

Biomass as a Waste Recovery Mechanism for Clean Energy in Algeria

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Abstract :

The circular economy aims to optimize the use of resources by reducing waste and promoting recycling. In this context, the recovery of agricultural waste represents a sustainable solution to limit the environmental impact while creating new economic opportunities. It is based on the transformation of agricultural waste into value-added products. The integration of these practices in Algerian SMEs would make it possible to boost the local economic fabric. However, this transition requires accompanying policies and increased awareness among the actors concerned. By promoting circular management of resources, the recovery of agricultural waste contributes to a more sustainable economic model, reconciling growth and environmental preservation.

Keywords: biomass; circular economy; Sustainable development; Algeria.

JEL Classification: Q21, Q42, Q53

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Introduction :

Faced with environmental challenges and the need to reduce dependence on fossil fuels, renewable sources are an essential alternative. Among them, biomass stands out for its high energy potential and its key role in the transition to a more sustainable model. In Algeria, the abundance of agricultural, forestry and urban waste offers a valuable opportunity for its energy recovery, thus reducing the environmental impact while optimizing the exploitation of available resources. (Banerjee, 2022) (Djaafri, et al., 2024).

Various processes, such as combustion, mechanization and the production of bio fuels, make it possible to convert these organic materials into usable energy. In addition to its energy contribution, the integration of biomass into a circular economy framework contributes to the reduction of waste and promotes more efficient management of natural resources.(Yaashikaa , Kumar, & Varjani , 2022) (Ali, et al., 2024).

Algeria, in its energy diversification strategy, is betting on the development of this sector to strengthen the production of clean energy and limit polluting emissions. By making the most of these untapped resources, biomass is part of a dynamic of modernization of the energy sector, while creating new economic and industrial opportunities.(Bensmail , Missoum , Elmir , Draoui, & Mehdaoui, 2024) (Hachemi, et al., 2024). Thus, its integration into the national energy landscape represents a strategic lever for a more sustainable and resilient transition, combining technological innovation and environmental preservation. (Bouznit , Pablo-Romero, & Sánchez-Braza, 2020).

1.Research problem:

Faced with the climate emergency and the need to reduce dependence on fossil fuels, Algeria is seeking to diversify its energy mix by relying on locally available renewable resources. Among them, biomass appears to be a promising alternative, still largely under-exploited. In this context, a central question arises: how can biomass be recovered in Algeria to support the energy transition, while limiting environmental impacts?(Alper, Tekin, Karagöz, & Ragauskas, 2020) (Benaissa , 2020) (Bouraiou , et al., 2020).

2.Hypotheses:

H1 : Biomass represents a renewable energy source capable of contributing to the diversification of the Algerian energy mix.

H2 : The energy recovery of organic waste in Algeria would reduce polluting emissions and generate economic benefits.

H3 : The development of the biomass sector in Algeria is hampered by institutional, technical and logistical constraints.

3.Objective of the study:

The objective of this study is to analyze the potential of biomass in Algeria as a lever for sustainable energy transition, highlighting its applications, its advantages, as well as the obstacles to its large-scale development.

4.Importance of the study:

This study is of strategic importance in the current context of energy diversification in Algeria. It makes it possible to develop a resource that is still under-exploited, to think about local solutions for the management of organic waste, and to propose

avenues for reflection to strengthen energy autonomy while reducing environmental impacts. It also provides useful insight for public decision-makers, researchers and economic actors involved in the transition to a more sustainable energy model.

1. Literature review:

In the face of the climate crisis and the gradual depletion of fossil fuels, the search for sustainable energy alternatives is a global necessity (Mahapatra, Kumar, Singh, & Sachan, 2021).

Renewable, versatile and environmentally friendly solution. Made from organic materials such as agricultural waste, forestry residues, livestock and municipal waste, it can be used to produce heat, electricity, biofuels and even hydrogen, all while contributing to the reduction of greenhouse gas emissions. (Kalak, 2023)(Ali, et al., 2024).

1.1. Definition of biomass:

Bioenergy, also known as biomass energy, refers to energy extracted from non-fossil organic materials such as wood, straw, oils, and various plant wastes from the forestry, agriculture, and industrial sectors. Just like fossil fuels, it originates from the solar energy that plants absorb and store through photosynthesis. However, the major difference between these two energy sources is their availability: while fossil fuels require thousands of years to become usable, biomass, when managed sustainably, is a renewable resource that can be used continuously. (Ali, et al., 2024)(Kalak, 2023)(Banerjee, 2022).

It exists in three main forms — solid, liquid and gaseous — and can be used in many applications. Currently, most of this energy comes from solids (such as shavings, sawdust, pellets, coal and household waste) as well as liquid substances, including residues from wood processing in industry Paper.(Alper, Tekin, Karagöz, & Ragauskas, 2020)

There are three main types of biomass used for energy production: (Kumar, Bhattacharya, Hasnain, Nayak, & Hasnain, 2020) (Mignogna, Szabó, Ceci, & Avino, 2024).

1.1.1 Dry biomass :

Dry biomass includes waste such as wood for heating, wood chips, wood chips from forestry and wood pellets.

1.1.2 Wet biomass :

This category includes organic matter with a high water content, mainly from the agricultural sector, such as manure, but also from the agri-food industry and urban areas, including green waste as well.

1.1.3 Biofuels :

Biofuels are liquid fuels derived from plant resources such as oilseeds (rapeseed, sunflower), cereals (wheat, corn) or vegetable oils. They come in several forms, including bioethanol and biodiesel, and are used as fuels for Transport. (Mahapatra, Kumar, Singh, & Sachan, 2021).

Biofuels from biomass represent a promising alternative to fossil fuels. Several studies indicate that they can reduce greenhouse gas emissions by more than 90%

compared to conventional fuels, thus strengthening their role in the energy transition (El-Fawal, et al., 2025).

1.2 Conversion technologies and applications :

The applications of biomass are diverse and historical, including food uses, soil amendment , as fuel and material. Currently, biomass is used as a feedstock for chemistry (surfactants, solvents, etc.) and for biofuels (biodiesel, bioethanol). It is also used as a biofuel for the production of heat and electricity, through wood, straw, and various organic wastes. Biomaterials, such as wood and hemp, are increasingly being used for insulation and in composite concretes.(Tshikovhi & Motaung, 2023) (Rial, 2024).

The transformation of biomass into energy is based on several processes. Combustion generates heat or electricity by burning organic materials such as wood and agricultural residues. Gasification, on the other hand, converts biomass into a fuel gas that can be used for energy or fuel production. Pyrolysis, carried out at high temperature and in the absence of oxygen, breaks down biomass into biochar, gas and pyrolysis oil. Finally, techniques such as fermentation and anaerobic digestion transform organic matter, including agricultural and urban waste, into biogas or biofuels, providing a renewable source of energy.(Mignogna , Szabó, Ceci, & Avino, 2024)(Ali, et al., 2024)(Osman, et al., 2023).

One of the main The main factor in biomass lies in its carbon neutrality. The CO₂ emitted during its accumulation is largely offset by that absorbed during the growth of the plants, making it a sustainable resource.(Kumar, Bhattacharya, Hasnain , Nayak , & Hasnain , 2020).

In addition, it contributes to the reduction of the volumes of organic waste, limiting the extent to which the environmental impacts related to their accumulation . On the socio-economic level, the sector Biomass promotes the creation of rural jobs, stimulates local value chains and Participates in the diversification of the energy mix (Tzelepi, et al., 2020).

1.3 Importance of biomass in the energy transition process

Fossil fuels include oil, coal and natural gas, which are finite and non-renewable resources. Unlike renewables, these fuels are gradually depleted as they are exploited. Their main advantage is their high energy density, but their use has many major drawbacks.(Alper, Tekin, Karagöz, & Ragauskas, 2020)

The constraints and impacts of fossil fuels present a major challenge for the sustainability of resources and the protection of the environment. Among the main constraints are: (Banerjee, 2022) (Bouznit , Pablo-Romero, & Sánchez-Braza, 2020) (Himri, et al., 2022)

- Their availability is limited and their intensive consumption accelerates their scarcity, making the search for more environmentally friendly alternatives urgent.
- They are unevenly distributed across the world, leading to significant geopolitical and economic tensions.
- Their extraction, processing and use cause considerable pollution and

produce hazardous waste.

- Their transport carries major risks, including oil spills caused by tanker accidents, which have disastrous consequences for marine ecosystems.
- The entire production cycle, from extraction to final consumption, requires a large amount of energy and is a major contributor to greenhouse gas emissions.

In the face of these challenges, it is essential to promote more sustainable energy solutions. The development of renewable energies is a viable alternative, although their share in global energy production is still limited. These energy sources have the advantage of being inexhaustible and not generating CO₂, making them major allies in the fight against climate change. At the same time, policies to reduce energy consumption must be put in place to limit dependence on fossil fuels and promote a transition to a more ecological model. (Zahraoui, Khan, AlHamrouni Mekhilef, & Ahmed, 2021) (Matallah, Boudaoud, Matallah, & Ferhaoui, 2023).

2. Methodology :

This study adopted a descriptive and analytical approach to assess the situation of renewable energy in Algeria, with a particular focus on biomass and its future prospects. The data was collected from reliable secondary sources, including official reports from the Ministry of Energy, as well as recent academic studies, in particular scientific papers.

The data was analyzed through a comparison between the national objectives set for the period 2030–2050 and the current capacities of the sector, while linking the results to Algeria's international commitments under the Paris Climate Agreement. A prospective approach has also been mobilized in order to estimate the environmental and economic impacts of integrating biomass into the energy mix, through the evaluation of avoided emissions, investment gains and job creation opportunities, while taking into account their effect on the sustainability of policies national regetics.

3. Results and discussion

3.1 Biomass potential in Algeria:

Forests in Algeria cover about 250 million hectares and constitute an important biomass reserve estimated at nearly 37 Mtoe. However, only a limited fraction, estimated at 10%, is currently exploited. (Himri, et al., 2022).

Algeria has a considerable biomass potential thanks to its agricultural and agro-industrial resources. Straw residues, date and olive waste, esparto grass, livestock manure and mixed waste are abundant sources of renewable energy. Studies estimate that these resources could cover up to 4.37% of the energy consumption of the transport sector, and that the development of energy crops could even exceed national consumption (Bouraiou , et al., 2020). This potential, still largely untapped, represents a strategic lever for reducing the country's dependence on hydrocarbons and for contributing to its commitments in terms of energy transition (Hachemi, et al., 2024).

Several valuation mechanisms stand out in the Algerian context:

- Anaerobic digestion (anaerobic digestion): this translates organic waste (household, agricultural, livestock effluents) into biogas — mainly methane — and digestate used as a biofertilizer (Bensmail, Missoum, Elmir, Draoui, & Mehdaoui, 2024). A mature technology adapted to the local context, it combines energy production and improved environmental hygiene (Benaissa, 2020).

- **Gasification:** this process converts lignocellulosic residues (e.g. date palm waste, olive grove residues) into syngas, which can be used for the production of heat and electricity. In Algeria, studies have revealed conversion rates of up to 95%, confirming the viability and energy efficiency of this technology.(Elias, Boumeddane, Vera, & Jurado, 2021) (Djaafri, et al., 2024).

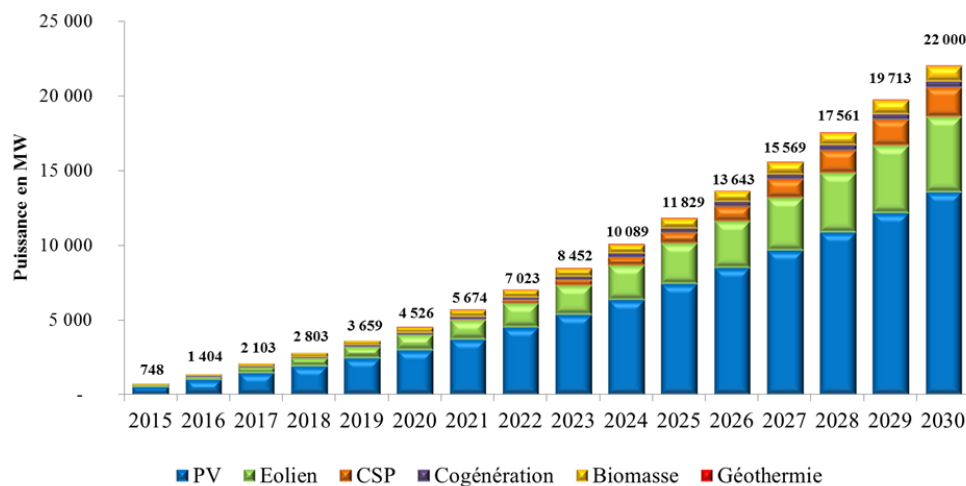
Biorefinery and agro-industrial valorization: this approach makes it possible to transform agro-industrial waste in biofuels, electricity, heat and value-added products (biofertilizers, bioplastics, green chemicals). It is fully in line with a logic of circulating economy, while contributing to the reduction of greenhouse gas emissions (Kalak, 2023).

3.2 The place of biomass in Algeria's renewable energy development program:

Algeria is fully integrating biomass into its energy transition policy, with an ambitious target of 1,000 MW of installed capacity by 2030. The exploitation of this resource through various technologies, such as combustion, mechanization or the production of biofuels, could allow electricity production of 622.4 TWh in 2050, representing an improvement of 15% compared to current projections. (Benaissa , 2020) (Bouraiou , et al., 2020).

In addition to its energy contribution, this sector would contribute significantly to the reduction of CO₂ emissions, estimated at 50.67 Mt by 2050, while generating savings estimated at \$153.69 million. Thus, the development of biomass is an essential lever to achieve the objective of 27% renewable energy in the Algerian electricity mix by 2030, based on the exploitation of the various sources available at the national level (Hachemi, et al., 2024).

Figure 1: "proportion of renewable energies"



Source: website of the Ministry of Energy <https://www.energy.gov.dz/?article=programme-de-developpement-des-energies-renouvelables> consulted on 21/05/2024

3.3 Example of a project for the successful use of biomass in Algeria:

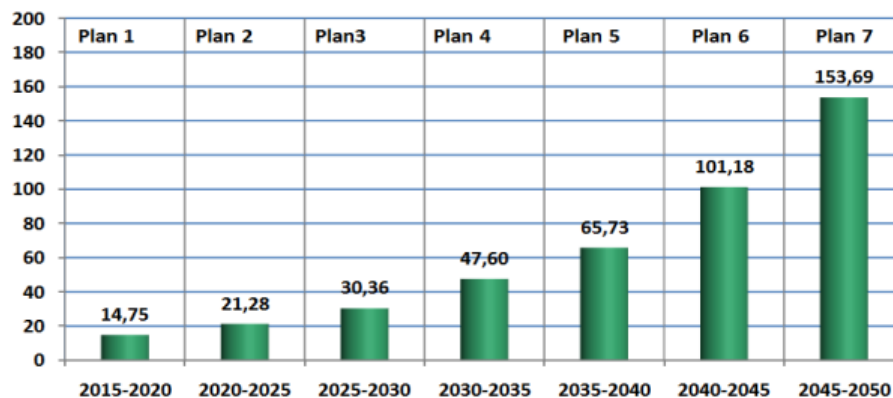
Algeria is integrating biomass into its energy strategy by exploiting sludge from wastewater treatment plants to produce biogas. A concrete example is the El Kerma treatment plant in Oran, which generated about 650 tons of dry sludge per month in 2013, transformed into a production of 216,000 Nm³ of biogas. (Bouraiou , et al., 2020)

On a national scale, with an estimated 250,000 tonnes of sludge produced each year, the country could exploit nearly 18 million m³ of biogas annually. This resource, if fully used, would generate more than 1,500 GWh of electricity, equivalent to the consumption of one million inhabitants. (Bensmail , Missoum , Elmir , Draoui, & Mehdaoui, 2024)

The adoption of biomass not only helps to diversify energy sources, but also reduces dependence on fossil fuels. According to some estimates, the energy recovery of organic waste could generate significant economic gains, rising from \$14.75 million to more than \$150 million depending on the scenarios considered.

By optimizing the exploitation of this resource, Algeria could not only strengthen its energy security, but also limit its CO₂ emissions and engage more effectively in the transition to a sustainable model. (Himri, et al., 2022).

Figure 2: "Evolution of electricity production from biomass by 2050"



Source: website of the Ministry of Energy <https://www.energy.gov.dz/?article=programme-de-developpement-des-energies-renouvelables> consulted on 21/05/2024

Figure (2) illustrates the upward trend in biomass electricity production in Algeria by 2050, reflecting both the commitments of the national program for the development of renewable energies and the government's orientation towards the integration of this source into the sustainable energy mix. In parallel with the national plan, which aims to install 2 2 000 MW of renewable energy by 2030, with a contribution from the

Of the planned capacity of about 37% of the installed capacity and 27% of the electricity production, a share has been allocated to bio mass as a complementary energy source to solar and wind energy. This growth is mainly based on the organized exploitation of a variety of local resources, including municipal and agricultural deposits (Djaafri, et al., 2024), as well as residues from the agro-food and forestry industry, thus creating opportunities for the development of waste and emission reductions. Although the share of biomass remains lower than that of other sources such as solar and wind, it is nevertheless an option strategic thanks to its relative stability in relation to intermittent sources, in addition to its positive effects on sustainable development through the creation of new local jobs (Himri, et al., 2022), (Hachemi, et al., 2024). However, the achievement of sustainable expansion at nearly 2030 remains conditioned by the overcoming of constraints related to the high costs of collection, transport and treatment, competition for land use, and the need to put in place legal incentive frameworks and infrastructure waste treatment and energy distribution (Bouraiou , et al., 2020). This requires strong national and regional coordination to ensure the economic and operational viability of this strategic orientation.

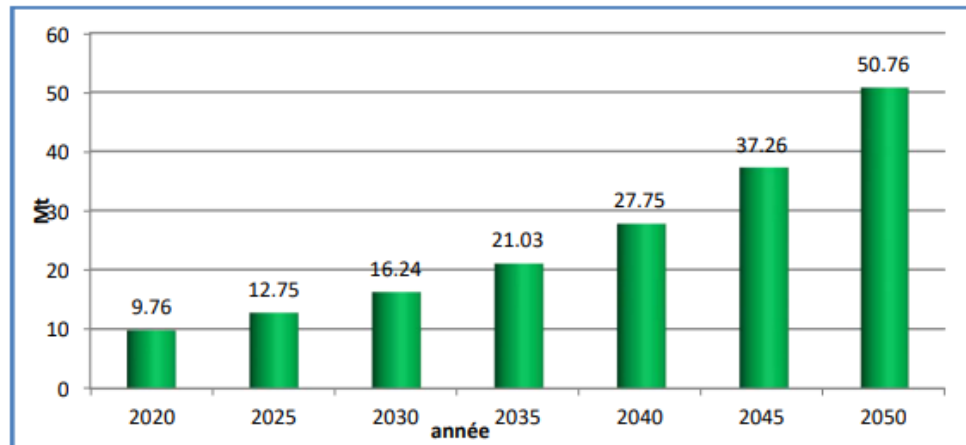
3.4 Environmental impact of biomass use:

Biomass is a renewable energy with a balanced carbon cycle: the CO₂ released during its combustion is offset by that absorbed by plants during their growth, thus limiting the greenhouse effect. (Alper, Tekin, Karagöz, & Ragauskas, 2020)

Its use also allows for better waste management by recovering agricultural, forestry and urban residues, thus reducing the volume of landfills (Ali, et al., 2024). In addition, it is an alternative to fossil fuels, reducing energy dependence and polluting emissions.(Ali, et al., 2024) (Banerjee, 2022)

In Algeria, where the electricity sector emitted 548 g of CO₂/kWh in 2011, the biomass boom could avoid nearly 50 million tonnes of emissions by 2050, contributing to a more sustainable energy model. (Bouznit , Pablo-Romero, & Sánchez-Braza, 2020).

Figure 3: "Evolution of avoided emissions in Algeria by 2050"



Source: website of the Ministry of Energy

<https://www.energy.gov.dz/?article=programme-de-developpement-des-energies-renouvelables>, Consulted on 22/05/2024

Figure (3) shows the projected evolution of avoided emissions in Algeria by 2050, a direct result of the expansion of renewable energies and the strengthening of energy efficiency within the framework of the national energy transition program. Grace by integrating clean sources such as solar, wind and biomass, Algeria will be able to reduce a significant share of greenhouse gas emissions generated by a strong dependence on fossil fuels, particularly natural gas. (Bensmail , Missoum , Elmir , Draoui, & Mehdaoui, 2024) (Hachemi, et al., 2024).

In this context, and in order to meet its commitments under the Paris Climate Agreement (2015), Algeria has committed to reducing its emissions by 7% by 2030, with the possibility of reaching 22% if international assistance is available. The energy efficiency program also aims to avoid approximately 193 million tons of CO₂ over the same (Himri, et al., 2022). According to low-carbon trajectory scenarios, the share of renewable energy in electricity production could increase from approximately 30% in 2030 to more than 94% in 2050, which would result in the avoidance of hundreds of millions of tons of emissions in the long term. Thus, the figure reflects Algeria's commitment to the objectives of the Paris Agreement and opens up broad perspectives for benefiting from green financing mechanisms and strengthening sustainable development (Matallah, Boudaoud, Matallah , & Ferhaoui, 2023).

3.5 Obstacles, challenges and prospects for biomass integration in Algeria

Despite the existence of ambitious national plans, the actual contribution of biomass to the Algerian energy mix remains almost zero. This situation is explained by the priority given to solar and wind power, the lack of economic incentives, the persistence of subsidies for fossil fuels and the absence of suitable infrastructure (HADDOUM, Bennour, & Zaid, 2024). Conversion technologies, such as anaerobic digestion or biofuels, also require significant investments as well as adaptation to local specificities (Kumar, Bhattacharya, Hasnain, Nayak, & Hasnain, 2020).

Among the main challenges identified are the current low exploitation of resources, insufficient infrastructure, the absence of incentive policies and awareness campaigns (Hachemi, et al., 2024), (Bouraiou, et al., 2020). These are compounded by constraints related to supply chain logistics, competition with food use, high conversion costs, and resource sustainability (Mignogna, Szabó, Ceci, & Avino, 2024).

Faced with these obstacles, several opportunities are emerging. Technological innovation, the integration of artificial intelligence into management and process optimization, and the development of appropriate incentive policies appear to be major levers for overcoming current constraints (Alper, Tekin, Karagöz, & Ragauskas, 2020). Furthermore, the deployment of mini-pilot stations, the integration of biomass into the national energy transition strategy, job creation in rural areas, and the reduction of CO₂ emissions represent promising avenues for the future (Benaissa, 2020). It is also necessary to integrate biomass into the circular economy model, which would optimize resource use by reducing waste, which would no longer be considered simple, valueless residues (Kalak, 2023), but would become raw materials for renewable energy production. This cycle would make it possible to exploit resources more efficiently, thus reducing dependence on fossil fuels (Djaafri, et al., 2024).

The results of this study confirm the validity of the hypotheses formulated. Indeed, it appears that biomass constitutes a renewable energy source capable of contributing to the diversification of the Algerian energy mix, complementing solar and wind power, thus strengthening energy security and reducing dependence on natural gas (HADDOUM, Bennour, & Zaid, 2024), (Hachemi, et al., 2024).

The analysis also showed that the recovery of organic waste makes it possible to significantly reduce polluting emissions while generating tangible economic benefits, notably through the creation of investment opportunities and new jobs, making it an important lever for sustainable development (Bensmail, Missoum, Elmir, Draoui, & Mehdaoui, 2024), (Himri, et al., 2022). On the other hand, the development of the biomass sector remains conditional on overcoming several institutional, technical and logistical constraints, such as the inadequacy of the legal framework, the high costs of collection and processing, as well as the lack of expertise and specialized equipment (Banerjee, 2022). Thus, the results obtained

reinforce the idea that biomass represents a strategic option that is both ecological and economic, but which requires structural reforms and accompanying measures to fully exploit its potential in Algeria (Osman, et al., 2023), (Hachemi, et al., 2024).

Conclusions:

The analysis of the potential of biomass in Algeria highlights its key role in the country's energy transition. By exploiting the available organic resources from forests, agricultural, agro-industrial and urban activities, as well as wastewater treatment plants, this renewable source could constitute a sustainable alternative to fossil fuels (Hachemi, et al., 2024), (Bensmail, Missoum, Elmir, Draoui, & Mehdaoui, 2024). Its development would not only help diversify the energy mix, but also limit greenhouse gas emissions and generate considerable economic benefits (HADDOUN, Bennour, & Zaid, 2024).

However, to fully exploit this potential, several levers must be activated. Sustainable management of forests and agricultural land is essential to avoid deforestation and preserve biodiversity (Ali, et al., 2024). The integration of energy crops into agroforestry systems and the optimization of irrigation practices will allow for more efficient and resource-friendly exploitation. In addition, the use of advanced conversion technologies, such as pyrolysis, gasification and anaerobic digestion, is essential to maximize energy efficiency and minimize environmental impact (Mahapatra, Kumar, Singh, & Sachan, 2021).

On the regulatory and economic front, financial incentives, subsidies and policy measures need to be put in place to encourage innovation and foster the emergence of a competitive sector (Bouznit, Pablo-Romero, & Sánchez-Braza, 2020), (Bouraiou, et al., 2020). The exploration of new sources of biomass, in particular agricultural and industrial residues, as well as the study of the socio-economic effects of this sector on employment and the development of rural areas, are priority areas of research (Djaafri, et al., 2024).

Finally, optimized management of biomass by-products, such as ash and non-combustible residues, will improve the overall impact of this sector on the environment and the economy (Banerjee, 2022), (Rial, 2024). If these conditions are met, biomass could play a central role in Algeria's energy transition, combining clean energy production, reducing dependence on fossil fuels and developing a more resilient and sustainable economic model (Matallah, Boudaoud, Matallah, & Ferhaoui, 2023), (Bouraiou, et al., 2020).

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