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ANAEROBIC DIGESTION OF AGRICULTURAL WASTE: A COMPARISON BETWEEN FRANCE AND ROMANIA

V. CLEMENT[1], L. VANBERTEN[1], N. BAGHINA[2], Alina LATO[2]
[1] UniLaSalle, Beauvais, France
[2] USV Timisoara, Romania
Corresponding author: victorien.clement@etu.unilasalle.fr, leo.vanberten@etu.unilasalle.fr

Abstract. *The management of agricultural waste, whether livestock effluents, crop residues or agri-food by-products, is a major issue for European agriculture. Its recovery should limit pollution, reduce greenhouse gas emissions and produce renewable energy. Anaerobic digestion contributes to these objectives by converting organic matter into biogas and digestate. The former can be used in cogeneration or upgraded to biomethane, while the latter can serve as a fertiliser. This article compares the development of anaerobic digestion in France and Romania, two countries whose sectors are at very different levels of maturity. At the end of 2023, France had 1,911 installations across the whole biogas sector, with a strong representation of small and medium-sized farm units (COUR DES COMPTES, 2025). In Romania, the sources consulted report about twenty biogas installations and no biomethane unit in operation in 2025, despite substantial agricultural resources (VINTILĂ, 2025; ENERGYNOMICS, 2025a; VINTILĂ & NEO, 2011; BĂDAN & DUMITRU, 2020). Based on a review of the scientific literature and institutional data, the comparison covers installations, substrates, support schemes, regulation and the agronomic use of digestate. It suggests that Romania's delay is due less to a lack of resources than to regulatory, economic and technical obstacles. The emergency ordinance of February 2026 is an important step towards a framework suited to biomethane (CMS, 2026). The French experience nevertheless shows that the development of the sector must remain attentive to the cost of support and to the risk of competition between food and energy uses of biomass (COUR DES COMPTES, 2025). Romania could thus build on certain French achievements while adapting installations to the realities of its farms. In both countries, the use of digestate remains a central issue for better linking energy production and nutrient recycling (SZWED et al., 2024; MÖLLER, 2015).*

Keywords: *Anaerobic digestion, biogas, biomethane, digestate, agricultural waste, livestock effluents, crop residues, organic fertilisation, France, Romania.*

INTRODUCTION

Agriculture produces large quantities of organic matter every year: manure, slurry, straw, crop residues and by-products from the processing of fruit, grapes or cereals. When poorly managed, these materials can contribute to water pollution and greenhouse gas emissions. Preventing pollution of agricultural origin is, in particular, one of the objectives of the Nitrates Directive (COUNCIL OF THE EUROPEAN COMMUNITIES, 1991). Conversely, appropriate management makes it possible to recover these materials as energy and fertiliser resources.

Anaerobic digestion follows this logic. In the absence of oxygen, microorganisms break down part of the organic matter and produce biogas and a residue called digestate, which retains nutrients useful to crops (MÖLLER, 2015; SZWED et al., 2024). Biogas can fuel a cogeneration unit to produce electricity and heat. After upgrading, it becomes biomethane, which can be injected into the gas grid or used as a fuel in the form of bio-NGV (bio natural gas for vehicles) (CMS, 2026). Anaerobic digestion thus links energy, environmental and agronomic issues.

The European Union encourages the development of this sector in order to reduce its dependence on gas imports and contribute to its climate objectives. According to the EUROPEAN BIOGAS ASSOCIATION, European production of biogas and biomethane reached 22 billion cubic metres in 2024 (EBA, 2025). National trajectories nevertheless remain contrasted. In France, the first injection unit was commissioned in 2011 and the fleet reached about 1,900 installations at

the end of 2023 (COUR DES COMPTES, 2025). Romania, for its part, has substantial agricultural resources, but its sector remains underdeveloped relative to the potential identified in the literature (VINTILĂ & NEO, 2011; VINTILĂ et al., 2012).

This contrast justifies comparing the two countries beyond the number of installations alone. This article presents the state of their sectors, then examines the available substrates, support policies and regulatory frameworks. It also analyses the place of digestate in fertilisation and seeks to identify the lessons the two countries can draw from each other's experience.

MATERIAL AND METHODS

This study is based on a comparative review of existing sources rather than on an experiment. It draws on three categories of documents in order to cross-check data on the development of anaerobic digestion and its agricultural implications.

Institutional sources form a first working basis. For France, they include in particular the reports of the COUR DES COMPTES. EUROSTAT data are used to compare agricultural areas, while the statistical report of the EUROPEAN BIOGAS ASSOCIATION and the Nitrates Directive provide information on the European context (COUR DES COMPTES, 2025; EUROSTAT, 2026; COUNCIL OF THE EUROPEAN COMMUNITIES, 1991; EBA, 2025).

The second category comprises scientific publications. The work of VINTILĂ and NEO (2011), VINTILĂ et al. (2012) and BĂDAN and DUMITRU (2020) documents the Romanian agricultural potential. The studies by SZWED et al. (2024), BRYCHKOVA et al. (2024), MYSZURA-DYMEK et al. (2024), ZOUI et al. (2023) and MÖLLER (2015) shed light on the agronomic effects of digestate. Finally, the work of MALET et al. (2023) and LEVAVASSEUR et al. (2023) addresses the mobilisable resources and the evolution of cropping systems in France.

Sector sources and the specialised press complete this documentation for recent developments, in particular industrial projects and regulatory changes. This information is used with caution and cross-checked where possible (ENERGYNOMICS, 2025a, 2025b; KINSTELLAR, 2025; CMS, 2026; PLEINCHAMP, 2026).

The comparison is organised around five dimensions: the number and size of installations, energy production, the substrates used or available, support schemes and the regulatory framework, and the agronomic use of digestate.

This method has several limitations. Figures may vary depending on the year, the scope adopted and the categories of installations counted. The data are therefore accompanied by their date and source. Some Romanian estimates rely on older studies and should be regarded as orders of magnitude rather than as a measure of immediately mobilisable resources (VINTILĂ & NEO, 2011; VINTILĂ et al., 2012). Similarly, an installed capacity cannot be directly compared with an annual energy output, and a theoretical potential does not necessarily correspond to a technically or economically exploitable potential.

RESULTS AND DISCUSSIONS

The comparison must first be placed in the agricultural context of the two countries. In 2023, France had 27.2 million hectares of utilised agricultural area, compared with 12.6 million for Romania. These areas ranked the two countries first and fifth in the European Union respectively (EUROSTAT, 2026). The French land base is therefore more than twice that of Romania.

This difference helps to situate the potential resources, but it is not enough to explain the gap between the two sectors. The quantities of mobilisable substrates also depend on agricultural production, livestock farming, cropping practices and collection conditions (MALET

et al., 2023; VINTILĂ & NEO, 2011). With a large agricultural area, Romania also has a favourable base. Regulatory, economic and industrial obstacles therefore play an essential role in the analysis of its delay (KINSTELLAR, 2025; ENERGYNOMICS, 2025a).

Situation of anaerobic digestion in France

According to the COUR DES COMPTES (2025), France had 1,911 installations at the end of 2023, of which 652 were injection units. Annual production reached 3 TWh of electricity, i.e. 0.7% of French electricity consumption, and 9.1 TWh of injected biomethane, i.e. 2.4% of gas consumption. These figures concern the whole biogas sector and should not be equated with the agricultural fleet alone.

An article from September 2026 mentions more than 1,781 installations, of which 823 are injection units (PLEINCHAMP, 2026). The gap with the 2023 data makes it necessary to check the counting scope before interpreting these figures as an evolution of the fleet. The same article lists 325 digesters in the Grand Est region, of which 142 are injection units (PLEINCHAMP, 2026).

The French sector is distinguished by the importance of small and medium-sized farm units, often run individually or collectively by farmers (COUR DES COMPTES, 2025). This organisation can help diversify income, make use of effluents and strengthen fertiliser autonomy (COUR DES COMPTES, 2025; LEVAVASSEUR et al., 2023). Mobilisable resources have also been the subject of mapping studies. MALET, PELLERIN and NESME (2023) thus studied the potential for biomethane production from livestock effluents, crop residues, catch crops and sewage sludge, in order to identify the most favourable territories.

The COUR DES COMPTES synthesis mentions a target of 50 TWh of biogas by 2030 in the draft multi-year energy programme submitted for consultation at the end of 2024 (COUR DES COMPTES, 2025). This ambition is nevertheless accompanied by reservations about the availability of biomass and possible conflicts between its different uses. The development of energy crops in particular must be monitored in order to preserve the balance with food production.

Financing is another point of vigilance. Biogas production certificates shift the support towards gas suppliers and, ultimately, towards consumers. According to the COUR DES COMPTES (2025), this scheme could also encourage larger installations and alter the historical organisation of the sector. The results of LEVAVASSEUR et al. (2023), for their part, emphasise the role of regulation and market conditions in limiting the current use of dedicated energy crops.

Situation of anaerobic digestion in Romania

The Romanian sector remains much smaller. A 2025 presentation reports 19 biogas installations in operation and no biomethane unit (VINTILĂ, 2025). Installed capacity was then estimated at about 23 MW according to a sector source (ENERGYNOMICS, 2025a). The country had nevertheless developed small rural digesters before 1989. CUCUI et al. (2018) mention about 5,000 domestic or community units, almost all abandoned after the political transition.

Agricultural resources do not appear to be the main obstacle. VINTILĂ and NEO (2011) estimate the theoretical potential associated with manure at more than 17 million MWh per year, of which about half would be technically exploitable, and that of crop residues at 76.7 million MWh per year. BĂDAN and DUMITRU (2020) also stress the importance of these residues. A more recent presentation puts the biomethane potential at 114 TWh for the whole country (VINTILĂ, 2025). These estimates are not necessarily based on the same assumptions and should therefore not be added together or compared without caution.

At the scale of Timiș County, VINTILĂ et al. (2012) assess the potential at more than 500 GWh per year for livestock effluents and more than 2,900 GWh per year for crop residues.

These results highlight the value of a territorial approach, while remaining estimates of potential rather than levels of production achieved.

The obstacles identified are first of all regulatory and economic. KINSTELLAR (2025) reports connection difficulties linked to legal definitions of gas networks considered unsuitable. Existing support mainly concerned electricity production rather than upgrading and biomethane injection, with no mandatory quota according to the sector sources consulted (ENERGYNOMICS, 2025b). Gas quality requirements are also an important technical issue (ENERGYNOMICS, 2025a). Finally, the dispersion of resources can complicate collection, which makes medium and large farms particularly relevant for certain projects (VINTILĂ & NEO, 2011).

Emergency Ordinance No. 9/2026, published on 27 February 2026, marks a step in the evolution of the Romanian framework. It clarifies the definitions of biogas and biomethane, regulates authorisations and licences, and organises the rights and obligations related to injection. It provides that ANRE must adapt its regulatory framework within 90 days and set biomethane quality conditions within 120 days (CMS, 2026; ROMANIAN GOVERNMENT, 2026). These deadlines correspond to the obligations laid down in the text and are not, in themselves, sufficient to establish that all implementing measures have been adopted.

This reform is part of the objective of reaching at least 5% biomethane in the volumes of gas carried by the networks by 2030 (CMS, 2026; ROMANIAN GOVERNMENT, 2026). According to EUROPEAN BIOGAS ASSOCIATION estimates reported by CMS, Romania's technical potential could reach 5.5 billion cubic metres per year by 2040 (CMS, 2026; EBA, 2025).

Several industrial announcements testify to a growing interest in the sector. Created in 2024 by BLACK SEA OIL & GAS, BSOG Energy plans biogas installations of at least 15 MW each (BLACK SEA OIL & GAS, 2024). In July 2025, it announced contracts with the dairy group DN AGRAR for a biomethane project fed in particular by the effluents of its farms (ENERGYNOMICS, 2025a). These large projects differ from the historical French farm model, but their announcement should not be confused with actual commissioning (COUR DES COMPTES, 2025).

Comparative table

The following table brings together the main available benchmarks. Years and scopes differ between sources; it is therefore a perspective on the sectors and not a strictly homogeneous statistical comparison.

Table 1

Comparison of the French and Romanian sectors. Years and sources are given in the cells.

Indicator	France	Romania
Number of installations	1,911, whole biogas sector, end of 2023 (COUR DES COMPTES, 2025)	About 19 biogas installations in operation in 2025 (VINTILĂ, 2025)
Utilised agricultural area	27.2 million hectares in 2023 (EUROSTAT, 2026)	12.6 million hectares in 2023 (EUROSTAT, 2026)
Injected biomethane	652 units at the end of 2023 (COUR DES COMPTES, 2025); 823 mentioned in 2026, scope to be checked (PLEINCHAMP, 2026)	No unit in operation according to 2025 data (VINTILĂ, 2025)
Available annual production	3 TWh of electricity and 9.1 TWh of injected biomethane in 2023 (COUR DES COMPTES, 2025)	Annual production not specified in the data used; about 23 MW of installed capacity in 2025 (ENERGYNOMICS, 2025a)
Organisation of the sector	Strong representation of small and medium-sized farm units (COUR DES COMPTES, 2025)	Limited fleet; announced industrial projects of at least 15 MW per unit (BLACK SEA OIL & GAS, 2024)

Target or potential, of a different nature	Target of 50 TWh of biogas in 2030 in the draft programme cited by the COUR DES COMPTES (2025)	Potential of 114 TWh of biomethane put forward in a 2025 estimate (VINTILĂ, 2025)
Main points of vigilance	Cost of support, biomass use conflicts and evolution of unit size (COUR DES COMPTES, 2025)	Implementation of the 2026 reform, grid connection and financing (CMS, 2026; KINSTELLAR, 2025)

French production data are expressed in TWh per year, whereas the Romanian figure of 23 MW describes an installed capacity. These two indicators do not measure the same quantity. Likewise, the French production target is not an estimate of theoretical potential, unlike the values presented for Romanian resources.

Digestate and its agronomic role

Digestate is the most direct link between anaerobic digestion and agronomy. It contains in particular nitrogen, phosphorus and potassium, and can replace part of mineral fertilisers when its characteristics and conditions of use are well controlled (SZWED et al., 2024). Its value nevertheless depends on its composition, on crop needs and on the possibility of storing, transporting and spreading it under good conditions.

In France, digestate does not automatically acquire the status of a fertilising product. Depending on the applicable regulatory route, its use may fall under waste status and a spreading plan, or under a scheme allowing it to be placed on the market. The DRAAF AUVERGNE-RHÔNE-ALPES noted in 2017 that only seven products had been approved between 2014 and 2017, illustrating the difficulties of this procedure (DRAAF AUVERGNE-RHÔNE-ALPES, 2017).

The approval of the DigAgri 1 specifications by the Order of 13 June 2017 opened a route for the use of certain agricultural digestates meeting specific conditions, notably in the context of direct bulk transfers between farmer and user (MINISTRY OF AGRICULTURE AND FOOD, 2017).

In Romania, the difficulties of use appear in the case study by CUCUI et al. (2018), devoted to a unit attached to a poultry slaughterhouse. The authors report that the digestate was disposed of there as waste in a municipal landfill. The company had started a patent procedure for a fertiliser, but its validation required laboratory analyses and three years of trials on experimental plots. A maturation platform also represented an investment estimated at between €40,000 and €70,000. This case illustrates a concrete obstacle, without allowing this situation to be generalised to the whole Romanian sector.

Use must also comply with water protection rules. The Nitrates Directive provides, in the action programmes concerned, a limit of 170 kg of nitrogen per hectare per year for inputs from livestock effluents, subject to authorised derogations (COUNCIL OF THE EUROPEAN COMMUNITIES, 1991). This limit should not be confused with a general ceiling applicable to all forms of nitrogen fertilisation.

For Romania, SIMOTA (n.d.) describes nutrient management obligations and indicates that farms with more than 100 livestock units must hold an environmental permit linked to a plan based on soil analyses. This undated source calls for verification of the currently applicable framework. In practical terms, the coexistence of large cereal farms and small family farms also raises the question of how digestate is distributed. Storage and spreading capacities may limit its use by the smallest structures (CUCUI et al., 2018; SIMOTA, n.d.). In the Banat, the combination of field crops and livestock farming could favour projects combining plant residues and effluents (VINTILĂ et al., 2012).

Recent studies show encouraging results, but these vary depending on the situation. SZWED et al. (2024) present digestate as a fertilisation alternative likely to improve yields. In an Irish grassland trial, a digestate derived from sewage sludge improved certain forage quality criteria, with an increase of up to 22.8% in crude protein content (BRYCHKOVA et al., 2024). The origin of this digestate and the conditions of the trial must be taken into account before transposing these results to agricultural digestates.

A Polish study on barley and maize emphasises that the response depends on the soil, the digestate and the dose applied, with a stronger effect for maize (MYSZURA-DYMEK et al., 2024). In Morocco, a pot trial on forage maize observed an improvement in growth and in soil organic matter content with inputs equivalent to 30 and 60 tonnes of dry matter per hectare, compared with the recommended NPK fertilisation. However, pH decreased while electrical conductivity increased. The authors also point to the risks associated with trace metals and pathogens (ZOUI et al., 2023). These experimental doses are not field spreading recommendations.

In the longer term, MÖLLER (2015) concludes that the direct effects of anaerobic digestion on soil fertility remain limited compared with the system changes that accompany it. Rotations, cover crops and the quantities of organic matter returned play a decisive role. The more stable residual organic matter can contribute to maintaining soil stocks in a way comparable to that observed with composting (MÖLLER, 2015).

In France, LEVAVASSEUR et al. (2023) observe that 67% of the farms studied did not change their land cover after the installation of a digester. The authors link this result in particular to regulation and market conditions, which limit dedicated energy crops. The COUR DES COMPTES (2025) also notes that research does not show systematic effects of anaerobic digestion on farming practices. The variability of digestates and nitrogen losses during poorly controlled spreading nevertheless remain important points of vigilance (MÖLLER, 2015; SZWED et al., 2024).

Discussion: two models, two challenges

The comparison shows that an abundance of agricultural resources is not enough for a sector to emerge. In Romania, the potential linked to effluents and residues has been documented for several years, without translating into an equivalent development of installations (VINTILĂ & NEO, 2011; VINTILĂ et al., 2012; BĂDAN & DUMITRU, 2020). Regulatory stability, connection conditions, gas quality and access to financing play a decisive role in the completion of projects (KINSTELLAR, 2025; ENERGYNOMICS, 2025a).

The difference in agricultural area provides a contextual element, but it is therefore not enough to explain the observed gap. France has a larger land base, while Romania retains significant potential relative to its current fleet (EUROSTAT, 2026; MALET et al., 2023; VINTILĂ & NEO, 2011). The February 2026 ordinance addresses part of the Romanian legal obstacles; its effects will nevertheless have to be assessed on the basis of the projects actually connected and commissioned (CMS, 2026).

The French experience shows the value of lasting support schemes, but also the need to adjust them. The cost of subsidies, the distribution of value and conflicts over biomass use become more sensitive as production increases (COUR DES COMPTES, 2025). Regulation and economic conditions have so far limited the use of dedicated energy crops, without removing questions about the future evolution of crop rotations (LEVAVASSEUR et al., 2023). For a sector centred on agricultural waste management, the priority given to effluents and residues therefore appears consistent with the initial objective of recovery (VINTILĂ & NEO, 2011; SZWED et al., 2024).

Two orientations emerge for Romania. Large industrial units, illustrated by the projects of BSOG Energy and DN AGRAR, can mobilise large volumes and substantial investment capacity (BLACK SEA OIL & GAS, 2024; ENERGYNOMICS, 2025a). Smaller farm units, individual or collective, could fit more closely into the local organisation of farms, along the lines of the historical French model (COUR DES COMPTES, 2025). These models are not necessarily mutually exclusive. Their relevance must be assessed according to substrate availability, transport distances, energy outlets and the possibilities for using digestate. The actual distribution of revenue will depend, in both cases, on governance and on contracts between the actors.

CONCLUSIONS

Anaerobic digestion can contribute to recovering agricultural organic matter while producing energy and recycling nutrients. The comparison between France and Romania nevertheless shows that these benefits depend on technical, economic and regulatory conditions that are not met in the same way in the two countries.

France has developed a substantial sector, with nearly 1,900 installations at the end of 2023 across the whole biogas sector, with a major place occupied by small and medium-sized farm units. Its experience shows the effectiveness of support schemes in bringing a sector into being, but also the need to better control their cost and to preserve the balance between energy production and food uses of biomass (COUR DES COMPTES, 2025; LEVAVASSEUR et al., 2023).

Romania has considerable resources relative to its current production. In 2025, the sources consulted reported about twenty biogas installations and no biomethane unit in operation (VINTILĂ, 2025; ENERGYNOMICS, 2025a). The absence of a framework sufficiently adapted to the injection and marketing of biomethane has held back investment. Emergency Ordinance No. 9/2026 aims to reduce this uncertainty, but the adoption of a text does not in itself guarantee that projects will be completed (CMS, 2026; ROMANIAN GOVERNMENT, 2026).

Digestate plays an essential role in the agronomic value of anaerobic digestion. It can reduce part of the need for mineral fertilisers, provided that its composition is known and that inputs are adapted to crops and soils. Its use also requires sufficient storage and spreading capacities, as well as compliance with health and environmental requirements (SZWED et al., 2024; CUCUI et al., 2018; COUNCIL OF THE EUROPEAN COMMUNITIES, 1991).

Romania could therefore draw on the French experience to build stable support, develop installations adapted to farms and organise the use of digestate. The aim is not to replicate a model identically, but to retain its achievements while anticipating the risks linked to dedicated crops, transport costs and the distribution of value between actors (COUR DES COMPTES, 2025; LEVAVASSEUR et al., 2023).

This study is limited by the heterogeneity of sources, years and comparison scopes. The potentials announced do not all correspond to resources that can actually be mobilised under the same conditions (VINTILĂ & NEO, 2011; VINTILĂ et al., 2012; MALET et al., 2023). Further work could compare farms in operation, measure the effects of digestate under the conditions of the Banat and of France, and assess the profitability of units of different sizes. It would make it possible to better link potential estimates to the concrete constraints of farms (VINTILĂ et al., 2012; ZOUI et al., 2023).

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