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Review

Key Processes for the Energy Use of Biomass in Rural Sectors of Latin America

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Abstract: An alternative to mitigate the consumption of fossil fuels is the use of biomass as an energy source. In this sense, the rural sector in Latin America has great potential due to its multiple biomass sources. For this reason, this study aims to analyze potential technologies related to the production of energy from biomass and its application in the Latin American rural sector. To achieve this, four key processes are analyzed. First is biomass conditioning through solar dryers. Next are the thermochemical processes that allow for their transformation into biofuels, for which the pyrolysis and the hydrothermal methods were selected due to the flexibility of the products obtained. Subsequently, cogeneration is studied to produce electrical and thermal energy from biomass or its derivatives. Finally, to close the CO_2 cycle, a balance of CO_2 fixation in a forest plantation is presented as an example of carbon accumulated in biomass. The literature systematic review allowed us to determine that the technologies mentioned in this work have different degrees of implementation in the Latin American rural sector. However, they have great potential to be applied on a large scale in the region, making it possible to adapt energy production to climate change and improve the life quality of its inhabitants.

Keywords: biomass; biofuel; sustainable resources; bioenergy; renewable energy

1. Introduction

A rural sector is a territory with a small number of inhabitants, where the main economic activity is agriculture. In this context, more than 123 million people live in the rural sector of Latin America, with a poverty rate of 45.7% and extreme poverty of 21.7%, two and three times higher than in urban areas, respectively [1]. Additionally, around 20 million Latin Americans do not have access to electricity [2], the rural sector being the most affected. Therefore, any initiative to obtain energy in the rural sector is highly relevant for the region.

Bioenergy is an essential alternative for energy production, thereby mitigating the continuous advance of global warming caused by the indiscriminate use of fossil fuels. The use of bioenergy is different in each country or region. Usually, it is 3% in industrialized countries, and in developing countries it can reach 22% on average [3].

Currently, the Latin American consumption of biofuels, natural gas, electricity, oil, and mineral coal is 27%, 6.5%, 6%, 5% and 1%, respectively [4,5]. The previous data show that Latin America is an important consumer of biofuel, mainly primary biofuels since this region has 23% of the world's forests [6] and 14% of the world's crops [7]. Worldwide, only 3% of biomass is used to generate electricity [5], while in Latin America it is 8.4% (or 5% of the total energy consumption), with a thermal installed capacity of 20.6 GW [8].

The technological use of biomass and biofuel to generate renewable energy is one of the new challenges that Latin America must take on to face climate change. Although Latin America is not a major emitter of greenhouse gasses, this region could face the greatest consequences if the planet's temperature continues to rise. Moreover, in Latin America, biomass is traditionally used to generate primary energy. In many rural areas of the region, the largest amount of energy comes from biomass, but not as a renewable source. A clear example of an unsustainable practice in poor countries is the use of firewood, from deforestation residues, for cooking, generating harmful effects on health. According to the International Renewable Energy Agency [9], biomass has a promising future as it could represent 60% of total renewable energy use by 2030, with great potential in all sectors: around 30% of global biomass could be used to produce electricity and district heating; another 30% in the production of biofuels for the transport sector; the rest in heat for the manufacturing industry and buildings. Biomass energy is a promising renewable energy source and has an enormous potential to fulfill the energy requirements of the country [10].

It is known that the use of biomass residues can vary according to: (1) the type and quantity of residues, (2) the method of utilization, (3) the community or rural sector needs and (4) the logistical cost. Additionally, residual biomass can be classified as: agricultural waste, urban waste, livestock waste, forestry waste and industrial agri-food or agricultural waste. Thus, this resource can be used to produce heat or electricity; for instance, biomass from energy crops is used to produce liquid fuels or gasses that can be burned and converted into heat energy. Therefore, the technology selection is determined based on the biomass characteristics, energy use and type of energy production (thermal or electrical) (see Table 1). It should be considered that a pre-treatment of the biomass can be required before use in the different processes mentioned in Table 1, for example, crushing, chipping, grinding, drying, and pelletizing, among other treatments that guarantee an optimal efficiency of the technology for generating heat or electricity. In the combustion, gasification and pyrolysis processes, the biomass must contain a low percentage of moisture to prevent the evaporation of water from consuming part of the energy and reducing the performance of the process.

Table 1. Processes and technologies based on biomass for producing electrical and/or thermal energy.

Biomass	Process		Technology	Biomass State	Product	Waste	Reference
Industrial agri-food and forestry waste, forestry waste, agricultural waste, energy crops, urban solid waste	Combustion	Direct combustion	Combustion Furnaces: Fixed Bed Combustion, Bubbling Fluidized Bed Combustion, Circulating Fluidized Bed Combustion, Pulverized Fuel Combustion. Grate furnaces: fixed, moving, traveling, rotary and vibratory. Operating temperature: between 700 and 1000 °C. Yield: 80% using dry biomass, 60% wet biomass. Operating pressure: 6–15 kPa.	Dry (moisture less than 13%). Wet (humidity greater than 40%). Calorific power for biomass 18 and 22 MJ/kg Particle size: Grills < 150 mm. Fluidized bed < 100 mm. Combustion of pulverized fuel < 4 mm.	Saturated or superheated steam	Solids (ashes) Inorganic compounds	[11–13]
	Thermochemical	Gasification	Gasifiers: Downdraft: ascending and descending fixed bed types. Updraft: cross flow/fluid bed or fixed bed. Fluidized Bed Gasifiers: bubbling and encircling. Operating temperature: 600–1000 °C. Approximate yield: 85%. Operating pressure: 101–3000 kPa.	Dry (humidity < 15%)	Syngas Low heating value 5.5 MJ/m^3	Solids (ashes)	[11,12,14,15]
		Pyrolysis	Pyrolytic oven fluidized bed. Operating temperature: Slow pyrolysis 250–600 °C. Fast pyrolysis 600–1000 °C. Flash pyrolysis can reach 1200 °C. Hydro pyrolysis 550 °C. If municipal solid waste is used, temperatures range between 550 and 1100 °C. Approximate yield: Slow pyrolysis: 40–50% liquid, 10–20% solid, and 20–30% gas. Fast pyrolysis: 60–75% liquid, 15–25 solid, and 10–20 gas. Flash pyrolysis: greater than 80% gas	Dry (humidity < 15%)	Charcoal, liquid fuel, gaseous fuel	Liquid (water, organic compounds), gasses, ashes	[11,16,17]
		Hydrothermal process	Reactor type: Plug flow, batch and continuous stirred tank, operating temperature, pressure, and residence time: Hydrothermal carbonization (HTC): 160–250 °C, 1–4 MPa, hours. Hydrothermal liquefaction (HTL): 250–400 °C, 5–20 MPa, minutes. Hydrothermal gasification (HTG): 400–700 °C, 20–35 MPa, minutes.	Wet	Hydrochar (solid biofuel), Biocrude (liquid biofuel), Fuel gases (CH_4 or H_2)	Liquid phase (water with polar organic compounds)	[18–20]

Table 1. *Cont.*

Biomass	Process		Technology	Biomass State	Product	Waste	Reference
Industrial agri-food waste, livestock waste, solid waste and urban wastewater	Biological	Anaerobic digestion	Biodigester: Continuous digesters and discontinuous digesters. Plastic or tubular bag digesters, fixed dome biodigester (Chinese type). Floating dome biodigester (Hindu type). Biomass fermentation: 30 to 90 days depending on the residue. Functional temperature: 30–35 °C.	Wet	Biogas	Biol, compost used for fertilizer	[11,21,22]
		Thermophilic digestion	Two-stage: Acidogenic bioreactor (the feed tank and acidogenic reactor were cylindrical stainless steel (AISI 321), volume of 12 L) and electromethanogenic reactors (cylindrical tank with a volume of 19 L). Biomass: Solid waste, 26 to 55 days of fermentation for stage. Functional temperature: 50–60 °C.	Wet	Producing biohydrogen and methane	solid and liquid	[23]

The profitability of transformation processes, even for the same technology, is highly dependent on each case. The different operating conditions of the various processes based on the use of biomass, such as climate and geographic location, type and quality of biomass, equipment, level of technological development, and waste generated, among others, affect its performance. For example, in the case of cogeneration, Marchenko et al. [24] showed that the cost of electricity of mini-CHP on wood fuel (wood chips or pellets) is significantly less than the cost of electricity from a diesel power station.

The profitability of using biomass as an energy source is conditioned by the type of biomass, logistics cost, technological acquisition capacity or technological replicability from the design stage, materials and technicians of the community [25–27]. On the other hand, biomass energy generation costs depend on its final use (industrial or domestic processes, heating or electricity). For example, in household applications, the energy from biomass is used in cooking, heating and biomass boilers to produce hot water for the home by burning chips, logs, olive pits, pellets or briquettes [28–30]. Meanwhile, in collective applications (industrial process), the cost will depend on the installed thermal power of the thermal plant, piping, maintenance, system operation and price of the biomass source [31–33]. Therefore, the profitability of using biomass is a challenge worldwide, for example, Zhao et al. [34] established a Five Forces Model (the competitors, suppliers, buyers, potential competitors and substitutes) for assessing the competitiveness of China's biomass power industry in 2015. In this industry, similar to the Latin American reality, the national support in the form of financial subsidies, tax benefits, tariff concessions and technical support policy has played a significant role in promoting the development of the biomass power generation industry. The vast majority of enterprises are dependent on the sensational support policies in order to be profitable. Therefore, the government support for bioenergy production in the rural sector is necessary to improve people's quality of life and become independent of a central energy supply.

This work aims to analyze examples of technological processes related to biomass and energy, which are applicable in the rural sector of Latin America (see Figure 1). Therefore, four technologies for obtaining energy, related to biomass and/or biofuel, are addressed. First, the solar dryer exemplifies the use of renewable energy (solar) for drying biomass, allowing one to eliminate or reduce the use of fossil fuels in this process. Then, two thermochemical processes are analyzed, pyrolysis and hydrothermal methods, as examples of obtaining energy sources from biomass. Next, cogeneration is an example of biomass and/or biofuel use to generate energy. Finally, the CO_2 emissions of the different technologies will return to the forest. Therefore, this article presents an example of the balance of CO_2 fixation in a forest plantation.

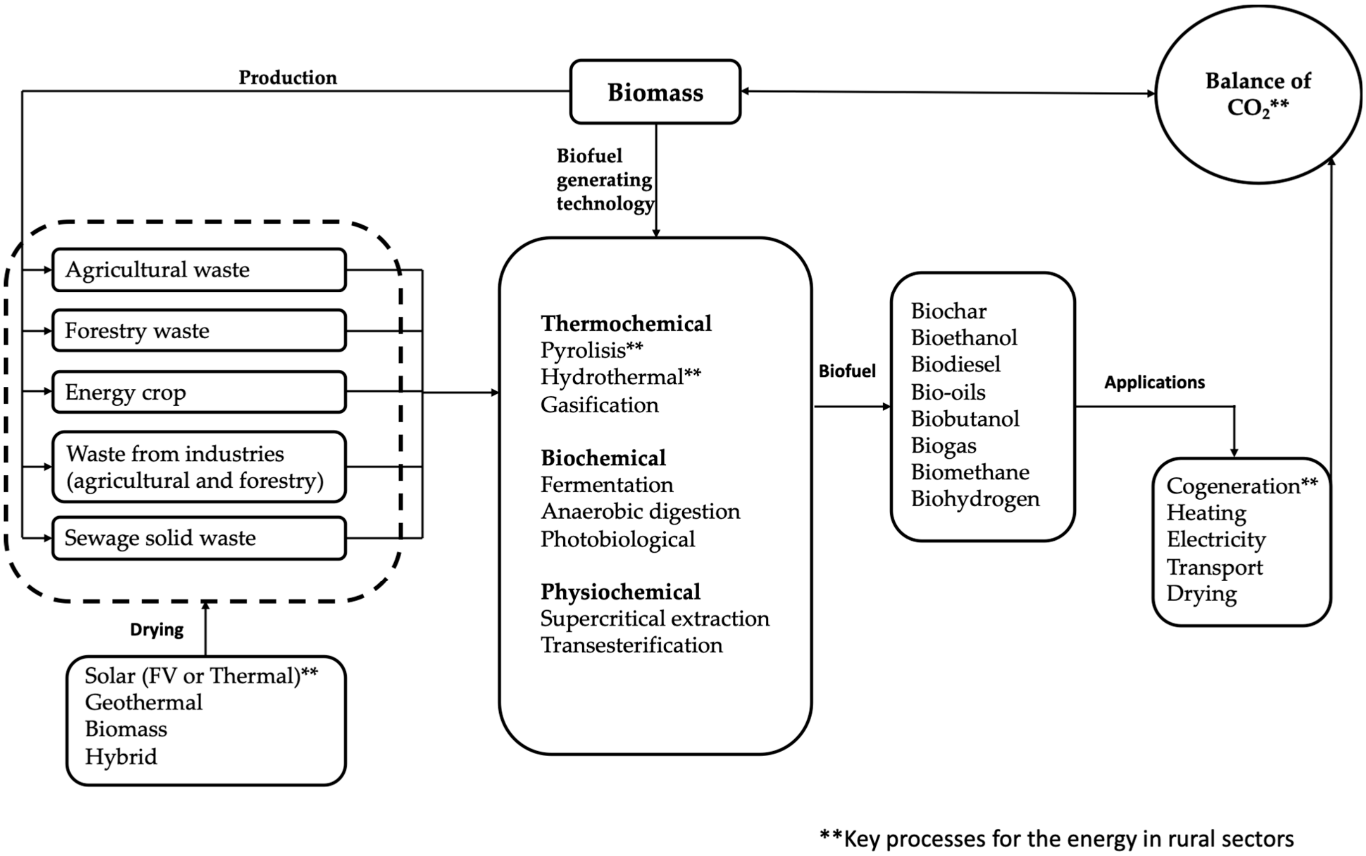


Figure 1. Scheme of the leading technologies related to biomass exploitation to produce energy.

2. Preprocessing: Drying Biomass Using Renewable Energy

The drying process is one of the oldest methods used to preserve grains, fruits, meats, and medicinal plants. It allows for food preservation for a long time and reduces the cost of logistics during the transport of the product. The drying technology varies depending on the production capacity, type of fuel used, moisture required to be removed from the product, time of use, and technological cost. However, it is clear that solar dryers are the most used in rural areas, in low-scale agricultural productions. However, it is a technology that has reached its maturity to be implemented for drying large-capacity grains and fruits. It is an alternative that allows for greenhouse gas mitigation and tackling climate change.

Research about the development of technologies in the applications of renewable resources has been deployed due to the increase in energy demand and the increase in environmental pollution [35]. To guarantee energy insurance in a country, it is necessary to work on the diversification, availability, reliability and accessibility of energy sources applied to various strategic sectors, such as agriculture [36].

The need to improve the quality and quantity of agricultural products has caused investment in new agriculture techniques. However, this need means high capital expenditure and new methods and tools to satisfy the energy demand. This last has been rising, especially in isolated areas due to growing population, food demand and agriculture automatization [37]. Fossil fuels are the typical energy source in agriculture processes, but transportation, difficult access to isolated areas and environmental pollution, such as CO_2 emissions [36,38], have made it necessary to use alternative energy sources to meet the demand in the agriculture process, for example, postharvest.

In the world, energy used for drying processes consumes 7–15% of industrial energy [39]. Therefore, the cost of this energy is a crucial challenge to looking for an alternative source of energy, for example, solar energy. Solar energy is available in almost all the world, is free and provides a clean and free pollution energy source [35,40]. Furthermore, solar energy has a higher development potential than other alternative energy sources, such as the ocean, biomass and geothermal [41]. According to the International Energy Agency (IEA) [42], in 2020, only 0.2% of the installed capacity for energy generation from renewable resources corresponded to solar thermal projects; this energy was equivalent to 6506.68 [MW]. Figure 2 shows the installed power generation capacity globally for the use of renewable energy sources.

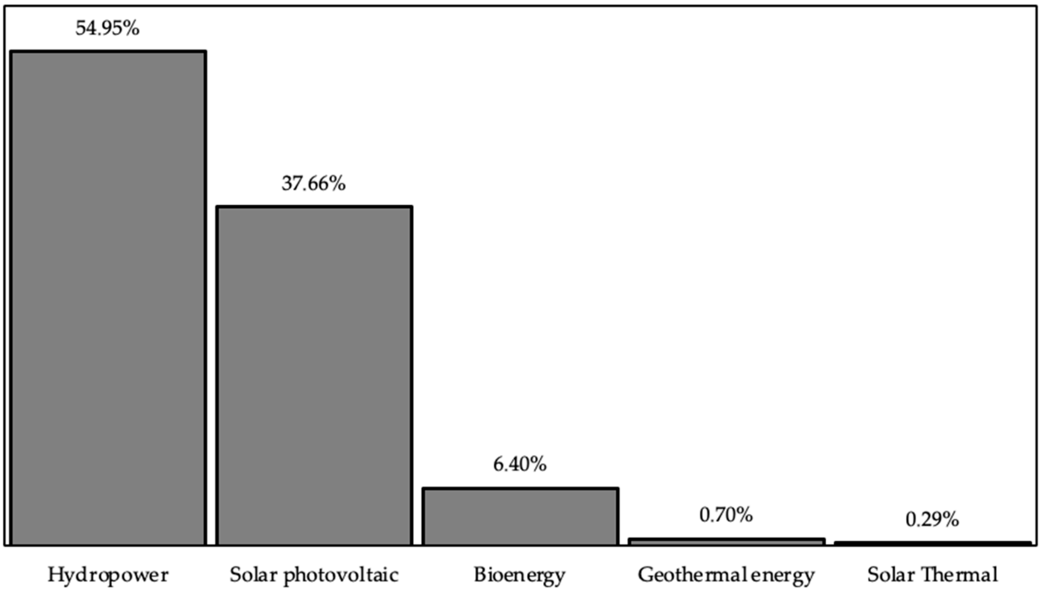
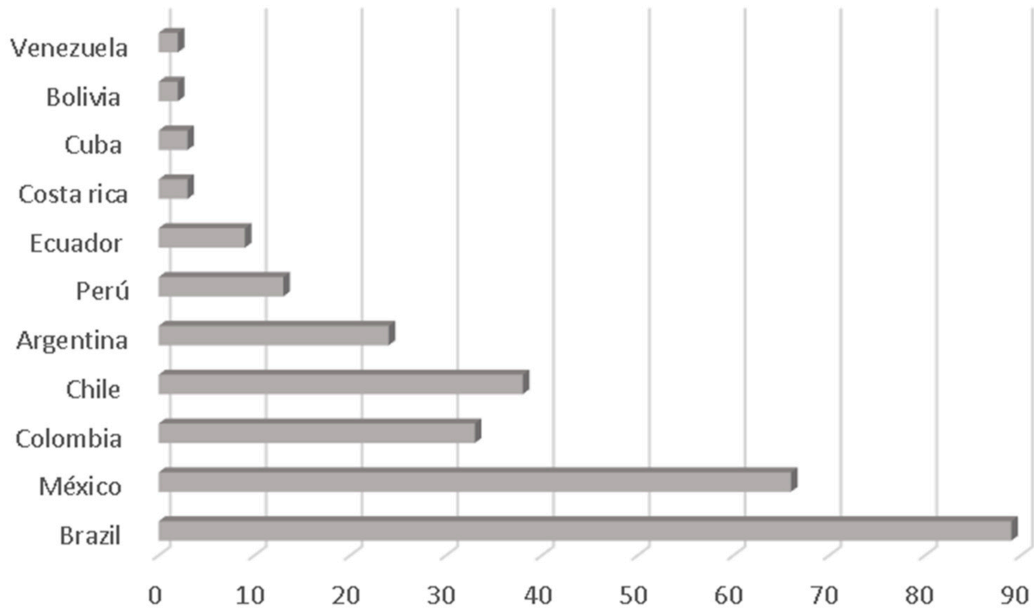


Figure 2. Installed power generation capacity worldwide from renewable resources by 2020 [42].

For the particular case of Latin America and the Caribbean, in 2020, the primary generation with renewable energies was more than 1.2 million barrels of oil equivalent (MBEP); this value represents 32.8% of the energy generated in the region, the primary sources being hydropower, sugar cane and firewood, each with a contribution of approximately 460 thousand MBEP [4].

On the Scopus platform, 3779 results are displayed searching for the keywords solar dryer from 2013 to 2023. India presents the largest number of publications, followed by Morocco, Iran, and Turkey. In Latin America, 282 results are recorded (Figure 3a). The review of each article shows results associated with the drying of products, analysis of biomass moisture, the adaptation of materials, radiation, and climate. When a deeper filter is applied to the keyword drying technology, 986 results are displayed, of which 73 are publications from Latin American countries (Figure 3b). In the region, the publication is diverse, as there are no specialized journals for this topic. For example, some works were published in *Solar Energy* (five publications), *Revista Brasileira de Engenharia Agricola Ambiental* (four publications), *Revista Mexicana de Ingenieria quimica* (three publications), *Energy procedia* (three publications); other journals such as *Applied Sciences*, *Renewable Energy* and others have published between one and two articles. On the other hand, it was evidenced that designs of solar dryers in the region are published in the databases of the Universities as undergraduate or postgraduate theses.



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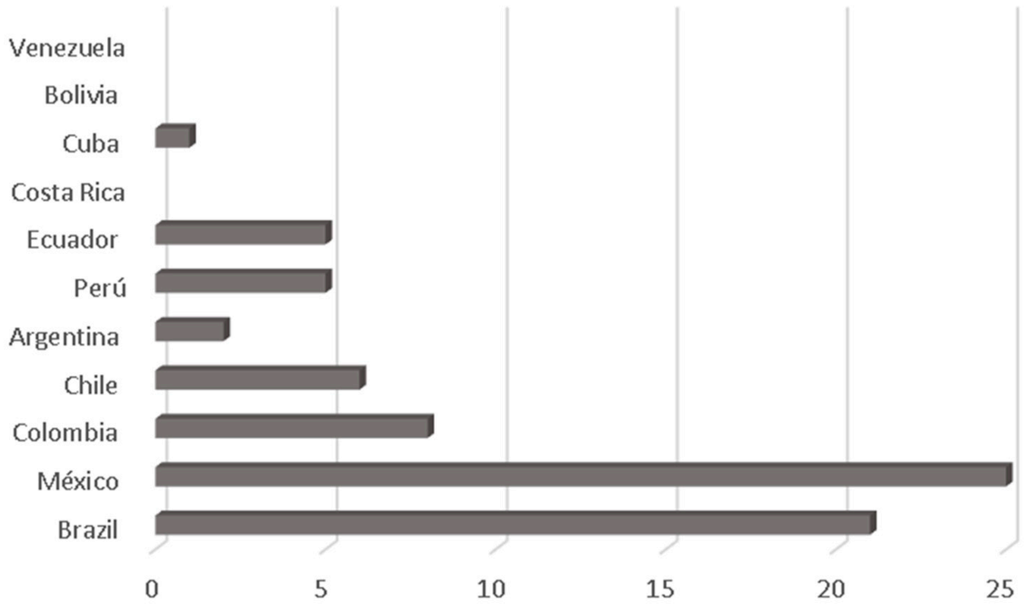

(**b**)

Figure 3. Results of publications from Latin American countries. (**a**) General search with the keywords solar dryer, platform Scopus 2013 to 2023. (**b**) Specific search for solar dryer technology. Scopus Platform 2013 to 2023.

Table 2 was made based on the information indicated above. This table shows examples of solar dryer technology studied in Latin America.

Table 2. Examples of applied solar dryer technology publications in Latin America.

Dryer Type	Description	Product	Drying Characteristics	Reference
Solar dryer (Argentina)	Argentina has promoted the development of solar drying systems for agricultural products on an industrial scale. An Indirect solar dryer is analyzed. Consists of a 30-tray chamber and solar collectors with an axial fan that forced the ambient airflow.	Fruits, vegetables. 12 kg capacity	Surface: 2 m^2 collector area Drying time: 5.5 h Average Solar Radiation: 807 W/m^2 Ambient temperature: 28.1 °C Relative humidity: 43% Drying temperature: variation between 11 °C in relation to the ambient temperature Efficiency: 50% solar collector, 17% drying performance Mass airflow: 0.022 kg/s Total potential: 1800 W	[43]
Hybrid dryer (Brazil)	A forced-ventilation solar-cabin hybrid dryer. The solar dryer consists of: drying chamber, solar collector, trays, electrical heater. The system is connected to: photovoltaic module, fans, batteries, charge controller and duct. The dryer is made of wood and covered with galvanized steel sheets and thermal insulation. The absorber plate is made of galvanized steel, painted in black, and covered by a glass cover. The trays are made of galvanized wire mesh painted in black.	Corn 16 kg capacity, 23% moisture content	Surface: 0.51 m^2 drying chamber, 1 m^2 collector, 1.6 m^2 air pre-heating (PV module) Inclination: 20°, collector and PV panel Drying time: 8.5 h Average Solar Radiation: 684 W/m^2 Ambient temperature: 22.8 to 33.9 °C Relative humidity: 57 to 28% Drying temperature: 68.9 °C Efficiency: 40% Mass airflow: 0.0103 kg/s Electrical power PV: 270 W	[44]
Hybrid dryer (Ecuador)	Solar-geothermal hybrid dryer systems. The systems consists of: drying chamber, solar collector, photovoltaic systems, aerothermal exchangers, and blower. The dryer is made of galvanized steel sheets and polycarbonate. The collector is made of galvanized steel, painted in black, and covered by a glass cover. The geothermal-heat exchanger is made of PVC.	Cocoa 7 kg. 45% moisture content	Surface: 1.5 m^2 drying chamber, 0.75 m^2 collector, 21 m^2 aerothermia Inclination: 10° collector Drying time: 8 h Average Solar Radiation: 450 W/m^2 Ambient temperature: 29 to 36 °C Relative humidity: 70% Drying temperature: 50 °C Efficiency: 60% Air velocity: 0.9 to 1.2 m/s Electrical power PV: 110 W Total potential: 2000 W	[45]

Table 2. *Cont.*

Dryer Type	Description	Product	Drying Characteristics	Reference
Hybrid solar-biomass dryer (Colombia)	The prototype dryer consists of a combustion chamber for generating flue gases and a solar panel for generating both electrical and thermal energy. Parts: dryer, trays, fan, solar panels, combustion chamber and heat exchanger.	Coffee bean 90 kg. 40 to 43% initial humidity	Drying time: 24 h Ambient temperature: 22 °C Collector Temperature: 23 to 44 °C Combustion chamber Temperature: 70 °C. Biomass: coffee husk in pelletized and disaggregated Husk moisture: 8.88% Drying temperature: 45 °C Potential thermal: 4.02 kW	[46]
Passive solar dryer (Argentina)	Dryer used in rural areas. Parts: drying chamber, chimney and wind turbine.	Fresh meat. 4 kg/m^2. Yield of 1 kg of dried per 3 kg of fresh	Surface: 2 m^2 drying chamber Drying time: 2 days Average Solar Radiation: 550 W/m^2 Inclination: 10° dryer Ambient temperature: 17 to 28 °C Relative humidity: 50% Drying temperature: 40 to 60 °C Flow: 800 m^3/s Air velocity: 0.2 to 0.8 m/s	[47]
Greenhouse dryer (Argentina)	The dryer consists in a tunnel greenhouse drier functioning as a solar collector and fan.	Red sweet pepper 70% humidity	Surface: 50 m^2 Flow: 0.5 kg/s Drying time: 2 days Drying temperature: variant Efficiency: 3%	[48]
Hybrid dryer (México)	Solar thermal and PV dryer cabin. The dryer is covered with cellular polycarbonate sheets with a copper chalcogenide semiconductor thin film coating. Parts: drying chamber, resistance, water extractors, electric heaters, PV modules.	Fresh produce fruits 80% humidity Yield of 40 kg of mango	Surface: 36 m^2 Drying time: 3 h Average solar radiation: 800 W/m^2 Drying temperature: 45–55 °C PV modules power: 30 kWp	[49]

Table 2. *Cont.*

Dryer Type	Description	Product	Drying Characteristics	Reference
Hybrid solar dryer (México)	Dryer used consist in a flat plate collector the air, drying chamber, solar water heater, water pump, drying trays, air inlet.	Medicinal plant 2.5 kg of product, 79% moisture content Reduces the moisture content to the product by 90%	Surface of dry: 1.12 m^2 Surface of solar water heater: 1.5 m^2 Surface of plate collector: 0.188 m^2 Average Solar Radiation: 200 to 800 W/m^2 Inclination: 45° collector Ambient temperature: 28 to 35 °C Relative humidity: 20% Capacity to store: 3250 latent heat Drying time: 14 h Drying temperature: 40 to 56 °C Collector Temperature: 55 °C Solar Water heater temperature: 50 °C Efficiency: 17.68 to 57.66%	[50]
Solar dryer (México)	Dryer used consist in a flat plate collector the air, drying chamber. thermal storage: beach sand and limestone.	Agricultural product in rural communities 0.89 kg, 96% moisture content	Surface of dry: 0.72 m^2 Surface of plate collector: 1.2 m^2 Average Solar Radiation: 489 W/m^2 Inclination: 21° collector Ambient temperature: 25.8 °C Relative humidity: 80% Charge Energy: 2391 to 5945 kJ Storage efficiency: 70 to 84% Drying time: 22 h Drying temperature: 40 to 70 °C Wind Speed: 0.63 to 0.87 m/s Collector Temperature: 65 °C Efficiency: 3 and 4% of the drying efficiency as compared to conventional	[51]

It can be indicated in a general way that in the Latin American region, solar thermal dryers are the most used technology in the rural agricultural sectors for their ease of operation, construction, use of local materials, and reduction in electrical energy consumption. Although, the efficiency of solar dryers is low due to the dependence on solar irradiation and geographic location. The use of solar radiation for drying is ancient and their customs go through tradition; therefore, rural communities have the vision that greenhouse-type dryers help to obtain a quality product, are ecological and are suitable for their economy in the short term.

Solar dryers are classified into direct and indirect concerning the incident solar radiation on the product. In direct dryers, the radiation is absorbed by the product itself, usually using a greenhouse-type drying chamber built with transparent plastic. The indirect-type dryer comprises a collector, a covered drying chamber, and a set of trays. The air is heated by the collector and enters the drying chamber passing through the trays, leaving the humid air through a duct to the environment; the system can be used by natural or forced convection [40]. The direct solar dryers may have reached higher temperatures than indirect ones due to the energy gain in the chamber [43].

Another technology analyzed is hybrid dryers with thermal performance and increased energy and efficiency of the drying process, coupling solar dryers to other energy. In Brazil, Ecuador, Mexico and Colombia, studies for drying cereal grains are presented. In the first case, the heat emitted by the photovoltaic panel is used to preheat the fluid, reaching a temperature of up to 40 °C, then it passes to a solar collector and drying chamber. The drying process only occurs during the day. At night, the electric heater works and heats the airflow [44]. The efficiency of the dryer reaches 40%. In the second case, geothermal energy is used as a temperature contribution to the solar collector; later, the hot air passes to the drying chamber, which is complemented by an electrical resistance connected to the network that provides the energy required in the chamber on cloudy days. The operating temperature is 50 °C and the dryer has an efficiency of 60%. If it works only as a solar dryer, the efficiency drops to 30% [45]. In the third case, the coffee dryer uses the coffee husk as a source of combustion energy. The combustion chamber was dimensioned referencing the energy release rate of the husk. It consists of a fixed grill with an inclination angle of 16°; it has 105 holes distributed, so there are 8 holes on each side with a diameter of 0.05 m [46]. The air enters through the solar collector to preheat it. Subsequently, it passes through the fan and is carried to the combustion chamber as primary and secondary air. Simultaneously, a feeder screw is used to administer fuel and coffee husk to the chamber to carry out the combustion. The combustion gasses are directed through a heat exchanger in order to transfer their energy to the drying air entering the dryer chamber of trays. The dryer leads to a reduction of 80% in operating costs compared to the traditional system [46].

The semi-continuous solar dryers for rice consist of solar heaters, a drying chamber, a heating channel, a fan and air connection ducts [41]. The dryer has a relatively high efficiency of 21.24% for this equipment and a short drying time of 3 h compared to a greenhouse with thermal storage of similar surfaces that requires 24 h to dry the product. There is a greenhouse that allows heat to accumulate using a packed bed, which has the function of collecting and emitting heat during the hours of low irradiation of the area. Finally, the air flows into the drying plates where the product is located [41]. Unlike the semi-continuous dryer, the mass flow is lower, being 0.278 kg/s; therefore, the product will take longer to dry.

In the region, ladder-type solar dryers are also used, where solar radiation is captured through the glazed sheet, which is converted into heat and raises the temperature inside the chamber to vaporize the water molecules of the product. Air enters by natural convection through holes in the wall, this plot of air is heated through solar radiation and it flows into the grid of the first tray, thus heating the scattered grapes. The hot air passes to a second floor or chamber to dry the fruit; this humid hot air is passed through the other floors successively until it comes out through a small chimney [42].

3. Thermochemical Processes

This section analyzes two thermochemical routes that allow for obtaining energy from biomass. Pyrolysis is a thermochemical route proposed for dry biomass exploitation, while hydrothermal methods are presented as a technology for wet biomass valorization. Both technologies were selected due to the flexibility of their products since, by varying the process conditions, it is possible to obtain solid, liquid, and gaseous biofuels, as can be seen in Figure 4.

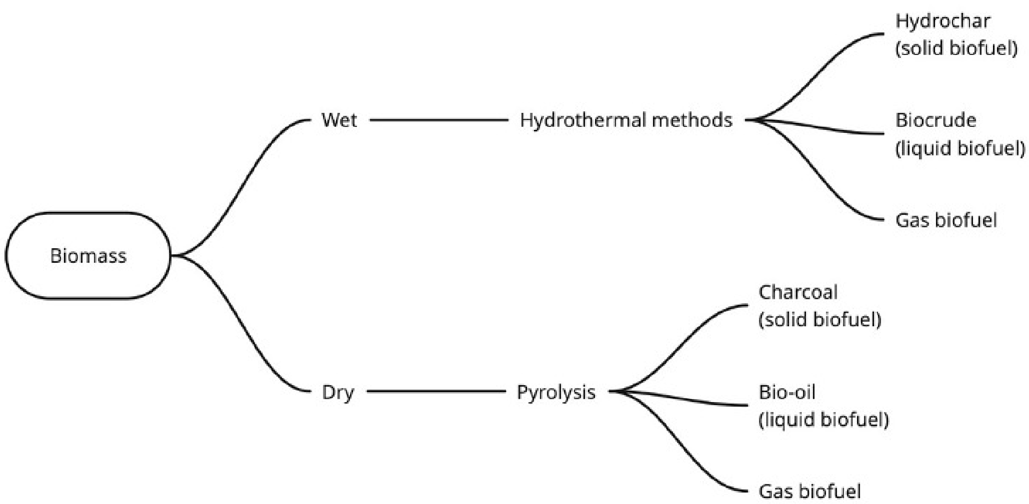

Figure 4. Products obtained by the thermochemical routes selected (pyrolysis and hydrothermal methods).

3.1. Pyrolysis Technologies

Pyrolysis is a thermochemical process that involves the slow heating of biomass in an oxygen-free atmosphere at temperatures above 400 °C, through which charcoal is produced. This process doubles the energy content of biomass and reduces the original weight by 75%, making it easier to transport and store [52]. In this sense, pyrolysis is one of the most used technologies that allow for the use of charcoal for power generation [53] through its conversion into solid, liquid or gaseous products suitable as materials for different industries or as fuels [54]. The pyrolysis technology for charcoal production is varied, and its use depends mainly on the socioeconomic conditions of each site. However, when biomass is used as raw material, this type of technology becomes an economically viable approach that offers the greatest potential to be competitive on a large scale shortly [55].

The selected kiln significantly affects charcoal quality and yield [56]. Additionally, the controlled carbonization conditions imply control of air intakes in the thermal decomposition zones inside the kiln. This control depends on the carbonization method used and/or the heating method applied. Carbonization yields are variable: in laboratory retorts, values of 25 to 30%; in commercial carbonation methods with furnaces, from 20 to 25%; and in artisanal methods, from 10 to 20% [57].

Traditional methods include the simplest type of kilns, which is called the parva type, built in places with a sensitively flat and compact surface, with no moisture in the ground and free of combustible material; a mound of firewood is formed that is covered with leaves and soil so that it is enclosed in a chamber isolated from the air, and ignition can start on one side or the top. In this same category are pit kilns, which are excavations made in the soil, where the firewood is introduced, covered with metal pieces to insulate it from oxygen, and the ignition is started at the inlet of the air [58].

Technical or industrial methods are used to produce charcoal on a larger scale, and high yields and high quality are obtained. In this category are metal kilns whose design is mainly cylindrical and simple, consisting of two or more pieces, and a metal lid is used. During the process, the air inlet is controlled through a set of chimneys that can be closed, achieving total water tightness; therefore, the process is carried out with a total absence of oxygen [58]. Some authors mention that brick kilns are more effective for charcoal production, have better yield, higher quality, lower GHG emissions, as well as higher economic gains to the producer [59,60]. In this category are the half-orange argentine kilns, rabo quente and brazilian beehive kilns, whose lifespan is estimated to be six to ten years. In test kilns, the gases generated during the pyrolysis process can be reused, so the energy consumption of the raw material is low, and the release of pollutants into the atmosphere is reduced [61].

On the other hand, others mention different yields, for instance, Flores and Quinteros [62] mention a yield of 22.22% for the pit-type kiln, 16.66% for the parva-type kiln, 47.61% for the brick kiln, 28.12% for the metal cylinder kiln, and 83.33% for the retort kiln. However, as already mentioned, yields will depend on various factors.

However, with the wide availability of pyrolysis technologies, the chosen production system must be sustainable to gain environmental and social advantages and promote economic and industrial development.

3.2. Hydrothermal Methods

Biomass with high water content is a limiting factor for dry thermochemical processes. In the case of gasification, it is recommended to use feedstock with moisture below 30% [63], while feedstock with moisture lower than 10% is typically recommended for pyrolysis [64]. Therefore, biomass with higher moisture content needs to be dried before being processed with these technologies, which implies an additional process for its transformation and the energy expenditure involved in the evaporation of water.

As described later, hydrothermal methods are carried out in water-rich environments. Waste materials with high moisture content, such as manure (91.9%) [65], sewage sludge (80%) [66], and organic solid waste (81.6–95.5%) [67], are suitable options to be transformed into biofuels by those technologies. Hydrothermal processes can typically handle feedstocks with 70–90% water content [18].

Hydrothermal methods are thermochemical transformations of biomass carried out in water-rich environments at temperatures between 160 and 700 °C and pressures of 5 to 40 MPa, often self-generated by saturated steam [68].

They are divided according to the phase-favored products under certain process conditions. Hydrothermal carbonization (HTC) is carried out at temperatures between 160 and 250 °C and retention times of several hours [69]. Under these conditions, the main product is a carbon-rich solid known as hydrochar. By increasing the reaction temperature to between 250 and 400 °C and reducing the residence time in the order of minutes, the main product is an oily liquid called biocrude [70]. This process is known as hydrothermal liquefaction (HTL). Finally, by increasing the temperature above the critical point of water at temperatures between 400 and 700 °C and retention times in the order of minutes [69], the main product is a combustible gas, and the process is known as hydrothermal gasification (HTG). Although a specific product increases its yield under different reaction conditions, in most cases, all the products are obtained simultaneously.

The reaction times and temperatures at which the different hydrothermal methods are carried out are presented in Figure 5 as well as the main product obtained in each condition. A comparison of these methods with the dry thermochemical processes that allow for obtaining products in the same states of aggregation is also shown.

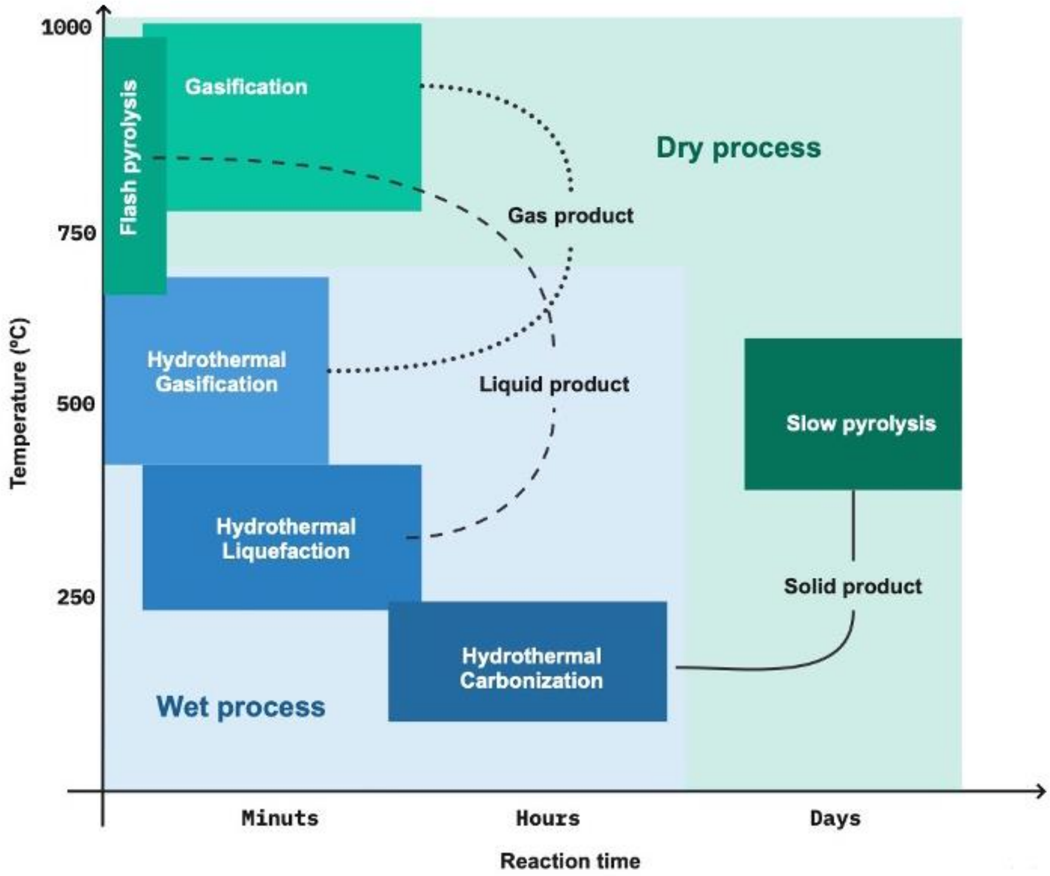

Figure 5. Temperature and reaction time of hydrothermal methods and homologous thermochemical processes.

Under hydrothermal conditions, water provides a medium where a series of complex reactions take place. First, the biomass undergoes hydrolysis of the macromolecules, resulting in oligomers and monomers. The soluble products undergo dehydration and decarboxylation reactions [71], which remove hydroxyl, carbonyl, and carboxyl groups, decreasing the oxygen content of the products. During the HTC, the dissolved molecules repolymerize, producing hydrochar and some by-products such as organic acids [72]. At HTL conditions, the intermediate molecules are rearranged by condensation, cyclization, and polymerization, producing hydrophobic macromolecules that form the biocrude [73]. Under HTG conditions, the predominant reactions are steam reforming, water gas shift and methanation [18]. Although the reaction routes and the distribution of the products are strongly dependent on the composition of the raw material, it is possible to group the biomasses in the following order of reactivity: lipids > proteins > carbohydrates (starch > hemicellulose > cellulose) > lignin.

The characteristics of the different products vary according to the reaction conditions and the feedstock. The biocrude produced by HTL has a low oxygen content (5–10 wt%) and high energy value (30–40 MJ/kg) [74]. Hence, it can be used as fuel in burners, turbines, and boilers [75]. Biocrude can also be upgraded and used as a transportation fuel [76]. Hydrochar has a carbon content similar to lignite [69], but its volatile compound content is higher [77]. Unlike biomass, hydrochar has a hydrophobic behavior that allows water to be removed efficiently by mechanical methods [70].

The production of biocrude and hydrochar has been studied using various rural residues. These materials can be classified into three groups: forest residues, agricultural residues, and manures. Different residues from the forest industry have been studied, such as pine sawdust [78], cherry and cypress wood [79], and eucalyptus wood [80], among other woody biomasses. A variety of agricultural residues have been studied, such as banana peel [81], tomato processing residues [82], rice husk [83], barley straw [84], cane bagasse [85], oil palm residues [86], spend coffee grains [87], and corn stalk [88]. Regarding manure, different types have been studied: cattle manure [89], pig manure [90], and rabbit manure [91].

Compared to other thermochemical processes, an advantage of hydrothermal methods is that the biomass does not need to be dried for processing, avoiding energy losses. On the other hand, hydrothermal methods convert organic chloride into inorganic salts preventing the production of dioxins [92]. In addition, these methods reduce the biofuel ash content since the acetic acid produced during the process favors the dissolution and leaching of inorganic compounds into the liquid phase [93], reducing its content in hydrochar and biocrude.

The number of companies dedicated to biomass exploitation by hydrothermal methods is scarce worldwide, probably due to their technological maturity [94]. HTC is the most widespread process on an industrial scale, followed by HTL. To the best of our knowledge, no companies have scaled HTG. Table 3 lists the companies that work in these methods.

Table 3. Companies based on hydrothermal methods (HTC and HTL).

Company	Country	Feedstock	Capacity	Reference
		HTC		
CPL Industries	United Kingdom	Landfill waste	-	[95]
SunCoal	Germany	Biomass	Pilot plant	[96]
Terra Nova	Germany	Wastewater and Organic waste	Industrial scale in China and Mexico	[97]
Ingelia	Spain	Biomass	Industrial scale	[98]
		HTL		
Licella	Australia	Biomass and plastic	Three scales of pilot plants	[99]
Genifuel Corporation	United States	Wet organic wastes	Pilot plants	[100]
Circlia Nordic	Denmark	Organic waste	Modular plant	[101]
Merrick & Company	India	Algae	1000 liters of fuel per day	[102]
Steeper Energy	Norway	Woody biomass	30 barrels per day	[103]

In Latin America, only one hydrothermal plant, specifically an HTC plant, is installed in Mexico using Terra Nova technology. The plant capacity is 72 tons of wet organic material per day. According to the information provided by the authorities, this plant is the first of 36 that are planned to be installed in this country [104,105].

In addition to being used for energy purposes, the products of hydrothermal methods can be used in other applications. The biocrude from lignocellulosic materials contains compounds of commercial interest, such as phenol, guaiacol, catechol, syringol, m-cresol, p-cresol and o-cresol [106–108]. The hydrochar can be used as a soil amendment; however, more research is needed to evaluate its ecotoxicity [93]. It can also be used as a pollutant adsorbent [81] and as an electrocatalyst [109].

Hydrothermal methods can improve wet waste management in rural areas by incorporating them into the value chain as biofuels or higher value-added materials.

4. Cogeneration in Rural Sectors

Cogeneration is a system for the joint production of electricity and useful thermal energy. This requires a primary energy source which is combusted, releasing thermal energy. This generated heat is used to heat water or produce steam. There are two alternatives to generate electricity: in the same cogenerator (diesel engine or gas turbine) and a steam turbine in series with the cogenerator. The basic elements of a cogeneration plant are: primary energy source, heat utilization systems, refrigeration systems, water treatment system, control system, electrical system and auxiliary systems [110]. Cogeneration processes achieve high performance levels, between 80 and 90% of all primary energy [111,112].

Traditionally, cogeneration has been applied in the industrial sector [113,114], but it has gradually been applied in other economic sectors that require electrical and thermal energy, for example, hospitals, hotels, airports, shopping centers, sports complexes, universities, etc. [115–117]. These facilities have variable energy needs depending on the weather season [118,119]. In winter, the energy needs will be electricity and heat, while in summer, the needs will be electricity and cold (air conditioning). While in spring and autumn, the need for heat and cold can coincide. Cogeneration must work throughout the year, as the project needs to be profitable. In addition, energy consumption fluctuates according to the time of day since these are associated with business and office hours [110]. Finally, the price of electricity is relatively high, favoring the profitability of cogeneration systems in the non-industrial sector since the rates are more expensive than for the industrial sector and the working hours coincide with the peak hours of electricity consumption. The internal combustion engine meets most of the requirements of this sector: continuous stops, large load variation and a reduced heat–electricity ratio [120].

The application of cogeneration in rural areas has the same drawbacks mentioned above for the non-industrial sector, plus difficult access to processed fuel (natural gas, liquefied gas, gasoline or other), and the engine size is at the microcogeneration level [121–123]. Preferably, biomass and biogas are used for cogeneration in rural areas. Biomass cogeneration systems are increasingly being researched and applied. Several studies have been accomplished in recent years to improve the environmental and economic efficiency and effectiveness of biomass cogeneration systems [124–127] because biomass cogeneration is an effective alternative to reduce greenhouse gas emissions due to their low CO_2 emission [128,129]. On the other hand, the use of biogas is complex because its production depends on the conditions necessary for the proliferation of microorganisms responsible for degrading organic matter of animal, plant, agro-industrial, or domestic origin. Biogas cogeneration (CHP-Biogas) exceeds the efficiency of a traditional electricity-generating process (35%); therefore, this process has been studied as an alternative for generating energy for rural areas. For example, Fan et al. [130] presented a rural multi-energy complementary system structure, which establishes the output model of wind power, biogas cogeneration, firewood-saving stoves, photovoltaic heat collectors, and air source heat pumps. A rural area in northern China is considered as the study area. The results of the calculation examples show that biogas cogeneration units and electric vehicles can improve the consumption of clean energy, reduce the system energy cost by 358.9 yuan, reduce carbon emissions by 1605.8 kg, increase energy consumption satisfaction, and improve the economic, environmental, service, and other benefits of the system. In general, CHP-Biogas has the following advantages: (1) alternative disposal of manure, slurry and biological waste, while taking advantage of energy, being a valuable substitute for conventional fossil fuels, (2) high potential for reduction in greenhouse gasses, (3) highly efficient for the combined generation of energy and heat in the facility, and (4) the remaining substrate is used as high-quality agricultural fertilizer, characterized by its neutralized acid, higher pH value, the nutrients retained and it being odorless.

Cogeneration has been applied in different rural areas that have the following in common: organic waste to produce biofuel and the need for energy independence. For example, Linares-Lujan et al. [131] determined the energy potential of human waste in rural areas of the Department of "La Libertad", where 7 of the 20 poorest districts in Peru are located. It was estimated that the area's total rural population by 2017 in the area will be 468,979 people, from which 3427.49 Nm^3/day of biogas can be obtained, representing 1,251,033 Nm^3 of annual biogas if the total waste is used. The biogas that would be generated in 2017 represents an energy potential of 7,506,198 kWh, which can be transformed into 2,251,859 kWh of electricity, valued at USD 245,685 per year. Zhang and Wang [132] conducted a case study in a rural area to research the effect of the age structure of the local population on the total capacity of the biomass cogeneration system. They conclude that: (1) the annual household electricity, heat and total energy consumptions peak at average family ages of approximately 40, 60 and 55 years, respectively. The heat–

electricity ratio of biomass cogeneration peaks at an average family age of approximately 68 years, (2) during the heating period, the heat–electricity ratio of biomass cogeneration is positively related to the difference between indoor and outdoor temperatures, while during the non-heating period, the ratio is stable, and (3) the total capacity of biomass cogeneration estimated based on the age structure of the local population may not be consistent with that estimated based on the per-capita energy consumption.

A rural area with no industrial development probably has an important forest resource and organic waste, making the rural area an ideal setting for the cogeneration of energy with biomass and/or biogas.

The biomass can produce heat and electricity for use in the industries and buildings (by cogeneration systems and using district heating systems). IRENA [9] estimates that use will grow by a factor of nearly eight to more than 8 EJ by 2050. However, in Latin and Central America for 2015, only 0.2% of installed Generation Capacity is used for energy purposes and there is yet potential to be scaled up. In practice, the cogeneration is a small market in the generation region, because of instability in the supply and the price of fuels, the need for more specific regulatory frameworks, deficiencies in the disclosure of information and socio-cultural conditions such as distrust.

5. Balance of CO_2 Fixation in Forest Plantations

Robert [133] reports that forests cover 29% of the land and contain 60% of the carbon of terrestrial vegetation; in addition, the Amazon Region is the ecosystem with the highest amount of carbon (305 t/ha approx.), storing 28% in the soil. On the other hand, Terrer et al. [134] states that CO_2 stocks increase in grasslands 8 $\pm$ 2%, but not in forests (0 $\pm$ 2%), and biomass in grasslands increase 9 $\pm$ 3% less than in forests (23 $\pm$ 2%). Grasslands can absorb large amounts of carbon, while carbon uptake by forest soils will remain virtually neutral. In addition, agroforestry (growing trees and crops in interacting combinations) systems have a higher potential to sequester carbon because of their perceived ability for greater capture and utilization of growth resources (light, nutrients, and water) than single-species crop or pasture systems [135]. Kongsager et al. [136] determined the aboveground carbon (C) sequestration potential of four major plantation crops: cocoa (65 tonC/ha), oil palm (45 tonC/ha), rubber (214 tonC/ha), and orange (76 tonC/ha), cultivated in the tropics.

The balance between the carbon accumulated in the tree, as a result of its growth, and that released by the detachment and decomposition of leaves, branches, fruits, bark, etc., determines the net fixation of carbon by the tree. The same reasoning can be made by changing the tree concept to that of forest mass, including the net balance of all the plant species that make it up: trees, shrubs, bushes and herbaceous plants. Precise knowledge of the dynamics of the net carbon flow between the forest and the atmosphere, or what is the same, the quantification of the emission–capture balance, is one of the main challenges that arise if carbon sequestration is to be incorporated as another objective of forest management [137]. For this reason, capturing CO_2 is crucial for using energy in the rural sector.

Next is a detailed case study about the determination of the balance of carbon capture in forest plantations, taking into account their final productive destination and the substitution of fossil fuels. The study area is a wetland linked to the Cuenca del Plata, particularly in the islands of the Buenos Aires Delta, insular areas of the Zarate and Campana districts. The climate of the Delta region can be considered temperate, with a relative humidity high in all seasons of the year, averaging about 75%. The confluence of three geographic factors (location, presence of the Paraná and Uruguay rivers and topographical situation of abrupt transition) condition the ecological characteristics of the Delta. As a result of all this, a set of characteristic communities are installed in the region, generally associated with certain hydrological and geomorphological conditions.

The case study was separated into two zones (see Table 4):

(a) Balance of CO_2 fixation of the case study (Zone A): establishment located in the zone of Isla del Partido de Campana. This establishment was chosen for its accessible location by land, typical conditions in terms of forest production. It has a total area of 10,000 ha, of which 5000 ha are productive for the forestry sector, and 2000 ha are degraded, some of which are also used for livestock. The 5000 ha under cultivation are forested with American Willow (*Salix babylonica CV sacramenta*), which turns out to be the predominant clone in the area, and Poplar. The property has a production of 7000 tons/month (average 2004–2006), which represents a total of 84,000 tons/year. This corresponds to an annual average of 16.8 tons/ha*year. In this zone, a harvest yielded an approximate amount of 205 tons/ha, leaving an amount of 55 tons/ha as woody residues [138]. Table 4 shows the use of wood by area.

(b) Extension of the CO_2 balance to island areas (Zone B): taking into account the island areas of the Zarate and Campana districts and the forestry activities carried out in both regions. The insular sector of the Partido de Zárate covers a little more than 55,600 ha of delta Surface. The soils of the lower parts, called wetland soils, are often flooded and covered with partially decomposed organic matter, which gives them an acid character. Under natural conditions, the interior of the islands is not very suitable for traditional productive activities. It occupies an area of 66,400 ha. This area is affected by the iteration of two floods, the one caused by the Paraná River and the one caused by the Río de la Plata. The forested area is approximately 35% of the total area of the island. Fundamentally, this geographical area is of great importance in terms of biomass production and biodiversity reserve.

Additionally, Table 4 shows the balance of CO_2 capture by the wood destination for Zone A and Zone B, according to Norberto [139].

Table 4. The distribution and balance of CO_2 capture (tonCO_2/year) (BCC) by productive destination of the wood for Zone A and Zone B.

Destination	Zone A	Zone B (Zarate)	Zone B (Campana)
Pulp and paper production	50% are 42,000 tons equivalent to 2500 ha BCC: 49,350 tonCO_2/year	Rest of the region 2000 ha: 50% (1000 ha) BCC: 19,740 tonCO_2/year	50% (6000 ha) BCC: 118,440 tonCO_2/year
Sawing for furniture and carpentry	2% is 1680 tons, equivalent to 100 ha BCC: 3988 tonCO_2/year	North Sector 3000 ha: 10% (300 ha) Rest of the Region 2000 ha: 50% (1000 ha) BCC: 51,844 tonCO_2/year	20% (2400 ha) BCC: 95,712 tonCO_2/year
Agglomerates	48% are 40,320 tons, equivalent to 2400 ha BCC: 51,840 tonCO_2/year	North Sector 3000 ha: 90% (2700 ha) Central Region 3000 ha: 100%	30% (3600 ha) BCC: 77,760 tonCO_2/year
Substitution of fossil fuel	Used 17,010 ton/year of crop residues to produce energy, thermal performance of the system of 30% and 3% for drying the wood, the total available will be 4950 tons/year BCC: 9797 tonCO_2/year *	- BCC: 15,680 tonCO_2/year **	- BCC: 23,520 tonCO_2/year ***
Total BCC	114,975	210,384	315,432

* Considering the emission factor of the Argentine electricity grid: 0.407 tonCO_2/MWh as of 2019 [140]. ** Substitution by crop residues, considering 1.96 tonCO_2/ha*year, from the witness case (8000 ha). *** Substitution by crop residues, considering 1.96 tonCO_2/ha*year, from the witness case (12,000 ha).

Table 5 shows an economic analysis of the relationship between the values obtained from the sale of the forest mass for the different activities and its relationship with the value obtained from the sale of the CO_2 captured. Considering that the total captured is 640,791 tonCO_2/year and considering a sale value of 10 USD/tonCO_2, the income would be 64,077,910 USD/year, representing 40% of the value obtained from the commercialization of the forest mass, which would be USD 15,823,920. A limitation regarding the assumed value of 10 USD/tonCO_2 is that it is a future value, meaning we can say that this value is not stable and depends on various factors, countries, and if an increase in the demand for tonCO_2 is present in the future [141]; a value in 2019 for forestry and land use was 4.3 USD/tonCO_2, [142], and an average of 4–5 USD/tonCO_2 hides some projects that are negotiated at much higher levels [143]. The application of carbon taxes and the emission trading systems realize that these values could significantly increase if the policies associated with carbon bonds are applied [144].

Table 5. Economic comparison, regarding the income from the sale of CO_2 and the sale of production according to destination.

Destination	Pulp and Paper	Agglomerates	Sawn	Total
Production (ton/year)	159,600	196,560	63,840	420,000
Position on the ground *	Average 4300 USD/ton	3100 USD/ton	Poplar 5750 USD/ton Willow 4950 USD/ton	
Sale (USD/ton)	41	30	Weighted average 53	
Total (USD/year)	6,543,600	5,896,800	3,383,520	15,823,920

* Values in Argentine pesos [145], Official Dollar 104 ARS/1 USD as of October 2021.

The replacement of fossil fuels represents an annual generation of 120,360 MWh/year (25,000 ha $\times$ 4.81 MWh/ha per year). This is equivalent to estimating an operation of a thermal power plant in 6750 h/year, a generation installation of 17.83 MW of power.

6. Discussion

Energy is essential for developing the rural sector since it allows many essential services that improve people's quality of life. However, the non-efficient use of energy produces a break in the environmental balance, causing a reaction in nature that can have adverse consequences for humans. Therefore, our relationship with the Earth will have to change, leaving traditional technologies to be replaced by technologies that are compatible with the environment.

After harvesting agricultural products, they have to be stored, which is one of the main stages in any production. During this process, deterioration of a considerable amount of the products may occur because of the existence of water in these products.

The application of solar energy in the agricultural sector is a new technology in most countries. However, different types of solar dryer systems are being developed; solar thermal systems would be the best option for agricultural applications, especially for the distant rural areas [45,146]. Solar dryers in agriculture have no impact on the environment. However, the cost of the system is the main factor to choose the energy source. The initial cost of the solar dryer is around USD 705 per kW for PV modules and about USD 720 per m^2 of solar collectors [147], making the system more sensitive to the proper design [148,149]. Dryer evaluation procedures reported in the literature mostly cover only a few selected parameters and a comprehensive evaluation; meanwhile, incorporating all the relevant parameters does not appear to have been reported. In postharvest products, some factors, such as moisture content, temperature, and humidity, affect the quality characteristics of the final product; all these parameters depend upon the type of the product to be dried and the ambient conditions [45,150,151]. For example, while higher drying temperatures quicken the drying process, it could also cause damage to the product (loss of color, flavor, aroma and vitamins). Fruits, vegetables and their products in dried form are good sources of energy, minerals and vitamins. However, during the process of dehydration, there are changes in nutritional quality. Some nutritional parameters, such as vitamins A, C and thiamine, are heat sensitive and sensitive to oxidative degradation [152].

Sensory properties of dried foods are also important in determining quality; these include color, aroma, flavor, texture and taste; aroma and flavor can change due to the loss of volatile organic compounds, the most common quality deterioration for dried products [152]. The quality of open sun-dried product is poor, but it is the cheaper way to dry products in rural areas; to introduce the driers to the farmers, the suitability of dryers for fruits and vegetables should be tested with different equipment and technology developed in some of the articles presented in this review [152–156].

Pyrolysis is a safe continuous process for treating a wide variety of waste and generating an energy source. In addition, this process has a high energy recovery efficiency from the available waste, with a significant reduction in the waste to be treated (>90%). Taking the above into account allows us to propose pyrolysis as a technology with the possibility of massifying its use in the rural sector of Latin America.

Hydrothermal methods do not require a drying pre-treatment of the biomass; in addition, this technology mitigates emissions and prevents the waste used as feedstock from generating said emissions. When compared to other thermal methods (pyrolysis, gasification and torrefaction), this thermal method is the one that produces the highest percentage of carbon (50–80%) that is widely used in the rural sector.

The cogeneration process has a high energy efficiency, that is, 30% higher than a traditional method; it also consumes half the fuel and, therefore, less CO_2 emissions [157]. The rural sector obtains its independence from the main electricity network and in turn thermal energy.

The region has significant potential for carbon sequestration. Such potential will allow for properly implementing forest certification and, as a consequence, the application of the CDM (Article 12 of the Kyoto Protocol), carbon bonds or green bonds in voluntary fields will allow the region to maintain activities, improve the use of soils and allow unused areas to preserve their biodiversity.

7. Conclusions

Latin America has great potential for generating renewable energy to help its sustainable development. Thus, this work exposes several technologies that can be used on a large scale in the rural sector to reduce dependence on fossil fuels.

The use of solar drying for agricultural products has a large potential from a technical and energy saving point of view. Still, the dependence on the drying characteristics, such as the quality of the final product or drying time, with the technology applied is a problem because most of the current dryers have low efficiency or require days to reduce the moisture from the food. Open sun drying is the best alternative because the quality of the dried crops is higher, and the loss of dried products is considerably reduced.

The valorization of residual biomass could be achieved by biofuel production through thermochemical processes, such as pyrolysis or hydrothermal methods. They offer several advantages, among which are: the reduction in greenhouse gasses production due to decomposition without control of these residues, decrease in the biomass volume, increase in the energy density of the products, the flexibility of the biofuels obtained and the possibility of generating products with higher added value. Currently, slow pyrolysis using traditional methods is employed in Latin America; however, charcoal yields and quality could be improved by adopting technical or industrial methods, while hydrothermal methods are a new technology beginning to permeate in the region and present great opportunities for implementation.

Finally, the balance of CO_2 would allow for the ordering and control of the region since there will be less chance of having leaks about its economic, social and environmental impacts by means of obtaining a profit from the sale of the bonds of the order of 40% concerning the value obtained from the sale of the forest mass in its different uses and the addition of the sale of energy injected into the network.

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