



KAPITEL 6 / CHAPTER 6⁶

ORGANIZING AGRICULTURAL BIOGAS IN EUROPE: MODELS AND SOCIAL CHALLENGES

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Introduction

Anaerobic digestion is the controlled breakdown of organic matter without oxygen, carrying significant economic, environmental, social, and technological implications. This review explores the organizational and social dimensions of developing agricultural biogas supply chains in Europe, with a focus on agricultural anaerobic digestion a distinct system alongside other biogas pathways such as sewage sludge, municipal waste, and industrial by-products. These systems often operate independently, with limited coordination at national or EU levels.

The growing interest in biogas, especially biomethane, highlights its increasing role in the energy transition. Agricultural anaerobic digestion relying on farm-based digesters fueled by crop residues or dedicated energy crops like maize and beet presents both ecological and economic value. The resulting biogas contributes to renewable energy goals, while digestate, a by-product, serves as a sustainable fertilizer alternative. This review, grounded in social science perspectives, examines how sectors evolve around these technologies considering the actors, institutional frameworks, and enabling conditions. Agricultural biogas sits at the intersection of energy and ecological transitions, connecting local farming practices with broader energy markets. It influences farmer livelihoods, market structures, and public policy. No longer a niche, anaerobic digestion is now a key player in Europe's renewable energy landscape and is projected to grow further as the continent leads in biogas electricity production.

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6.1. Literature research

Urban green spaces (UGSs) play a vital role in mitigating the urban heat island (UHI) effect through several key biophysical processes, including shading, evapotranspiration, albedo modification, and improved ventilation. While the spatial configuration and structural diversity of urban vegetation have long been acknowledged, recent research has increasingly focused on quantifying their cooling potential and associated environmental co-benefits across diverse urban contexts.

This review draws on two corpora of publications—one in French and one in English—assembled and analyzed using a unified protocol. The aim was to identify key themes and debates around agricultural biogas from a social science perspective. The process followed three main methodological steps.

First, the corpora were constructed between February 2024 and February 2025 using the BibCNRS SHS portal, which provides access to a wide range of national and international databases. Unlike other reviews that rely on just one or two sources, this study consulted 16 databases—six in French (Cairn, Érudit, Gallica, HAL, OpenEdition, and Persée) and ten in English (JSTOR, Sage, ScienceDirect, SocIndex, SpringerLink, Web of Science, Wiley, EBSCO, EDP Sciences, and Nature) [1].

Searches were conducted using keywords such as “méthanisation agricole,” “agricultural biogas,” and “agricultural anaerobic digestion.” Two filters were immediately applied: only peer-reviewed journal articles were considered (excluding books, theses, and reports), and only full-text articles available through BibCNRS SHS were included to allow for qualitative analysis. When databases returned fewer than 100 results, all were retained; otherwise, only the top 100 ranked by relevance were reviewed. To improve specificity, additional filters were used for broader databases: keywords had to appear in both the abstract and full text (in JSTOR and Pestalozzi [6]), and articles had to be categorized under humanities or social sciences (in ScienceDirect, SpringerLink, EBSCO, EDP Sciences, Web of Science, and Wiley). This approach ensured a diverse and methodologically robust literature base for synthesizing social and organizational perspectives on agricultural anaerobic digestion.



Each article identified was screened in successive steps. First, we verified that it was published in a scientific journal, then reviewed its abstract to assess relevance based on (i) the research topic and (ii) disciplinary orientation.

Following this initial screening, three databases—EBSCO, EDP Sciences, and *Nature*—were excluded due to a lack of relevant results, leaving 13 databases for in-depth analysis. Duplicate entries (21 articles appearing in multiple databases) were removed, resulting in a total of 114 unique articles: 64 in English and 50 in French.

A full-text review was then conducted for all 114 articles [2]. The final selection was refined based on the following criteria:

- **Eighteen articles** focusing on non-European or cross-continental comparisons were excluded to maintain a European scope;
- **Nine articles** were removed for lacking a clear social science focus;
- **Six articles** addressed anaerobic digestion only marginally;
- **Seven articles** resembled practitioner reports rather than academic studies.

This resulted in a curated, contextually and thematically relevant body of literature for the review.

6.2. Urban green spaces variations

Agricultural anaerobic digestion is shaped by two defining characteristics. First, farmers were the early adopters of biogas in Europe, but their roles have evolved as the sector has shifted from a purely agricultural model to one increasingly influenced by industrial and mixed business approaches. Second, the growth of biogas plants is closely tied to regulatory environments and public subsidies, highlighting the sector's reliance on national support schemes. Development varies across Europe, reflecting the extent to which policies favor biogas, and raising questions about a broader paradigm shift. Farmers played a foundational role in countries like Germany, a biogas pioneer since the 1990s. In the Czech Republic, biogas gained traction as a way to repurpose underused farmland following major agricultural reforms. In France, biogas has developed within the context of a transforming agricultural sector marked by



intensification and specialization. Regional case studies show variation: in Brittany, biogas is primarily used to manage livestock waste under environmental regulations; in Grand Est, especially the Aube area, it serves as a strategy for diversifying crop-based revenue streams. These examples underscore how local agricultural systems shape biogas adoption.

Unlike wind, solar, or hydro power, biogas is deeply embedded in rural social and agricultural structures. It relies on organic inputs—like manure and crop residues—that are already part of existing farming practices. As such, biogas production is not only a technical process but also a socially organized system, centered on farmers operating at the intersection of environmental responsibility and rural development.

The growing influence of the energy transition discourse has reshaped biogas production, shifting its focus from farmers and local networks to more complex, multi-actor systems. This shift is especially evident in upstream biomass supply, where farmers increasingly interact with industrial and financial stakeholders. As early as 2006, Germany—Europe's forerunner in anaerobic digestion—showed signs of this evolution, with financial investors playing a notable role in large-scale plants. A comparison between Germany and the Czech Republic illustrates this divergence: while farmers led biogas development in both, the sector in Germany evolved within both the agricultural and electricity regimes, whereas in the Czech Republic it remained rooted primarily in agriculture [3].

In other countries, the trend is similar. Finland's biogas debate is driven by energy-sector priorities, Poland and Denmark have promoted large centralized plants, and multi-stakeholder collaborations are expanding. Farms now supply biomass for industrial biofuel production, while the agri-food sector feeds anaerobic digesters. Within the circular economy narrative, biomethane is increasingly valued for its role in waste recovery and bioenergy production, particularly within agro-industrial systems. A multi-country study across 18 European nations confirms this, highlighting biomass cultivation as a key component of the emerging bioeconomy.

In France, two phases stand out: during the 2000s, livestock farmers adopted biogas to gain energy autonomy and manage manure locally. Post-2015, the sector



became more structured, with new intermediaries and growing financialization—especially due to the expansion of biomethane injection into gas grids. While this growth opens new opportunities, it also raises concerns: farmers risk being reduced to raw material suppliers for capital-intensive operations, potentially undermining their original central role in biogas production. The rise of biogas as part of the energy transition has pushed farmers to evolve into so-called “energy farmers” or *énergiculteurs*—entrepreneurial actors who go beyond input supply to take on roles in project management, coordination, and negotiation. These farmers operate across agricultural and industrial domains, requiring skills in finance, regulation, and local engagement. However, in some contexts, such as Germany, there is growing pressure to shift plant operation away from farmers and toward specialized industrial actors, especially with the rise of technologies like power-to-gas.

This evolution has exposed structural divides within the farming community. Larger, capital-rich farms are better positioned to benefit, while smaller farms may be sidelined. Biogas development thus risks reinforcing inequalities and reshaping farming identities. Adoption depends not only on technical or financial capacity but also on farmers’ values and visions of their profession. Some embrace biogas as an opportunity for innovation and income diversification, while others see it as a threat to traditional, place-based agricultural identities and food sovereignty.

The biogas sector is far from uniform. Instead, it reflects a mosaic of socio-technical configurations, what Oosterveer and Spaargaren call “modernized mixtures”—systems that vary in scale, ownership, organization, and governance. Key variables include input and distribution networks, revenue sharing, accessibility, and integration levels between producers and consumers. While traditional classifications of biogas plants focus on size, input type, or valorization pathways, emerging research emphasizes the social and organizational diversity behind these projects. Collective models, for example, raise questions about governance, coordination costs, and power dynamics—where some farmers may initially participate, then branch out with individual projects. These patterns reveal broader shifts in agricultural power structures and market integration.



Studies, such as Garambois et al. [4], highlight the growing heterogeneity in farmers' trajectories—ranging from autonomy in cooperatives to deeper integration in financialized systems. A case study from Tuscany identifies three main biogas models:

1. **Multifunctional farms** maintaining food/feed production while producing biogas for autonomy,
2. **Entrepreneurial farms** aiming to scale up and increase profitability, and
3. **Energy companies** managing diverse renewable assets—now the dominant model.

Despite the influence of upstream industrial actors, peer-to-peer learning—such as site visits to nearby plants—remains a key factor in farmers' decision-making. This underlines the territorial anchoring of biogas projects in Europe, which resist standardization and reflect the socio-economic and cultural diversity of local agricultural contexts.

Recent developments show that biogas production is now following multiple trajectories shaped by diverse technologies, governance structures, and actor networks. Based on four criteria—knowledge base, technology, actor networks, and institutional context—Garambois et al. identify five distinct business models for agricultural biogas. The first three are outlined below:

1. **Internalization and Symbiosis Model.** This model emphasizes self-sufficiency, where farmers use on-farm manure as input, minimize external involvement, and internalize maintenance. Knowledge is gained through hands-on experience. Common among early adopters (pre-2015), these units often benefited from public subsidies and favor cogeneration heating systems.
2. **Small Farmers Group Model.** Based on collaboration between livestock and grain farmers, this model supports joint agricultural projects and shared investment. Operations are often overseen by specialized personnel, with many inputs purchased externally (e.g., from cooperatives). Knowledge exchange is central—livestock farmers share operational expertise, while grain farmers contribute digestate management know-how.
3. **Grain Farmer Biogas Injection Model.** Typically run by individual or small



groups of grain-focused farmers, this model revolves around biomethane injection into gas networks. It reflects a more specialized, technically advanced approach, often involving external financing and service providers.

Biogas production today is increasingly shaped by multi-actor networks, where local coordination and shared identity are key. A study of a French biogas cluster highlights how “organized proximity”—regular interactions and cooperation among geographically close actors—supports both project emergence and long-term stability. Effective stakeholder coordination is crucial for successful biogas development [7]. The creation of national bodies like the French Association of Biogas Producing Farmers reflects a shift from purely technical roles to political engagement. Farmers now need to navigate policy landscapes, leveraging information, networks, and symbolic legitimacy to influence regulations. These dynamics reveal that project viability hinges not only on technology or funding but also on the ability to mobilize institutional support and maintain territorial anchoring.

Adopting a multi-scale perspective, successful biogas projects often combine local roots with broader structural support. For instance, Swedish case studies emphasize both economic conditions—such as long-term investment planning and stable pricing—and organizational factors, including strong public-private cooperation, entrepreneurial experience, and the involvement of "influential enthusiasts" who champion projects and connect with policymakers and investors.

These often form mixed business models, where modest returns are accepted in exchange for long-term viability and community value. Across Europe, however, the common thread is the critical role of public regulation and economic incentives. As early as 1984, it was clear that biogas could not compete with fossil fuels without state support—a conclusion still echoed today.

Yet, these support systems can also create institutional barriers. Bureaucratic complexity, inconsistent subsidy criteria, and shifting policy priorities (e.g., reduced feed-in tariffs) often delay or block projects—particularly disadvantaging smaller farmers. Studies from France highlight how poorly tailored funding mechanisms disproportionately benefit industrial actors who are better equipped to navigate



administrative procedures. This challenge persists across countries. In Switzerland, Germany, and Austria, legal frameworks directly influence the sector's structure and technical performance. In Finland and Italy, heavy dependence on subsidies and the central role of government policy are repeatedly cited by sector stakeholders. The success or stagnation of biogas expansion across Europe remains tightly linked to the quality and accessibility of public support frameworks.

Differences in public support and regulatory frameworks have led to significant disparities in the development of biogas across Europe. A comparative study by Béline et al. highlights contrasting national trajectories: while countries like Germany, Denmark, and Italy integrated biogas early into their energy strategies, others, such as France, followed a slower and more complex path.

Germany is widely seen as a model due to its structured support, notably the Renewable Energy Sources Act (EEG) of 2000, which guaranteed fixed feed-in tariffs for 20 years. This triggered rapid expansion, with nearly 7,100 installations by 2011, supplying 3.1% of national electricity. However, policy adjustments were later introduced to curb negative effects like maize monoculture, promoting crop diversification instead. Simulations show that a 25% cut in feed-in tariffs could reduce new plant capacity by 22% in regions like Bavaria and North Rhine-Westphalia, underscoring the sector's sensitivity to policy changes. In Italy, generous feed-in tariffs (up to €0.28/kWh) led to a biogas boom between 2009 and 2011, particularly in agriculture. But this support also encouraged large-scale plants and an overreliance on energy crops, raising concerns over land use and sustainability [8]. A 2012 policy reform responded by shifting support to smaller plants (<500 kW) prioritizing livestock manure—mirroring adjustments in other countries seeking to align biogas with environmental goals.

In Finland, biogas is framed both as an economic opportunity and a risky investment. Despite potential benefits like energy savings and peatland reuse, high capital costs and modest returns make subsidies essential. Many farmers, especially in dairy, remain hesitant without stronger public backing. Across the board, research confirms that biogas viability is closely tied to subsidies and feed-in tariffs, raising



concerns about long-term sustainability. Policy volatility, subsidy reforms, and shifting energy priorities generate uncertainty for farmers and investors.

For instance, in Poland [9], biogas progress has stalled due to restrictive and unstable regulations. Legal ambiguities—such as unclear rules on digestate—and the lack of financial incentives have deterred development, despite high agricultural emissions and reliance on fossil fuels. A similar pattern is seen in Romania, where biogas remains marginal despite vast biomass potential and agriculture's economic importance. As of 2020, biogas accounted for just 0.002% of installed renewable capacity. Weak legal frameworks and absent support mechanisms have made financial institutions reluctant to invest. These examples underscore a central lesson: while technical potential for biogas exists across Europe, its realization depends on stable, well-designed public policies and a supportive regulatory environment.

Looking ahead, two potential pathways emerge for the biogas sector in response to diminishing public support—both shaped by the assumption that subsidies will decline over time. The first path envisions a shift toward industrial-scale, interconnected biogas systems, driven by policy harmonization across Europe. This model features the expansion of cogeneration and biomethane injection into national and transnational gas grids. However, as Magnani [5] suggests, this scaling-up may result in a "governance paradox": while centralized systems require more oversight due to their environmental impact and growing involvement of major industrial players, the shift to supranational coordination may limit the capacity for direct, localized regulation. The second path focuses on localized, agriculture-centered models. Here, farmers and community stakeholders acknowledge their reliance on national regulations and subsidy schemes, but also begin to adapt to post-subsidy realities. This involves building more autonomous systems that prioritize:

- Cooperation among local actors in both governance and project implementation;
- The use of locally available organic waste and agricultural residues as primary inputs.

The case of the Czech Republic illustrates this transition: once subsidies were removed, the sector reverted to a small-scale, niche role within agriculture. This



highlights a broader challenge—how to maintain biogas viability without financial incentives, and how local resilience might offer an alternative to large-scale, industrialized models.

Conclusion

Our social science review highlights key themes and ongoing debates across various national and regional contexts. Despite differences in local priorities and responses over time, a distinct European model of farm-based anaerobic digestion emerges. This model is marked by:

- a stronger emphasis on energy transition goals over agricultural and ecological concerns;
- a central tension between the role of farmers and localized practices versus the industrialization and globalization of the supply chain.

Against this backdrop, a growing field of research is focused on envisioning the sector's future and exploring possible development paths. These prospective studies, especially in France, often adopt a techno-economic perspective, proposing technological solutions and “best practices” to ensure sustainability. For example, Cadiou et al. [10] compare 16 biogas scenarios for 2030–2050, most of which stress economic benefits such as additional income and reduced farm operating costs.

Soil carbon sequestration is another recurring topic—12 studies consider it, with 7 linking it to energy crops, root systems, and digestate application. Regarding the nitrogen cycle, 13 studies evaluate impacts, with 8 suggesting reduced mineral fertilizer use thanks to digestate, though views differ: some warn of increased N₂O emissions depending on crop fertilization.

Overall, most studies support anaerobic digestion, but their focus reflects their institutional origins. Studies with energy-sector affiliations tend to prioritize carbon reduction, often neglecting broader agricultural or social dimensions. In contrast, the most comprehensive assessments of agri-environmental impacts come from NGOs and non-profit organizations focused on sustainable agriculture.



Although the agricultural energy transition is often framed as an environmentally and economically beneficial shift, Garambois et al. highlight its overlooked paradoxes and limitations. Anaerobic digestion exemplifies this tension: while promoted as a low-carbon solution, its broader impacts on farming practices and territorial organization are insufficiently explored. Existing research tends to favor a techno-economic perspective shaped by national policy and industrial agendas, often neglecting implications for the sustainability of agricultural and food systems. Garambois et al. advocate for a more localized and systemic view, treating anaerobic digestion not just as an energy technology, but as a means to enhance agricultural and environmental resilience—especially concerning soil health, biodiversity, and water management. This broader view aligns with calls to reassess societal transitions not only through technical lenses, but also through their political, social, and ecological dimensions. Anaerobic digestion should be recognized as a “boundary-crossing innovation”, sitting at the intersection of energy, waste, agriculture, transport, and fuel systems. A holistic approach is thus essential, integrating technical, economic, social, and environmental concerns.

In this regard, Lyytimäki et al. offer a nuanced framework for the Finnish context, outlining ten key tensions shaping biogas development: producer vs. consumer, urban vs. rural, local vs. national, domestic vs. foreign, centralized vs. distributed, food vs. energy, environment vs. economy, tradition vs. innovation, long-term vs. short-term, and private vs. public. These tensions influence not only the direction of the energy agenda but also the scope for action, protest, or inertia—especially as public perceptions and media narratives play a significant role.

Adding complexity, multiple, misaligned timelines shape the evolution of anaerobic digestion projects:

- The long-term project cycle from planning to operation,
- The short-term political cycle, influenced by elections,
- And the non-linear social timeline, shaped by local actors, audiences, and settings.

Austria illustrates the effect of these competing timelines and perspectives, where



three narratives coexist:

- “Greening of gas”, promoting large-scale biomethane production as key to the energy transition;
- “Champagne of the energy transition”, expressing skepticism over costs, scalability, and land use competition with food crops;
- “Energy farmer 2.0”, focusing on local benefits like job creation and rural development.

These divergent narratives reflect the fluid and contested socio-technical foundations underpinning anaerobic digestion. As such, the field demands further comparative, multiscale, and interdisciplinary research, rooted in the complexities of the social world.



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