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Crop waste management proposal in rice systems at the department of Cordoba, Colombia

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Abstract

The claim for food increases with the waste caused by its production. Rice is appetized but the agro-industrial residue, such as straw and husk, becomes a problem when they're not properly managed. However, renewable source demands grew, indeed, the chains of rice residue as cellulose, lignin, hemicellulose, carbon, and silica could be transformed into: fuel, power generation, gas production, paper manufactory, and fertilizer for the production of fungi and building material. The industrial implementation of rice residue management worldwide has a lack. In this case, it was observed more closely the rice cultivation in a local region of Colombia. The aim of this research was to present the current market, challenges and the proposal of a proper management residue on a circular economy incorporated into Córdoba department rice market. The study was conducted through scientific and comprehensive insights on rice crop waste management options. The selection criteria of the articles were rice production, major components of rice paddy, straw, and husks, and waste disposal in rice systems. Farmers, researchers, federations, administration, and management, need to work on, improving the nutrients of the soil, the quality of the crop, and the management of the residue, the one that remains in the mills and the one that remains in

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the fields. Finally, in all processes, the required investment to obtain a product that meets current market requirements on renewable fuels or raw materials.

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1. Introduction

According to the report of FAO-Food and Agriculture Organization, rice production was 759.6 million tons of paddy in the worldwide production in 2017, Asia is approximately 516 million tons/year, and Latin America is 28 million tons (FAO, 2022). National Federation of Rice Growers (FEDEARROZ by its acronym in Spanish) indicates in the 2018 annual balance, Colombia has an estimated production of 1,904,819 tons, planted on 33,377 hectares; the department of Córdoba, the use of flat areas estimated production of rice 111,687 tons in 2016 and 142,940 tons in 2017 were harvested (DANE, 2022).

Management of rice husk (RH) and rice straw (RS) waste is not adequate in Colombia or worldwide. The RH waste is being disposed of in landfills, the same rice mills, or burnt. Some planters burn RH and RS due to simplicity and to avoid the high costs of managing rice waste. The Open-air burnt process generated problems for rice cultivators and neighbors. Caused by CO_2, CH_4, N_2O, hydrocarbons, dioxins, and other particle emissions and represents a toxicological risk (Ribó, Albiach, Pomares, & Canet, 2017). Rice farmers believe that the direct placement of rice husk and straw in paddy fields would guarantee a cycle of soil nutrients, and organic fertilizer. Moreover, agronomists indicate that this practice could bring problems of air pollution, underground water, and soil, may be as damaging as burning it (Ahmed, Ahmad, & Ahmad, 2015; Colombian Ministry of Agriculture and Rural Development, 2005).

The rice husk is used as fuel for the dried process, industries used the husk in mills to feed the furnace boilers as a substitute for traditional and expensive fuels (gasoline, gas, electricity); for this, mixtures are made with kerosene as an activator in combustion, burning the material. To harness the energy of the rice husk in the rice drying process (Jittin, Bahurudeen, & Ajinkya, 2020). The rice husk used as fuel is due to activated carbon since it contains around 30% to 50% organic carbon. Rice husk burnt or used as fuel contributes to greenhouse gas emissions (Singh B., 2018). Moreover, rice husk has electrical and thermomechanical properties and as promising electric resistivity (Raheem, Oriola, Kareem, & Abdulwah, 2021; Sanchis, Ferrer, Calvet, Coscollà, & Yusà, 2014). The ash obtained from the calcination of the husk is used in the cement industry, as the production of Supplementary Cementitious Materials (SCMs), the RH can be a cost-effective raw material to produce silicates and silica materials (Bonifacio & Archbold, 2022). Rice husk presents noticeable properties, such as lightweight, and low thermal conductivity, and from the microscopic view is loose and porous (Janbuala & Wasanapiarnpong, 2015). Lately, rice husk has engrossed research in the thermal insulation field (Bahrami, Pech-Canul, Soltani, & Guti, 2017). The husk has been used as a fertilizer, fuel, energy source, building material, and insulation material (Singh, Yadav, Ravisankar, Yadav, & Singh, 2020).

Despite the economic and practical benefits of burning rice straws, it has been environmentally regulated and restricted in many regions worldwide. For example, burning straws has been banned by the common agricultural policy (CAP) of the European Union (Ribó, Albiach, Pomares, & Canet, 2017). In Colombia, the Environment Ministry, with the Colombia Society Farmers-CSF, and Fedearroz, published the Environmental Guide to Rice, here describes laws, restrictions, environmental policies, entire cultivation process and briefly mentions the disposal of waste (Colombian Ministry of Environment and Housing, 2000; Colombian Ministry of Agriculture and Rural Development, 2005). Whereby requirements, terms, conditions and obligations established for controlled open burning in rural areas in agricultural and mining activities (Resolution number 532 of 2005, 2005).

A number of alternatives to the merged entity residue burning, many of which are, theoretically at least, added value to the waste. For growers around the world, there are not many options apart from burning the residue left. At the same level, management proposals that are viable, economically profitable and sustainable are required (Sanchis, Ferrer, Calvet, Coscollà, & Yusà, 2014; Shyamsundar, Springer, Tallis, & *et al.*, 2019). This persistence of residue burning has multiple likely causes: options are often encouraged in isolation and rely on changes in farmer behavior, awareness of the problem, the system of policies, the priority of food security, and water conservation that have gradually forced residue management (Gupta, 2019). Benefits and risks campaigns for moving away from residue burning between farmers that modifications in agricultural performance can indicate and thus incentivize governmental support (Downing, Kumar, Andersson, & *et al.*, 2022). So an improvement in rice production is needed, in addition to rice waste disposal and adequate utilization, due it is not yet efficiently industrialized and abundantly available. This study aimed to present the different alternatives that rice residue both husk and straw, as a proposal for managing rice crop residues in the department of Córdoba, Colombia.

2. Methodology

Department of Córdoba, located in the north of Colombia, known as the Caribbean region. They have an average annual rainfall of 1,346.1 mm, relative humidity of 84%, average annual temperature of 27.4 ºC and a lifezone called tropical dry forest. Each year there is variation in the production of rice cultivation, in 2017 around 9,198 hectares of mechanized rice were planted, of which a production of 44,404 t was obtained and an average yield of 4.5 t/ha (DANE, 2022). Multiple studies have been carried out to increase productivity and optimize the industrial process, but the elimination of waste currently has a gap.

A comprehensive methodology used in the study is presented in this section. The study was conducted to get scientific and comprehensive insights on rice crop waste management options. The selection criteria of the articles were: a) Rice production at the department of Cordoba, Colombia, b) Major components of rice paddy, straw, and husks, c) Analysis Greenhouse Gases of Rice Crop Cycle, d) Crop residue management options in rice systems (Open Burning and Controlling Burning), and e) Crop waste management proposal in rice systems at the department of Cordoba, Colombia. Scopus, Google School, Science Direct, National Federation of Rice Growers website, institutional statistical data, government sites of Colombia and the department of Córdoba database were consulted. Updated files were selected. The bibliographic search was limited to that period to have documents that are up to date with the advances that have emerged regarding this topic.

3. Rice production at the department of Córdoba, Colombia

Green paddy rice is the grain just after its collection, including its wet husk, and that has not undergone any industrial process (Colombian Ministry of Agriculture and Rural Development, 2005). Later it is cleaned to separate impurities, milled and bleached to obtain white or excelso rice, suitable for human consumption. Rice production in Colombia is separated into five regions, the department of Cordoba belongs to the region known as the lower basin of Cauca, join to the departments of Antioquia, Bolívar, Chocó and

Sucre with 165,808 hectares corresponding to 27.19% of rice plantation of the country. By 2019, the department of Córdoba, had an area of 15,417 hectares of rice cultivation (DANE, 2022).

Rice production slips into mechanized rice, irrigated rice, mechanized rainfed rice, and manual rainfed rice. The department of Córdoba, Colombia, have a number of mechanized rice producers in 2016, which was 724 and the number of Colombian Rice Producing Unit (RPUs) was 826, with an annual planted area of 11,588 ha, harvested area of 10,594 ha, and a production of 47,184 tons (FEDEARROZ, 2016).

Below are the most important data on rice cultivation in the department.

Table 1 - Planted area, production, and yield in rice in the department of Córdoba (FEDEARROZ, 2016)

	Área ha	**Production (t)**	**Performance t/ha**
	First semester		
Mechanized rice	327	15.184	4.6
Irrigated rice	2.466	11.980	4.9
Mechanized rainfed rice	811	3.205	5.2
Manual rainfed rice	4	10	2.4
	Second semester		
Mechanized rice	7.318	32.000	4.4
Irrigated rice	1.632	8.731	5.4
Mechanized rainfed rice	5.687	23.269	4.1
Manual rainfed rice	225	519	2.3

Table 2 - Planted area and production units of mechanized rice, irrigated rice, mechanized rainfed rice, and manual rainfed rice, in the Department of Córdoba, first and second semester 2016 (FEDEARROZ, 2016)

	Area	**RPUs (1)**	**Area**	**RPUs (1)**	**Anual Area**
Mechanized rice	6.918	641	4.670	434	11.588
Irrigated rice	1.714	81	1.573	135	3.287
Mechanized rainfed rice	5.204	560	3.096	299	8.300
Manual rainfed rice	–	–	–	2.714	2.822

* Colombian Rice Producing Unit (RPUs) – National Agricultural Census in 2016 (DANE by its acronym in Spanish).

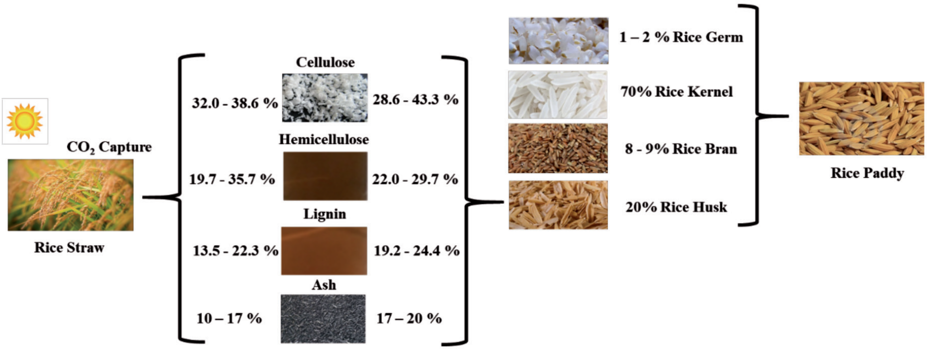
4. Rice crop

The outer hard protective covering of the paddy grain is removed during rice milling and represents 20%-25% of its weight. After the paddy is milled, the husk obtains about 20% of the weight of the paddy (Memon, Shaikh, & Akbar, 2011).

Once the rice kernel and germ are gotten, its two by-products are brown rice and rice husk (RH). Rice straw and husks were formed from hard materials, including cellulose, hemicellulose, and lignin, along with considerable amounts of silica and other minor components, as summarized in (Figure 1). Both are agro-industrial waste.

Though rice is a significant source of food for many people around the world, it produces a lot of straw and husks each year, with an estimated annual production of around 8×10^{11} kg of straw and 1.5×10^{11} kg of husks, respectively (Singh & Arya, 2021).

Figure 1 - Major components of rice paddy, straw, and husks (Dejkriengkraikul, Semmarath, & Mapoung, 2019; Mirmohamadsadeghi & Karimi, Recovery of Silica from Rice Straw and Husk, 2020)



4.1. *Rice Straw*

From the processing and cultivation of rice, the main by-products generated are rice straw from agro-waste; thus, natural fibers from agro-waste (Danish, Naqvi, Farooq, & Naqvi, 2015), this volume of the outgrowth is more than the actual agricultural product (rice), 1.5 tons of RS per 1 ton of rice (Morales, Agudo, & J., 2021). Rice straw's size-specific surface area is large and has beneficial adsorption characteristics for ammonium nitrogen and humidity (Zhang *et al.*, 2016; Guan *et al.*, 2021). Rice straw and rice husk had a similar chemical composition, with lignocellulosic materials and composed of structural carbohydrates. RS main components are structured as follows: cellulose (30-45%), hemicellulose (20-25%), and 15-20% lignin; silica, inorganic compound (ash) content is relatively high, a minor amount of organic composite and other minor components (Mirmohamadsadeghi & Karimi, 2020; D. Sietske Boschma, 2013).

Cellulose is a linear polymer and crystalline molecular structure; also sets exclusively β-glucose monomers. Hemicellulose´s composition with different carbohydrate polymers and amorphous molecular structure; and holds a polymer that seats sugars (Ibrahim, El-Zawawy, Jüttke, Koschella, & Heinze, 2013). Lignin is an irregular three-dimensional; branched phenolic polymer whose monomeric units' alcohol, and is a polymeric aromatic structure that involves the oxidative coupling (Cao *et al.*, 2020).

Appropriate management of the soil, nutrients, fertilizers and water resources, rice crop residues such as RS is considered renewable, abundant and several by-products still require research to be applied to the industry; Cellulose, hemicellulose and lignin extraction processes were suggested (Xiao, Sun, & Sun., 2001). RS is a source of cellulose to obtain pulp and paper manufacturing through chemical pulp due to its organic origin it shares other components such as high silica content, which is optimal to be used in various uses in the construction but it causes scale in the chemical recovery equipment of the pulpers, thus reducing the useful life of the equipment, which makes difficult the production of this material (Leiva-Candia *et al.*, 2014; Luo *et al.*, 2019; Himmel *et al.*, 2007). Cellulose, hemicellulose, and lignin could produce biofuels, biochemicals, and biomaterials. Hemicellulose is less stable than cellulose; hence, easily degraded when exposed to heat temperature (Ma, Gao, Wang, & Liu, 2018).

Hemicellulose removal has numerous techniques such as dilute acid pre-treatments, alkaline extraction, alkaline peroxide extraction, vapor treatment, liquid hot water treatment, ionic extraction, ultrasonication, and microwave treatment is a significant stage in the production of different chemicals (Kaur, Bhardwaj, & Lohchab, 2017). Lignin manifestation and paddy straw's structural complexity are noteworthy obstacles to enzymatic and microbial attacks (Leiva-Candia *et al.*, 2014). Rice straw has been used, as support for many polymers matrices and mainly studies, the mechanical properties of these composites were informed (Pandey *et al.*, 2000). Nevertheless, pre-treatment exposure helps lingo-cellulosic materials to get a high level of fermentable sugars (Peng, Peng, Xu, & Sun., 2012). The abundant availability of rice straw makes it an interesting lignocellulosic material for bioethanol production; only many difficulties and limitations for the transformation of rice straw into etanol (Malik, S., Kumari, Mehta, & Kumar, 2020). Approachability, low cost, and small-scale energy production from RS have a potential; still poorly developed a high-value utilization of rice-derived biomass (Swain, Singh, & Sharma, 2019), regardless of their contributions to solving environmental issues due to air pollution or ecosystem degradation (Thabah, Singh, & Bedi, 2021). Mechanic composting and livestock feeds encourage farmers not to practice open field burning (Wi, Choi, Kim, Kim, & Bae, 2013), even though field burning and soil amassing of rice straw persist in collective performance, rice straw has been more improper to burn due to the significant atmosphere pollution caused by greenhouse gas emissions and the smoke that comes with it (Goodman, 2020). Rice crop management policies add value to the feed product, improve the environment, and encourage the paddy-producing countries to adopt a sustainable bio economy.

4.2. *Rice Husk*

Rice plants can captivate the silica content from the soil over the rice growing the silica is absorbed (R.G. Smith and G.A. Kamwanja, 1986). The density of rice husk is low in the range of 90-150 kg/m^3 (Singh B., 2018). Rice husk can absorb water ranging from 5% to 16% of unit weights, and the unit weight of rice husk is 83-125 kg/m^3 (Mansaray & Ghaly, 1998). Rice husk is a lignocellulosic material, which consists of cellulose, hemicellulose, lignin and moisture content. Rice husk is mainly composed of cellulosic sugars and 20% of lignin. The amount of lignin is about 18±4% which makes rice husk unsuitable for the manufacturing of papers and cellulose production. The observed deviation in the composition is due to the type of paddy used, climate and geographical conditions. Most importantly, the ash content in rice husk is 18±2% (Mirmohamadsadeghi & Karimi, 2020; Jittin, Bahurudeen, & Ajinkya, 2020).

Rice husk is produced in large quantities and is an organic waste, promoted by-product of the rice milling and agro-based biomass industry. Rice husk constitutes approximately 23% of the weight of rice (Jittin, Bahurudeen, & Ajinkya, 2020). Also, is a cellulose-based fiber and contains approximately silica, which at the amorphous structures has nutritional value and chemical-physical resistance (Hu *et al.*, 2008; Nair, Fraaij, Klaassen, & Kentgens., 2008; Ndazi, Karlsson, Tesha, & Nyahumwa, 2007). Rice husk also contains volatile matter (60-65%), fixed carbon (10-15%), and 17-23% ash (Karam *et al.*, 2021; Kwong, Christopher, Chao, Wang, & Cheung, 2007).

Organic compounds are main constituents of husk: cellulose (40%-50%), lignin (25%-30%), silica (15%-20%) and humidity (10%-15%) (Bakar, Yahya, & Gan, 2016; Soltani, Bahrami, Pech-Canul, González, & Gurlo, 2017). Rice husk can absorb water ranging from 5% to 16% of unit weights, and the unit weight of rice husk is 83-125 kg/m^3 (Mansaray & Ghaly, 1998).

4.3. *Open Burning*

It has been challenging the threat of residue burning, despite advancements in agricultural sciences and current environmental demand (Bimbraw, 2019; Mondal *et al.*, 2020). The rice straw open burning (RSOB) is unfortunately a very common practice, it is considered as a clean-up method for the next harvest.; also, the farmers believe that rice straw burning has benefits (Singh & Sharma, 2021). With exposure to oxygen, the burning of RH and RS has an incomplete combustion; this releases pollutants into the atmosphere as by-products (G. Tabasso, Cravotto, & van Ree, 2020; Singh, Yadav, Ravisankar, Yadav, & Singh, 2020). Can emit toxic air pollutants such as particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), NO, SO_2, CO_2, and greenhouse gases (J. Chen, 2017; Chi & Oanh, 2021; Pham *et al.*, 2021). One of the main components of the soil is organic carbon, which is regulated through the microbiota, the effects of biochar residues or carbonate. Burning under natural conditions could be affecting the renewal of soil organic carbon, interfering with its reserves (Bi *et al.*, 2020).

Several investigations have been carried out to know the impacts of the RSOB on air quality and human health on a global scale; however, data from some places is still lacking to know its true damage (Pastorello, Caserini, Galante, Dilara, & Galletti, 2011). The investigations carried out show that the activity of burning in the air seriously affects the quality of the air, human health (that is, cancer and bronchial asthma). In addition, the planet has political but not physical borders, so toxic gas emissions can travel between countries, for example the combustion of waste in India affects air quality in Pakistan and vice versa (Ghosh *et al.*, 2016; Conde, Ayala, Afonso, & González, 2005; Torigoe *et al.*, 2000).

In summary, burning in the open causes deterioration of the upper layer of the soil, decrease in the capacity of the crop, health problems, compromise the quality of the air and can influence climate change; which could be improved by efficient recycling of rice straw in a sustainable way (Raheem, Sajid, Iqbal, Bilal, & Rafiq, 2019).

4.4. *Controlled Burning*

With the increased energy demand, cleaner, and more efficient fuels can be obtained in thermochemical. Many technologies like pyrolysis (Ai, Chen, & Fu, 2022), gasification, combustion, etc. are available and applicable. Pyrolysis is an adaptable and appealing technique for producing bio-oil as an alternate transportation hydrocarbon. It is no efficient as natural gas, but it is correlated with ash and liquid return is achieved (Ai, Chen, & Fu, 2022). The Pyrolysis methods are made by Muffle furnace, gas furnace, fluidized bed reactor, reactor Torbed and fix bed reactor. According to a case study, 4,947 MWh electricity could be produced in a year from 6432 tons of husk through fluidized bed combustion (FBC) technology in which rice husk was taken in a boiler with a capacity of 15 t h^{-1} and a combustion efficiency of 88% and the high pressurized steam generated was applied to the turbine coupled to a shaft that ran the generator (Memon, Harijan, Soomro, Meghwar, & Valasai, 2017).

Gasification is an effective method to transform a wide diversity of biodegradable materials into raw syngas for use immediately as energy, electricity, or transformed into a biological production of gas (oxygen and carbon monoxide) (Vinoth *et al*., 2021; Chi *et al*., 2015).

Combustion systems convert all of the fuel into CO_2, H_2O, and heat, while gasification systems only partially oxidize the fuel, creating intermediate products such as CO_2, H_2, and hydrocarbons. Gasification systems and intermediate products that rarely leave the combustion chamber must be understood (Ai, Chen, & Fu, 2022; Jittin, Bahurudeen, & Ajinkya., 2020).

4.5. *On-field use of crop residues*

The ample disposal of paddy straw can be cost-effectively, and viable employed as a substrate for the crop growing of mushrooms, for converting rice straw into appreciated food rich in protein; straw can smear as the principal substrate for the growth of mushrooms (Bánfi *et al*., 2015). Rice straw does not offer good physical strength to the composted it should be composted and improve its nutrient percent by mixing with a number of materials like gypsum, urea, rice bran, chicken manure, etc., with different ratios will show superior results; one of the simplest rising mushrooms is rice straw mushroom (RSM) (Volvariella volvacea) owing to their short maturing time and have less fat (Zikriyani, Saskiawan, & Mangunwardoyo, 2018).

4.6. *Analysis Greenhouse Gases of Rice Crop Cycle*

Open burning is not the only rice crop factor that emits gases and has an environmental concern. The evaluation of greenhouse gases has been analyzed in the different stages of a rice crop cycle. The first phase analyzed the soil chemistry and land preparation; the second part considered the entire cultivation process, and the last stage attributed to residue management. The main GHGs analyzed were carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). At each stage, emissions were analyzed by various factors and indicators. For example, in the first stage, CO_2 and CH_4 are the final organic matter decomposition products of these soils and the aeration of the land. In the second phase, consider the following factors: water management, intermittence between dry and flooded soil, inappropriate practices, the high use of nitrogenous fertilizers, and the application of pesticides, and herbicides, lead to higher emissions of CH_4 and N_2O. Finally, the residue management emissions will also depend if it is removed, burned, incorporated by 'fangueo' (mud driving), or deposited on the ground as a cover (Sanchis, Ferrer, Calvet, Coscollà, & Yusà, 2014).

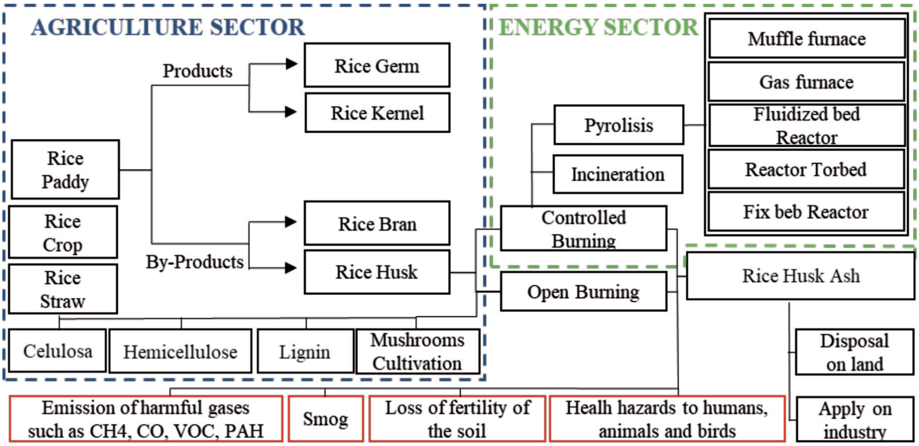
From germination to panicle initiation, it was the stage in which the lowest CH_4 emissions occurred. Within this stage, the incorporated straw alternative achieved the highest CH_4 emissions. The early stage of the development of the plant reflects low emission of pollutants. During the reproductive stage, which spans from panicle initiation to flowering, the highest CH_4 emissions were reached. The straw management alternatives, burning and removal, showed the lowest emissions (Sanchis Jiménez, López Jiménez, & Calvet Sanz, 2014). Worldwide, rice cultivation annually releases around 60-100 million tons of CH_4, contributing substantially to global warming of the atmosphere. This means that 5-19% of anthropogenic (CH_4) emissions are due to rice cultivation (IPCC, 2006; Yusuf, Noor, Abba, Hassan, & Din, 2012). The anaerobic oxidation of the straw inside the paddy field generates a considerable amount of CH_4, which has a global warming potential 21 times higher than CO_2 (Sanchis, Ferrer, Calvet, Coscollà, & Yusà, 2014). The impact measurement methodology will depend on reference functional units: product mass, energy use (Gg CO_2 eq. M $kcal^{-1}$), land area (kg CO_2 eq ha^{-1}), and economic value (Cerutti, Bruun, Beccaro, & Bounous, 2011).

5. Crop waste management proposal in rice systems at the department of Cordoba, Colombia

Rice cultivation in the department of Córdoba is having several problems: the level of soil nutrients is unknown, the low economic profitability that is causing fewer hectares of rice to be cultivated each year, the yield per hectare of the crop, the management of residues, residue incorporation into another industrial process, reducing the emission of greenhouse gases throughout the rice cultivation cycle, producing rice with less environmental impact among others. Figure 2 presents everything that involves the rice crop cycle, which corresponds to the agricultural sector, components of the husk and straw, the potential energy use of residue, and the pollutants.

The rice waste disposal governance approach starts with a vision and high ambition level, pro transition from open-air burning of rice crop residues to

Figure 2 - Describes the main topics presents in the paper



Source: adaption from (Jittin, Bahurudeen, & Ajinkya, 2020).

an industrial process that will give added value to rice husks and rice straw. This vision should be developed by FEDEARROZ and local government, in co-creation between local government, large or small producers, academic institutes, industrial partners and the Colombia government, in particular the Ministry of Agriculture and Rural Development affairs. The policies have to focus predominantly on high-efficiency, green manures, low-cost, bulk products, such as paper, or biomass co-firing for energy production, while the highest value added in the bioeconomy comes from high quality products. It is actually a combination of a top-down and bottom-up approach, using the principles of transition management.

Green manures are an option that, taking advantage of their ability to fix atmospheric N_2, help recover soil nutrients due to degradation by toxic fertilizers. Instead of emitting polluting gases, green manures increase carbon sequestration. Precision agriculture (using the required fertilizer at the appropriate time) or the use of biofertilizers (compost, etc.) should also be implemented (Gómez, Manrique, Moreno, L, & Torres, junio 2021).

Paddy rice does not undergo 100% transformation to excelso rice. On average, for every 1000 g of rainfed paddy rice, 595 g of excellent rice, 55 g of medium grain or crystal rice, 30 g of industrial broken rice, 100 g of rice flour, 200 g of husk and 20 g of rice impurities are obtained (Gómez, Manrique, Moreno L, & Torres, junio 2021). Few investigations have been carried out in the country to estimate CO_2 emissions, they report emissions of 998.1 ± 365.3 kg CO_2 eq. ha^{-1} per cycle. Nitrogen fertilizers contributed with the highest emission, with 65% of the total (647.6 ± 19.0 kg CO_2 eq.ha^{-1} per cycle and 106.8 kg CO_2 eq per each ton of rice), due to the use of high doses (Gómez, Manrique, Moreno L, & Torres, junio 2021). The table 4 presents the Emissions in kg CO_2 eq considering rice yield. Table 5 an estimative energy production, if it is consider, rice production and power generation integrated system with rice production capacity of 200 tons per day was found out to generate surplus electricity of 3.4 MW (Darmawan, Biddinika, Huda, Tokimatsu, & Aziz, 2018).

In Colombia, the greatest contribution of irrigated rice crops to global warming is through CH_4 emissions, while in rainfed rice it is N_2O emissions from the application of synthetic fertilizer. Likewise, the reviewed literature confirms that there are mitigation solutions, such as the use of green manures, precision agriculture and the production and consumption of biofertilizers, which allow organic benefits to be obtained in rice production, reducing the emission of toxic gases (Gómez, Manrique, Moreno L., & Torres, junio 2021). According with Sanchis *et al.* (2014) for current waste management, the alternative that produced the lowest greenhouse gas emissions was the removal of straw. The other lower polluting emission is through the burning of rice straw, with an appropriate process of drying the

Table 4 - Emissions intensity in kg CO_2 eq considering rice yield (Gómez, Manrique, Moreno L, & Torres, junio 2021; FEDEARROZ, 2016)

	Yield t/ha	**Paddy Rice Yield per hectare Kg.ha. year^{-1}**	**Excelso Rice Yield per hectare Kg.ha. year^{-1}**	**Total emission CO_2 eq ha year^{-1}**	**Husk waste per hectare Kg.ha.**	**Silice by Husk per hectare Kg.ha.**	**Straw waste per hectare Kg.ha.**	**Silice by Straw per hectare Kg.ha.**
				First semester				
Mechanized rice	4.6	4.600	2.737	4.591	920	184	6.900	1.380
Irrigated rice	4.9	4.900	2.915	4.890	980	196	7.350	1.470
Mechanized rainfed rice	5.2	5.200	3.094	5.190	1.040	208	7.800	1.560
Manual rainfed rice	2.4	2.400	1.428	2.395	480	96	3.600	720
				Second semester				
Mechanized rice	4.4	4.400	2.618	4.391	880	176	6.600	1.320
Irrigated rice	5.4	5.400	3.213	5.389	1.080	216	8.100	1.620
Mechanized rainfed rice	4.1	4.100	2.439	4.092	820	164	6.150	1.230
Manual rainfed rice	2.3	2.300	1.368	2.295	460	92	3.450	690

Table 5 - Rice production and power generation integrated system, an estimative for the Department of Cordoba (Darmawan, Biddinika, Huda, Tokimatsu, & Aziz, 2018)

	Production (t)	Husk waste (t)	Husk waste potential (MW)	Straw waste (t)	Straw waste potential (MW)
First semester					
Mechanized rice	15184	3036.8	51.6256	22776	387.192
Irrigated rice	11980	2396	40.732	17970	305.49
Mechanized rainfed rice	3205	641	10.897	4807.5	81.7275
Manual rainfed rice	10	2	0.034	15	0.255
Second semester					
Mechanized rice	32000	6400	108.8	48000	816
Irrigated rice	8731	1746.2	29.6854	13096.5	222.6405
Mechanized rainfed rice	23269	4653.8	79.1146	34903.5	593.3595
Manual rainfed rice	519	103.8	1.7646	778.5	13.2345

straw and in minimum humidity conditions. Nevertheless, further studies are required to improve rice straw management. Appropriate off-site uses of this straw should be investigated and implemented in practice to avoid open-field burning (Sanchis, Ferrer, Calvet, Coscollà, & Yusà, 2014).

Although it is important that rice production increases with demand, the production process must be improved so that it works optimally economically, environmental impact, t/ha yield, pollutant emission, waste disposal and investment is required to give added value to production agriculture as for the residue. However, it is proposed to include in future studies the emissions generated by the machinery used, considering the economic and energy costs that each of them entails.

The hemicellulosic fraction of rice straw can be fermented to ethanol and mycelial biomass, it is able to produce ethanol in anaerobic cultivation on glucose, and aerobic cultivation on xylose and glucose. The production cost of straw-based ethanol is sensitive to key parameters, such as the type, composition, and price of the feedstock, the size of ethanol plant, the conversion efficiency, and the level of investment costs. The net production cost of ethanol is divided into (1) investment costs, (2) fixed operating costs (including salaries, general overhead, insurance, taxes, and maintenance), (3) variable operating costs (including purchase of consumables and sales of excess electricity), and (4) feedstock costs (Swain, Singh, & Sharma, 2019).

Investment is required in managing the crop residue in the department; to develop the fuels obtentions, to later carry out a controlled burning to generate energy or gas obtention, to lastly obtain silica, which, like the silica, is obtained from RH and RS. The high reactivity of amorphous silica is favorable for many applications such as Supplementary Cementing Materials (SCM). Amorphous silica obtained from RH can chemically react with cement chemicals and increase the strength of cementitious matrices. Furthermore, rice husk silica is used for the immobilization of transition metals and organic fractions, with a high potential to be used as a catalyst (Bakar, Yahya, & Gan, 2016; Mirmohamadsadeghi & Karimi, 2020; Jittin, Bahurudeen, & Ajinkya, 2020). Therefore, future studies on processing methods and their influence on the reactivity of Rice Husk Ash (RHA), which is used up to 20% in brick production, whereas for soil stabilisation, 10 and 20% of RHA is used either as sole material or in combination (with cement or lime) to improve the properties of brick and soil respectively (Jittin, Bahurudeen, & Ajinkya, 2020).

6. Conclusion

Agro-industrial waste has gained value because its composition contains compounds of organic origin that could get into renewable fuels, bio-based chemical products, biofuels, gas, sources of electricity, fertilizers, and raw construction materials. The industrialization of rice residue into Cordoba's economic axe; depends on the analysis proving that it brings benefits to the region in the solvent and energy aspects and is a wise investment. in the mills and the fields.

Cordoba's rural areas demand biomass and energy, especially the ones that are not connected to the system of public services. The agricultural residues will provide economic benefits of improving the quality of life, reducing environmental pollution, and providing employment opportunities to many people in the agro-based power plants established for electricity generation.

The current balance matrix of the entire rice crop cycle is related to the emission of CO_2, CH_4, and N_{2O}, the performance of the rice system t/ha, yield economics, and no proper waste management. It is predicted a non-profitable crop, due to fertilizer-high prices, will also increase the environmental impacts. So, a current solution is organic compost use, which could guarantee CO_2 capture in the cultivation process and mitigate the pollutant emission in the rice cultivation cycle.

The commitment and hard work will come from the farmers, researchers, federations, and administration will be to study the improvement of the soil nutrients, the quality of the crop, and the management of the residue, the one that remains in the mills (husk) and the one that remains in the fields (straw).

The necessary investment to obtain a product that meets current market requirements on renewable fuels or raw materials. Hence, vitality could be suitable pathway that exists between the energy sector and construction sector with direct benefits, including biomass-based energy, green construction products, and reduction in land pollution.

Depends, on the articulation of the farmers, industry, and local government, together with research, innovation, and feasibility studies, demonstrating that they are sustainable projects, have a point of balance, and cost-analysis proves that it brings benefits to the region in the solvent and energy aspects.

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