Applied Energy xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Methodology for estimating biomass energy potential and its application to Colombia

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HIGHLIGHTS

- Methodology to estimate the biomass energy potential and its uncertainty at a country level.
- Harmonization of approaches and assumptions in existing assessment studies.
- The theoretical and technical biomass energy potential in Colombia are estimated in 2010.

ARTICLE INFO

Article history:
Received 25 October 2013
Received in revised form 2 July 2014
Accepted 3 July 2014
Available online xxxx

Keywords:
Bio-energy
Biomass
Energy potential
Review
Colombia
Estimation

ABSTRACT

This paper presents a methodology to estimate the biomass energy potential and its associated uncertainty at a country level when quality and availability of data are limited. The current biomass energy potential in Colombia is assessed following the proposed methodology and results are compared to existing assessment studies.

The proposed methodology is a bottom-up resource-focused approach with statistical analysis that uses a Monte Carlo algorithm to stochastically estimate the theoretical and the technical biomass energy potential. The paper also includes a proposed approach to quantify uncertainty combining a probabilistic propagation of uncertainty, a sensitivity analysis and a set of disaggregated sub-models to estimate reliability of predictions and reduce the associated uncertainty. Results predict a theoretical energy potential of 0.744 EJ and a technical potential of 0.059 EJ in 2010, which might account for 1.2% of the annual primary energy production (4.93 EJ).

1. Introduction

Global interest on biomass as the largest renewable resource today [1] with the potential to reduce dependency on fossil fuels and decrease greenhouse gas emissions continues to grow. Today biomass is primarily used in developing countries as an energy source for cooking and heating. To a lesser extent, biomass is employed in industrialized countries to supply heat, combined heat and power (CHP) and biofuels. In the future, biomass demand is likely to increase as population grows, cost-effective technologies become available and various countries promote policy mechanisms [1–3]. However, significant challenges need to be addressed to make use of biomass and bioenergy. Hurdles include land use competition, direct and indirect land-use change, deforestation, crops for food vs. biofuels, pressure on water resources, etc.

In order to ensure a sustainable exploitation of biomass resources in the future, governmental and industrial efforts will be required in developing countries and emerging economies in Africa, Asia and Latin America. These efforts include diffusing best agricultural practices, modernizing agriculture and bioenergy technology, as well as promoting national and regional policies [4]. It is therefore essential to formulate well-structured and strategic approaches to exploit biomass resources. This paper deals with one of the critical challenges to exploit biomass in a country: how to estimate the current biomass energy potential. This challenge is further complicated in developing countries where availability and quality of data is limited. This paper presents a methodology to estimate the biomass energy potential and its associated uncertainty at a country level when availability and

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http://dx.doi.org/10.1016/j.apenergy.2014.07.004
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Nomenclature

Abbreviations

CHP	combined heat and power
CI	confidence interval
EUD	extended uniform distribution
FFB	fresh fruit bunch
MSW	municipal solid waste
R&D	research and development
UPME	Unidad de Planeación Minero Energética

Symbols

a	availability factor
b	biogas yield from manure
c	by-product to product ratio in forestry
d	dry basis
f	manure production per head
k	by-product to product ratio in agriculture
H	heads, animal stocks
HHV	higher heating value
LHV	lower heating value
M	moisture content
N	number of references
P	production
Q	theoretical energy potential
Q^T	technical energy potential
w	wet basis
$\bar{x}$	mean of x
$\propto$	constraint factor to calculate availability
β	width factor for EUD distribution
σ	standard deviation
η	energy efficiency
ρ	density

Subscript

AR	agricultural residue
AW	animal waste
$current$	state-of-the-art technology
F	forestry
i	i-th agricultural crop
j	j-th residue for each i-th agricultural crop
m	m-th type of animal
$modern$	future technology
n	n-th sub-category of type of animal
r	r-th forestry resource
s	s-th biofuel
x	x-th type of urban waste
U	urban waste

quality of data are limited. It is therefore an extension of the methodology proposed by authors to estimate the current biomass energy potential at a country level in Ref. [5], and it also relates to a methodology published by authors to assess the future biomass energy potential in a country [6]. The proposed methodology is a bottom-up resource-focused approach with statistical analysis that uses a Monte Carlo algorithm to stochastically estimate the theoretical and the technical biomass energy potential. It includes a proposed approach to quantify uncertainty combining a probabilistic propagation of uncertainty, a sensitivity analysis and a set of disaggregated sub-models to estimate reliability of predictions and reduce the associated uncertainty. The current biomass energy potential in Colombia is assessed following the proposed methodology and results are compared to existing assessment studies.

Potential advantages of the proposed methodology include transparency, reproducibility, low cost and possible adaptability to analyze other countries. This paper is structured as follows: Section 2 presents a literature review of state-of-the-art methodologies to assess biomass energy and address uncertainty. Section 3 describes the proposed methodology, while Section 4 presents the application of the proposed methodology to the case study of Colombia. Finally, conclusions and recommendations are presented in Section 5.

2. Literature review

2.1. State-of-the-art methodologies

Detailed comparison of approaches, methodologies, key drivers and results of state-of-the-art biomass energy assessment for different countries are provided by Batidzirai et al. [7], Heistermann et al. [8], Berndes et al. [9], Gnansounou and Panichelli [10] and Van Schrojenstein Lantman et al. [11]. Batidzirai et al. [7] suggest three key elements to categorize state-of-the-art assessments: the type of potential, the type of approach and the type of methodology. Four types of potentials exist, namely theoretical potential (maximum amount of biomass), technical potential (fraction of the theoretical potential available at current conditions and constraints), the ecologically sustainable potential (fraction of technical potential under restrictions related to nature conservation and preservation of soil, water and biodiversity) and market potential (fraction of the technical potential that satisfies certain economic criteria). Similarly, three types of approaches are identified: resource-focused, demand-driven and integrated. While resource-focused approaches estimate the overall biomass resources and competition among different uses, demand-driven assessments investigate the cost competitiveness of biomass and bioenergy systems and evaluate biomass supply to meet exogenous targets. Integrated approaches combine features of both approaches and offer the possibility to evaluate multiple sustainability aspects. Finally, various types of methodologies are employed depending on the type of approach. Two main types of methodologies are commonly employed in resource-focused approaches as defined by Batidzirai et al. [7]:

- Statistical analysis (non-spatial specific): it relies on statistical data to estimate the availability of biomass for energy conversion and other uses. Advantages include simplicity, transparency, reproducibility and low cost. However, it offers limited considerations for macro-economic impacts, environmental and social aspects.
- Spatially explicit analysis: it combines spatially explicit data and land use to assess biomass energy potential. The main advantage is the ability to evaluate distribution of biomass and impacts at a local and regional level. Drawbacks include lack of reproducibility, labor intensiveness and high complexity that does not necessarily provide more accurate results.

Likewise, two main types of methodologies are employed in demand-driven assessments [7]: