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Routes of technological exploitation of agricultural waste for power generation

R. R. Batista[1], M. S. Bacelos[2], G. L. D. Chaves[2], T. S. Lira[2], L. S. Arrieche[2*]
[1]Aluno do Programa de Pós-Graduação em Energia, Universidade Federal do Espírito Santo – UFES, campus São Mateus, ES
[2]Professor do Programa de Pós-Graduação em Energia, Universidade Federal do Espírito Santo – UFES, campus São Mateus, ES
*Autor para correspondência, E-mail: leoarrieche@hotmail.com

Abstract: The use of agricultural residues as a bioenergy source has aroused increasing interest in the bioenergy sector. This paper discusses the exploitation of cocoa and coffee husks using anaerobic digestion, pyrolysis and direct combustion technologies. The structural synthesis method that was used to obtain electricity was performed using a State Tree. Structural elements were combined to form branches for each chemical route. Structural optimisation was conducted using the heuristic method. The promising technological routes included the anaerobic digestion of cocoa husks in a batch reactor and the pyrolysis of coffee husks preceded by pelletisation. The systematic representation of the problem using the process engineering approach was a promising method for evaluating the process of obtaining energy from fruit wastes.

Key-words: fruit residues, anaerobic digestion, pyrolysis, direct combustion, state tree, heuristic method.

1. Introduction

The augmentation of the global population and the increasing purchasing power of developing countries are increasing the demand for electricity. As Brazil's population increased by 0.9% in 2012 (IBGE, 2012), the final electricity consumption increased by 3.8% (EPE, 2013). The use of non-renewable energy sources to supply this demand has been widely criticised. Biomass is the only fuel that is available for renewable combustion based on the generation of electricity; thus, biomass has gained significant attention as a substitute for fossil fuels (Evans *et al*., 2010).

According to EPE, 2013, in Brazil, most electricity is supplied by hydric sources (84.5%). However, hydric sources result in high supply risks due to falling water levels in reservoirs. The Brazilian electricity sector faces significant infrastructure challenges in addition to the seasonal characteristics associated with the hydric potential. During the dry season, the risks of energy disruption are greater because hydric reserves are very low. To minimise the country's dependence on this energy source, the Brazilian government is developing policies that encourage the implementation of thermoelectric power plants that use biomass as an energy source (Coelho *et al.*, 2002). The final electricity consumption was augmented as the conventional thermal generation increased, the participation of which increased in the electric matrix in 2013 from 4.4% to 7.9% (EPE, 2013).

Energy sources should be available with a constant supply and at a low cost because energy security is a global and critical issue for governments (Evans *et al.*, 2010). The adoption of incentives for expanding power generating enterprises that use biomass is important for energy policy. The generation of power from biomass has been legally established in Germany, which promoted the implementation of nearly 8000 combined heat and power (CHP) plants across the country. Strengthening the role of power from biomass in the energy policy can foster the introduction of flexible power and may support the technical development of biomass provision and conversion (Thrän *et al.*, 2013). The electricity produced by biomass is generally favourably priced, efficient, results in low emissions, and decreases the availability of feedstock (Evans *et al.*, 2010). Moreover, Carbon dioxide (CO2) emissions from biomass combustion are traditionally assumed to be climate neutral because they are approximately equal to the amount of CO2 sequestered in the biomass (Bernesson *et al.*, 2006; Cherubini *et al.*, 2011; Hillier *et al.*, 2009; Ingham, 1999).

The use of biomass from agricultural waste has been highlighted as a promising alternative to the use of non-renewable resources. Despite several limitations, such as low fuel values and high transportation costs per unit of energy (Thornley, 2006), there are many benefits of using residues for energy production, including the redirection of landfill waste products (Moghtaderi *et al.*, 2007), which can be obtained at little or no cost (Evans *et al.*, 2010).

The heterogeneity of the residual biomass makes it difficult to select an energy recovery technique for the employed residue. Such characteristics allow for the adjustment of multiple chemical technologies for the recovery of a specific residue. This article aims to use State Trees for different processes to represent possible routes for energy recovery from cocoa and coffee husks and to obtain promising technological routes for each State Tree.

In addition, this article emphasises the use of waste coffee and cocoa husks (as examples of agricultural waste) for energy. Thus, the fundamentals of direct combustion, pyrolysis and anaerobic digestion were analysed to discuss the performance of each technology. By using an exhaustive search technique, the respective branches of each State Tree were determined for each analysed residue (coffee and cocoa husk). Technological and structural optimisation was performed by applying the heuristic inductive method.

Overall, the results suggest promising technological routes for each investigated agricultural residue. This study provides a promising methodology for evaluating the energy obtained from fruit residues and significantly contributes to the current literature in the field of process engineering.

2. Background

Inadequate disposal methods for agricultural and agro-industrial residues and energy security issues motivated this study regarding environmental control and corresponding bioenergy generation technologies. Therefore, the proper use of the residues proposed in this study was considered in previous studies. Next, the fundamentals of chemical conversion technologies are presented.

2.1. Biomass for energy generation

2.1.1. Cocoa *(Theobroma Cacao L.)*

Cocoa is a fruit that originated in America. The development of cocoa mainly began in the state of Bahia, from the city of Ilhéus, before spreading to the southern regions of the state and reaching the northern region of the state of Espírito Santo. Cocoa fruits are oval in shape, 20 to 30 cm long, and have a hard shell that surrounds its almonds (available at www.ceplac.gov.br, 2013). Fig. 1 highlights the cross-sectional view of the cocoa fruit husk.

Figure 1: Open Cacao Fruit (cross section) showing the seeds and the bushy husk (Source: Letícia Comério).

Cocoa husks are red or yellow in colour when the fruit is suitable for harvesting (available at: www.ceplac.gov.br, 2013). Flour generated from the cocoa peel has a low fat content (1.5 mass %), a high ash content (6.7 mass %) and a protein content of 8.6 mass % as described in previous studies (Aregheore, 2002) The main crop residue is composed of cocoa husks, which constitutes approximately 75-76% of the cocoa bean fruit (Donkoh *et al.*, 1991), and has a mean humidity content of approximately 12% (Cardoso *et al.*, 2003).

2.1.2. Coffee (*Rubiaceae, gênero Coffea*)

Brazil is the largest producer and exporter of coffee beans and the second largest consumer of coffee after the United States. The climate and soil types of the State of Espírito Santo allowed for the expansion of Conilon coffee as an alternative to agricultural diversification and has significant social and economic relevance (available at www.ceplac.gov.br, 2013). The visual appearance of the coffee husks after beneficiation is shown in Fig. 2.

Figure 2: Coffee husk (Source: Vanessa Dal-Bó).

Coffee husk residues result from cleaning coffee beans and are composed of exocarp (husk), mesocarp (pulp or mucilage) and endocarp (parchment). The pulp contains the residue obtained from pulping the wet coffee bean and is composed of the epicarp and mesocarp of the coffee beans (Matiello, 1991). The obtained husks are dry and contain parchment. The pulp is moist with no parchment because it is enveloped in the coffee bean and is protected (Barcelos *et al.*, 2013).

This extraction process is used to remove the dried pulp of the coffee bean. After harvest, the coffee fruit must be submitted to a series of technological steps to adjust the grain market standards. This adjust the grain is intended to separate the seeds from the surrounding parts (pulp, mucilage, parchment or endocarp), its tegument, and any impurities and defects. According to Prado and Campos (2007), although the wash step in the post-harvest processing of coffee is beneficial, it requires considerable energy consumption, mainly for the drying step.

Due to different environmental conditions and different species in permanent agricultural cultures, each raw material has distinct characteristics that depend on the plant or on the mixing of several residues. Thus, the pre-treatment step of residual biomass is important for establishing the technical foundations for the collection, drying, grinding and classification of the materials to obtain good uniformity, quality and efficiency for future use in biomass conversion processes.

2.1.3 Technologies for recovering energy from biomass

The main technological methods for residual recovery include the branches of the state trees of chemical processes, which are composed of the core technologies of processing and the chemical conversion of biomass. Among the key processing technologies addressed, it is important to note natural and forced drying technologies, which are beyond compression technologies for briquetting or pelletising. Thus, the literature review is focused on the following chemical conversion technologies: anaerobic digestion, pyrolysis and direct combustion.

The drying step is important due to the high water content of the residue after harvesting the fruit and removing the pulp. The fruit husk residues have low fibre contents and high moisture contents (greater than 50%) (Malisius, 2000). The residue drying process can be natural or forced. Natural drying is promoted by storing the biomass in an open environment for two to three months until the moisture content is reduced to approximately 15-20% on a wet basis. In the forced drying stage, equipment is required to reduce the water content of the biomass to the desired time scale of minutes or hours (Nogueira and Lora, 2003).

According to Silveira (2008), to perform the compression technique, the water content of agricultural waste should be between 8 and 12%.

The use of compression technology depends on the different characteristics of the agricultural residues. Among these differences, we highlight differences in particle size, energy density and water content, which are aspects that indicate the raw material should be compacted. This step aims to increase the energy density to generate more power while using a smaller volume of raw materials and to facilitate the storage and transport of these materials. Among the possible compression techniques, we used briquetting and pelletising. The remarkable features of pellets and briquettes are shown in Table 1.

Table 1: Characteristics of briquettes and pelle ts (adapted from Saião, 2009, apud www.eubia.org, 2013).

Characteristics	Pellets	Briquettes
Raw material	Triturated dry wood or agricultural residues	
Shape	Cylindrical: diameter of 6 to 12	Cylindrical: diameter 80 to 90 mm
Density	650 to 700 kg/m³	650 to 1200 kg/m³
Aspect	Soft	Rough
Transport	Sacks	Units, pellets
Handling	Manual or automatic use	Manual use
Calorific power	16-17 MJ/kg	16-17 MJ/kg
Moisture	8 to 12% (SILVEIRA, 2008)	10 to 12% (SILVEIRA, 2008)
Ash content	Maximum 0.5%	0.2%

2.1.4 Chemical conversion technologies: anaerobic digestion, pyrolysis and direct combustion.

Anaerobic digestion is a process in which organic matter is converted to methane (CH_4) and carbon dioxide (CO_2) and forms liquid and solid residuals. The biomass used for this process can consist of forest, organic or solid wastes. The raw material that presents a high biodegradability due to low fibre content is usually intended for chemical processing (Chernicharo, 1997). The formation of gaseous fuel from the anaerobic digestion of organic wastes is economically attractive because this process enables the use of raw materials with high moisture contents and can operate at ambient temperature and pressure. However, a major obstacle exists regarding the adequacy of raw materials for inserting into the process equipment because the residues normally have heterogeneous granulometry. Physical pre-treatment includes reducing the particle size and the pre-incubation of the waste material with water (Sharma *et al.*, 1988). Table 2 lists several advantages and disadvantages of using anaerobic digestion technology.

Table 2: Several advantages and disadvantages of the anaerobic digestion technology for recovering energy from waste.

Advantages	Disadvantages
Disconnection of electricity production.	Heterogeneity of residues hinder the control of operational variables.
Lower air pollutant emissions.	Unconsolidated technology for agricultural waste at the commercial scale.
The production of biofertilisers associated with biogas generation.	The effects of the corrosion problem on the internal metallic portions of the equipment.

The pyrolysis process involves the thermal decomposition of organic matter in the absence of oxygen and with heat injection from an external thermal source. The main products include rich hydrocarbon gas mixtures, an oily liquid and vegetal coal. The organic compounds resulting from biomass pyrolysis include the following: gaseous fractions containing CO, CO2, H2 and some hydrocarbons; a condensable fraction containing water and organic and low molecular weight compounds (aldehydes, ketones, alcohols and acids); and a solid fraction containing residual and higher molecular weight polysaccharides derived from furan, phenolic compounds and solid waste particles in suspension and smoke-forming compounds (Virmond, 2007).

The energy for this process can be maintained by burning gases and through volatilisation. Regarding the theoretical foundations of the exposed pyrolysis technique exposed, the main advantages and disadvantages of the pyrolysis technology for recovering waste energy can be summarised as shown in Table 3.

The direct combustion process is the oldest process for using biomass and accounts for more than 97% of bioenergy production globally (Virmond, 2007). Biomass burning is the most widespread dendroenergetics process and can be performed using various types of equipment, including stoves, furnaces and boilers. Biomass burning is used for various domestic purposes, such as cooking in the service sector and in restaurants, steam production in the industrial sector, and cleaning, heating or power generation equipment in the turbine. Biomass is believed to be a convenient and inexpensive source of energy because it does not require technological improvement of the process equipment. However, the combustion process is typically very inefficient (Cortez, 2011). When assuming ideal reaction conditions, combustion represents the complete oxidation of the fuel gases in the organic fraction. Three steps describe this conversion, drying the fuel, pyrolysis/gasification (thermal degradation) and the oxidation of the solid residue and exhaust gases. The rate of biomass combustion mainly depends on multiple physical phenomena, including the heat transfer rate and the kinetic reaction rate (Virmond, 2007).

Table 3: Some advantages and disadvantages of pyrolysis technology for recovering energy from waste (adapted from FEAM, 2012).

Advantages	Disadvantages
Disconnection of electricity production.	Heterogeneity of the residues hinders the control of operational variables.
Low emission of air pollutants.	The technology is not consolidated on a commercial scale.
Reduction of the volume of waste to be disposed of.	High operational and maintenance costs.

Regarding the theoretical foundations of the direct combustion technique, the main advantages and disadvantages of this technology can be summarised for recovering energy from waste, as shown in Table 4.

Table 4: Some advantages and disadvantages of direct combustion technologies for recovering energy from waste (adapted from Wiecheteck, 2009).

Advantages	Disadvantages
Allows the use of residues generated by the farm itself;	Heterogeneity of the residues hinder the control of the operational variables;
Allows the use of the thermal energy from combustion in other processes, such as the generation of electricity, provided that adequate equipment is available;	Equipment manufacturers are concentrated in the south and southeast regions of Brazil, resulting in high equipment shipping costs to communities in other regions of the country;
Domestically manufactured equipment is available through multiple suppliers.	Direct combustion is a polluting energetic alternative.

3 Methodology

3.1 Systematic design

Systems are created to perform new tasks or for more efficient execution of known tasks. The creation of a system includes a large number of operations that are called projects. The systematisation of a project begins with its statement as a problem. Generally, this problem is used to determine the best structure for a system to accomplish the desired purpose and consists of the following sub-problems: the generation of a set of feasible structures for the system, and forecasting and evaluating the performances of each generated structure. The first sub-problem is called synthesis, and the second sub-problem is called analysis (Perlingeiro, 2005). This paper focuses on the structural synthesis.

3.2 Structural synthesis

The synthesis phase is the creative phase of the project and includes its conception. Synthesis begins after selecting the chemical route and consists of choosing the equipment and defining a flowchart to perform the chosen chemical route. In addition, the equipment is chosen according to the required functions of the process. Synthesis essentially includes a combinatorial problem and is characterised by a multiplicity of solutions. Various types of equipment can be used for the same function, and the equipment can be interconnected in various ways by replacing one element or a current to provide different process or performance (Perlingeiro, 2005). Thus, cocoa and coffee husks can be processed using anaerobic digestion, pyrolysis and direct combustion technologies to obtain electricity by using various process structures. Here in after, the processing of cocoa and coffee husks into electricity is simply referred to as "the process".

The process design begins by organising its actions according to its subsystems. The options available for these actions in their respective subsystems are described below.

(a) Crushing subsystem: slicer;

(b) Chemical pre-treatment subsystem: the addition of basic aqueous solution or water;

(c) Drying subsystem: natural sunlight or artificial drying by forced convection in a fixed bed;

(d) Compaction subsystem: pelletising or briquetting;

(e) Subsystem for chemical conversion into liquid fuel: pyrolysis in a fixed bed reactor;

(f) Subsystem for biochemical conversion into gaseous fuel: UASB or anaerobic batch reactor;

(g) Subsystem for chemical conversion to generate heat: boiler with a fixed grate, gas boiler, and liquid fuel boiler;

(h) Subsystem for electricity production: gas power generator, liquid fuel power generator or steam power generator.

From the list of devices provided for each subsystem, synthesis (the generation of plausible flowcharts) is accomplished to obtain the final product. This systematisation is concretised using a State Tree, as shown in Fig. 3. By using this representation, it was possible to cover the maximum number of technological (chemical) and structural routes without repetition or the risk of omitting the optimal solution.

Fig. 3 shows the simplified tree for the three considered technologies. In this simplified version of the tree, only the relevant subsystems for each route are included. Attention is given to the combinatorial characteristic of the process and the multiplicity of the possible solutions for this design. This article addresses optimisation problems at the structural level (synthesis). In this problem, viable system structures are generated successively based on Fig. 3 to search for a promising structure.

A promising flowchart is one with superior performance to that of any other flowcharts. However, such a complex problem cannot be solved efficiently without using special techniques. The Process Engineering technique includes various resolution methods, such as the heuristic method, the evolutionary method, the search guided by the state tree and the superstructure method (Perlingeiro, 2005). In this design, the heuristic method for generating a flow chart next to the optimal flow chart was used.

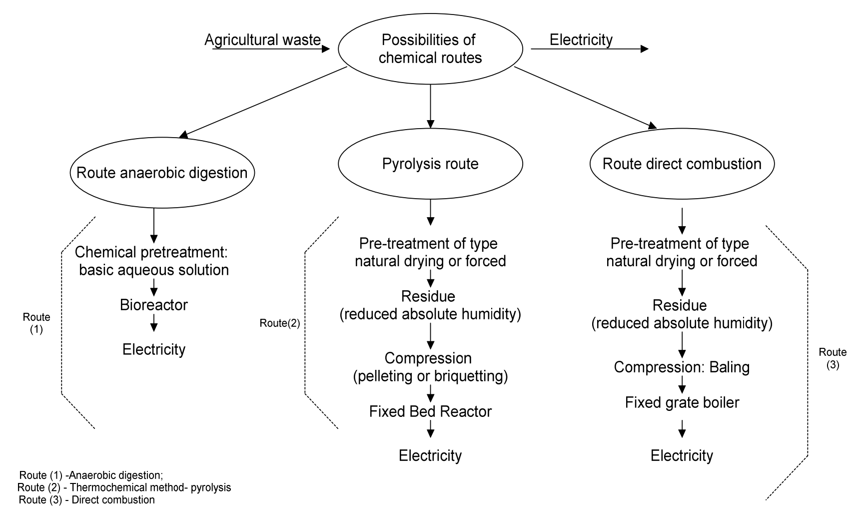

Figure 3: The problem of process design represented by a State Tree (Technological Route 1: anaerobic digestion. Technological route 2: pyrolysis. Technological route 3: direct combustion).

3.3 Heuristic method

The heuristic method consists of a catalogue of practical rules (which may or may not be ordered) that form an intuitive basis for the decision making process. These rules are applied in each state, beginning with the root and considering the heuristic rule, which is more appropriate for situations in that state and result in the following state. Thus, the heuristic search results are obtained by considering a flowchart. Although the heuristic solution is not necessarily optimal, it may be nearly optimal depending on the quality of the rules used (Perlingeiro, 2005).

It is possible that conflicts may occur between the elaborate rules. In addition, it is possible that different solutions could be found depending on the criteria that are used to prioritise them. Thus, this approach is characterised as subjective. To obtain the most optimal solution, it is important to obtain knowledge gained through industrial practice or through simulations and process analyses, which are verified as consistent through experimental observation (Carvalho 1995). The solution generated by the heuristic method provides a starting point for obtaining a better solution.

3.3.1 Heuristic rules for prior processing

Towards the processing steps of biomass for subsequent application of chemical technology, it is worth mentioning the inherent characteristics for application of the process of anaerobic digestion, direct combustion and pyrolysis. For the processing of via pyrolysis, it should be noted that the organic waste must have a moisture content of up to 12%. Furthermore, it is necessary subsequent step of pelletizing /briquetting technology, in the preparation of biomass. For the pre-treatment of biomass with subsequent application of the direct combustion technology, emphasizes the need for high fiber content and low biodegradability of waste evaluated. In relation to the processing of biomass for anaerobic digestion technology, mentions the importance of the chemical pre-treatment step with basic solution (NaOH or $Ca(OH)_2$).

Heuristic rule for grind stage

Before the applicability of one of the three chemical process of conversion, its important highlights the heuristic rule - grinding step – as following next:

- If the particulate agricultural waste material present characteristic particle size greater than 5 to 10 mm: applying grinding step, and
- If the particulate material of the present agricultural waste characteristic particle sizes less than or equal to the range of 5 to 10 mm: not apply the milling step.

3.3.2. Heuristic rules to choose the chemical route - Anaerobic digestion, pyrolysis and direct combustion

The heuristic rules drawn up for the chemical pathways based on technical requirements. For Anaerobic digestion technology is worth mentioning: perishable residue and presence of bioreactor equipment. Regarding the pyrolysis technology, it is necessary that: the residue is resistant to environmental conditions - humidity up to 12% on a wet basis (Silveira, 2008), has high fiber content and low organic biodegradability and the presence of reactor equipment fixed bed with an average operating temperature of 700 °C. For the technology of direct combustion, it is necessary that the waste presents high fiber content and low organic biodegradable, although the literature is not mentioned specific humidity range for application of this technology; and fixed grate boiler type equipment.

Heuristic rules - biological pathway Biodigestion Anaerobic

Anaerobic bioreactor equipment batch:

- If the particulate residual bark is defined size (characteristic diameter 5 - 10 mm): Using anaerobic bioreactor batch;
- If the particle is like "straw": using anaerobic bioreactor and upstream blanket (UASB).

Heuristic rules – thermochemical pathway Pyrolysis

Step 1. Assess the moisture content of the analyzed biomass.

- If the moisture on a wet basis is less than or equal to about 12%, is not carried out pretreatment for drying;
- If moisture on a wet basis is greater than about 12%, perform pre-treatment by drying.

Step 2. Pre-treatment of drying, such as:

- If the particulate residual bark is a high surface of contact, can be processed in an open environment and if it is possible to perform the drying process in the time scale of days or even months, if the waste is low biodegradability: using drying natural;
- If the particulate residual shell for low-surface contact with the ambient conditions, highly biodegradable and if necessary drying in the time scale in minutes or even hours: use forced drying.

Step 3. The compression type pre-treatment

- If the residual shell particles have: characteristic diameter smaller than the average particle diameter value representing 5 to 10 mm, humidity between 8 and 12% on subsequent drying wet basis (Biomax; Biomachine, 2007 cited, Silveira. , 2008), and moreover it is necessary to pre-treat the natural or forced drying with tumbling equipment (Malisius, 2000): using the pelletization technique;
- If the residual shell particles have: Residual defined granulometry (average representative particle diameter of 5 to 10 mm) (Silveira, 2008) or greater moisture content between 10 and 12% after the drying ((Biomax;. Biomachine, 2007 *apud.*, Silveira, 2008), pretreatment forced drying equipment with the type rotary drum (Malisius, 2000): Use briquetting technique.

Step 4. Evaluate the gross calorific value of the agricultural waste

- If the particulate agricultural waste present minimum gross calorific value value in the range of values from 22 to 24 MJ / kg (Orsini, 2012): apply the chemical via pyrolysis;
- If the particulate agricultural waste present minimum gross calorific value value in the range of values 19-20 MJ / kg (Orsini, 2012): apply the chemical via direct combustion.

<u>Heuristic rules – via direct combustion</u>

With respect to the conventional route of direct combustion, the application of heuristic rules aims at the utilization of thermal energy. Although it is a low-efficiency technology; it is not prioritized conducting a pre-treatment of biomass with the technical accuracy in the same way as the pre-treatment of the pyrolysis thermochemical means. Thus, the choice of this pathway is based on the constraints of the processing steps of said biomass, in addition to technical requirements for proper application of this technique. As it is a chemically high temperature as well as thermochemical via pyrolysis in case of use of biomass by pyrolysis of chemically; It has also the possibility to apply via the direct combustion. In such case, prior to the direct combustion, applies heuristic rules pretreatment of biomass related to thermochemical via pyrolysis. It is noteworthy that the grinding step proves too difficult, due to the mechanical consistency of biomass under review, carried out direct combustion itself, without necessarily applying heuristic rules pretreatment related to thermochemical via pyrolysis.

Thus, in addition to not perform forced drying to waste characteristic diameter greater than the figures for the range of 5 to 10 m (Biomax;. Biomachine, 2007 *apud.*, Silveira, 2008), takes place the compression category type baling.

As discussed, the methodology is directed to obtain the following results for each evaluated residue:

- Promising chemical technology as residue characteristic under study;
- Proposition of the state trees of chemical processes for the recovery of waste;
- Determination of promising technological route for each state tree according to the evaluation of heuristic rules.

It should be noted that the methodology of this article was based on research literature sources on the use of waste from coconut shell, cocoa and coffee; to support the development arm of the state tree for each waste in question. Among the sources of research, it is worth mentioning: Elsevier journal, Scientific Interfaces – Health and Environment magazine as well as dissertations and theses.

4. Results

To recover the energy from coffee and cocoa husks, multiple flow charts were created by combining the possible chemical routes and processing operations. A schematic of these flow charts is presented that uses state trees for each residue based on the technical aspects inherent to the characterisation of cocoa and coffee husks. The respective state trees are shown, followed by those chosen for each residue. In addition, the structural neighbours of the chosen routes are presented as alternatives.

4.1 State tree – cocoa husk

Figure 4 shows the multiple chemical and structural routes proposed for the energy exploitation of cocoa husks.

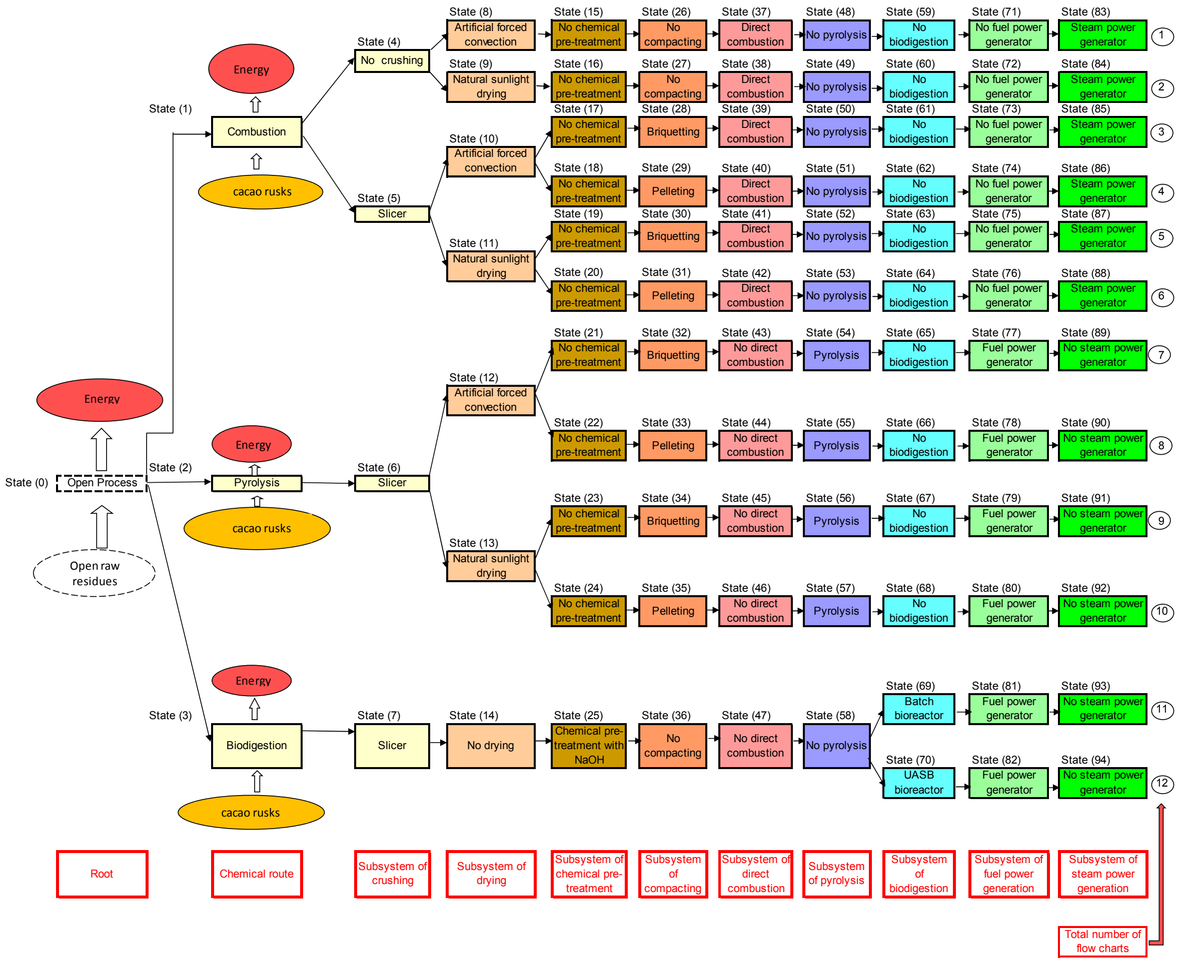

Figure 4: State tree for the energy exploitation of cocoa husks.

Each level of the state tree in Fig. 4 corresponds to one of nine subsystems considered for the energy exploitation of agriculture residues, crushing, drying, chemical pre-treatment, compacting, direct combustion, pyrolysis, biodigestion, fuel power generation and gas power generation. In this tree, each vertex is numbered and corresponds to a state of the problem. Thus, the vertex (0) corresponds with the "no flowchart" state. For example, at vertex (1), the chemical route of combustion is stated and the incomplete state is a flowchart that is only formed by the particle size reduction process. Vertex (5) corresponds to a state in which the incomplete flowchart is formed by size reduction, followed by artificial drying by convection in a fixed bed in vertex (10).

At state (17), the chemical pre-treatment step is eliminated, and at state (28), the particles are processed into briquettes. At state (39), direct combustion of the briquettes occurred in the previous states and the operation at states (50) to (73) are eliminated. At state (85), the heat generated by burning briquettes at state (39) was used to feed a steam electricity generator. Thus, flowchart number 03 is obtained. In addition, Fig. 4 shows states (83) thru (94), the twelve completed flowcharts, and the other intermediate flowcharts generated for solving the problem. Multiple solutions are evident and must be reduced to one flow chart based on heuristic rules.

4.2 Energy recovery from cacao husks as a function of their chemical characteristics

The main technologies applied to cacao husks are presented in Table 5 based on their chemical characteristics. Table 5 was constructed based on a literature review. The principal characteristics that can be observed include a high biodegradability and a high moisture content of approximately 12% (wet basis). In addition, the lipid content varied from 1.58 to 1.42 and the sugar content varied from 10.90 to 9.90 g/100 g, which demonstrated the high biodegradability of this residue. These characteristics indicate the application of anaerobic biodigestion technology. Other possible applications for cacao husks include use as fertilisers and substrates for enzyme production (Cardoso *et al.*, 2002 *apud.*,Gonzales *et al.*,2013).

Table 5. Energy recovery from cocoa husks as a function of their chemical characteristics.

<table>
<tr><td rowspan="7">Cocoa</td><td rowspan="3">Composition characteristics of cocoa husks</td><td colspan="3">Technologies and assumptions</td></tr>
<tr><td rowspan="2">Anaerobic biodigestion</td><td colspan="2">Briquettes/Pellets</td></tr>
<tr><td>Pyrolysis</td><td>Direct combustion</td></tr>
<tr><td>Moisture content: 12% (wet basis) (Cardoso et al., 2002)</td><td rowspan="2">Favourable to ambient conditions (Gonzales et al., 2013)</td><td colspan="2" rowspan="2">Considered inadequate to pericible residue of low cellulosic content (Gonzales et al., 2013).</td></tr>
<tr><td>High biodegradability (Gonzales et al., 2013)</td></tr>
<tr><td colspan="4">Other promising applications for cacao husks</td></tr>
<tr><td colspan="4">Biogas production, fertilisers, briquette, pellets and substrate for enzyme production (Gonzales et al., 2013)</td></tr>
</table>

4.3 Promising chemical route - Cocoa husk

Considering the composition characteristics presented in Table 5 and the application of the heuristic rules, the flow chart shown in Fig. 5 was used as a promising technological route for recovering energy from cocoa.

The selection of the promising technological route its depending on heuristic rules as follow:

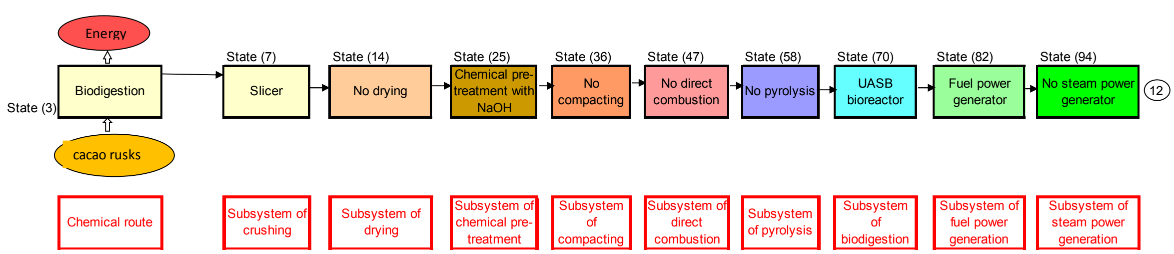

Figure 5: Promising chemical route - Cocoa husk

The following justifications were obtained for this route.

- According to heuristic rules 3.1 and 3.2, size reduction and chemical pre-treatment subsystems are very important because cocoa husks are large and their surface contact must be improved to enhance their chemical pre-treatment and biodegradation rates (Gonzales *et al.*, 2013, Batista, 2014). The drying and compacting subsystems were not considered as relevant for this type of residue, in agreement with heuristic rules 3.1 and 3.2 because the cocoa husks are suitable for biodegradation and because no compaction is required for this chemical route. Obviously, the pyrolysis, direct combustion and steam power generation subsystems are not present in this flow chart.

- Two bioreactors could be used, the batch bioreactor and the UASB bioreactor. The batch bioreactor was chosen in agreement with heuristic rule 4. This equipment is more suitable for loading small quantities of organic feedstock without requiring continuous flow of feed for proper equipment operation. In addition, operating conditions with a temperature of approximately 34 °C and at a pressure of 1 atmosphere are used for perishable waste. Thus, it is important to use a technology that is appropriate for nearby crops.

4.4 State tree – coffee husks

Fig. 6 shows the multiple chemical and structural routes proposed for the energy exploitation of coffee husks.

4.5 Energy recovery from coffee husks as a function of their chemical characteristics

The main technologies applied to coffee husks are presented in Table 6 based on their chemical characteristics. Table 6 was constructed based on a literature review. The principal characteristics that can be observed include a low biodegradability and the moisture content up to approximately 8,86% (wet basis). In addition, the fiber content varied from 17.7 to 21% and the sugar content varied from 84,2% a 92,8% according Table 6. These characteristics indicate the application of pyrolysis technology. Other possible applications for coffee husks include use as biogas production and briquettes.

Table 6. Energy recovery from coffee husks as a function of their chemical characteristics.

<table>
<tr><td rowspan="7">Coffee</td><td rowspan="3">Composition characteristics of coffee husks</td><td colspan="3">Technologies and assumptions</td></tr>
<tr><td rowspan="2">Anaerobic biodigestion</td><td colspan="2">Briquettes/Pellets</td></tr>
<tr><td>Pyrolysis</td><td>Direct combustion</td></tr>
<tr><td>Moisture content: 8,86% - wet basis (Orsini, 2012)</td><td rowspan="2">Favourable to ambient wet basis conditions (Prado et al., 2008)</td><td rowspan="2">Favourable if dry process of coffee (Orsini, 2012)</td><td rowspan="2">Applied together eucalyptus wood for indirect worm of air drying of agricultural products</td></tr>
<tr><td>High fiber content: - gross fiber content: 17,7% a 21% and dry matter content: 84,2% a 92,8% (Ribeiro Filho et al., 2000 apud., Baggio, 2006)</td></tr>
<tr><td colspan="4">Other promising applications for coffee husks</td></tr>
<tr><td colspan="4">Biogas production, briquette (Orsini, 2012)</td></tr>
</table>

Each level of the state tree in Fig. 6 corresponds to one of nine subsystems considered for the energy exploitation of agriculture residues, crushing, drying, chemical pre-treatment, compacting, direct combustion, pyrolysis, biodigestion, fuel power generation and gas power generation. In this tree, each vertex is numbered and corresponds to a state of the problem. Thus, the vertex (0) corresponds with the "no flowchart” state. The systematic of steps for each branch of state tree follow the same method of building like in the Fig. 4.

4.6 Promising chemical route - Coffee husk

Considering the composition characteristics presented in Table 6 and the application of the heuristic rules, the flow chart shown in Fig. 7 was used as a promising technological route for recovering energy from coffee.

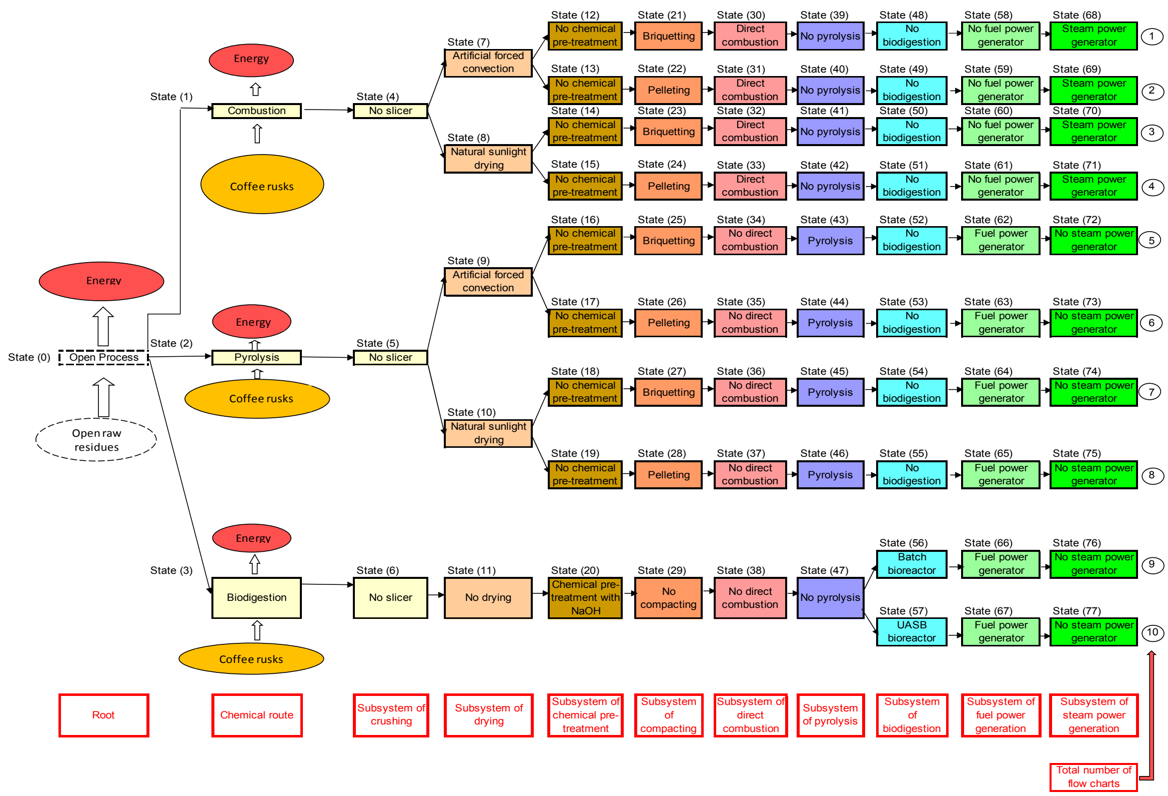

Figure 6: State tree for the energy exploitation of coffee husks.

The selection of the promising technological route its depending on heuristic rules as follow

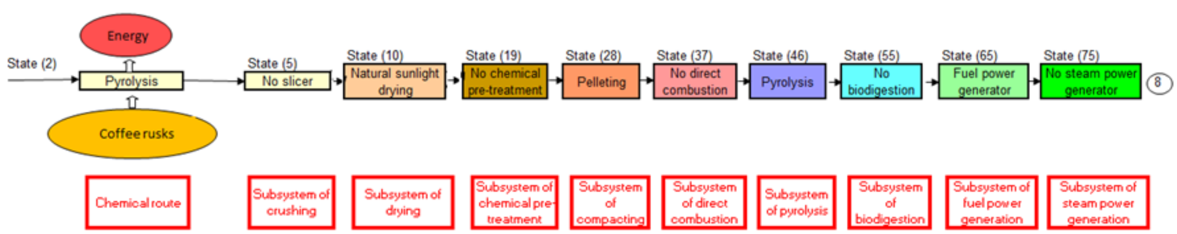

Figure 7: Promising chemical route – Coffee husk

The following justifications were obtained for this route.

- According to heuristic rules 3.3.1.1 up to 3.3.2.3, according size reduction of straw from coffee, it was chosen the dry with respect to the processing step selects for separating the fruits in relation to coffee straw. The fruits of coffee are arranged in a horizontal yard, which favors the drying of the natural type. As a consequence of the huge surface contact with drying air, the drying and compacting subsystems were considered as relevant for this type of residue, in agreement with heuristic rules to choice the promising chemical route. Obviously, the characteristics of high-fiber and low organic biodegradable, does not justify the choice of anaerobic digestion in this flow chart.
- In view of the coffee straw present particle size with a diameter less than 5-10 mm, 8.86% moisture content on a wet basis and the high calorific power of 23,64 MJ/kg (PCS), it has been chosen the application of pyrolysis route by compression technique as Werther, 2000. It is worth mentioning for it, which is necessary the use of reactor equipment with temperature around 700 ° C. (Orsini, 2012).

5. Conclusions

The methodology with emphasis on synthesis processes used was adequate by applying heuristic rules for creation of branches of the state of trees for coffee waste and cocoa. The characterization of waste from cocoa husk and coffee, as Table 5 and 6 respectively, and the analysis of the fundamentals of the technologies cited in the literature review. From the state of trees prepared by using heuristic method for carrying out the technological and structural optimization, made possible to obtain the promising technological route from each tree proposed states, so that the main results obtained were:

- Route the anaerobic digestion preceded by chemical pre-treatment in basic solution as promising route to the residue of the cocoa shell;
- Thermochemical conversion route type pyrolysis preceded by the type pelletizing compression proved a promising route to the residue of coffee pods.

Upon the selected promising routes sure the feasibility of applying heuristic search from the references, since the emphasis of the method was tackled synthesis processes.

In view of the diversity of the particular characteristics of each residue, summarized in Table 5 and 6, and accordingly the feasible set of possible routes of utilization of biomass demonstrated in each tree, it is certified that the determination of promising route is a multiple solutions to the problem .The evolutionary method can be assessed on the basis of branches of trees proposals are improved with the increase of new possibilities for energy recovery technologies, and those mentioned in literature review so that the tree states can introduce new routes from the proposals.

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