw biomass [**]	0.191	0.176	0.181

[**] CO2 savings based on boiler fuel substitution (mainly natural gas/diesel fuel). It has been taken into account CO2 emissions due to biomass transport, collection and pelletization process (Alfonso *et al.*,2009; Perpiñá *et al.*,2008).
Table 3. Main results of methodology application for three districts of C.V.

CONCLUSION

Distributed Biomass resources management requires a complex multicriteria methodology where logistic strategy is the main factor in performing the optimization for a selected scenario. However, other features must also be considered: scale, cogeneration system capabilities, biomass availability, and properties and potential consumers.

A methodology fulfilling all these requirements has been developed. It is based on flexible biomass transfer centers with multiple possible energy products as biofuels, electricity, and heat.

Preliminary application of the methodology showed big differences between counties, from counties with high demand as 4,600 L´Horta (grouped small counties around Valencia city) but without including city demand) which could consume three times the available biomass, to big counties as 4,620 La Plana de Utiel-Requena, with high biomass availability (due to the higher agricultural/forestry sources) but with very limited demand so consuming only 3% of available biomass. Using the county as management, biomass properties, quantity, and feasibility analysis for pellet production plants were adequate.

REFERENCES

"**Chemical Engineering** : BIOBIB." https://www.vt.tuwien.ac.at/biobib/EN/ (accessed Jul. 28, 2021).

C. Perpiñá, D. Alfonso, Á. Pérez-Navarro, E. Peñalvo, C. Vargas, and R. Cárdenas, "METHODOLOGY GIS-BASED FOR BIOMASS LOGISTIC AND TRANSPORT OPTIMISATION."

D. Alfonso, C. Perpiñá, A. Pérez-Navarro, E. Peñalvo, C. Vargas, and R. Cárdenas, "Methodology for optimization of distributed biomass resources evaluation, management and final energy use," Biomass and Bioenergy, vol. 33, no. 8, pp. 1070–1079, 2009, doi: 10.1016/j. biombioe.2009.04.002.

F. Passalacqua *et al.*, "Pellets in southern Europe. The state of the art of pellets utilisation in southern Europe. New perspectives of pellets from agri-residues.," 2nd World Conference on Biomass for Energy, Industry and Climate Protection, no. June 2014, p. 5, 2004.

G. Thek and I. Obernberger, "Wood pellet production costs under Austrian and in comparison to Swedish framework conditions," Biomass and Bioenergy, vol. 27, no. 6, pp. 671–693, 2004, doi: 10.1016/j.biombioe.2003.07.007.

M. S. Roni, D. N. Thompson, and D. S. Hartley, "Distributed biomass supply chain cost optimization to evaluate multiple feedstocks for a biorefinery," Applied Energy, vol. 254, no. July, p. 113660, 2019, doi: 10.1016/j.apenergy.2019.113660.

O. Sun and N. Fan, "A Review on Optimization Methods for Biomass Supply Chain: Models and Algorithms, Sustainable Issues, and Challenges and Opportunities," Process Integration and Optimization for Sustainability, vol. 4, no. 3, pp. 203–226, 2020, doi: 10.1007/s41660- 020-00108-9.

"**Phyllis2**- Database for the physico-chemical composition of (treated) lignocellulosic biomass, microand macroalgae, various feedstocks for biogas production and biochar." https://phyllis.nl/ (accessed Jul. 28, 2021).

R. L. Graham, B. C. English, and C. E. Noon, "A Geographic Information System-based modeling system for evaluating the cost of delivered energy crop feedstock," Biomass and Bioenergy, vol. 18, no. 4, pp. 309–329, 2000, doi: 10.1016/S0961-9534(99)00098-7.

R. Zailan, J. S. Lim, Z. A. Manan, S. R. W. Alwi, B. Mohammadi-ivatloo, and K. Jamaluddin, "Malaysia scenario of biomass supply chain-cogeneration system and optimization modeling development: A review," Renewable and Sustainable Energy Reviews, vol. 148, no. June, p. 111289, 2021, doi: 10.1016/j.rser.2021.111289.