Biomass Energy Potential for Bio-smart Metropolitan Area (BMA) in Southern Europe

J.P. Paredes-Sánchez[1]

[1] Corresponding author: Department of Energy, University of Oviedo, Oviedo, Asturias (Spain), C/ Independencia 13, 33004,
e-mail: paredespablo@uniovi.es, tfno.:+34 985 10 43 05.

Abstract

Purpose

The development of modern cities in Europe favours the formation of metropolitan areas where waste management is one of the most visible environmental problems. Waste Management System (WMS) is sustainable when it is capable of maintaining environmental protection over time. Biomass such as wastes and by-products from forestry and agriculture, among others, can be converted to biofuels. The aim of this work is to present the Bio-smart Metropolitan Area (BMA) as a conceptual view of a modern city that promotes the biomass use for energy purposes from Biomass Logistic Centres (BLCs). A case study is applied to Metropolitan Area of Barcelona (MAB) (Spain).

Methods

This study has assessed the available biomass residue supply and the management to maximize the biomass availability for bioenergy. The methodology used for the evaluation of the residue mass, energy and costs incurred in the collection and transport is based on BIORAISE GIS software. The principles and parameters of the analysis model are outlined.

Results

The total available residues amount to 515 dry kt/year, equivalent to 9,142 TJ/year which generates 944 kt/year of CO_2 neutral emissions. The results show that it is possible to get supply of biomass for energy from residues in the MAB.

Conclusions

The present work improves optimization in the assessment and use of biomass residues in accordance with the safety and environmental requirements for waste management in a BMA. It is possible to implement a BLC for solid biofuels production in the MAB.

Keywords: biomass, bioenergy, Biomass Logistic Centre (BLC), Bio-smart Metropolitan Area (BMA), waste management.

Introduction

Biomass is expected to make an important contribution to the European Union (EU) energy and climate targets by 2020, where 20% of energy consumed in the EU should be based on renewable energy sources with an estimated two-thirds of this biomass-derived [1]. More than two-thirds of the population of Europe lives in urban areas [2]. Key development challenges in metropolitan areas of Europe are to meet an energy demand and ensure both the security and sustainability of energy supply.

Biomass, whether it is from forest or agricultural sources, plays a relevant role in meeting these challenges and decreasing CO_2 emission in relation to climate change. Sustainable development is about people: their economic and social needs as well as environmental conservation. Waste management involves the activities of collection and treatment, either to recover materials and reintroduce them to the production cycle in order to obtain energy, or to deposit them in safe environmental conditions.

Waste Management System (WMS) includes management operations that contributes positively to the conservation of resources. The potential of energy could provide a thorough understanding of the sources production. The Geographic Information System (GIS) may be considered one of the best tools to enable and facilitate this target [3]. Biomass residues in particular have the potential to become a significant primary energy source [4], where wood residues can be used for making solid biofuels, such as pellets [5]. Solid biofuels are widely used for heating in households and in both commercial and public buildings [6]. The use of the indigenous biomass residues in a metropolitan area as an alternative to fossil fuels defines the new concept of Bio-smart Metropolitan Area (BMA).

The Metropolitan Area of Barcelona (MAB), located in the north-east of Spain, is one of the most populated areas in Europe and 48% of the 636 km^2 which its territory comprises is built area. More than 25,000 hectares of natural areas take the rest of the land [7]. No studies have been conducted in this metropolitan area or its regional surroundings in terms of size of the waste stream of biomass for energy purposes in connection with the technical and environmental restrictions within the concept of BMA. The provincial territory of Barcelona is considered as study area because of its influence and potential supply of biomass residues for the MAB, Fig. 1.

Fig. 1 Characterization of the provincial study area and Metropolitan Area of Barcelona (MAB)

The novelty of this work is to bridge the gap between biomass resources and costs to design a framework for effective decision making in the bioenergy management in a BMA. The main objective of this paper is to evaluate the biomass residues and the bioenergy, in accordance with BMA concept, for the MAB in the Barcelona province.

Materials and Methods

Several studies depict methodologies to quantify the potential biomass from study areas. The characterization depends on the variables used, such as: (i) mass production parameters, (ii) accessibility and ecological factors, and techno-economic suitability by production costs. The combination of these aspects can lead to an accurate GIS estimation of potential biomass, according to local specificities such as geographical structure, waste management and economic conditions [8]. There are some studies, based on GIS, carried out to determine the biomass management in a territory [9-12].

BIORAISE GIS tool from the Research Centre for Energy, Environment and Technology (CIEMAT) has been used for the evaluation of biomass in the study area. The BIORAISE GIS tool allows us to obtain the residue mass, energy and cost in a collection area, its energy content and the production costs incurred in collection and transportation [13].

The biomass residues have been calculated taking the collection area within the provincial borders into consideration. The geometric center of the province has been taken as a collection point to supply biomass for the MAB [2]. This point can be defined by its coordinates in EPSG:900913 WGS84 Mercator. The collection point is considered the location of a Biomass Logistic Centre (BLC). These biomass residues can then be further processed to produce bioenergy or biofuels.

a) Available mass

The calculation method is based on the European cartography of land uses Corine Land Cover (CLC), Mean Annual Productivity Values (MAPV) and production data of residual biomass from the BIORAISE GIS software. The forestry data have been obtained from the National Forest Inventory (NFI). The agricultural data for productions and surfaces are from the EUROSTAT Regional Statistics. The considered biomass resources, wastes and by-products, have been produced in the agricultural and forestry sector. Agricultural and forest field residues are considered to be those biomass produced in crop lands and forests. Agricultural residues can be divided into two categories: herbaceous residues and woody residues. Herbaceous residues are considered to be those crop residues which remain in the field after the crop is harvested; their nature is diverse according to crop type or harvesting method. Woody residues are produced as a result of pruning and regenerating of orchards, vineyards and olive groves. Forest residues consist of branches and tops, including leaves, obtained from cleaning, thinning and felling operations. The annual available quantities were evaluated in terms of dry tonne (dry t/year) because the moisture content in the residue is variable [13].

The Mass of Total Residue (MTR) in the collection area is the biomass residue from forest and agricultural management production from BIORAISE GIS database, Equation 1.

$$\mathrm{MTR} = \sum \mathrm{m_i} \cdot \mathrm{A_i} \qquad (1)$$

where MTR is the total mass (dry t/year), A_i represents the existence area of residues i (ha) and m_i is the annual amount of biomass (dry t/ ha year).

The Mass of Available Residue (MAR) is calculated by the analysis model of BIORASE GIS software, which considers techno-economical and environmental restrictions. Techno-economical factors derive from the management methods to collect the raw material and from the different operations. Environmental parameters can also limit the quantities of harvestable biomass; limitations like the slope, the erosion risk and the needs of organic carbon content in topsoil. The MAR is the recoverable mass to be energetically exploited under those constraints, obtained from existing and recoverable one (MTR). The relationship between MAR and MTR defines the Useful Factor (UF), Equation 2.

$$\mathrm{MAR} = \mathrm{MTR} \cdot \mathrm{UF} \qquad (2)$$

where MAR is the available mass (dry t/year), MTR is the total mass (dry t/year) and UF is a dimensionless parameter. The parameter UF can be expressed as a percentage.

b) Available bioenergy

The Bioenergy Potential (BP) can be defined as the expected energy production from the MAR obtained as described in the previous section. It represents the total amount of energy from the considered biomass residues that is available for bioenergy purposes. Equation 3 is used for the estimation of the energy from residual biomass is the following:

$$\mathrm{BP} = \mathrm{MAR} \cdot \mathrm{LHV} \qquad (3)$$

where LHV represents the Lower Heating Value (GJ/ dry t), data for the latter variable corresponding to the type of residues considered in the present work from BIORAISE GIS database.

c) Production costs

The Collection Cost (Cc) is the cost of the MAR. Collection cost of the MAR includes harvesting and conditioning. The Transportation Cost (Ct) is the cost of the MAR transported to the collection point. Transportation cost includes driver, vehicle and fuel, for the latter, a diesel average price of 1 EUR l.45/l is assumed.

The total cost (TC) of the MAR is the sum of the collection (Cc) and transportation (Ct) costs, Equation 4.

$$\mathrm{TC} = \mathrm{Cc} + \mathrm{Ct} \qquad (4)$$

where TC is total cost (EUR/dry t), Cc is the collection cost (EUR/dry t) and Ct is the transportation cost (EUR/dry t) [14].

Results and Discussion

The BIORAISE GIS software has been used to determine the available residues. The most difficult component of setting up a WMS for biomass residue in a BLC is establishing the mechanism to bring enough residues to a central point for conversion to bioenergy. Table 1 shows the mass and energy of the considered residues in the collection area.

Table 1 Mass and energy of the residues in the collection area

Biomass Type	Mass of Total Residue (MTR) (dry t/year)	Mass of Available Residue (MAR) (dry t/year)	Useful Factor (UF)	Bioenergy Potential (BP) (GJ/year)
Rainfed	533,412	169,951	0.32	2,902,516
Irrigated	78,997	63,152	0.80	1,064,898
Vineyard	74,545	59,746	0.80	1,062,078
Orchards	8,965	7,147	0.80	122,330
Olive	957	769	0.80	13,741
Dehesas with annual crops	51	38	0.74	649
Broadleaves	75,368	35,920	0.48	633,668
Conifers	238,507	118,576	0.50	2,248,200
Mix conifers-broadleaves	66,344	35,198	0.53	644,136
Shrubs	51,626	24,091	0.47	449,654
Total	1,128,771	514,587	-	9,141,868

The main residues produced are rainfed and conifers. Rainfed residues represent 170 dry kt/year, equivalent to 2,902 TJ/year. Dehesas with annual crops and olive residues produce smaller amounts. The average UF in the collection area is 46%. Table 2 shows the involved costs of the defined residues in the study area.

Table 2 Biomass costs in the collection area.

Biomass Type	Collection Cost (Cc) (EUR/dry t)	Transportation Cost (Ct) (EUR/dry t)	Total Cost (TC) (EUR/dry t)
Rainfed	23.28	17.08	40.36
Irrigated	7.00	17.83	24.83
Vineyard	37.79	19.32	57.11
Orchards	30.53	17.44	47.97
Olive	37.79	18.51	56.30
Dehesas with annual crops	34,16	18.23	52.39
Broadleaves	66.35	21.52	87.87
Conifers	51.38	19.07	70.45
Mix conifers-broadleaves	61.43	19.62	81.05
Shrubs	37.04	19.33	56.37

Wood fuels are often found to have lower environmental impacts when compared to functionally equivalent from fossil or mineral resources [15]. The TC of the forest residues delivered to the plant is under 88 EUR/dry t. Biomass residues can be used to produce biofuels [2, 16]. In addition, the TC in the conifer residues and mix conifer-broadleaves is below 83 EUR/dry t, which is a viable cost of wood biomass feedstock at the door of a pellet plant gate in Europe [17].

Conclusions

The study area generates large amounts of these resources, suitable for both recovery and energy assessment, taking into account environmental and techno-economical restrictions. The high amount of biomass available from agriculture and forestry may constitute an important resource for bioenergy that could contribute significantly to the total energy supply as fuel in the MAB. BIORAISE GIS software calculates the available mass of the residues by taking into account the waste management operations of the collection area under techno-economical and environmental constraints, with a collection efficiency over 32%. The study indicates that the total amount of residue is 1,129 dry kt/year in the study area. The total available residues amount to 515 dry kt/year, equivalent to 9,142 TJ/year which generates 944 kt/year of CO_2 neutral emissions. The results make it possible to implement a BLC for solid biofuels production in order to optimize the conversion and use of biomass residues in the MAB. Therefore, MAB may be considered viable as BMA.

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