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# METHANIZATION OF FISH WASTE FOR THE PRODUCTION OF RENEWABLE ENERGY: PROSPECTS FOR TRADITIONALLY FRIED MOROCCAN FISH*

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**Abstract.** Methanization, also known as anaerobic digestion, is an innovative and environmentally friendly approach that reduces and adds value to harmful bio-organic waste. The valorisation of fish waste, especially from traditional fish farming in Morocco, can be achieved by converting this type of waste into biogas, making it a renewable energy source with no ecological impact. In this article, we discuss the theoretical basis of methanization, the different reactor technologies available, the recent advances in the field and the potential uses of the biogas produced. It highlights the benefits of anaerobic digestion of bio-organic waste and the potential applications for fish waste to improve the methanization process and maximise the environmental and energy benefits.

**Keywords:** Renewable energy; anaerobic digestion; waste; valorization; biogas; methane; environment; fish waste

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**Additional disciplines** biochemistry; ecology and environment; electricity electronic engineering; environmental engineering; energetics and thermoenergetics.

## 1. Introduction

Faced with the growing challenges of renewable energy production and the valorisation of fermentable waste, agricultural methanization is experiencing significant growth on a national scale (Liu, 2018) (Jeremiah & Kabeyi, 2022). This development is particularly relevant in an evolving agricultural context, where the diversification of resources is becoming crucial to support the main activity, a biological conversion process, relies on the use of easily biodegradable and renewable organic materials, referred to as substrates (Barbot, Al-Ghaili & Benz, 2016) (Ingabire, Ntambara & Mazimpaka, 2023). These substrates include a wide range of materials such as food waste, fish waste, animal manure, agricultural residues, as well as invasive aquatic plants like water hyacinth. The

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substrates for methanization are divided into two main categories: (i) plant residues, including crop waste, forest residues, wood scraps, and other lignocellulosic materials; and organic waste from various sources, such as industrial waste, fish waste, food scraps, municipal waste, and animal effluents. Due to their rich organic matter content, these materials represent a valuable resource for biogas production, a renewable energy vector that contributes to reducing the carbon footprint (Atelge et al., 2020). The composition of raw materials, particularly their carbohydrate, lipid, and protein content, plays a crucial role in biomethane yield during the anaerobic digestion (AD) process (Bharathiraja et al., 2018). These compounds influence the ease of organic matter degradation and, consequently, the amount of methane that can be produced (Hernandez & Edyvean, 2008). However, lignocellulosic substrates, such as plant residues, often exhibit resistance to degradation, requiring specific pretreatments to enhance their methanization potential (Hashemi et al., 2021). Besides nutritional composition, other properties of raw materials, such as total solids (TS) content, moisture content (MC), volatile solids (VS), as well as the carbon/nitrogen (C/N) ratio, can have a significant impact on the performance of the anaerobic digestion system (Bharathiraja et al., 2018). These factors influence process stability and biogas production, requiring precise characterisation of the substrates used. The dry matter concentration, sugar, protein, and lipid content determines the selection and quantity of raw materials used in the anaerobic digestion process. Substrates rich in easily degradable organic matter, such as food and agricultural waste, wastewater, human and industrial waste, or household refuse, have a high potential for biomethane production, often surpassing more degradation-resistant lignocellulosic materials. Among these resources, the use of microalgae to produce high-value-added compounds has attracted increasing interest in recent years. Their major advantage lies in their high productivity and non-competition with food crops or processing industries, making microalgae a promising option for substrate valorisation in methanization (Chandra et al., 2018). In the early 2000s, the quest for renewable energy sources rekindled researchers' interest in fish waste, a largely underutilised and often overlooked resource. Before commercialisation, more than 70% of fish was processed, generating between 20% and 80% of by-products or waste not intended for direct human consumption. These fish by-products pose a major environmental challenge, threatening the long-term sustainability of aquaculture (Boyd et al., 2020). Their sustainable management has become a global priority, necessitating innovative solutions for their valorisation (Wang et al., 2022). Using these by-products for biogas production is particularly promising (Rashama, Ijoma & Matambo, 20219). To maximise the quantity and quality of the energy produced, a thorough understanding of the physicochemical properties of the substrates is essential. A rigorous preliminary assessment of the raw materials, based on available data from the scientific literature, allows for determining their cost-effectiveness and suitability for methanization (Qi et al., 2022). In the Moroccan context, managing fish waste is particularly important given the significance of fishing and seafood processing industries to the national economy (Mahrad et al., 2020). Morocco, with its vast Atlantic and Mediterranean coastlines, is one of the largest fish producers in Africa (Dinçer, 2017). However, the sustainable management of by-products from this industry remains a challenge (Nawaz et al., 2020). Much of the fish waste generated is not valorised, contributing to increased environmental pressure (Lopes et al., 2015). The valorisation of these by-products for biogas production represents a strategic opportunity for Morocco (Rudovica et al., 2021). The development of renewable energy solutions from fish waste could reduce the fishing industry's environmental footprint and contribute to the national goal of energy transition (Scroggins et al., 2022). Fish waste methanization thus offers a dual opportunity: reducing waste while producing clean, renewable energy, aligned with Morocco's commitments to sustainable development (Eiroa et al., 2012). This article aims to explore the potential of fish waste, particularly those generated from traditional fish processing in Morocco, for biogas production. The primary objective of this study is to provide an overview of current research on fish waste methanization, focusing on their composition, methanization potential, and the technical challenges associated with their valorisation. To achieve this objective, an extensive literature review was conducted, covering scientific articles, technical reports, and relevant case studies. This review provides a comprehensive assessment of the current knowledge on fish waste methanization, while also identifying gaps and future research prospects. By focusing on the Moroccan context, this study also examines local specificities, such as the availability of fish by-products, traditional processing practices, and opportunities to integrate this waste into a national energy valorisation strategy.

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## 2. Definition and Principles of Anaerobic Digestion

Anaerobic fermentation is the biological decomposition of organic substances without oxygen. It is also known as biomethanization or anaerobic digestion (Adekunle & Okolie, 2015). This process involves a series of steps, as shown in the figure below. During these steps, complex organic compounds such as carbohydrates, proteins and lipids are converted into simpler organic molecules such as sugars, amino acids and volatile fatty acids and finally into methane ($CH_4$, 50 to 70%), carbon dioxide ($CO_2$, 20 to 50%), water and small amounts of other gases ($NH_3$, $N_2$, $H_2S$) ( Mata-Alvarez, Macé,  & Llabrés, 2000).

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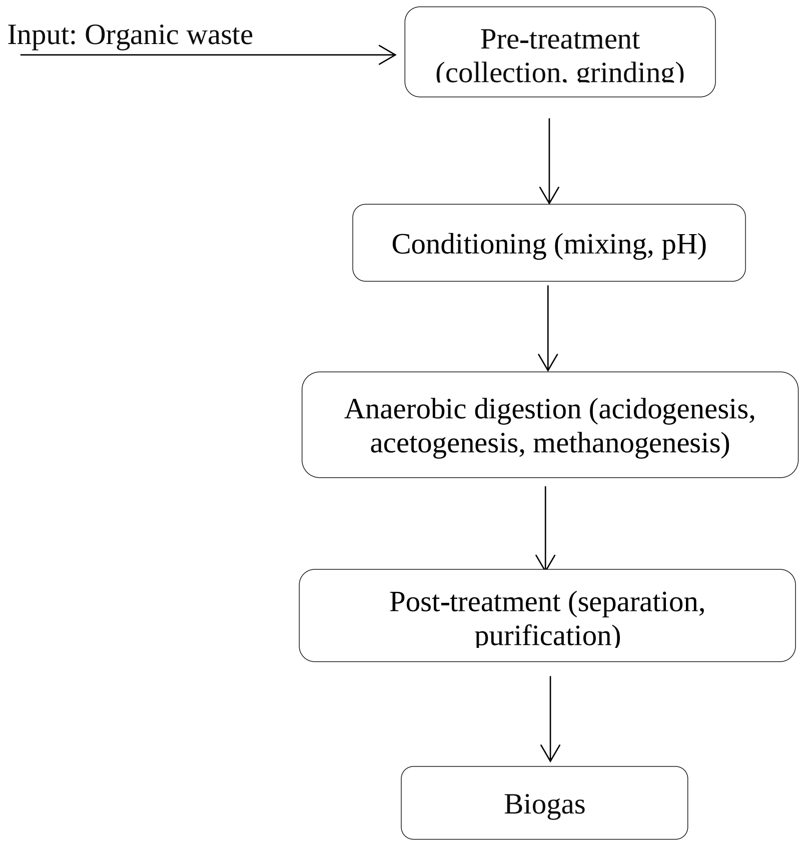


**Fig. 1.** Organic waste anaerobic digestion process

Biogas production has a positive impact on the climate in two ways: it reduces potentially harmful emissions and reduces dependence on fossil fuels, It contributes significantly to the fight against climate change and supports a renewable and flexible economy (Adekunle and Okolie, 2015).

## 3. Reactor technologies for anaerobic digestion

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Biogas production from organic materials is optimised through reactor technologies for anaerobic digestion, which primarily include batch reactors, continuous reactors and plug-flow reactors. Batch reactors are practical and cost-effective and are ideal for laboratory testing and small-scale plants as they allow the system to be fed and closed until the organic material is fully digested. Continuous reactors, such as plug flow reactors, allow for more stable and consistent biogas production by continuously feeding and removing material. In addition, fixed bed reactors and floating blanket digesters are also used. These advanced technologies enable the treatment of a broader range of substrates, including high solids waste, and improve operating parameters such as temperature, pH and hydraulic retention time (Sánchez et al., 2020).

## 4. Technological innovation in anaerobic digestion

In recent years, there have been significant technological advances in the field of anaerobic digestion that have transformed this traditional method into a highly efficient and adaptable process. High-performance reactors, such as fluidised bed and membrane reactors, improve the contact between microorganisms and organic material, increasing the efficiency of degradation and biogas production efficiency.

The integration of advanced control systems, such as sensors and sophisticated software, enables real-time monitoring and regulation of conditions in the digester. These systems facilitate the maintenance of optimal temperatures, pH levels and organic loading, which are critical for maximising methane production. In addition, computer modelling and artificial intelligence are increasingly being used to predict and improve digester performance (Ramachandran, Rustum & Adeloye, 2019). These technologies enable the simulation of different scenarios and the adjustment of operating parameters accordingly.

Furthermore, the use of co-digestion technologies allows the combination of different types of organic waste, optimising the carbon to nitrogen (C/N) ratio and improving process stability (Esposito et al., 2012). Co-digestion of agricultural, industrial and municipal waste leads to increased biogas production and more effective waste management (Paranjpe, Saxena, and Jain, 2023).

Technological progress has also been made in the purification and utilisation of biogas. New purification processes enable the production of high-quality biogas that can be used as biofuel or fed into natural gas networks. Technologies such as pressure swing adsorption (PSA) and separation membranes are increasingly being used to upgrade biogas to biomethane (Kapoor et al., 2019).

## 5. Utilisation of fish waste in anaerobic digestion

The use of fish waste in anaerobic digestion offers an extremely effective solution for the management of organic resources and the production of renewable energy (Kapoor et al., 2019). Despite their significant potential, these wastes are often underutilised. Their conversion into biogas through anaerobic digestion offers a double advantage: it reduces the environmental impact of organic waste while generating a clean energy source (Ivanovs, Spalvins & Blumberga, 2018).

Fish waste is rich in organic compounds, mainly proteins (15-25%), lipids (10-15%) and hydrocarbons (5-10%) (Hortence, Boniface, and Ezgad 2023). These properties make them excellent substrates for anaerobic digestion, which yields more biogas compared to many other types of organic waste, as shown in the examples in the table below (Cadavid-rodríguez, Vargas-muñoz, and Plácido 2019). Certain microorganisms break down these organic materials anaerobically, producing biogas rich in methane (CH4) and carbon dioxide (CO2). The recovered methane can be used for electricity and heat generation or purified for natural gas networks. Optimal conditions for the anaerobic digestion of fish waste are temperatures between 35-55°C and a pH value of 6.5 to 7.5 (Ivanovs, Spalvins & Blumberga, 2018).

**Table 1.** Comparative table of methane ($CH_4$) production from different types of organic waste

| Type of organic waste | Methane production ($m^3$ $CH_4$/kg of VS*) | References |
|---|---|---|
| Fish waste | 0,2 à 0,9 $m^3$ $CH_4$/kg VS | (Ivanovs, Spalvins & Blumberga, 2018) |
| Pig slurry | 0.2635 $m^3$ $CH_4$/kg VS | (Zhang et al., 2014) |
| Dairy waste | 0.30 à 0.40 $m^3$ $CH_4$ / kg VS | (Li, Chen, & Li, 2010) |
| Vegetable residues | 0,42 $m^3$ $CH_4$/kg VS | (Bouallagui et al., 2005) |

## 6. Potential applications of biogas

Biogas can be used in various ways. This section examines some possible applications of biogas from fish waste.

- **Electricity Generation:**

Biogas can be used to generate usable electrical energy through gas engines, heat pumps and waste treatment plants. This helps to reduce dependence on fossil fuels and cut greenhouse gas emissions.

- **Heat Production:**

Biogas can also generate heat for heating buildings, drying agricultural products, or industrial processes. Combined heat and power (CHP) plants offer the possibility of generating electricity and heat simultaneously, improving biogas utilisation.

- **Injection into Natural Gas Networks:**

After purification, biogas can be fed into natural gas systems as biomethane. Biomethane must be purified to achieve a methane content of 95% or more, making it a direct substitute for fossil natural gas. Through this application, biogas can serve as a renewable energy source for households and businesses (Collet et al., 2017).

- **Fuel for Vehicles:**

Biogas can also be used as vehicle fuel, such as Bio-CNG (Compressed Natural Gas). Buses, trucks and even cars can run on this environmentally friendly fuel, reducing $CO_2$ emissions and air pollutants (Mustafi & Agarwal, 2020).

## Conclusions and Perspectives

Anaerobic digestion of fish waste is an innovative and sustainable approach to recycling organic waste that reduces environmental impact while generating a renewable energy source. Fish waste, with its high protein and lipid content, can serve as an effective substrate for methane production. Technological advances in reactors, control systems and biogas purification methods have significantly improved the efficiency of the process. The biogas produced can be used for various applications, e.g. for electricity and heat generation, feeding into natural gas grids, and as fuel for vehicles, thus contributing to energy independence from fossil fuels and reducing greenhouse gas emissions.

To maximise these benefits, it is crucial to explore different areas of research and development and improve the efficiency of anaerobic digestion by optimising operating conditions, such as temperature, pH and carbon-nitrogen (C/N) ratio, to promote microbial activity. Dealing with methanogenesis inhibitors such as sulfides and volatile fatty acids is also crucial for increasing biogas production. Technological innovation, particularly through improved reactors and advanced monitoring systems, will play a key role in optimising digester conditions in real-time. Co-digestion of agricultural, industrial and municipal waste can further improve process stability and yield by balancing nutrients essential for methanogenesis.

Anaerobic digestion of fish waste could be critical in transitioning to a more sustainable and circular economy by driving research and incorporating innovation. This approach would support sustainable waste management and renewable energy production while addressing environmental challenges. The next step involves setting up a laboratory to test and evaluate biogas production from various types of waste and from mixtures of these wastes.

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