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Biofuels from agricultural biomass in Zimbabwe: Feedstock availability and energy potential

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Abstract

Crop residues and animal dung can contribute a significant portion to the biomass available for conversion to biofuels in Zimbabwe. This paper will extend a quantitative methodology involving the use of probability distributions to rigorously address uncertainty in the quantification of this biomass. The results of 100 000 Monte Carlo simulations using Palisade's @Risk tool indicates the following at a 90% confidence interval: 2.55-5.50 million Mg/yr. of crop residue and 2.99-4.99 million Mg/yr. of dung is generated. The total exploitable energy was estimated at an annual mean of 26.6 and 16.9 million GJ for crop residue and dung respectively

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Keywords: agricultural biomass ; probability distributions ; Monte Carlo ; stochastic modelling ; risk analysis ; crop residue

1. Introduction

The exploitation of biomass is a much-needed lifeline to cope with prevalent issues of inadequate energy supply, energy diversification and sustainability in Zimbabwe. The promotion of sustainable bioenergy production from agricultural wastes and crop residues requires, as an initial step, the quantification of the potentially suitable crops and subsequent residue generation rates. A model that can accurately predict the probable availability of biomass for biofuels is therefore needed to make well- grounded decisions.

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Nomenclature

P_{CR}	potential amount of crop residue available for bioenergy production in Mg/yr.
A_{CR}	actual available amount of crop residue available for bioenergy production in Mg/yr.
C_{iPDF}	annual crop production in Mg/yr based on the probability distribution function for crop *i*
Y_{RPR}	percentage yield of residue based on residue-product-ratio
p	% P_{CR} collected and diverted to other uses based on probability distribution function for *p*
P_D, A_D	potential and actual amount of animal dung available for bioenergy production in Mg/yr.
D_{ACF}	Dung Accessibility and Collection Factor

The uncertainties associated with agricultural and livestock productivity imply that the quantity of biomass (dung and crop residues) available for conversion into biofuels is a function of random events. Agricultural output in Zimbabwe, for example, has been declining over the years resulting in persistent cereal shortfalls. Deteriorating soil fertility, erratic rainfall patterns, high input costs, low management standards and instability in the market have contributed adversely to the sustainability of the farming sector [1]. The practice of spreading crop residues such as stover, dry grass or leaves commonly referred to as mulching is not prevalent in communal farms in Zimbabwe. A certain quantity of residue must be used as field cover depending on soil properties, field slope, crop rotation, and tillage system amongst other factors to reduce soil erosion and recycle nutrients. Instead, crop residues are either burned after harvesting or used as stock feed [2] directly competing with the residues available for bioenergy production. Livestock productivity faces similar risks arising from the natural environment, maladapted livestock and the socioeconomic context [3]. This study aims to deal with the uncertainty in the availability of biofuel raw materials by introducing a probabilistic model supported by 100 000 Monte Carlo simulations to predict animal waste and crop residue generation rates.

2. Materials and Methods

The proposed model was developed on an Excel spreadsheet equipped with Palisade's @Risk risk-profiling plug-in software tool. First biomass production data was retrieved from FAOSTAT's normalized database for crop and livestock production. Data for the major agricultural crops and livestock for the country of interest was then extracted. The annual production data (1961-2014) for each category was fitted to a suitable distribution based on Akaike's Information Criterion (AIC). Distribution fitting allows the development of valid models of random events thus minimizing errors due to selection of unrepresentative probability models. For example, an assumption of a normal distribution for crop outputs would introduce error if real-life data suggests an alternative model. The penultimate step of estimating the quantities of the potential and actual available biomass for biofuel production and its energy content was carried out using equations (1) to (4). The potential amount of crop residues generated was calculated using the formula:

$$P_{CR} = C_{iPDF} \times Y_{RPR} \tag{1}$$

P_{CR} is the potential amount of crop residue available for bioenergy production in Mg/yr assuming non-competitive/alternative uses, C_{iPDF} is the annual crop production in Mg/yr based on the probability distribution function for crop i and Y_{RPR} is percentage yield of residue based on reported residue-product-ratios [4, 5]. From (1), the actual available crop residue (A_{CR}) for bioenergy production after accounting for collection efficiency and competitive uses of residues can be estimated by

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