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Tecnologias Limpas

Corn harvest residues for co-generation assessment: availability at Mato Grosso do Sul State, and energy characteristics

Resíduos da colheita do milho para avaliação de cogeração: disponibilidade no Estado de Mato Grosso do Sul e características energéticas

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ABSTRACT: After harvest, usually a significant amount of crop residues are available and part of it can be a feedstock for biomass energy. This paper´s objective is to quantify sustainable residual biomass from corn harvesting, husk leaf, and cob, and its solid-fuel characterization for energy co-generation assessment. The methodology considers geographical distributions of corn production on a municipal basis, at Mato Grosso do Sul (MS) State in Brazil. Residual biomass from corn harvest has its mass fractions and energy characteristics determined via proximate and ultimate analyzes, bulk density, and heating values. Also, assessment of energy and power obtained by using co-generation power plants technology. The conclusions identify that residual biomass from corn harvest (husk leaf and cob) have large amounts available for energy use ($\sim$190.10^6 kg), and a main one geographic micro-region at MS. Its characteristics as solid fuel, i.e., HHV$\sim$18 MJ.kg^{-1} and $T_{MC,db} < 10\%$, as well as high availability for oxygen for combustion ($T_O \sim 43\%$) and low ash content ($T_{Ash} < 4\%$) corroborate with its energy use, as in co-firing with sugarcane bagasse or coal thermal power plants. Bulk density values suggest densification as an interesting option for the commercialization of pellets or briquettes. Assessment of energy and power has a significant contribution to the Dourados micro-region ($\sim$2 $GW_{Electric}$) and could attend farm and other rural energy demands through co-generation power plants. Altogether, husk leaf and cob are adding-values co-products that can play a significant role in the corn productive chain.

Keywords: Agribusiness. Biomass. Energy waste to energy. Renewable energy.

RESUMO: Após a colheita, usualmente uma quantidade significativa de resíduos da cultura fica disponível e parte dela pode ser matéria-prima para energia de biomassa. O objetivo é quantificar a biomassa residual da colheita de milho, palha da casca e sabugo da espiga, além da caracterização como combustível sólido para estimativa na cogeração de energia. A metodologia considera as distribuições geográficas da produção de milho em base municipal, no Estado de Mato Grosso do Sul (MS), Brasil. A biomassa residual da colheita de milho tem suas frações de massa e características energéticas determinadas por análise imediata e elementar, densidade a granel e poder calorífico (superior e inferior). Além disso, avaliação de energia e potência obtidas através da tecnologia de usinas de cogeração termoelétrica. As conclusões do trabalho indicam que existe grande quantidade disponível para uso energético ($\sim$190.10^6 kg) de biomassa residual da colheita de milho (palha da casca e sabugo da espiga), e uma microrregião geográfica principal no Estado de Mato Grosso do Sul (MS). Suas características como combustível sólido, i.e., PCS$\sim$18 MJ.kg^{-1} e $T_{MC,db} < 10\%$, com elevada disponibilidade de oxigênio para combustão ($T_O \sim 43\%$) e reduzido teor de cinzas ($T_{Ash} < 4\%$) corroboram seu uso para energia, como na combustão combinada (ou co-combustão) a bagaço da cana-de-açúcar ou carvão mineral em termoelétricas. Os valores de massa específica aparente sugerem o adensamento como uma opção interessante para a comercialização de peletes ou briquetes. A avaliação de energia e potência gerada têm uma contribuição significativa para a microrregião de Dourados ($\sim$2 $GW_{Electric}$) e poderia atender a agricultura e outras demandas de energia rural por meio de usinas de cogeração. Ao todo, palha da casca e sabugo da espiga são coprodutos de valor agregado que podem desempenhar um papel significativo na cadeia produtiva do milho.

Palavras-chave: Agronegócios. Biomassa. Energia de resíduos. Energia renovável.

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INTRODUCTION

Corn culture agribusiness is responsible for the second-highest amount of grain production in Brazil, after the soybean. Estimation from MAPA is for ~93,600 tons in 2022/23 harvest (RIBEIRO, 2014; BRASIL, 2013), highlighting the Brazilian States of PR, MT, MS, GO, MG, and RS. Corn cultivation in three countries corresponds to 2/3 of the world's production, the USA, China, and Brazil (FAOSTAT, 2017).

Bioenergy refers to energy from the burning of biological materials, as wood and biomass – both containing carbon in their constitution. Residual biomass is classified according to its origin (BRAND, 2010), as forestry (native or planted), agro-industrial, and agricultural and urban waste; or according to their use (CORTEZ *et al.,* 2008), as traditional biomass which are part firewood, charcoal, straw, and rice husks, and other plants/animal waste, and modern biomass, residues of industrial use of wood, bagasse, municipal waste, and energy crops.

A significant amount of residual biomass occurs in agro-industries (SILVA *et al.,* 2017), thus adding value to these co-products is a relevant economic aspect to consider. Typically they are not used as food, such as husks (from rice and coffee), straw and bagasse (from sugarcane), husk leaf, and cob (from corncob). Other examples in animal production include pig and cattle manure (SILVA; SILVA, 2016), beef tallow in the slaughter, among others. The corn plant, i.e., corn stover (or straw) consist of leaves, stalks, and cobs that ate typically left in the field after corn crop harvest mainly due to: a) soil quality and degradation, based on soil organic carbon; b) No market demand often occurs outside the farm site. Husk leaf and cob are usually used as ground cover after harvest, along with other parts of the corn plant.

Many countries have assessment studies on sustainable agricultural residue removal and geographic distributions availability for using only part it as waste to energy for co-firing power plants. Crop residues assessment for bioenergy generation purposes shows promising scenarios in European countries, corn as one of the main crops (KYRYZYUK *et al.*, 2020). It is important to point out that part of crop residues must be kept in soil for protection from water and wind erosion, and carbon loss and the surplus is an important feedstock for bioenergy, thus requiring careful land-use planning (LIU, HUFFMAN; and GREEN, 2018). Biomass residues, as sugarcane straw and eucalyptus harvest residue, are very recently also being considered for biojet fuel production assessment in Brazil (CERVI *et al.*, 2021).

The aim is to quantify residual biomass availability (husk leaf and cob) and provide solid fuel characteristics for energy co-generation assessment. Novelty is on co-product valorization for energy use; feedstock availability is on a municipal basis, at Mato Grosso do Sul State in Brazil. The results may provide greater interest in those co-products for waste to energy use also in small-scale demands, as grate furnaces and boilers, mainly if we consider pellets or briquettes as commercial fuels.

2 METHODOLOGY

2.1 BIOMASS GEOGRAPHIC AVAILABILITY

The data basis for residual biomass availability (corn straw and cobs) considers the Municipal Agricultural Production - PAM (IBGE, 2015). Corn production (grains) was evaluated in the area corresponding to Mato Grosso do Sul State (MS). Cartograms (geographical representation) and worksheets are grouped in the 1990-2009 period, for identification and quantification of the main producing sites.

Figure 1 shows cartograms for meso-regions (4) and micro-regions (11), corresponding to 79 municipalities (IBGE, 2017). Those are: (A) Central-Norte, with micro-regions Alto Taquari and Campo Grande; (B) Leste, with micro-regions Cassilândia, Nova Andradina, Paranaíba, and Três Lagoas; (C) Pantanais, with micro-regions Aquidauana and Baixo Pantanal; (D) Sudoeste, with micro-regions Bodoquena, Dourados, and Iguatemi. The Dourados microregion – identified as "7" in Figure 1 – consists of 15 municipalities, namely: Amambaí, Antônio João, Aral Moreira, Caarapó, Douradina, Dourados, Fátima do Sul, Itaporã, Juti, Laguna Carapã, Maracaju, Nova Alvorada do Sul, Ponta Porã, Rio Brilhante, and Vicentina.

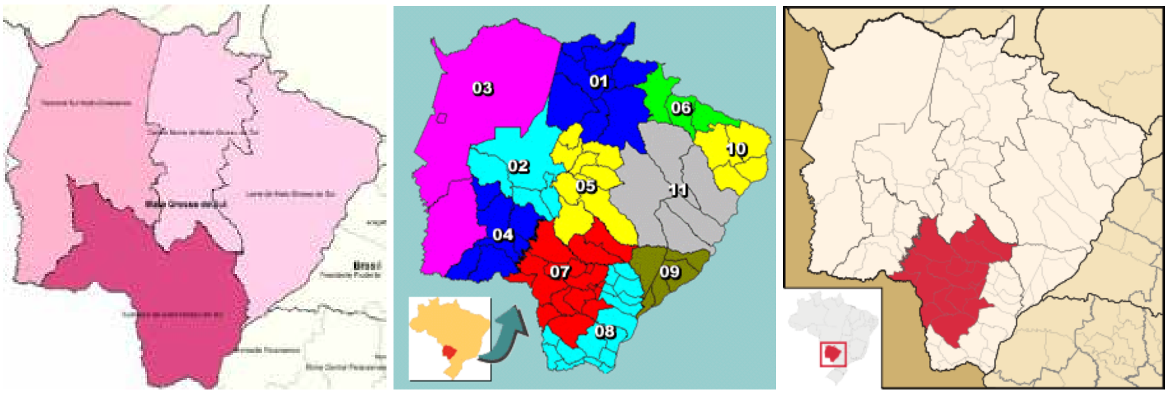

Figure 1. Meso-regions and micro-regions at Mato Grosso do Sul, Brazil.
Source: IBGE (2017).

2.2 SAMPLES PREPARATION

The methodology for the determination of mass fractions was proposed by authors, and it considers the complete corncob (or corn ear) parts. Samples of 20 corncobs were split into its 4 (four) mains components: husk leaf (or straw); silk (or styles or "hair"); cob (or corn cob "carrot"), and; seed (or grain or kernel). Figure 2 shows weight determination: (a) the complete corncob; (b) husk leaf removal; (c) cob and seeds after silk removal; (d) seeds only; (e) remaining cob. Husk leaf and cob are the residual biomass for this work.

Figure 2. Corncobs components for residual biomass (husk and cob) determination. (a), (b), (c), (d), and (e), respectively from left to right.
Source: authors.

Corncob weighting used a scale with 0.1 g accuracy and 0-8 kg range. Milling and sieving were by knife grinder (Marconi, MA-680) and stainless steel sieves (mesh 20 or 0.841 mm openings). Drying was by a re-circulation kiln (Sppencer scientific, up to 110ºC). A muffle furnace (Fornitec, up to 1100ºC) and analytical scale (0.01 g accuracy and 3100 g) were used for ash and volatile matter determination.

2.3 PROXIMATE AND ULTIMATE ANALYSIS

Proximate analysis was obtained experimentally with 1g in duplicate samples, according to NBR 8112 (ABNT, 1986), and providing contents for: 1) Moisture at 105±10ºC, wet and dry basis ($T_{MC,wb}$ and $T_{MC,db}$; $\Delta T_{UM} \leq 5\%$; particle size < 19mm); 2) Volatile matter at 900±10ºC (T_{VM}; $\Delta T_{VM} \leq 2\%$; 0.150mm < particle size < 0.210mm); 3) Ash at 700±10ºC (T_{Ash}; $\Delta T_{Ash} \leq 10\%$; particle size < 0.210mm); 4) Fixed carbon (T_{FC}), that last one calculated by difference. Sample preparation recommendations were adapted to NBR 7402 and NBR 6922 (ABNT, 1981; 1982).

For moisture content determination, the sample must be left drying until there are no significant changes registered by the weigh device (digital scale). That is necessary to determine the drying time for each sample analysis. Assessment with time intervals of 30 minutes for sample drying was performed; 4 h were required to identify the minimum amount of time required for moisture removal.

For ultimate analysis (or elemental chemical composition), it is determined the weight fraction (%): hydrogen (T_H), oxygen (T_O), carbon (T_C), nitrogen (T_N), sulfur (T_S), and ashes (T_{ash} – inorganic material). T_S and T_N are typically small values in biomass originated from plants. The ratio between the quantities of H, O, and C implies directly the amount of energy that can be obtained from biomass combustion. In the absence of the equipment for experimental determination according to NBR 8631 (ABNT, 1984a), it is possible to use empirical equations (PARIKH *et al.,* 2007) - based on experimental proximate analysis results for the most significant components in biomass of plant origin. See Eqs. (1), (2) and (3) - neglecting the effect of ash composition in ultimate analysis assessment.

$$T_H\ (\%) = 0.052\ (T_{FC,db}) + 0.062\ (T_{MV,db}) \tag{1}$$

$$T_O\ (\%) = 0.304\ (T_{FC,db}) + 0.476\ (T_{MV,db}) \tag{2}$$

$$T_C\ (\%) = 0.637\ (T_{FC,db}) + 0.455\ (T_{MV,db}) \tag{3}$$

Such correlations have been validated (PARIKH *et al.,* 2007) for proximate and ultimate analysis results in the following ranges: $57.2\% \leq T_{VM} \leq 90.6\%$; $4.7\% \leq T_{FC} \leq 38.4\%$; $36.2\% \leq T_C \leq 53.1$; $4.36\% \leq T_H \leq 8.3\%$; $31.37\% \leq T_O \leq 49.5\%$.

2.4 HEATING VALUES AND BULK DENSITY

The High Heating Value (HHV, $kJ.kg^{-1}$) is determined experimentally by using a bomb calorimeter, NBR 8633 (ABNT, 1984b). Also; for comparison purposes, it was determined the HHV by literature correlations based on the proximate analysis (PARIKH *et al.,* 2005), Eq. (5); and on the ultimate analysis (RENDEIRO; NOGUEIRA, 2008), Eq. (6); among other possibilities (UZUN *et al.,* 2017). Low Heating Value (LHV, $kJ.kg^{-1}$) is from empirical equations only, and by its definition depends on HHV (GARCIA, 2013), see Eq. (4). Eqs. (1) and (3) were used to obtain T_H and T_C required in Eqs. (4) and (6).

$$HHV\ (MJ.kg^{-1}) = 0.3536\ (T_{FC,db}) + 0.1559\ (T_{VM,db}) - 0.0078\ (T_{Ash,db}) \tag{4}$$

$$\text{HHV (MJ.kg}^{-1}) = 0.4371\ (T_C) - 1.6694 \quad (5)$$

$$\text{LHV (MJ.kg}^{-1}) = \text{HHV}_{\text{Experimental}} - 2240.\ [\ (9.T_H + T_{MC,wb})\ ] \quad (6)$$

The HHV corresponds to the maximum amount of thermal energy that can be released through the combustion of biomass (solid fuel). The LHV corresponds to HHV less the amount of thermal energy required for change of state of water, from superheated steam to saturated liquid obtained; water is represented by the moisture content in the biomass (CORTEZ *et al.,* 2008; RENDEIRO; NOGUEIRA, 2008).

Bulk density (ρ_{bulk}) is determined experimentally, NBR 6922 (ABNT, 1981), see Eq. (7). A ceramic crucible is used as a container, with a known volume of 100 mL. The crucible is filled with grinding biomass and weighted; where V (m^3) is the volume, and ΔM (kg) is the mass difference (M2 - M1), where M1 and M2 are, respectively, for the empty and filled container. The uncertainty of the specific mass (u_ρ) is given in Eq. (8), obtained according to Balbinot and Brusamarello (2010).

$$\rho_{bulk}\ (\text{kg.m}^{-3}) = (M_2 - M_1)\ .\ (V)^{-1} \quad (7)$$

$$U_{\rho\text{-bulk}} = [\ (V^{-1})^{\ 2} + (-\Delta M\ .\ V^{-2})^{\ 2}\ ]^{\ 1/2} \quad (8)$$

2.5 THERMAL ENERGY OBTAINED FROM RESIDUAL BIOMASS CONVERSION

For assessment of thermal energy obtained from residual biomass, we consider a methodology analogous to the one proposed for rice (husk) by the Brazilian Reference Center on Biomass - CENBIO, and others (SILVA *et al.,* 2017), see Eq. (9). The amount of energy is given by $E_{Potencial}$ (kW.year^{-1}), while $T_{residual\text{-}biomass}$ (kg) is the annual quantity of residual biomass available *in natura* (raw conditions), η (%) is the conversion efficiency in the process of thermal/electric power generation.

Availability of residual biomass for a power plant is assumed to be with 95% of operation hours annually (8322 h.year^{-1}); minimum process efficiency is considered, η = 15% (boilers operating at 2 MPa or 20 bar), in a low-efficiency thermodynamic cycle (SILVA *et al.,* 2017). Conversion to S.I. units requires applying the factor indicated as 3.6.

$$E_{potential}\ (\text{kW.year}^{-1}) = (T_{Residual\text{-}biomass})\ .\ (\text{LHV})\ .\ (\eta)\ .\ [\ (8332).(3.6)\ ]^{\ -1} \quad (9)$$

In this work, $T_{residual\text{-}biomass}$ is about 20% of the corn crop grain weight; in comparison to European assessment for all crops residues that consider 25% as a residue-to-product ratio (RPR) for energy purposes, and data sources similar to the ones in this work (KYRYZYUK *et al.*, 2020; GOJIYA, DEB; and LYER, 2019).

3 RESULTS AND DISCUSSION

Figure 3 provides cornfield availability, thus identifying as major production site the mesoregion Sudoeste, i.e. micro-regions Dourados, Bodoquena, and Iguatemi; it reaches more than 2.5 million tons of corn (seed) in 2008 and represents ~65% of MS State along 1990-2009. As for Fig. 4, it points out the historical evolution along 20 years (1990-2009) of cornfield production in all 15 municipalities at the Dourados microregion. From those, three ones provide almost 50% in 20 years: Dourados (~20%) with 471,000 tons in 2003, Maracajú (~18%), and Rio Brilhante (~11%). Thus, the exceptional availability of residual biomass - husk leaf and cobs - can be used, even partially as energy feedstock.

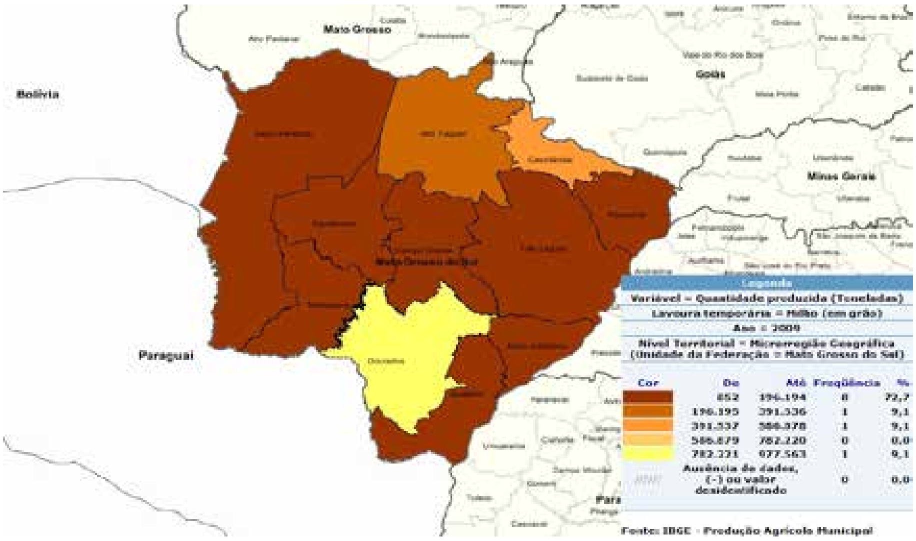

Figure 3. Cornfield production in MS.
Source: authors.

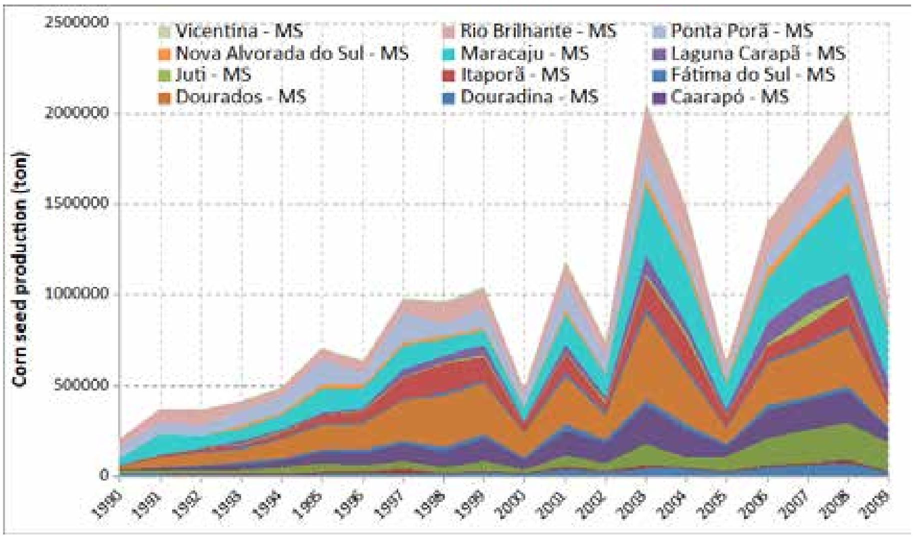

Figure 4. Evolution in cornfield production at Dourados microregion.
Source: authors.

Mass fractions mean values for each corncob part from samples are in Figure 5. Corn seeds are prominent once they have food destination while remaining parts are ~20% (cobs and husk leaf), and a negligible contribution for silk (↓0.5%, also known as corn hair).

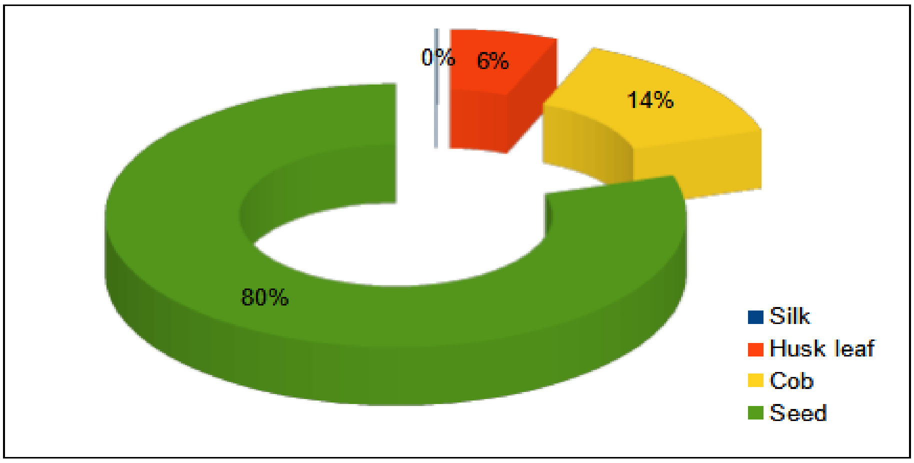

Figure 5. Residual biomass fractions from corncob: seed, cob, husk leaf, and silk.
Source: authors.

Still in Figure 5, even considering different corn plant species, results here obtained are close to other countries species that indicate 18-20% for husk leaf and cob (DU *et al.,* 2015); and 5-8% for husk leaf only (NOGUEIRA; LORA, 2003). Thus, is quite reasonable to consider a general fraction at Brazil´s cornfield crops as ~20% of residual biomass available for an energy assessment. Soil organic matter is still possible by using other plant parts, as the stalk and the leaves; they correspond, approximately, to the same weight amount as the corncob already harvest.

Table 1 shows proximate analysis results for the two residual biomass mains components husk leaf and cob. Both have reduced values for $T_{MC,db}$ (9-10%) in comparison to 15-30% from other crops residual biomass (RENDEIRO; NOGUEIRA, 2008); Rice husk and straw, coconut husks, animal manure, among others have $T_{MC} \leq 13\%$ (BRAND, 2010). Reduced moisture content is a desirable feature in solid fuels for direct combustion, once it does not require energy from artificial drying; Also, the low the T_{MC}, the longer will be the storage in good conditions, avoiding the decomposition process of the molecular structure (water connected to the cellulose walls).

Table 1. Proximate analysis for husk leaf and cob samples

Sample	$T_{MC,db}$ (%)	$T_{MC,wb}$ (%)	$T_{MV,wb}$ (%)	$T_{Ash,wb}$ (%)	$T_{FC,wb}$ (%)
Husk leaf	9.0 ±1.1	9.9 ±1.3	81.7 ±1.4	3.5 ±0.4	14.8 ±1.4
Cob	8.8 ±1.8	9.7 ±2.2	81.7 ±1.0	3.3 ±1.6	15.0 ±2.1

Furthermore in Table 1, husk leaf and cob have large T_{VM} (~82%) - as usual in biomass materials, i.e., volatile gases help in keeping combustion flames on - another indicator of good characteristics for energy use; the same order of magnitude for other literature results for corn cob, 80% (BRAND, 2010). As for T_{Ash} (~3.4%), it is a bit lower than critical values for other residual biomasses as cotton branches (~6%), rice husk (~9%), sugarcane bagasse, and coconut shell - both ~10% (BRAND, 2010). Best combustion quality occurs for smaller T_{Ash}, once it corresponds to inorganic materials, i.e., minerals that are not combustion reagents.

Results in Table 2 are for ρ_{bulk}, ultimate analysis, HHV, and LHV. Bulk density is slightly higher than sugarcane bagasse, ~200 kg.m^{-3} (BRAND, 2010; RENDEIRO; NOGUEIRA, 2008); and lower than some

Amazonian species (wood and forestry waste) that hardly surpass 300 kg.m^{-3}. That is another indication of good quality as solid fuel, ↑ ρ_{bulk} when it comes together with ↓ T_{MC}, as indicated for husk leaf and cob. As for HHV ~17.6-18.8 MJ.kg^{-1}, it corresponds to excellent results; it is equivalent to typical residual biomass from agroindustry (~18.4 MJ.kg^{-1}, e.g., sugarcane bagasse). It is even higher than those of agricultural origin (~15.7 MJ.kg^{-1}, essentially straw, leaves, and stalks) and from forestry (~13.8 MJ.kg^{-1}, e.g., sawdust, bark, shavings, etc), (CORTEZ *et al.,* 2008). As for HHV^1 (empirical results), in comparison to experimental results (HHV^1), it seems to be underestimated (1.0 up to 6.0%) for corn husk leaf, and overestimated (0.5 up to 4.5%) for cob; but it is a good assessment at the same order of magnitude.

Table 2. Bulk density and ultimate analysis for husk leaf and cob samples

Sample	ρ_{bulk}^{2} (kg.m^{-3})	T_H^{1} (%)	T_O^{1} (%)	T_C^{1} (%)	HHV^1 (kJ.kg^{-1})	HHV^2 (MJ.kg^{-1})	HHV^2 (MJ.kg^{-1})	LHV^{1,2} (MJ.kg^{-1})
Husk leaf	248.8 ±12.1	5.8	43.4	46.6	17,598 ±188	17.94	18.70	16.20
Cob	250.7 ±12.3	5.8	43.4	46.7	18,849 ±293	18.02	18.76	17.45

^{1} Experimental; ^{2} Equations (4), (5) e (6), see methodology section for details.

Still, in Table 2, ultimate analysis indicates that T_H (~6%) and T_C (~47%) also have equivalence to sugarcane bagasse, while T_O (~43%) is slightly higher than ~38% for sugarcane bagasse (BRAND, 2010; RENDEIRO; NOGUEIRA, 2008); it indicated less air/oxygen requirements during combustion. The energy contained in carbon is superior to the ones, individually enclosed, into oxygen and hydrogen. The low values for T_H and T_C, slightly higher than T_O, are characteristics that make this residual biomass attractive to use as feedstock for thermal energy conversion.

Table 3 shows the assessment of energy and power generation at the Dourados micro-region, see Figure 3 (right side). Total energy achieves equivalent to ~3.5.10^6 GJ$_{Thermal}$ or ~2 GW$_{Electric}$ by thermoelectric power-plants, it represents ~0.7% of the 2014 amount of electrical energy consumption in the whole state (SILVA *et al.,* 2017). It is possible to increase energy and power generation if the biomass torrefaction process is to be considered previously to combustion (CHEN *et al.,* 2014; SATPATHY *et al.,* 2014), or even via gasification process (DU *et al.,* 2015) – in this case obtaining gas biofuel that also can be stored.

Table 3. Assessment energy and power generation at Dourados micro-region from corn and husk leaf as residual biomass available

Feedstock (raw material)	Production, 1999-2009 (Tonns)	HHV (kJ.kg^{-1})	Thermal Energy (GJ or TEP)	Power Generation (MW. year^{-1})$_{Electric}$
Corn (seeds) and annual mean values	18,916,974 (945,848.7)	---	---	---
Husk leaf (6%)	~56,751	17,598 ± 188	998,704 (~23,779 TEP)	4,994
Cob (14%)	~132,419	18,849 ± 293	2,495,966 (~59,428 TEP)	12,482
Annual Mean Value (husk leaf and cob)	**189,170**	**---**	**3,494,670**	**17,476** **(~2GW.h)**

Nevertheless, ~2 $GW_{Electric}$ is a quite significant amount for energy use in farms and agricultural activities taking as reference monthly consumption of 3 $MW_{Electric}$ in a rural electrification cooperative with 4500 consumers at Dourados-MS (RECH *et al.,* 2015). Thus more than 600 similar cooperatives and their associates could have electricity supply from husk leaf and cob from corn.

From the economic viewpoint, corn (seed or grain) commercialization occurs in four ways: before the harvest, the futures market, during harvest, or in the off-season (which requires product storage). In Brazil´s Central-West region, more specifically in MS State (REIS *et al.,* 2016), the off-season is the best economic option in a multi-criteria analysis (logistics, price, availability, and productivity). However, logistics (storage and transport) is the most significant parameter on the decision, and at the same time a bottleneck on the corn production chain; intermodal transport seems to be the best option for higher efficiency (OLIVEIRA *et al.,* 2015). So, considering the strategic necessity of seed/grain storage, the energy availability from residual biomass (husk leaf and cob) can add value to the producer, contributing to products and co-products storage, other than only energy use.

Thus, there is a potential market for adding value, with a possibility of evolution in the corn production chain. It is similar to the one, which occurred in the sugarcane production chain, where initially when its bagasse had no economic value as a valued co-product. A crop residue value chain similar to the one suggested by Gondwe *et al.* (2017) can be considered as an initial proposition for future research, based on the results obtained here. The typical costs of corn crop (ARTUZO *et al*., 2018), mainly the ones represented by machine operation - as for corn processing and storage - can be mitigated with the commercialization of an added-value co-product as husk leaf and cob.

4 CONCLUSIONS

A large amount (~190.10^6 kg) of husk leaf and cob are available as residual biomass for energy use - both from corn harvesting, and a main one geographic micro-region at MS State. Its characteristics as solid fuel, i.e., HHV~18 $MJ.kg^{-1}$ and $T_{MC,db}$ <10%, as well as high availability for oxygen for combustion (T_O ~43%) and low ash content (T_{Ash} < 4%) corroborate with its energy use, as in co-firing with sugarcane bagasse or coal thermal power plants. Bulk density values suggest densification as an interesting option for the commercialization of pellets and briquettes, as an option for firewood and/or charcoal demands. Assessment of energy and power has a significant contribution to the Dourados micro-region (~2 $GW_{Electric}$) and could attend farm and other rural energy demands through co-generation power plants. Altogether, husk leaf and cob are adding-values co-products that can play a significant role in the corn productive chain.

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