A bibliometric analysis of the uses of the cocoa pod shell

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Abstract. The research explores the use of cocoa pod shell (CPS) in rural areas and accessible to the cocoa farmer, applying VOSviewer software. The results show that the production of ethanol or biochar with CPS is not feasible, the first due to its low sugar content and the second, due to the requirement of processes with high temperatures for the extraction of different chemical compounds (i.e. activated carbon). On the other hand, obtaining pellets represents a viable energy potential, since the calorific value is competitive with other biomass; Also, through anaerobic digestion under the ideal conditions, it can generate 55% in biogas of the solid matter used. Additionally, the ashes produced in direct combustion or pellets represent an excellent catalyst, which can be used in transesterification, for the generation of biodiesel, used with other residual oils, giving a plus in the efficient use of resources.

1. Introduction
Cocoa (*Theobroma cacao*) is an economically important crop because it has been used mainly in the manufacture of chocolate. During the cocoa bean production process, the ripe fruits are harvested from the trees and then cut open to extract the almonds from the interior. After the fermentation of the pulp, the juice is drained, the beans are dried and bagged even more, which constitutes the cocoa bean [1].

The cocoa pod shell (CPS) represents more than 60% of the weight of the fruit, originating plant material that is normally discarded in situ for natural degradation, causing a negative impact on the environment, generating a bad smell and a source of disease inoculum, due to its lignocelluloses components and biological decomposition [2]. Therefore, cocoa farmers are encouraged to use SCP as feed for farm animals and as a source of alkali for soup making, in addition to its use as a potash fertilizer (rich in potassium) in the cocoa plantation u other cultivation fields, since around 10 tons of wet CPS are generated from one ton of dry cocoa beans produced, which represents a large volume without harvesting [3], but without neglecting a series of other uses that are can give this material, with
techniques and methodologies accessible to the cocoa farmer, such as: the manufacture of pellets for different thermal applications due to its considerable calorific value [4], highlighting the use of residual ash [5] as a catalyst in the biodiesel production [6]. Furthermore, the production of biogas in up to 55% solid matter under ideal conditions that can be controlled [7][8]; among other uses at an industrialized level.

In this research, the Web Of Science (WOS) database is addressed, with the aim of identifying the energy potential of the residual biomass that is generated in the production of cocoa, highlighting the different methodologies used for the production of biofuels. For this, a bibliographic analysis methodology is implemented, which uses a network visualization tool (software) VOSviewer. This tool efficiently improves information processing and facilitates understanding of areas of greatest interest, along with trends in academic and technological development.

2. Formatting the title, authors and affiliations
In the planning of this research, two thematic centers were proposed, for the approach of the databases specifically speaking in the development of this with the Web Of Science (WOS). The first thematic center is cocoa (*Theobroma cacao*) which represents a self-sustainable development opportunity for the Santander region and Colombia in general, and the second is the use of residual biomass from the production of cocoa almonds, which is mainly represented by its bark or rind, which makes up approximately 70% of the fruit.

For this reason, to address the search for research focused on the use of this residual biomass, the following keywords are implemented: Cocoa, Biomass, Biogas and Biofuel, within which they are identified as the main forms of energy use of the residual biomass of cocoa. The first equation used to approach the database is: cocoa AND (biomass OR biogas OR biofuel *) with this equation a set of scientific articles consisting of 221 publications is obtained. This record is analyzed using the VOSviewer graphic visualization tool, which allows to efficiently recognize different fields of research in less time, among other things. Taking into account that within the first stage of research it is important to determine the data set to study is a practical way to filter those articles that are not within our field of interest. For this reason, the registry of the 221 articles is downloaded, obtaining information such as, title, abstract, authors, citations, bibliography, keywords, among other relevant data, to carry out a bibliographic analysis through a text file.

It should be noted that the main functionality of VOSviewer is the visualization of similarities, which allows to identify within a two-dimensional map, the strength and relationship that different nodes have, which can be represented by authors, keywords, entities, magazines, etc. To start, a co-occurrence map of keywords is made on the downloaded articles. Within these, the program identifies 1,567 words which must be revised to make a duplicity filter and within this it is possible to reduce 10 words which are corrected so as not to generate a distortion within the map by observing two separate components when they should be displayed. like one. Within these duplicities it is highlighted that the program does not recognize the pluralization of words such as cocoa pod husk and cocoa pod husks (see Figure 1).

Now with this first map it is possible to make several deductions, firstly the intense strength of the word "biomass" within this research field is observed, fully maintaining centrality, which implies that it is the main subject of study within this data set. Now looking at the entire map, two large fields are identified. The first one that is on the right side of the map, is mainly oriented to agroforestry, biodiversity and agriculture, which makes relevance to the fact that cocoa is a crop that stands out for its degree of environmental sustainability, because it has the advantage if implemented through the combination of trees (leftover) and cocoa, since it has a biodiversity within the crop, it allows mitigating the environmental impact of deforestation.
Now with this first map it is possible to make several deductions, firstly the intense strength of the word “biomass” within this research field is observed, fully maintaining centrality, which implies that it is the main subject of study within this data set. Now looking at the entire map, two large fields are identified. The first one that is on the right side of the map, is mainly oriented to agroforestry, biodiversity and agriculture, which makes relevance to the fact that cocoa is a crop that stands out for its degree of environmental sustainability, because it has the advantage if implemented through the combination of trees (leftover) and cocoa, since it has a biodiversity within the crop, it allows mitigating the environmental impact of deforestation.

The second field on the left side of the map made up of two groups, the first of which is yellow in the upper left, is defined by themes of organic waste, where the quantities of heavy metals found, the absorption processes of nutrients among others. The second group, represented in red, is made up of studies on the production of biogas, biofuels, biodiesel, combustion, improvement of thermal efficiency, temperatures and energy in general. This same represents the center of study that you want to address, so it is therefore necessary to generate a more precise search equation.

Taking into account the aforementioned, the equation is adjusted as follows: cocoa AND (biomass OR biogas OR biofuel * OR biodiesel OR bioethanol) AND (energy OR combustion OR temperature OR pyrolysis). With this equation, a record of 90 documents is obtained that allows us to more precisely address our field of interest.

The activities for the debugging of the key words within this registry are repeated. The program identifies 662 words of which only those with a minimum co-occurrence of 2 documents will be displayed, granting the following map (see Figure 2):
Figure 2. Keyword map - second record (135 nodes, 4 groups and 1031 links).

With this map of keywords, a network according to the research theme is identified, in which 4 groups stand out, red is centralized by biodiesel, which is why it is generalized by topics such as production, alcohols, yield and even Observe the incorporation of cooking oil waste, taking into account that it is one of the main components for its production. In the blue group, the centrality of biogas stands out, accompanied by topics such as generation, combustion, hydrolysis, lignocellulose and the use of different agricultural residues for its production [9].

The green group is mainly dominated by pyrolysis, where temperature is the main factor analyzed in this process and the use of pellets is taken into account. This group focuses on the direct combustion of plant material. Yellow represents a theme oriented to the study of activated carbon, where chemical processes are analyzed, the composition of the waste generated by the plant, ranging from the shell of the cocoa bean, to the shell of the almond among other organic wastes that Chocolate production is generated (see Figure 3).

Figure 3. Links related to the cocoa pod shell (CPS).
When this research begins, it starts with a hypothesis about the cocoa pod shell (CVC), which consists of using it as a source of biomass, to be used in thermal processes. With this map it is possible to demonstrate the importance of this resource for the generation of biogas, pellets and biochar in general and its strength within this network of keywords, is a clear example of the relevance that it represents for the academic community on issues of energy use of renewable resources, taking into account that the biomass of the cocoa pod shell is normally discarded to be used as fertilizer (see Figure 4).

With the VOSviewer tool, it is possible to graphically observe the use of keywords over time and this works as a trend analysis tool, in order to identify new research topics for decision-making in the continuity of this renewable energy field. For example, in this network it is observed that optimization begins to be used from 2018 approximately with recurrence, taking into account the links that this word has, it can be pointed out that this is achieved through anaerobic digestion processes, pre-treatments, biomass in pellets, heterogeneity catalysis, among other topics that will be addressed in more detail in the results section (see Figure 5).
With the bibliographic link it is possible to see the different documents and their strength within the map thanks to the citations they have between them. The strength of the older articles is identified, which as they have been published for a longer time can obtain a higher number of citations, with this tool it is possible to access the document just by clicking on the node of interest, so a general scan of these documents to analyze their content taking into account those nodes with the greatest strength (co-citations) and with the highest number of citations, selecting the first 5 of each list in the table 1.

Finally, the documents processed by the VOSviewer tool are read and analyzed, which serve to have a more precise idea of the results obtained by the tools and the research approach.

**Table 1. Selected documents.**

| Author                                | Citations | Links of strength | Documents |
|----------------------------------------|-----------|-------------------|-----------|
| Moses Hensley Duku (2011)              | 106       | 1                 | [10]      |
| L. Fryda (2010)                        | 86        | 1                 | [11]      |
| Cecile Bessou (2013)                   | 82        | 5                 | [12]      |
| Disney Ribeiro Dias (2007)             | 48        | 2                 | [13]      |
| T G Chuah (2006)                       | 47        | 6                 | [14]      |
| J. Ratte (2011)                        | 44        | 3                 | [15]      |
| Wen-Tien Tsai (2020)                   | 1         | 50                | [2]       |
| M. P. González-Vázquez (2018a)         | 15        | 40                | [16]      |
| Chi Hung Tsai (2018)                   | 7         | 39                | [17]      |
| M. V. Gil (2019)                       | 7         | 30                | [18]      |
| J. Daniel Martinez-Angel (2015)        | 10        | 29                | [19]      |
To start reading and analyzing the documents processed by the VOSviewer tool, which serve to have a more precise idea of the results obtained. Firstly, the content of the work published by Chuah (2006) is read, this document is titled “Biomass as a renewable energy source in Malaysia: an overview”, this document provides an overview of the types of biomass used, among which stands out the energy potential of the waste generated in the production of cocoa, the research work on the conversion of biomass into energy and the projects that at the time focused on the development of biomass energy in Malaysia.

The second work that is read is that of Dias (2007) which is entitled “Elaboration of a fruit wine from cocoa pulp (Theobroma cacao L.)”, in this the alcohol levels generated in the process of fermentation, which have served as a documentary basis for research into the generation of different biofuels.

Consecutively, the document published by [11], which is entitled "Study on the deposition of ash in the combustion of oxyfuel from coal/biomass mixtures", exposes the behavior of the combustion of coal with cocoa flour additives, with the which seek to minimize CO₂ emissions, taking into account that biomass contributes to energy generation. This work identifies that the temperature and the levels of the fuel mixture are the main factors that affect emissions and the ash generated during combustion.

A document that represents a very interesting vision for this research and is incorporated due to its relevance, is the one published by [15] which is entitled “Mathematical modeling of a continuous biomass roasting reactor: TORSPYD ™ column", in her work it was describes the roasting of biomass, by depolymerization consisting of a "gentle" heat treatment (<250 ° C) that allows the definitive removal of biomass water, as well as the transformation of part of the organic matter from biomass. The biomass is heated evenly. The roasting process dries the biomass, makes it irreversibly non-hygroscopic and concentrates its energy potential in a solid fuel to facilitate its transportation and grinding. As part of their research they use the cocoa shell in their tests.

Taking into account the list of documents that is ordered by number of citations [10] is the leader, his work is entitled "A comprehensive review of biomass resources and biofuel potential in Ghana" and it is possible to demonstrate the potential energy from renewable resources from biomass, among which cocoa is named, as a fundamental part of them.

To finish in the list of the leading documents in citations there is the work of [12] entitled "LCA applied to perennial cultivation systems: a review focused on the farm stage" this focuses on the cultivation systems for the proportion of bioenergy raw materials, this is important to keep in mind, to maintain an efficiency margin from the point of production.

Now it is not only important to take into account those documents that have been most frequently cited, but also those that can generate a new field of research and represent an opportunity for development in a specific topic, which is why the first 5 documents ordered by their strength link level. To start, we talk about the work carried out by Daniel Martinez-Angel (2015), his work is entitled “Characterization and evaluation of the cocoa husk (theobroma cacao l.) As a renewable energy source” this work is carried out in Colombia, and It directly analyzes the energy poten

tial of the cocoa shell, and concludes that the gasification method is the most appropriate to adequately take advantage of this renewable resource.

The next work chronologically speaking is the one published by [16] this study investigates the air-vapor gasification of ten commercial and alternative lignocellulosic biomass fuels (pine sawdust, chestnut sawdust, roasted pine sawdust, almonds, cocoa hul, grape marc, olive stones, pine nut shells and pineapple shells) to assess the product gas composition and process performance in a bubbling fluidized bed gasifier with focus on the different properties of the biomass. The work published by [17] is entitled "Thermochemical characterization of biochar from cocoa pod shell prepared at low pyrolysis temperature." In this, the energy behavior and the waste produced by the cocoa shell when processed as biochar are studied very precisely, with this it is found that it has a calorific value close to 17.8 MJ / kg, using these data it is possible to start from comparative values in the results of the work.

Taking the continuity of the documents based on the strength of their links, there is the one published by [18] whose title is "Assessing the influence of biomass properties on the gasification process using
multivariate data analysis" in this work use multivariate analysis to study the influence of biomass characteristics on the gasification process, within which they use different types of biomass such as the cocoa shell between them.

The last article with the strongest links and which has been recently published is the work carried out by [2]. This work focuses on the study of the use of cocoa beans for the preparation of activated carbon through the use of potassium hydroxide. Low contamination as activating agent.

As it could be intuited within the documents previously described, the first group that stands out for having been cited more frequently, are documents that describe an energy potential of the cocoa biomass, these documents were located approximately 10 years ago and were the first engines in the research of this renewable resource. Subsequently, the documents that stand out for the strength of their links, describe in a more specific and detailed way, the thermochemical capacities of the different wastes generated in the production of cocoa, such as the cocoa pod shell, the shell of the almond and the pulp.

In order to solve the research question, the different documents continue to be analyzed using the VOSviewer visualization tool and with this, clarify the continuity of the research aimed at the cocoa biomass.

3. Results and discussions
The objective of this research is to achieve a complete overview of the energy potential of the biomass that is discarded in the cocoa growing process (Theobroma cacao), especially to know those processes that are required to transform the biomass conditions into a fuel, whether solid, liquid or gaseous. All this in order to implement this knowledge in support of agricultural, regional and national activities, taking into account that they can benefit from implementing new technologies that generate new economic or energy resources for their ordinary work activities [20][21].

Taking into account the different ways in which the residual biomass of cocoa crops can be used, it is evident that fermentation for the production of biofuels such as ethanol, does not represent a sustainable opportunity in terms of energy use, this counting on the different pretreatments that have been explored in the different investigations, due to the levels of sugars present in the CVC, also when compared to other plant residues that have greater potential such as banana or corn waste [22][23].

On the other hand, the pyrolysis process, used to generate biochar, is analyzed, which is a methodology with a high energy requirement, when working with temperatures between 300 to 900°C, this represents an energy storage strategy, not very viable for rural-type implementations, bearing in mind that this technological process or implementation has other types of purposes, such as the extraction of different chemical compounds or as some researchers establish activated carbon [24][25].

Now within the aforementioned processes, it is necessary to clean, dry and crush the CVC, in order to extract the fuel through fermentation or pyrolysis, and this also applies to the production of pellets, bearing in mind that after being crushed they are sieved. or tablets, with the aim of increasing their density, facilitating their transport and combustion. In the investigations it is identified that the cocoa pellet is not explored as the main raw material for commercial reasons, taking into account that the pellet industry already has an important participation of other biomass such as pine. The calorific value of cocoa is approximately 17.5 MJ/Kg, so it is located on the average of different solid vegetable materials and represents an opportunity for energy use in different agricultural processes, such as cooking, food drying, generation of energy in non-interconnected areas, among others [19]–[21]. It is important to highlight that in terms of pellets it was mainly implemented as an additive for other solid materials, such as pine, sawdust, coal, among others, with the aim of giving greater consistency to the pellet or reducing costs as it is a waste from a food industry.

As mentioned above, cocoa does not have the potential to generate liquid fuels, but this does not completely displace it from belonging to a biodiesel production line [29][30], the ashes generated after the combustion of the CVC plant material is used in the transesterification process as a catalyst, these residues within a thermal process at a temperature close to 70°C. The results obtained by the researchers in this area highlight the catalytic capacity of this ash, which is really important considering that for these production processes the main raw material is cooking oil waste, animal fats and even research
with other types of oil with palm oil, in which Colombia has a stake. In terms of generating new products, the incorporation of the use of all cocoa wastes in different industrial processes such as the biodiesel industry is quite innovative.

When talking about biogas generation, CVC has been quite remarkable as the main raw material, by achieving a transformation of close to 50% of its solid matter into gaseous, researchers through pretreatments manage to increase this percentage and thereby increase the energy use of this Biomass, through the anaerobic digestion process and implementing different inocula in controlled environmental conditions, it is possible to generate biogas efficiently. With this, a new viable energy product is opened to be used in the cocoa food industry, which generally continues to grow and represents one of the crops with the least environmental impact due to its diversity of trees, which maintain the consistency of the ground [18][31].

4. Conclusions and recommendations
The bibliographic analysis methodology implemented for this research allows us to advance efficiently in the search for specific information on the use of cocoa residues, the graphical network visualization tool, allows us to observe the links between the different topics, such as for example, pretreatments to improve the production of biogas, biodiesel, bioethanol, among others. It should be noted that these topics were identified before making a deep reading of the documents and investigations registered with the search equation.

With this research it is possible to point out that the main methods for the energy use of biomass in rural areas are the drying, crushing or milling of the biomass, to be used in two ways, the first as solid plant material in direct combustion, with a low humidity percentage, it becomes a fuel with great potential for different thermal processes. If it is compressed or sieved into pellets, it can be marketed for different applications. For the second option, this material can be used within a biodigester, through anaerobic digestion with pretreatments and, under the ideal conditions, it can generate 55% in biogas of the solid matter used, the researchers highlight it as a biomass with a potential to be used in industrial biogas generation plants, incorporating different raw materials in rural areas.

Additionally, the ashes produced in the combustion of the solid plant material of the cocoa pod shell are linked, as an excellent catalyst, which can be used in transesterification, for the generation of biodiesel, this biofuel uses residual oils such as that of the cooking, animal fats, among others that are commonly used in rural areas, this represents an opportunity to take advantage of the different wastes generated during cocoa production. Giving this industry a plus in the efficient use of its resources.

It is recommended in the first instance the recurrent use of the VOSviewer application or network visualization tools, to carry out an efficient analysis of the databases in those projects that require an overview of the level of research or technological progress, for a given subject, as is the case of the energy potential of cocoa. This improves efficiency at the time of understanding or directing certain investigations from which it is desired to generate a significant advance or that causes a greater impact at the academic and social level.

In terms of research, the implementation or development of a pilot plant in cocoa growing areas is recommended, in order to establish a cocoa biomass production line. With this, a production line must be founded that involves cleaning the hulls of the cocoa pod (CVC) to remove impurities such as dirt, drying looking for a humidity close to 10%, grinding to decrease the size of its particles, in the order of mm and pressing or sieving to increase the density of the material, facilitating its commercialization and transport. This production line does not represent a high investment and can lead to an improvement in the economic sustainability of cocoa farmers.

For the generation of biogas, a control of the environmental conditions of anaerobic digestion is commonly required, in order to improve its production, including temperature and monitoring of different thermochemical variables. In addition, it is important to implement suitable equipment for the extraction process of the same for its corresponding storage and transport. For this reason, it is recommended for the production of biogas with the CVC, to implement a central pilot plant that processes all the waste from a region.
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