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Biorefinery study of availability of agriculture residues and wastes for integrated biorefineries in Brazil

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ABSTRACT

Brazil has a great potential for use renewable raw materials in biorefineries. It is one of the largest producers of agricultural and animal commodities, which produce large amounts of residues and wastes. These agricultural residues and animal waste can be effectively transformed to energy and other products in systems similar to a ethanol refinery where an integrated process involves conversion for biomass into fuel, energy and chemicals, integrated in the context of a biorefinery. The objective of this work is the determination of the actual availability of main agricultural residues and animal wastes generated in Brazil and of their generation potential index and their prospects for 2020. The results indicate that the sugarcane has the highest agronomic availability, reaching 157 million tons of fresh material and an estimated reuse potential of 19.6 million tons (dry basis), followed by soybeans, rice, maize, orange, wheat, cotton, cassava and tobacco.

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1. Introduction

The increasing energy demand and the associated dependency of fossil fuels is one of the major challenges of the XXI century, as renewable sources are the key to a sustainable model of energy supply. However, developing attractive economically renewable fuels is a difficult task due to the relatively low cost of the energy produced by fossil fuels, and despite some innovative technologies are technically feasible, they present themselves more expensive than the non-renewable sources and, therefore, their industrial application becomes difficult (Goldemberg, 2007). Nevertheless, energetic levels of efficiency have improved over the past years globally, through the increase of efficiency in all economic sectors, including the introduction of modern technologies and more efficient processes (OECD, 2008). Energetic efficiency is renowned as an essential strategic change of policy mitigation. The use of energy in a more efficient way, presumes lower dependency of fossil fuels, higher competitiveness and the consumer's welfare (Taylor et al., 2010; Lopes et al., 2012).

The concept of biorefinery is analog to petroleum refinery that produces multiple fuels and petroleum products (Demirbas, 2009). Sustainable biomass process occur in a biorefinery in a range of commercialized products – food, livestock feed, chemical materials and products – and energy – fuels, electric, thermal (IEAB, 2010; Ghatak, 2011; Cherubini and Ulgiati, 2010). Livestock for biorefineries can come from energetic cultures originated from agriculture – sugarcane, maize, etc. – or it can be obtained from agricultural residues, forest residues and industrial residues – straw, bark and used edible oil, black liquor, etc. – e.g. sugarcane used for sugar or ethanol, while its residue – bagasse – is used in boilers to produce electric and thermal energy.

Presently, four large groups of conversion processes are involved in biorefinery systems. They are the thermo-chemical – pyrolysis, gasification, frequently called thermo-chemical routes or biomass-to-liquid (BTL) (Pravat et al., 2011). Pyrolysis is a form of decomposition which takes place in an environment with little to no oxygen which is very hot, and may also be at high pressure. This form of decomposition can occur in nature, and it can also be used in controlled environments for various purposes (Miao and Yang, 2004; Troy et al., 2013; Ben et al., 2013; Pan et al., 2010). Gasification is a thermo-chemical process in which carbonaceous (carbon-rich) feedstocks such as coal, petro-coke or biomass are converted into a gas consisting of hydrogen and carbon monoxide (and lesser amounts of carbon dioxide and other trace gases) under oxygen depleted, high pressure, high-heat and/or steam conditions. The resulting gaseous compound is called Syngas (Bin et al., 2010; Smoliński et al., 2011; McKendry, 2002). Thermo-chemical routes can present low cost, high efficiency and lower production of greenhouse effect gases, with potential to accept a large range of biomass sources for biological routes.

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Table 1
Survey on the applications of feedstocks and raw material for production of value added products.

Feedstocks	Bioproducts	References
Sugarcane, beets, corn	Bioethanol	Watkins (2001)
Sorghum juice	Ethanol production	Laopaiboon et al. (2009)
Forest wastes	Ethanol production	Tenborg et al. (2001)
Agricultural wastes	Cellulolytic enzyme	Nigam and Singh (1996)
Eucalyptus kraft pulp	Xylanase	Beg et al. (2000) and Rezende et al. (2002)
White-rot fungi	Animal feed	Huettermann et al. (2000)
Lignocellulose	Biochemicals, biopesticides, biopromoters	Tengerdy and Szakacs (2003)
Olive stone	Bioactive compounds	Rodríguez et al. (2008)
Sisal stems waste	Lactic acid	Muruke et al. (2006)

Agricultural wastes constitute an important category of livestock source with high application potential in biorefineries and that are not against food availability. Agricultural waste is a broad term in meaning and refers to any lignocellulosic residue produced by agri-food industries in their daily operations, such as leaves, roots, stalks, bark, bagasse, straw residues, seeds, wood residues and animal residues. All these residues represent a source of billions of tons a year, largely available, renewable and practically free; biomass residues are an important resource. Agricultural residues are composed by cellulose, hemicellulose and lignin (Taherzadeh and Karimi, 2007).

These lignocellulosic residues bear three basic constituents: cellulose, hemicellulose and lignin, and it can be transformed into multiple products. A typical composition of agricultural residues is 40–50% cellulose, 25–35% hemicellulose, 15–20% lignin (Ghatak, 2011). Therefore, the biomass resources are multiple and can be applied to the achieving fuels, chemical products and energy sources as shown in Fig. 1. Table 1 showed the most recent works about sub-products such as bio-products of resins, of polymers and film barriers, biodegradable plastic, dispersers, flocculants, as well as other more traditional uses such as cellulose, paper and textile fibers, resulting from fermentation of lignocellulosic.

Additionally, the term biomass has to do with all living matter present on Earth, from algae to trees, and agricultural cultures or even animal waste. The cost of electric energy, together with strict environmental rules related to manure accumulation and organic waste, have forced agri-food industries to invest on renewable resources through the application of process integration (Muster-Slawitsch et al., 2011).

Animal waste offers potential directly, both, as a fuel combustible and as an input to produce biogas. The environmental point of view lies in the application of methane biogas captured and used to provide energy. Solid residues remaining from fermentation process can still be used as fertilizer. Laboratory studies of fermentative processes with organic residues proceeded from food and animal waste and sewage sludge have shown excellent energetic efficiency – high production of biogas and high percent of methane. The energetic efficiency of processes with biogas reuse is possible by a global superstructure of heat and cool flows. This way it is possible to produce self-sufficient energy for biogas production, in closed circuit of water configuration, and synthesis of heat-integrated (HEN) (Forster-Carneiro et al., 2004).

Residues generated from biomass worldwide represent a great potential resource for energy achievement (Cortez et al., 2008). The feasibility survey of agricultural and feedstock residues and of its respective analyses as to generation potential should be evaluated carefully, considering the presence of these biomasses in the sites and around them, as well as production systems in use according to the agronomic needs and weather characteristics of the region under study. Globally, 140 billion tons of biomass of the agriculture sector are generated every year; this biomass volume can be converted into great amounts of energy and feedstock, which is equivalent to approximately 50 billion tons of oil and that can substantially move fossil fuels and reduce the emission of greenhouse gases. Besides, being considered feedstock, biomass residues have potential attractiveness for large industries and corporations.

The agricultural world context shows that since the end of the 90s, few countries have grown so much in international trade of this sector as Brazil. The country is one of the world leaders in production and exportation of several agricultural products, being the first producer and exporter of sugar and orange juice. It is leader in the rank of foreign sales of the soybean complex (grain, bran and oil). In the beginning of 2010, one out of four agribusiness products in circulation worldwide was Brazilian. Projection is that "until 2030, one-third of products traded will be from Brazil, because of the increasing demand of Asian countries".

Brazilian livestock is being developed in a traditional way, toward extensive production in large areas with low application level of technologies and more suitable techniques to management and administration in all its chain. The bovine segment points a Brazilian production of 227.7 million animal units in year 2009/2010. Out of this herd, 90.1% corresponds to beef cattle and the remaining to dairy cattle. The bovine herd has been keeping an average of participation in livestock, among the herds – including poultry, out of 17.3% over all the analyzed period. The swine herd represents an average of 2.7% from the total of the herds. With 38 million of animal units in year 2009, the greatest part of this production is for export. The poultry segment in Brazil has shown a production of 1.23 billion animal units in year 2009 – an average of 80% of the livestock sector. Chicken stands out and leads this production, placing Brazil as third major poultry producer in the world.

Thus, livestock production in the Brazilian rural sites – of small, medium or large sizes – have a great diversity and show strong pluriactivity due to the varied productive adopted systems and of regional specificities. Therefore, there is great heterogeneity in chemical composition and solids content for the same rural residue derived from different regions of the country (Torres et al., 2011).

The aim of this paper is to examine the parameters that have to do with the implementation of sustainable biorefineries from agricultural waste and animal waste. The objective is to perform a performance analysis and market trends worldwide and the Brazilian one of agriculture and livestock through two types of documents for the rough estimate of rural residues in Brazil: (i) statistical data of livestock production and products; and (ii) technical studies about the production systems. The main selected products – cultures and herds – are analyzed from the point of view of Brazil economy and also about the necessary conditions for the rural producer to keep up with sustainable growth. In addition, this paper shows the main alternatives for the sustainable exploitation pointing paths of economic diversification of agricultural activities in Brazil, as the use of agricultural residues and animal waste in platforms of biomass or biorefineries.

2. Materials and methods

2.1. Feedstock for biorefineries

This paper critically examines the emerging idea of biorefineries in the light of sustainability which can be fed by agricultural residues and animal waste. A biorefinery would be more sustainable if it had a diversified feedstock portfolio, thereby reducing

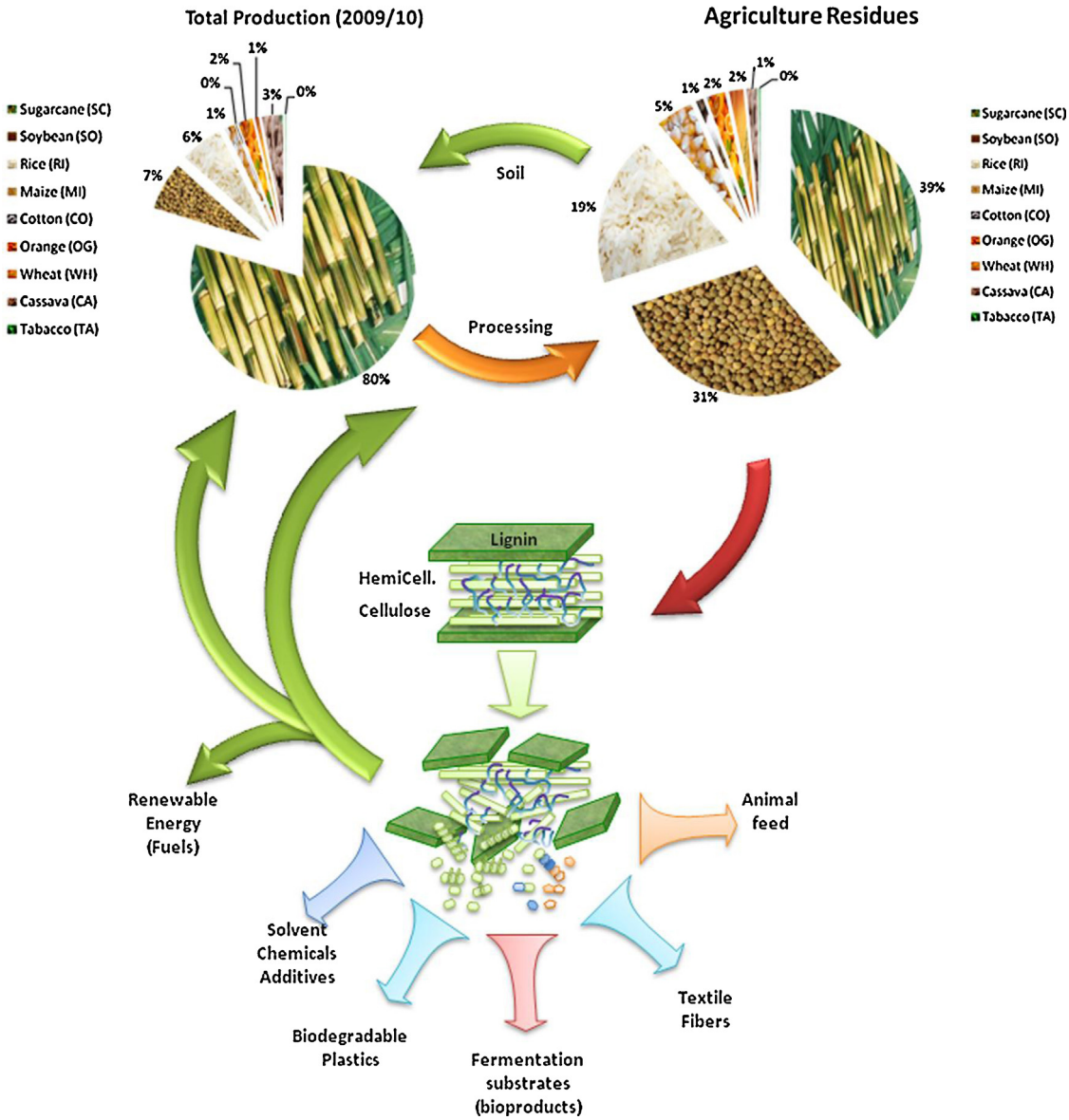

Fig. 1. Percent of total production of agricultural crops and residues in 2009/2010 and sustainable exploitation alternatives of agricultural activities in Brazil.

the supply side uncertainties. With such information available and ready to fulfill the segments selection, nine cultures have been selected: cotton, rice, sugarcane, tobacco, orange, cassava, maize, soybean, wheat (Table 2). Animal species that have been selected to this paper are poultry – chicken and hen; bovine (beef and dairy cattle); and confined swine.

Table 2
Agricultural residues and animal waste selection for bio-refinery feedstock.

Feedstock
Agricultural residues
Sugarcane (SC)
Soybean (SO)
Rice (RI)
Maize (MI)
Cotton (CO)
Orange (OG)
Wheat (WH)
Cassava (CA)
Tobacco (TO)
Animal waste
Poultry (PT)
Swine (SW)
Bovine (BO)

2.2. *Methodology for assessing the availability of agricultural residues and animal waste*

This paper does performance analysis and world and Brazilian livestock markets trends by two types of inquiries for a rough estimate of agricultural residues and animal waste in Brazil:

- Statistical data of agricultural and livestock production and products; and
- Technical studies of production systems.

Statistical data of agricultural and livestock productions were obtained in the Brazilian Institute of Geography and Statistics (IBGE, 2012) of automatic recovery:

(a) For agricultural production – Municipal Agricultural Survey (PAM, 2011)

(b) For livestock production – Municipal Livestock Survey (PAM, 2011).

The main selected products (agricultural residues and animal waste) are analyzed from the point of view that the economies of emerging countries, like the one in Brazil, in general, are the ones that have been presenting the best performances up to now and meaningful opportunities for the agribusiness; and also, about the necessary conditions to the rural producer for the continuity of sustainable growth, as the governmental support to keep liquidity and the use of supporting instruments to production and trade. This way, selection has been made in a way that respectably, 96% of all Brazilian agriculture and 97% of animal herds are considered in the data base. The physical production of the cultures and herds has the base year of 2009/10, about which GP index is obtained. In case of livestock, besides the Ministry of Agriculture, Livestock and Supply data – MAPA – we have made use of production data, consumption, exportation and constant productivity of the Research of Municipal Agricultural Production (2011) and Research of Municipal Livestock Production (MLP), by state and total in the sector, by culture type and animal herd. In prospective terms, the GP index is obtained by considering physical production in the horizon of 2019/2020, according to the MAPA.

The calculus of moisture content (%), agronomic availability (%) of agricultural residues and animal waste has been performed in a disaggregated way by state and/or region. However, agricultural residues and animal waste can be solid, liquid or gas; this way, the estimated calculus of the potential estimate by culture and by herd only considers the solid residues and, whenever it applies, "deducting" from the parcel of agronomic indication necessary for soil fertilization, and the liquid residues resulting from the treatment of the herds by the cleaning and urine, getting the slurry. Slurry is formed by degradation of organic material and is characterized by an elevated oxygen biochemical demand (OBD). The slurry availability calculus has been calculated with the solid residue of the livestock activity. The gas residues are not being considered in this paper.

The calculus of the "generating potential (GP) index has been done by the relationship between the generated total residues by type and physical production (t/ha/t/ha). This index supplies results of easy interpretation as it is applied on the existing data base and it allows that the "deciding agent" may make economical use of residues and waste from agriculture and from animals. The use of this index allows required measurement and is based upon data availability and upon the called "harvest index". This index shows the proportion of total biomass accumulated in the grains, expressing the percent rate between the total amount of generated biomass by planted hectare of a determined culture or herd residual biomass and the "final product" amount, economically feasible by agribusiness – physical production. In general, each culture should be handled so as to allow the maximum biomass accumulation, and that a maximum proportion of this biomass may be "diverted" for grains. For instance, in the case of cassava, the harvest index will be the rate between the root weight and the total weight of the plant, possibly varying according to the weight of the aerial part, the production of tuberous roots, the cultivation purposes, among others. It means that instead of the roots' weight, the amount of generated residues in the agricultural phase of this tuber. The use of the harvest rate for agriculture has been one of the main indicators for productivity comparisons for cultures and herds. The harvest index is the indispensable indicator to evaluate the agriculture and livestock handling, according to Duraes et al. (2002). The Brazilian Enterprise of Agriculture and Livestock Research – EMBRAPA, also suggests the use of the harvest index as an indispensable indicator to evaluate the agriculture and livestock handling.

Table 3
Estimates of generating potential index (GP) for agricultural residues and animal waste in Brazil.

Feedstock	Abbreviation	Generating potential index – GP[a] (tons/total residues – tons/total waste[b])
Agricultural residues		
Sugarcane	SC	0.22 t TR/SC
Soybean	SO	2.05 t TR/SO
Maize	MI	1.42 t TR/MI
Rice	RI	1.49 t TR/RI
Cotton (Perennial)	CO	2.95 t TR/CO
Orange – 100	OG	0.50 t TR/OG
Wheat – 70	WH	1.42 t TR/WH
Cassava – 100	CA	0.20 t TR/CA
Tobacco	TO	0.75 t TR/TO
Animal waste		
Poultry (chicken)	PT	1.58 t TW/PT
Swine (pork)	SW	0.06 t TW/SW
Bovine (beef)	BO	0.07 t TW/BO

[a] Generating potential index: GP (tons/culture).
[b] GP index abbreviations: TR = total residue; TW = total waste.

3. Results and discussion

3.1. Quantification of agricultural residues potential

The availability survey of agricultural residues, animal waste, and its respective analyses as to generation potential, have been carefully evaluated considering the presence of those biomasses in the sites and around them, as well as production systems in use according to the agronomical needs and weather characteristics of different Brazilian regions. The quantification of the existing residue potential in several rural areas in Brazil, by agricultural type and by the animal production type uses the GP index that has been calculated (Table 3).

The results of residues generation and animal waste found except those proceeded from the harvest of the perennial orange farming (cycle of 18 years) are values that consider moisture percent and agricultural need of those growth that need to leave part of its residues in the soil for annexation and fertilization of new plantations (Torres et al., 2011). A detailed discussion will be detailed in respect to other obtained results of GP index by livestock.

3.1.1. Sugarcane (SC)

The main studies for sugarcane residues consider electric energy generation. For every 1000 kg sugarcane – total residue, TR of the culture – results in 220 kg residue production – leaves, tips. Evaluation studies of burning utilized as a basis sugarcane residues percentage with of 30% humidity. Stoichiometric determination of moisture content requires own methodology development and specific tooling laboratory. The residue availability calculation of sugarcane culture regarding 80–85% moisture content and 30–50% residue loss that remain on the field was:

$$\text{GP index} = 0.22\,\text{t TR/t SC}$$

3.1.2. Soybean (SO)

Soybean residues have been traded as additive to livestock feed and traditional food. The conventional mixture of soybean residues allows cost reduction and a complementation of chemical constitution, besides offering functional characteristics to the products many times. In case of soybean grains – total residue, TR of the culture – it has been considered arithmetic mean for GP index between the maximum values found in mechanized plantations, with high chemical charge and minimum values estimates of 2.7 t TR/t and average of 2.05 t TR/t SO. The calculation of residue availability – GP of soybean culture – has been performed considering 15–20%

moisture content and 75% loss of residues that remain in the field was:

GP index = 2.05 t TR/t SO

3.1.3. Maize (MI)

After maize harvest in the field, the main residues found were: stem, straw, bark, corn cob – total residue, TR. Those residues, once crushed, can be used in animal feeding, however, with little nutritional value. Straw can also be burned in rural areas, discharged or used as soil cover, after the mechanized harvest, which, in excess, has been causing serious problems of plagues that proliferate in moist and protected environments. Presently, maize straw has been designated to cigarette production, packaging of sweets, handicraft of basketry and of dolls. The production of craft products is also helping with valorization of that abundant residue. More recently, maize straw has been extensively used in studies of enzyme production, through solid state fermentation, both as a support and as nutrient source for microorganisms. In case of maize grains, the average value has been considered as GP indicator. The calculation of residues availability of maize culture regarding 25–30% moisture content and 70% loss of the residues that remain in the field was:

GP index = 1.42 t TR/t MI

3.1.4. Rice (RI)

Rice bark residue has been studied as energy source and it is already being consumed by industrial boilers and clinker furnaces. Apart from the production system applied during the agricultural phase with the grain harvest, there are straw and bark generation – total residue, TR of the culture. The weight relation between bark and straw is very small (13 times smaller). The straw, which shows the most representative volume, remains in the field after all. In this article, it has been assumed the composition of two kinds of residues (straw and bark) for availability analysis purposes of this culture. The calculation of residues availability of rice culture regarding 18–23% moisture content and 75% loss of residues that remain in the field was:

GP index = 1.49 t TR/t RI

3.1.5. Cotton (CO)

Cotton culture produces residues in its agricultural phase with branches and cotton plum/seed covers, as bark is generated in the phase of seed defibrillation of the plum. The branches and cotton plum/seed covers show residue/production relation – GP – of 2.45 tons of residues. In case of seed bark, after defibrillation, the estimated amount is of around 0.5 tons of residues. In this paper, for analysis purposes of residue of cotton availability – total residue, TR of the culture – it has been adopted the arithmetic sum of the estimated indexes for GP index. The calculation of residues availability of cotton culture regarding 30–35% moisture content and 30% loss of residues that remain in the field was:

GP index = 2.95 t TR/t CO

3.1.6. Orange (OR)

The residues of orange culture are only noticeable in the agroindustry – residue of agroindustry, OR. In the agricultural phase, because it is a perennial culture, it shows an 18-year cycle. Falling leaves and small branches residues are of marginal amounts, as they are absorbed by the soil. It is worth mentioning that in the orange industrialization phase for juice production there is the generation of great amounts of residues, which are equal to 50% of the fruit weight and 82% moisture. For illustrative purposes, it is considered for the residue volume orange industrialization that for each 1000 kg processed orange, results in about 500 kg residues, with 80% average moisture. The calculation of residues availability of orange culture regarding 80% moisture content in the industrial phase of orange was:

GP index = 0.50 t TR/t OR

3.1.7. Wheat (WH)

In the wheat culture, besides wheat grain, the rest of the plant is constituted of straw – stems and leaves. After grain harvest, the straw can be burned, removed or left in the field. According to Torres et al. (2011), in the Southern region straw destination depends on several factors, including the residue amount, the next culture to be planted, the weather conditions, the nutritional needs of the soil, the land slope, as well as any market that can be available for straw demand. It is also remarked from the reading of technical literature that research has been found about the use of wheat straw in vehicles, in the production of edible mushrooms and also in the valorization of this residue in crafts products, although in a marginal way. Wheat straw can be used as raw material for paper and heat and electricity production. The use of this residue in composting has been recommended due to its carbon (C)/nitrogen (N) relation. In general, the residues of agricultural farming present to the relation between C/N values from 10 to 100, while wheat residue is of 80:1. The relation between the straw and wheat production is similar to maize's. In this sense, the rough availability estimate of wheat straw/production – total residue, TR of the culture – apart from the adopted production system GP index has been considered, a value similar to maize's. The calculation of residues availability of wheat culture regarding 18–23% moisture content and 100% loss of residues that remain in the field was:

GP index = 1.42 t TR/t WH

3.1.8. Cassava (CA)

Cassava production results in liquid and solid residues – total residue, TR of culture. Liquid residues are composed of washing water of roots, "manipueira" (liquid residue resulted from cassava's pressing) and extraction water of solid residues are composed by branches and straws, being more representative in volume than liquid ones. The calculation of residues generation regards a residue/production rate, in which each 1000 kg cassava results in 200 kg solid residues generation. For estimative of availability purposes of residues for this culture, it is considered only the rural solid residues as GP index. The calculation of residues availability of cassava culture regarding 77–82% moisture content and 70% loss of residues that remain in the field was:

GP index = 0.20 t RT/t MA

3.1.9. Tobacco (TO)

Tobacco culture generates a meaningful amount of residues – stems, new leaves, flowers and roots – at the end of the culture cycle, since only part of the leaves are used commercially – total residue, TR of culture. Leaf production for cigarette and cigar manufacturing can generate around 75% residue, in relation to the total farmed biomass. Concerning the solid residue composting generated from the tobacco culture, the estimated calculation of residues available of tobacco culture should consider the residue/production rate for GP index. The calculation of residues availability of tobacco culture regarding 80–85% moisture content and 100% loss of residues that remain in the field was:

GP index = 0.75 t TR/t TO

3.2. Quantification of animal waste potential

Quantification of animal waste potential in several rural areas in Brazil by animal production type from the estimates of generating potential index (GP) can be analyzed in Table 3. A more detailed discussion for each animal production type will follow.

3.2.1. Poultry (chicken) (PT)

Poultry production (chicken) generates several types of residues such as bed, dust, odor, washing water and waste of carcass cleaning. In this context, waste of slaughterhouses is also considered. The calculation of poultry waste was estimated regarding as waste: chicken beds – beds that come from an only production cycle – and carcass of dead birds, collected in commercial poultry farms – total waste, TW. An estimate of waste/production rate for GP index considering two parcels of residues was: 1.08 t TW/t PT – beds and swabs (feces) and 0.5 t TW/t PT– dead poultry carcass, making a total of GP index of 1.58 tons of residue per ton of poultry. The calculation of the waste availability of poultry was:

$$\text{GP index} = 1.58\,\text{t TW/t PT}$$

3.2.2. Swine (SW)

According to EMBRAPA (2011), the total amount of manure plus urine produced by swine individually varies by its weight, but it presents decreasing figures from 8.5% to 4.9% in relation to its carcass weight, in the rate of 15–100 kg – total waste, TW. Estimates of waste availability have been made regarding the 6% waste rate – manure + urine – or 6 kg for each 100 kg carcass, and results of the GP index:

$$\text{GP index} = 0.06\,\text{t TW/t SW}$$

3.2.3. Bovine (BO)

For estimates of bovine waste availability, the production system has been considered with confinement, where animal raising occurs in a controlled area, whose necessary food and water are provided in troughs, the nearest phase to slaughter and carcass acquisition. In case of confinement, it is estimated 27 kg generated waste – total waste, TW – for each 400 kg carcass (Torres et al., 2011). This way, GP index was calculated by the waste/production rate:

$$\text{GP index} = 0.07\,\text{t TW/t BO}$$

3.3. Discussion of the availability of agricultural residues and animal waste in Brazil

Agricultural residues and animal waste availability and their respective analyses about the generation potentials have been evaluated carefully by a survey regarding these biomass presences in their respective sites and in their surroundings, as well as the production systems in use according to their agronomic needs and weather characteristics in the region. The complexity in quantifying these residues have to do with different soil characteristics and their relation with productivity, treatment types, weather characteristics and handling used with final destination environmentally appropriate or inappropriate. In this context, chemical analysis is fundamental of the moisture content, qualifying variable of residues and waste that can benefit or become impossible to their energetic reuse in economic terms.

Table 4
Estimates of moisture content (%) and agronomic availability (%) of the soil for agricultural crops in Brazil.

Agricultural crops	Moisture content (%)	Agronomic availability (%)
Sugarcane (SC)	80–85	50
Soybean (SO)	15–20	75
Maize (MI)	25–30	70
Rice (RI)	18–23	75
Cotton (CO)	30–35	30
Orange (OG)	Perennial	Perennial
Wheat (WH)	18–23	100
Cassava (CA)	77–82	70
Tobacco (TO)	80–85	100

3.3.1. Agricultural residues

The advance of Brazilian agricultural production in recent years presents in return increasing the volume of waste in rural areas. However, the economic utilization of this waste is still marginal, with limitations, both the existence of a very flexible environmental legislation, favoring the low commitment to environmental protection, the lack of incentives and policies to leverage the sustainable reuse of waste in rural areas.

Table 4 showed the estimates of moisture content (%) and availability agronomic (%) in the soil for agricultural crops in Brazil. The availability of agricultural agronomic residues, by culture, presented in Table 4 indicates the availability of raw (technical potential) that can be exploited. A refinement of this potential can be obtained by considering, for example, the moisture content and agronomic requirements indicated waste which must remain in the soil, for reasons of fertilization and/or plant. For example, sugarcane has a maximum moisture content of 85%, indicating that 50% of waste paper and spots must be left in the ground. It is composed of lignin by 19–24%, 27–32% of hemicelluloses, 32–44% of cellulose and 4.5–9.0% of ashes (Jacobsen and Wyman, 2000; Soccol et al., 2010). In this case, from a total of 157 million tons of waste, in the field would be 78.5 million to 19.6 million tons (dry basis), available for reuse would be economically. However, according to Rodrigues et al. (2003), the sugar mills generate approximately 270–280 kg of bagasse (50% moisture) per metric tons of sugarcane.

Table 5
Total availability of agricultural residues: generating potential index (GP), total production (10^6 tons) in 2009/2010 and prospective for 2019/2020; and total production of agricultural residues (10^6 tons) in 2009/2010 and prospective for 2019/2020, and growth percent 2009/2010–2019/2020 for agricultural crops in Brazil.

Agricultural crops	GP index[a]	Total production 2009/10 (10^6 tons)	Total production 2019/20 (10^6 tons)	Agricultural residues 2009/10 (10^6 tons)	Agricultural residues 2019/20 (10^6 tons)	Growth percent 2009/10–2019/20 (%)
Sugarcane (SC)	0.22	714.31	893.00	157.14	196.46	25.02
Soybean (SO)	2.05	61.77	81.95	126.62	168.00	32.68
Maize (MI)	1.42	53.85	70.12	76.46	99.57	30.22
Rice (RI)	1.49	12.59	14.12	18.75	21.03	12.15
Cotton (CO)	2.95	01.27	02.01	03.74	05.92	58.37
Orange (OG)	0.50	18.99	21.06	09.49	10.53	10.89
Wheat (WH)	1.42	05.09	07.07	07.22	10.03	38.90
Cassava (CA)	0.20	26.80	30.19	05.36	06.04	12.64
Tobacco (TO)	0.75	0.920	1.08	0.690	0.810	17.71

[a] GP index: tons/total residues – tons/culture.

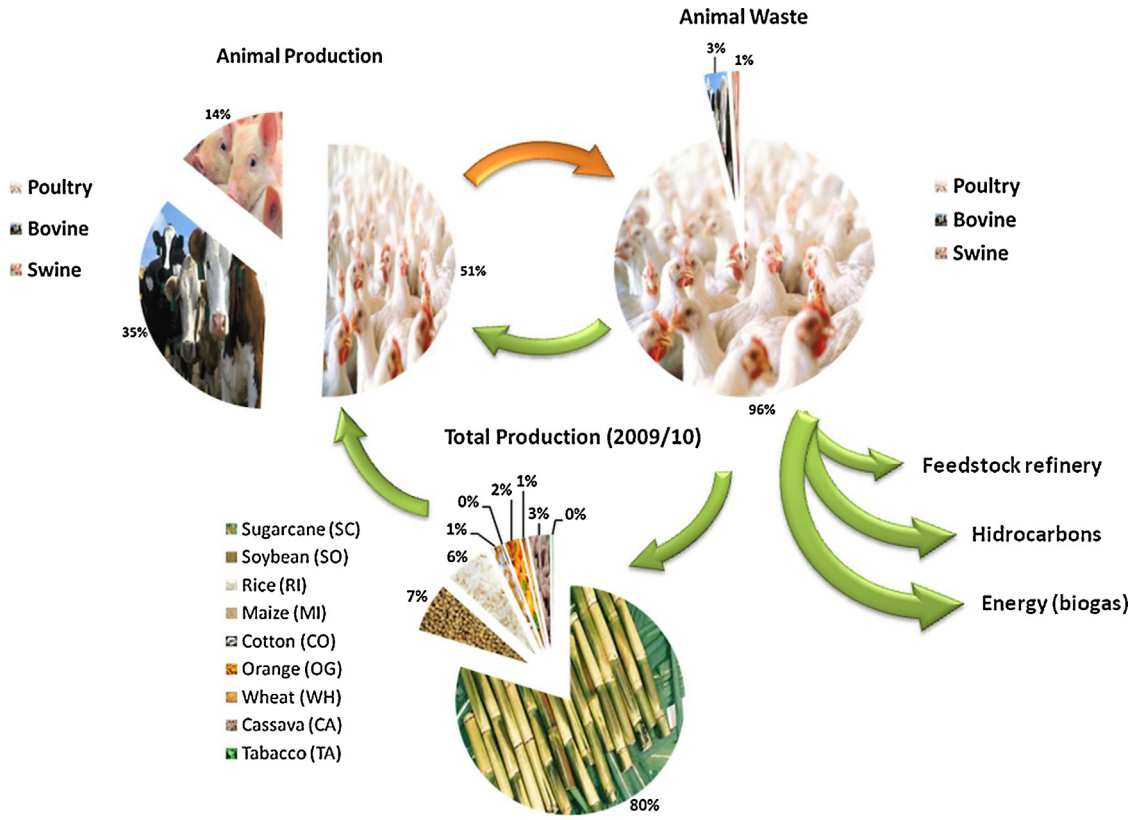

Fig. 2. Percent of total production of animal waste in 2009/2010 and sustainable exploitation alternatives of agricultural activities in Brazil.

In tobacco plants, there is also a maximum humidity of 85–100% indicating availability of agronomic, which can be incorporated into the soil or re-used in other thermo-chemical processes. In this case, it is observed that Brazil is losing the opportunity to generate business from agricultural production by turning your waste into different co-products and energy. The orange crop to be a perennial, produces no waste in significant quantities in the agricultural phase. The average lifetime of the orange is about 18 years.

Table 5 shows the total availability of agricultural residues, generating potential index (GP), total production (106 tons) and total agriculture residues production (106 tons) in 2009/2010 and prospective to 2019/2020, and percentage of growth 2009/10–2019/20 for agricultural crops in Brazil. The table shows the whole of agriculture among the species cultivated in Brazil, the culture with the highest biomass production was the sugarcane: 714.00 tons (2009/2010) and an estimated production of 893.00 tons for the year 2019/2020. Thus represents the culture with greater production of biomass residues, 157 million tons of waste and total growth of 25.2% by 2019/2010 with a production of 196.46 tons of total waste. In step agricultural or after harvesting, the residue of sugarcane GP showed relatively low index (0.22) with respect to the cottons, for example, GP index of 2.95. In this case, the rate of potential generator (GP) of 0.22 indicates the relationship between waste generated and the physical production (t/ha/t/ha), permitting easy interpretation of results and enable the selection among the various options, the type of reuse of waste (cane sugar) for power generation. So, for every 1000 kg of sugarcane has been the production of 220 kg waste (leaves, spikes) with potential energy. Considering the assessment of the potential for burning waste of sugarcane with humidity up to 30 and the loss of 30–50% of the residues that remain in the field PG content of 0.22 may be considered low when compared with culture cottons, for example, GP has an index of 2.95. The cottons waste produced at its agricultural phase, as the core shells (after defibrillation), with low moisture content 30–35% and 30% loss of residues that remain in the field, showing that the recovery of waste cottons is under explored in Brazil.

These results are superior to those found by Nogueira et al. (2003) that showed a production forecast of 23.4% dry matter for sugarcane and a total waste of sugarcane (only bagasse) from 59,401,824 tons as well as a production of 90.5% dry matter production of corn and corn stove (cobs and straw) of 64,028,870 tons. As such the results found by Macedo et al. (2004) that he thought the sugarcane as the raw material of higher production in the world, led by Brazil with nearly 400 million (Mt) per year, followed by India, China, Thailand, Pakistan and Mexico. China, for example, is the largest producer of rice (187 million Mt), the United States is the largest producer of corn (300 million Mt) and soybeans (86 million Mt) and the European Union's largest producer of beet with almost 127 million Mt. Thus, Europe and the United States are the main competitors of the highest energy product obtained from biomass, ethanol from sugarcane since the beets and corn are used by these countries to obtain an emergent product.

There is still a discussion about the competitive use of food commodities as fuels sources due to the growing world population and its nutritional needs and the actual supply model for the installed technology used for the production of bio-ethanol. The Brazilian bioethanol industry was poised for a major jump between 2006 and 2008 according to a new national plan to increase the sugarcane production (Renewable Energy Policy Network, 2006). This results show that sugarcane growth does not seem to have an impact in food areas, since the area used for food crops has not decreased. The expansion is taking place over pasturelands. Besides, the expansion of sugarcane area, the increase onethanol production was also

due to the growth of overall productivity (both agricultural and industrial) in the country (Goldemberg et al., 2008).

Sugarcane, sugar beets, molasses and fruits are good raw materials for production of bioethanol due to the high concentration of fermentable sugars. Molasses, which contains approximately 50 wt% of sugars, is the most used as fermentation substrate for the bioethanol production. According to Hahn-Hagerdal et al. (2006) and Lin and Tanaka (2006), ethanol obtained by direct fermentation of sugars from the raw materials is also termed "1st generation" bioethanol. On the other hand, corn and other crops are mainly composed by starches and therefore need to be pretreated before being used as fermentation substrate, and the high amounts of starch present (60–75%) are the main reason of the use of crops as bio ethanol sources (Bothast and Schlicher, 2005; Lin and Tanaka, 2006).

In general, in Brazil has seen an increasing number of products that favor investments in clean technologies and environmentally sustainable comes in response to minimizing environmental damage, with waste reduction/waste from production processes to the extent that production technologies are adopted, integrated, cost-effective for the reduction of production costs and the generation of co-products. The use of waste for energy generation sector began the use of bagasse in the sugar-feeding of boilers with a low yield of sugar and alcohol, and in the agricultural sector by the use of animal waste (pigs, mostly) for the production of biogas and bio-fertilizers which waste from the poultry industry shows a great potential. The Brazilian cane system of agro-energy is considered very efficient, but significant increase in the production of ethanol will only be possible with the development of technologies that can use lignocellulosic materials sugarcane residues present in the fermentation substrate (Goldemberg, 2007).

In this context, the chemical hydrolysis of sugarcane biomass is a consolidated methodology in laboratory conditions, its large-scale application but is not yet economically viable in Brazil (Soccol et al., 2010.). That is regardless of the methods of pre-hydrolysis treatment and used, the main challenge is to achieve high yields fermentable sugars and low concentrations of compounds that inhibit the microorganisms in the fermentation process. Although there are several methods for the removal of inhibitors of fermentation, the ideal situation would be one with processes and techniques for efficient hydrolysis pretreatment favorable to this technology. Among the available technologies, the hydrolysis of sub- and supercritical water is proving to be an attractive alternative to conventional chemical and biological processes (Prado et al., 2012 and Follegatti-Romero et al., 2012). It is expected that the feasibility of using sugarcane bagasse in Brazil, will promote the reuse of waste in the biorefinery itself resulting in more effective action to obtain renewable energy from agro-industrial residues such as to ethanol production of second generation, fuel gas, electricity and heat, upgraded products (premium diesel fuel, kerosene, refinery feedstock, waste soluble products such fertilizers (see Fig. 2).

3.3.2. Animal waste

Animal waste residues are completely different from lignocellulosic residues; these residues are composed of manure and other products resulting from biological activity of the herds. This study evaluated only the most important residues, namely those of cattle, pigs and poultry. The complexity in the quantification of these residues is due mainly to the diversification of livestock on the production system, family or facing internal and external markets, and their productivity vis-à-vis the treatment, climatic and management systems used. The location of the residue can be introduced in the area of cultivation – commonly known as the residue left in the field, those that are located exactly in the area where the crop has been made. This is the case, for example, the straw of cane sugar harvested green, or the leaves of soybean, that dry and remain in the field.

The animal wastes can be determined by the capacity of farms manure, the output changes in accordance with the cultural practices, as in the case of designs of containment, the cost of collection of the viability is smaller. Table 6 shows the total availability of pet waste, generating potential index (GP), total production (106 tons) and total waste animal production in 2009/2010 and to prospective 2019/2020, and 2009/10percentage of growth to 2019/20 is animal production in Brazil. It is observed that, in the livestock sector, between species of animals in confinement, there is greater generation of waste in the activity of poultry farming. A rough estimate of the technical potential for energy from agricultural residues was performed, taking into account the absence or the difficulties of obtaining information about the implementation of an alternative method called GP index – Potential Generation and based in the "index harvest" widely used in the agricultural sector, the statistics of production and physical products and the technical studies of production systems.

The total residue is coming from poultry bedding, dust, odor, wash water and debris cleaning carcasses, besides the abattoir waste (carcasses of dead birds collected in commercial farm). Therefore the estimate of the relative waste/production ratio for the GP should consider the total residue of the sum of the index GP 1.08 tons RT/tons AV (litter and feces) and RT 0.5 tons RT/tons AV (poultry carcasses dead), totaling the index GP 1.58 tons of waste per 1 tons of AV. This index GP value of 1.58 is greater than 0.06 and 0.07 tons RT/residue of swine and cattle confined.

To estimate the availability of cattle waste was considered the production system with confinement, where breeding occurs in the controlled area, which needed food and water are provided in troughs, step closer to the slaughter and collection of carcasses. Under the conditions of confinement, it is estimated to generate 27 kg of waste (residue total) for each 400 kg of carcasses.

The reverse is true when it comes to waste coming from the production activity of cattle, followed by pork, poultry, and finally goat and sheep. In Brazil, cattle and pigs are the main herd of approximately 200 and 33 thousand heads, respectively. The amount of manure produced by each animal 500 cattle kg ranging from 0.028 to 0.037 m^3/day depending on whether cattle or dairy cattle. These values correspond to 0% by weight dry or wet weight of excrement values ranging 28–36 kg/day (Cortez et al., 2008).

With respect to livestock waste, the main way of obtaining energy is through the production of biogas from animal wastes from different cultural practices and types of livestock. The biometanization of organic wastes is accomplished by a series of biochemical transformations, which can be toughly separated into a first step where hydrolysis, acidification and liquefaction take place and the second step where acetate, hydrogen and carbon dioxide are transformed into methane (Forster-Carneiro et al., 2010). Additionally, in addition to energy use, waste from pigs and cattle are used as fertilizer, reducing pollution in corn, improving the physical, chemical and biological soil properties.

The total quantity of nutrients contained in the excrement, especially P and K, is high and can be used as a fertilizer since the fecal material can give a significant increase in crop. In addition to providing macro and micro nutrients, organic matter contains excrement, which increases the ability to retain water and soil filling capacity increases and the concentration of microorganisms is important for improving soil structure. The nutrient phosphorus (P) is particularly valuable for plants in the early stages of development and important for good root development. However, the risk of high concentrations of pathogenic organisms increases requiring.

We conclude that, animal waste (fish waste, chicken waste, feather and hair) can be hydrolyzed into new products with high industrial value: amino acids, unsaturated fatty acids, oil,

Table 6
Total availability of animal waste: generating potential index (GP), total production (10^6 tons) and total animal waste production (10^6 tons) in 2009/2010 and prospective for 2019/2020, and growth percent in 2009/10 and for 2019/20 for animal production in Brazil.

Animal production	GP index[a]	Total production 2009/10 (10^6 tons)	Total production 2019/20 (10^6 tons)	Animal waste 2009/10 (10^6 tons)	Animal waste 2019/20 (10^6 tons)	Growth percent 2009/10–2019/20 (%)
Poultry (PT)	1.58	11.62	16.63	18.36	26.27	43.13
Swine (SW)	0.06	3.24	3.95	0.19	0.24	21.92
Bovine (BO)	0.07	8.02	9.92	0.56	0.69	23.75

[a] GP index: tons/total waste – tons/culture.

polysaccharide, hydrogen and methane (Fig. 2). However, the results show that controlling the main operating parameters (temperature and pressure) is very important to obtain high yields of amino acids as a final product of high industrial value. Thus, it is possible to obtain different percentages of income or the same amino acid or biofuel production in reaction atmospheres of air, carbon dioxide from the disposal of biomass wastes with cost reduction (Yoshida and Tavakoli, 2004; Cheng et al., 2008).

3.4. Biorefinery in Brazil: agricultural residue and animal waste as "bio-based"

Brazil is an emerging country with high growth rates in industry, commerce and services sectors. As all societies facing and giving internal solutions to problems resulted from climate changes it will have to adjust its development standard slowly into a decarbonizing growth in its economy. The country must achieve its economic growth in medium or large extent as it ratifies the Kyoto Protocol, based on using energy sources in a more efficient way, also establishing a green-based economy in which renewable energy sources shall have a fundamental role to reach the goals for decarbonizing its economy. In this context, there should be better monitoring of energy consumption in several economy sectors, as well as implementing carbon cost effectively and measures of energetic efficiency.

According to Cortez (2010), production of chemicals and fuels – especially ethanol – in integrated chemical platforms of biorefineries through biomass to liquid technology (BLT) is an excellent alternative to Brazil. The main advantage of this technology is low energetic request of products and processes because the greatest energetic efficiency is related with reducing energy demand, the one consumed for producing the same level of energy services. Besides, it accounts for highly efficient reuse of biomass regarding logistics, sustainability and markets.

According to Table 3, availability of sugarcane residues – bagasse – consists about 157 million tons. From this total of agricultural residues, concerning maximum moisture and agronomical needs of recommended residues that must remain in the soil for fertilization and orphytosanitary purposes, 19.6 million tons – dry base – are available for economic reuse. It is also noticed that sugarcane and soybean production figures, for instance, are more meaningful in terms of agricultural biomass volume, and that the crops are located in concentrated lands, which makes their own reusing logistics issues much easier.

In this context, by only considering the residues generated from the industrial phase of sugarcane processing, estimated in approximately 55.0 million tons of bagasse processed every year, it would be necessary to build twenty power plants to make a BLT biorefinery technologically feasible (Cortez, 2010). This biomass amount represents about 25% from the total agricultural residues that would be available in the agricultural phase of sugarcane production. From this premise, it seems to be reasonable to foreseen the economic reuse of agricultural residues, especially from sugarcane.

Soybean residue also represents a great reuse potential, as soybean culture is presenting itself in complete growth, responsible for the agricultural exports growth in Brazil in the last years. The exportation deals more than quadrupled, growing from US$ 4.2 billion in 2000 to US$ 17.2 billion in 2009. The same is noticed with poultry sales that increased from US$ 735.0 million to US$ 5.8 billion in the same period. According with the data of Table 3, a total production of 61.77×10^6 was recorded in 2009/2010 that disregarding maximum moisture of 15–20% and the agronomical needs of 75% of residues that remain on the field results that each 1.000 kg soybean – total culture residue – result in 2.050 kg residues with energetic potential.

Concerning the analysis of animal waste, the residues from the poultry production (chicken and laying hens) stands out from bovine and swine (Table 3). In case of waste with high organic load in biomass to liquid technology (BLT) processes, we can consider the broad concept named XTL, or the transformation of any carbon source (X) into high added-value liquid fractions (TL = to-liquid). This way XTL includes traditional technologies like GTL (gas-to-liquid) and CLT (coal-to-liquid) ones as well as other more innovative ones like BTL (biomass-to-liquid) (CGEE, 2010). From these pieces of information, it is noticed that the configuration of a biorefinery depends on the kind of feedstock as much as on the kind of conversion process. For instance, lignocellulose's biorefineries are based upon biomass fraction in rich lignocellulosic stocks (cellulose, hemicelluloses and lignin). Lignin can be used as feedstock for surfactant products. Hemicelluloses can be used as feedstock renewable source for packaging coatings and application as barrier film. The soluble hemicellulose can generate products such as xylitol and mannitol used as sweeteners for diabetics. On the other hand, animal waste is also considered potential carbon source easily transformed into liquid fractions of high added value in terms of XTL concept of biorefineries. Biorefineries that process animal waste as "bio-based" or as feedstock have new chemical products as goals to be achieved, such as amino acids besides electric energy and of heat through biogas (Fig. 1).

The increase in productivity has been the main factor contributing to the growth of Brazilian agricultural production. From 1975 to 2008 the agricultural and livestock products growth rate was 3.68% a year. During a more recent period, from 2000 to 2008, the improvements have been even greater, a yearly average of 5.59%, which points that the dynamic sector increases constantly. In the 1970s, Brazil has started a program to substitute gasoline by ethanol and this sugarcane was chosen as the feedstock to produce ethanol and, as a consequence, agricultural and technological studies were greatly intensified, leading Brazil to a very favorable position in terms of energy security (Soccol et al., 2010). However, it must be noticed that an only part of the biomass produced is used for bioenergy production; one-third of the plant is used for sugar production, one-third is bagasse, which is burnt for electricity production and the remaining one-third is left in the field, which is decomposed by microorganisms (Cortez et al., 2008). This way the resulting residues of sugarcane and soybean cultures as well as poultry production could aggregate value to the respective production chains by the biorefinery concept, by reusing biomass discharged up to now and that many times they have

empowered environmental damage, e.g. proliferation of pests and water pollution.

A biorefinery comprises two chemical platforms: the sugar platform, which is based on biochemical conversion process and is related to fermentation of sugar extracted from biomass; and the platform based on thermo-chemical conversion processes. Bio-based is applied as feedstock through these chemical platforms and the so-called "bio-based products" are produced.

The biorefineries apply diversity of conversion technologies according to the feedstock and on the aimed yield, being gasification mostly used. However, the greatest difficulty for the economical use of sugarcane, soybean residues and poultry waste regards the absence of evaluation of research opportunities and development of BTL technologies in chemical platforms under the concept of biorefineries.

It is assumed that Brazil has several technological institutes and non-governmental organizations presently that are devoted to technical studies and projects that deal with reuse of residues and waste, besides offering technical support for implementing projects. Out of those, some organisms of national performance stand out, a university network of federal scope and some of state scope that keep specialized research centers with local and national focus. The resulting data presented in Tables 4 and 5 may help identify where the inputs are and what productive processes result from them by evaluating biomass offer – agricultural residues – by means of the most important agricultural production identification of generated residues, according to types and volumes. Residue and waste use as energy source in Brazil still finds itself in an initial stage, showing some cultural limitations, such as agricultural production practices aiming to final product only and low commitment with environment protection; and limited technological offer of equipment and process for small production.

4. Conclusion

The agricultural residues and animal wastes currently generated in Brazil, represent an enormous amount of underutilized raw material that can be better explored in the context of an agro-biorefinery. Furthermore, the prospects for 2020 are that agriculture and animal production will increase and therefore the volume of residues and wastes generated. The results indicated high percentage of availability (over 50%) for reuse in biorefineries. The study of the technical, economic and social feasibility for implanting a biorefinery from sugarcane and soybean residues and poultry waste remains as a suggestion to future research. Today availability of main agricultural residues and animal wastes generated in Brazil and of their generation potential index and their prospects for 2020. The results indicate that the sugarcane has the highest agronomic availability, reaching 157 million tons of fresh material and an estimated reuse potential of 19.6 million tons (dry basis), followed by soybeans, rice, maize, orange, wheat, cotton, cassava and tobacco. Brazil has sufficient biomass to supply biorefineries. A number of plant configurations are possible for production of biobased fuels and products. Advanced technologies can further improve energy balance for biobased fuels. Further studies are required to understand factors influencing optimal size of biorefineries

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