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METHANISATION IN AGRICULTURE: ECONOMIC, ENVIRONMENTAL, SOCIAL BENEFITS AND INTERNATIONAL EXAMPLES

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Abstract

Methanisation is the process of anaerobic digestion of organic materials, including animal manure and plant residues, resulting in the production of biogas. In agriculture, methanisation provides sustainable waste management solutions, reduces the carbon footprint and contributes to energy independence for farmers. This article explores the economic, environmental and social benefits of methanation, presenting detailed examples from Germany, France, Bulgaria, Italy and Sweden where this technology has been successfully implemented at different levels. It highlights the challenges of using methanisation, namely high initial costs and the need for regulatory support. It also looks at prospects for future development, such as the establishment of cooperative structures for centralised methanisation, the expansion of financing and opportunities for integration with other renewable energy technologies. The findings show that methanisation is a key to sustainable agricultural development and has the potential to reach new areas with appropriate policy and financial support.

Key words**:** *methanisation, agriculture, economic benefits, environmental benefits, sustainable development*

INTRODUCTION

Agriculture is one of the most important sectors for feeding the population, but it is also a source of significant environmental challenges. The large amount of organic waste generated by agricultural activities, as well as emissions of greenhouse gases such as methane, require urgent measures for sustainable management. Methanisation reduces methane emissions compared to traditional manure management [13]. In this context, methanisation is emerging as an innovative solution that not only addresses these environmental problems but also offers significant economic and social benefits.

Methanisation is defined as the process of anaerobic decomposition of organic materials in the absence of oxygen, which generates biogas composed mainly of methane (CH_4) and carbon dioxide (CO_2). This process occurs in four main steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Methanisation is an integral part of the circular economy and contributes to sustainable waste management and the energy transition to renewable sources. This renewable source of energy can be used to generate electricity, heat or fuel vehicles. The residual product of methanisation, known as digestate, is rich in nutrients and finds application as a high-quality organic fertiliser.

Methanisation not only helps to recover waste but also plays an important role in the transition to a circular economy where waste is turned into a resource. It contributes to reducing the carbon footprint of agriculture, increases the energy independence of farmers and promotes the sustainable management of natural resources.

In the face of growing global challenges such as climate change, the energy crisis and the need for sustainable development, methanisation is emerging as a key technology. Examples from Germany, France, Bulgaria and other countries show that with appropriate policies and investment, this technology can be successfully deployed and lead to significant economic and environmental benefits such as job creation and increased awareness of sustainable practices [17]. Methanisation was developed as an industrial technology in the 20th century, when the possibilities of producing energy from waste attracted attention. The first anaerobic digesters were designed for wastewater treatment, but over time the technology found application in agriculture [18].

An important role in the development of methanisation has been played by the European Union, which through directives and funding programmes such as Horizon 2020 has encouraged the deployment of this technology in Member States.Experts believe that Europe has the most developed biogas infrastructure, with countries such as Germany and France leading the way.

Methanisation is a multi-layered technology with economic, environmental and social dimensions. The main challenges identified in the literature include high initial costs and lack of technical capacity in some regions. However, with increasing investment in research and support from international programmes, methanisation has the potential to play a key role in sustainable agricultural development.

MATERIALS AND METHODS

The goal of this paper is to analyze the impact of methanisation on agriculture through a review of international practices, to explore the economic, environmental and social benefits, and to outline the challenges and opportunities for its development.

The paper will examine specific examples from countries with advanced methanisation programmes and from countries that are just introducing the technology to highlight diverse approaches and successful models.

RESULTS AND DISCUSSIONS

To identify concrete conclusions, the benefits of methanisation are divided into economic, environmental and social. The economic benefits of methanisation are: reduced energy costs; additional revenues from biogas sales; more efficient waste management. Environmental benefits of methanisation include: reduction of greenhouse gases; production of organic fertiliser (digestate); improvement of environmental quality. Social benefits of methanisation are: job creation; specific education and awareness of sustainable practices; improved quality of life.

Economic benefits of methanisation

Methanisation allows farmers to meet their energy needs by producing biogas that can be used for heating, electricity and other needs. For example, farms in Germany use biogas to heat greenhouses, reducing costs and increasing energy independence [9]. Excess biogas can be sold to the national grid or processed into biomethane and injected into the gas transmission system. In France, farmers receive subsidies and feed-in tariffs for the biogas they produce, giving them a stable additional income [6]. Methanisation allows farms to manage their waste in a sustainable way. It enables organic waste to be used as a raw material for energy production, which reduces pollution and alleviates removal costs.

Environmental benefits of methanisation

Methanisation prevents the uncontrolled release of methane and reduces the greenhouse footprint of farms. Through the controlled decomposition of organic waste, the technology reduces emissions of methane, which is up to 25 times more potent a greenhouse gas than carbon dioxide.

The residual product of methanisation, digestate, is a valuable organic fertiliser rich in nutrients that contribute to soil fertility. In Denmark, digestate is a major substitute for chemical fertilisers, which improves the ecological status of soils and water resources [4]. The establishment of centralized methanation facilities allows waste to be handled on a more controlled scale. This leads to a cleaner environment in regions with intensive agriculture, reducing soil and water pollution [8].

Social benefits of methanisation

Methanisation facilities require skilled personnel to build, maintain and manage, which contributes to rural economic development and reduces migration to cities [1]. Methanisation reduces odours and pollution from traditional organic waste management. This improves living conditions in settlements close to large farms and livestock centres [11]. By introducing methanisation facilities, awareness is raised about the benefits of sustainable waste management, which motivates farms and communities to implement environmentally friendly practices [2].

Opportunities and challenges for methanisation deployment

The establishment of methanisation cooperatives, in which several farms share biogas production facilities, is a promising option. In Denmark and the Netherlands, cooperatives allow pooling of resources and lower costs as waste from different sources is processed. By incorporating organic waste from the food industry and cities, methanisation can provide a sustainable solution for dealing with organic waste outside agriculture as well, while providing additional resources for farmers [14]. Creating hybrid energy hubs by combining methanisation with solar and wind provides additional security and sustainability for farms [15]. Expanding government and EU funding programs for methanisation projects will encourage more farmers to adopt the technology. Subsidies, interest-free loans and tax breaks can make methanisation more affordable for smaller farms [12]. Expanding research and education programs will provide farmers and students with greater knowledge about methanisation technologies and sustainable waste management. Digestate, which is a residual product of methanisation, can be used as organic fertiliser for sale or export. This will provide an additional source of income for farms and promote environmentally friendly practices. Methanisation facilities require significant investment, which can be a constraint for smaller farms. Subsidies and financial support from the government are needed for successful implementation of this technology [7]. The maintenance and management requirements of methanisation plants require specific skills and experience that are sometimes lacking in smaller areas. Training and education programs could alleviate this problem. Regulatory requirements in different countries can make methanation difficult to implement. The introduction of unified legislative frameworks would facilitate the deployment of the technology locally and internationally [10].

Examples of international practices

In Bulgaria, methanisation is at an early stage of development but has significant potential, especially in livestock areas. With the support of European programmes and national initiatives, pilot methanisation facilities are starting to be built. Methanisation is gaining popularity in the country as an effective method for organic waste management and renewable energy production. Several municipalities, including Sofia, Gabrovo and Blagoevgrad, are implementing projects in this area. The Agricultural Methanisation Unit project aims to introduce methanisation at national level. The pilot farms involved report significantly improved energy efficiency and reduced waste costs. A farm in the Plovdiv region produces 200 kW of electricity per day from animal manure, covering all its energy needs.

Sofia Municipality is taking steps to improve waste management by introducing innovative technologies. Although specific methanisation projects have not been widely publicised, the municipality is actively working on energy efficiency and sustainability programmes, which may include methanisation initiatives.

Gabrovo Municipality is among the leading municipalities in Bulgaria in terms of sustainable waste management. Since 2015, an infrastructure has been built to separate waste into dry and wet fractions. There are 138 sites with binary collection bins on the territory of the municipality, with specialised vehicles collecting waste according to a set schedule. In addition, Gabrovo has implemented a deposit system project, with vending machines for packaging waste placed in public places.

Blagoevgrad Municipality is also taking steps towards implementing methanisation technologies. Under the Operational Programme "Environment" (2014-2020) anaerobic digestion plants for biodegradable waste have been financed in Blagoevgrad, Burgas and Ruse. The municipality of Blagoevgrad is planning to start separate collection of food waste from households, and a contract with a selected operator of the installation is foreseen. Information campaigns to raise awareness among citizens are also planned [3].

These examples show the commitment of Bulgarian municipalities to sustainable waste management and the implementation of methanisation technologies. Although the challenges are significant, local efforts demonstrate the potential of methanation to improve the environmental and energy efficiency of the country.

With more than 9,000 biogas plants, Germany is the European leader in the deployment of methanisation technologies. The country offers government support and subsidies to encourage farmers to invest in methanisation facilities and contribute to the energy transition towards renewable energy. The biogas plant in Bavaria, for example, produces enough energy to power nearly 1 500 households a year using animal manure and vegetable waste.

France has also played a key role in the development of methanisation in Europe. The country is actively developing methanisation through national programmes and EU funding, such as the Fléville project, which produces 200 Nm^3/h of methane. Regions with developed agriculture, such as Bretagne, rely on methanisation for sustainable waste management and to power local grids In Bretagne, one of France's most agriculturally intensive regions, farmers use methanisation to recycle animal waste, which reduces greenhouse gas emissions and generates energy for the local community [5].

Italy is among the leading countries integrating methanisation with the national gas grid. The country provides subsidies for methanisation projects, allowing farmers to produce biogas for sale or domestic use. Italian farmers often work in cooperatives to optimize costs and increase efficiency. Biomethane production is a key component of Italy's energy transformation strategy.

In the Lombardy region, farmers produce over 300 Nm^3 of biomethane per day, which is used for domestic and industrial purposes.

Sweden uses biogas produced by methanisation to power public transport. The main objective is to reduce urban pollution and protect the environment. Biogas from rural areas is transported to cities where it is used as fuel for buses and other vehicles.

Biogas is the main fuel for public transport in Stockholm. In the city of Malmö, over 60% of public transport uses biogas produced by methanisation of agricultural waste and food residues [16] (Table 1).

Table 1. Examples of methanisation implementation by country

Country	Number of installations for biogas	Main economic benefits	Main environmental benefits
Germany	Over 9 000	Energy reduction costs	Reduction of emissions greenhouse gas emissions
France	~ 500	Additional revenue from sale	Organic fertilizer production
Bulgaria	< 50	Waste management	Carbon footprint reduction
Italy	200	High quality organic fertilizer	Water resources protection
Sweden	150	Powering public transport	Clean air and reduced pollution

Source: Own calculation on the basis of data from European Biogas Association, 2023.

Denmark is known for its cooperative approach to methanisation. Small and medium-sized farmers pool resources to build centralised digestion plants that serve several farms simultaneously. This model reduces the cost of technology implementation and maintenance. Centralized facilities process large volumes of waste, increasing efficiency and reducing the environmental footprint.

At a centralised plant in Jutland, waste from 50 farms is processed, generating energy for over 5,000 households.

The examples from these countries show a diversity of approaches to methanation. While Germany and France focus on individual and cooperative models, Denmark relies on centralised facilities, and Sweden and Italy demonstrate innovative ways to use biogas in urban environments and the national energy system. These approaches can be adapted and applied in other regions, taking into account specific conditions and needs.

Examples of methanisation outside Europe

India is among the leading countries outside Europe to use methanisation as part of its rural development and sustainable waste management strategy. The country has over 5 million small-scale biogas plants operating in rural areas. They use animal manure and vegetable waste as their main feedstocks. Biogas produced through methanisation is used for cooking and lighting, replacing traditional sources such as wood and coal. The technology reduces household air pollution, which is key to improving health, especially of women who traditionally engage in cooking. India's National Biogas Programme (NBP) has created an infrastructure for the deployment of small and medium-scale biogas facilities that serve millions of rural households.

China is a world leader in biogas production, using methanisation on a large scale for waste management in agriculture and industry. There are over 30,000 large biogas plants in the country that process waste from livestock, food and wastewater systems. The Chinese government subsidises the construction of digestion facilities and their integration into the country's energy system. Methanisation plays a key role in reducing pollution of soil and water resources, which is of great importance for a country with intensive agriculture.

The biogas plant in Shandong province produces more than 10 000 Nm³ of biogas per day using waste from pig farming. The biogas produced is used to power power plants.

The United States uses methanisation as a way to manage waste from large farms and to produce renewable energy. There are more than 2,000 biogas plants in the country, most of them focused on processing waste from dairy farms and large livestock complexes. The biogas is processed into biomethane and injected into the gas grid or used as fuel for transport. Municipal programs use organic waste from the food industry and households to produce biogas, which is then used for electricity and heating.

In California, the CalBio project uses methanisation to process waste from dairy farms and produce biomethane that powers the state's buses and trucks.

Brazil uses methanisation as part of the waste management associated with ethanol and sugar production. Biogas plants in the country treat wastewater and residues from ethanol production, which are the main pollutants. The biogas produced is used to generate electricity that powers the plants themselves and local communities. Through biogas projects, local communities gain access to cheap energy, which improves quality of life.

The biogas plant in São Paulo treats wastewater from ethanol production, producing energy to power 20,000 households.

Australia is integrating methanisation as part of efforts to reduce carbon emissions from agriculture. Methanisation plants are used to manage waste from dairy farms and livestock production. Australian farmers use digestate as an organic fertiliser to restore soil fertility. Biogas is used to generate electricity that supports rural communities.

In the Victoria region, farmers have established a cooperative digestate project that processes waste from several farms and generates electricity for over 5,000 households.

Examples from India, China, USA, Brazil and Australia show that methanisation is a universal technology that can adapt to different economic, social and environmental conditions. While in Europe methanisation often focuses on sustainable agricultural management, outside Europe the technology plays a key role in addressing challenges related to energy access, pollution and environmental protection. These examples highlight the global potential of methanisation as a solution for sustainable development.

CONCLUSIONS

Methanisation is a technology with huge potential to transform agriculture into a more sustainable and environmentally responsible sector. By deploying methanisation facilities, farms can not only reduce their dependence on conventional energy sources, but also manage their waste in a way that minimises environmental pollution. Methanisation contributes directly to reducing greenhouse gas emissions by processing waste in controlled conditions and using the biogas produced for energy purposes. This sustainability makes methanisation an important tool in the fight against climate change and the transition to a green economy. Examples from countries such as Germany, France and Bulgaria show that the deployment of methanisation technologies not only improves the energy independence of farmers but also provides additional sources of income through the sale of biogas and organic fertilisers. Establishing cooperative structures for centralised methanisation provides an opportunity to reduce costs and scale up operations. The integration of methanisation with other renewable energy sources such as solar and wind further increases the efficiency and sustainability of farms. At the same time, methanisation also offers significant social benefits for rural communities. By creating jobs and improving quality of life, the technology contributes to the social and economic development of rural regions. One of the major opportunities for methanisation relates to the education and training of new professionals, which will enable farms to implement the most efficient technologies and maintain sustainable waste management in the long term. Looking ahead, the development of financial programmes and subsidies, as well as an improved regulatory framework, will make methanisation more accessible to more farmers. This will allow even more farmers to switch to greener and more efficient practices, which in turn will help build a circular economy and a sustainable future for agriculture. Successful implementation of methanisation requires collaboration between governments, the private sector and scientific institutions to continue to drive innovation in this sector. With expanding support and adaptation of international best practices, methanisation has the potential to be one of the key technologies for sustainable development in global agriculture.

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