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Research paper

Sustainability assessment of selected biowastes as feedstocks for biofuel and biomaterial production by emergy evaluation in five African countries

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A B S T R A C T

Africa is a continent with enormous natural resources in the form of biomass and innovative ways are needed to exploit those ones available from agricultural processes and other production systems. This paper aims to assess the sustainability of a set of potential feedstocks for the production of biofuels and other value added products in Egypt, Ghana, Kenya, Morocco and South Africa. These feedstocks are residues from agricultural and industrial food processing systems that we assess by emergy evaluation for insights into their sustainability. The feedstocks are grouped into sugar-rich (corn stover, cassava peels, pineapple peels, olive oil pomace and rejected bananas) and nutrient-rich (cocoa pods, discarded cabbage leaves, cattle manure and soybean processing residues). Where possible, comparison is made between traditional and commercial production of the same good. Despite higher environmental impacts, commercial systems were found to perform better in exploiting natural resources. Finally, sugar- and nutrient-rich feedstocks were compared on the basis of glucan and ash content, respectively. *Cassava peels* and *cattle manure* gave the best performance from an emergy point of view. This approach enabled emergy evaluation of feedstocks that also considered their potential for the production of useful bio-products.

1. Introduction

The transformation of biomass into various products has seen much development and today there is a range of opportunities for upgrading bio-based materials to products such as medical chemicals, food, feed, biofuels and fertilizers.

Africa is a continent with enormous natural resources in the form of biomass. For African countries and people to benefit from the emerging bioeconomy sector, innovative ways are needed to exploit the biomass available from agricultural processes and other production systems [1–3].

According to Gustavsson et al. [4], bio-resources that have an economic or other value are usually classified as bio-residues, while those ones without (or with only a nominal) economic or other value can be considered bio-wastes. In this study these “former” bio-wastes can be considered as residues since they are identified as possible bio-resources we wish to add value, by means of new transformation processes aimed at producing biofuels and biomaterials.

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List of abbreviations

tf	traditional farming
cf	commercial farming
fg	free grazing
zg	zero grazing
Em	Emergy
UEV	Unit Emergy Value
τ	Transformity
sej	solar emergy joule
R	emergy flow related to local renewable resources
N	emergy flow related to local non-renewable resources
F	emergy flow related to resources purchased outside the system
%R	fraction of emergy from renewable inputs
ELR	Environmental Loading Ratio
EIR	Emergy Investment Ratio
EYR	Emergy Yield Ratio

Emergy evaluation and corresponding indices and ratios can be used to assess the long-term sustainability and efficiency of various systems. Based on thermodynamics, it quantifies the nonmonetized and monetized resources, services and commodities necessary for production in the common units of the solar energy it took to make them (known as Solar Emergy) [5,6].

The literature on emergy evaluation of bioenergy production systems includes ethanol production. Ulgiati [7] analyzed the potential of maize to produce ethanol in Italy. Since the biofuel option is unsustainable on a large scale, he proposed clustering of biofuel production with other agro-industrial processes, using byproducts as feedstock. Bastianoni and Marchettini [8] demonstrated that ethanol production from selected crops in various countries is still far from sustainable. Patrizi et al. [9] evaluated a proposed biorefinery project in the Province of Siena (Italy), fed by residual heat and material such as straw from local agriculture, highlighting the feasibility of a partial substitution of gasoline with ethanol from an emergy viewpoint. Agostinho and Ortega [10] analyzed other biorefinery scenarios in Brazil and found that an integrated system of food, energy and environmental services (IFEES) was the best solution in terms of energetic-environmental performance.

Here we used emergy evaluation to assess the sustainability of a set of potential feedstocks for the production of biofuels and other value-added products in Egypt, Ghana, Kenya, Morocco and South Africa. These feedstocks are mainly residues from agriculture and industrial food processing. The aim is to determine whether African countries could benefit from exploiting underutilized biomass as energy feedstock.

2. Materials and methods

2.1. Selected feedstocks and related production systems

The agricultural and industrial food production systems analyzed are in Egypt, Ghana, Kenya, Morocco and South Africa. We selected a sugar-rich and/or nutrient-rich feedstock for each country [4] (see Table 1). Where possible, we compared traditional and commercial farming systems for the same feedstock:

- Traditional farming system (tf): defined here as small-scale cultivation for the local market or subsistence, characterized by low-input of matter and energy;
- Commercial farming system (cf): defined here as large-scale intensive cultivation aimed at a wider market.

The systems selected are representative of average or usual kinds of production [4].

2.1.1. Selected feedstock from Egypt

Corn residues consisting of corn stover i.e. leaves, stalks and husks left in the field after harvesting, was selected as a sugar-rich (cellulose) feedstock. The stover to grain mass ratio was estimated at about 0.9:1 fresh weight [11]. The system analyzed is commercial cultivation of 142 ha at Ismailia Research Station.

2.1.2. Selected feedstocks from Ghana

Cassava-processing residue in the form of peelings is a sugar-rich (starch) feedstock. A traditional cultivation was compared with a commercial system (both in Nkwanta South district). The farm under traditional cultivation has an area of 2 ha and produces 23 t per cultivation cycle (10 months) and the commercial farm has an area of 10 ha and produces 250 t of cassava.

Residue from a cocoa plantation, i.e. the empty cocoa pods left after the harvest, is the selected nutrient-rich feedstock. We analyzed a traditional cultivation at Akim Tafo, which produces 2 t y^{-1} of cocoa beans and the same quantity of cocoa pods (bean to pod mass ratio 1:1) in an area of 5 ha.

2.1.3. Selected feedstocks from Kenya

We selected peels from pineapple processing as a sugar-rich feedstock. The commercial pineapple farm is at Mangu, measures 1 ha and produces 30 t per cultivation cycle (24 months), that give 15 t of peels.

We also selected the nutrient-rich feedstock cabbage (discarded leaves) from the vegetable market wastes. The system concerns the market company in Molo, which buys vegetables from farmers within a radius of 60 km. One traditional and one commercial cabbage farm were analyzed. The amount of cabbage waste collected at the vegetable market is about 5% of the harvested yield.

2.1.4. Selected feedstocks from Morocco

Pomace from olive oil production was selected as a sugar-rich feedstock in Morocco. The traditional cultivation system is a 5 ha olive grove in the region of El Hajeb, representative of small Moroccan olive producers. An annual olive harvest of 3.5 t is processed in an oil press at Dkhissa and yields 451 kg of oil and 3.05 t of pomace. The commercial cultivation is near Meknes. The olive grove covers 16.5 ha and produces 49.5 t of olives that yield 8.2 t of oil and 41.3 t of pomace.

The nutrient-rich feedstock selected for Morocco was cattle manure. Two cattle breeding systems were analyzed: “free-grazing” (fg) and intensive raising based on forage “zero-grazing” (zg). The former is a farm with 8 cows that produces 24,000 L y^{-1} of milk and generates 72 t y^{-1} of manure. The zero-grazing system has 36 cows producing 252,000 L y^{-1} of milk and 432 t of manure.

2.1.5. Selected feedstocks from South Africa

Bananas rejected in the field is the sugar-rich feedstock we selected in South Africa. The traditional plantation is at Tshakhuma (Limpopo province), measures 1 ha and produces 25 t of bananas per cultivation cycle (16 months). The commercial system is at Levubu, covers 40 ha and produces 1600 t per cycle. Rejected bananas are 5–10% of total production.

The nutrient-rich feedstock selected for South Africa is soybean