Université de Strasbourg

Laboratoire Sociétés, acteurs, gouvernement en Europe | SAGE | UMR 7363 de l'Université de Strasbourg et du cnrs

Is There a "European Model" for Agricultural Anaerobic Digestion? A Review Based on the Social Science Literature

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1. Our Scope

- We focus on **agricultural anaerobic digestion** (AD).
- At the intersection of 2 configurations —agricultural residue & digestion methods— we examine the **processes through which sectors develop and organize**, looking both at actors and at the conditions of this development, drawing on social science approaches.
- AD has now gained **an important place in the energy mix in Europe**, the world's leading biogas electricity producer (Source: Brémond *et al.*, 2021).

Indicator	Europe	Global
Share of global biogas production (2017)	54% of global production (364 TWh)	Asia: 31%, Americas: 14%
Number of biogas plants (2018)	18,202 plants	China: ≈6,000 plants (mostly small-scale); USA: ≈2,200 plants
Installed capacity for electricity generation from biogas (2018)	12.6 GW, representing 68% of global biogas electricity capacity	Global capacity: 18.1 GW China: 0.6 GW (≈3%) USA: 2.4 GW (≈13%)
Biogas energy use (2018)	88.5% of European biogas is used for electricity and heat generation via combined heat and power (CHP) systems	USA: 40% for electricity, 60% for other uses (heat generation and biomethane production)
Ongoing market trends	Shift towards agricultural waste utilization and biomethane production	USA: Market dominated by municipal solid waste valorization China: Rapid development of both household-scale (cooking, lighting) and industrial biogas plants
Projected biomethane potential for 2050	64.2 billion m^3/year (≈4.8% of UE-28 energy consumption)	Global potential estimate: ≈200 billion m^3/year
Share of agricultural feedstocks in biogas production	Over 70% (crops, livestock manure, agricultural residues)	USA: 25-30% // China: 40% (remainder from biowaste and wastewater treatment plants)

2. Goal of the Study

- We investigate the dynamics and implications of the deployment of a sector around **a possible "European model" for agricultural AD.**

- We aim **to fill a gap in terms of literature review**, as existing reviews have tended to:
  - adopt a global approach,
  - focus on barriers to adoption and the socio-cultural acceptability of biogas.

- Our research was supported by *the French National Centre for Scientific Research* (CNRS) under the interdisciplinary programs supported by the *Mission for Transversal and Interdisciplinary Initiatives* (MITI), as part of the research project 80|Prime **METHATIP** "Socio-Environmental Implications of Agricultural Anaerobic Digestion: Energy Transition, Professional Identities and 'New Ruralities'" (2022–2025).

- For this purpose, we built parallel corpora of French- and English-language studies following **a systematic protocol.**

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3. Materials and Methods

3.1. Literature Search

- The 1st step consisted in **assembling the two French- and English-language corpora**. Between February 23 and March 6, 2024, we used the BibCNRS SHS portal (https://bib.cnrs.fr/).
- For the purposes of **a systematic literature review**, we chose not to limit ourselves to a few selected bases, or a specific approach, as has been generally done on the subject:
  - For instance, **Alan & Köker** (2023) have examined the implications of the valorization of agricultural waste in a circular economy using the *Web of Science* database.
  - **Nevzorova & Kutcherov** (2019) used the *Scopus* database to consider barriers to biogas adoption in developed and developing economies in 32 countries.
  - **Mancini & Raggi** (2022) reviewed the socio-cultural factors informing the acceptability of biogas projects on the global level, drawing on two databases: *Scopus* and *Web of Science* and focusing on Life Cycle Analyses.
  - **Brémond *et al.*** (2021) devised their scenario for the development of the European biogas sector for 2020–2030 and beyond by focusing on 5 European countries, based on a search on 4 databases: *Google*, *Web of Science*, *Google Scholar* and *ScienceDirect*.

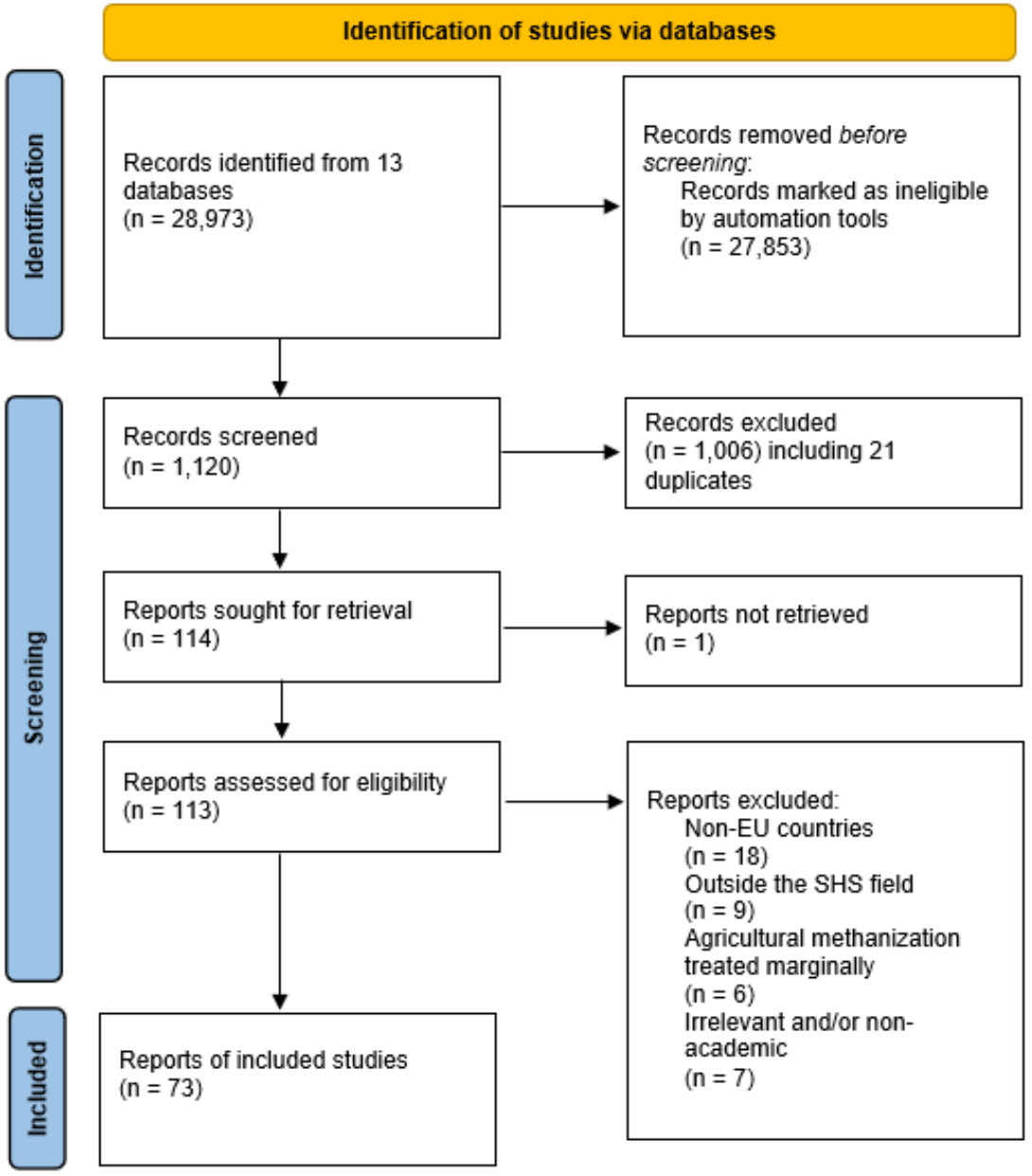
3. Materials and Methods

- We searched **16 databases:**
  - **6 in French**: *Cairn, Érudit, Gallica, HAL, OpenEdition, Persée.*
  - **10 in English**: *Jstor, Sage, ScienceDirect, SocIndex, SpringerLink, Web of Science, Wiley, Ebsco, Edp Science, Nature*.
- We performed **an advanced keyword search** using terms associated with "méthanisation agricole" in French-language bases, and "agricultural biogas" and "agricultural anaerobic digestion" in the English-language bases, using '*full text*' or '*all-field*' queries depending on the terms.
- We immediately introduced **3 restrictions** by searching specifically for:
  1. **Articles**;
  2. **Available in full-text version** through BibCNRS SHS;
  3. **Written in French or English**.
- Results were **shown sorted by relevance**—we selected all hits for bases offering under 100 references, and otherwise the first 100.
- This selection process allowed us to **automatically exclude 27,905 results**.

3. Materials and Methods

3.2. Literature Assessment

- We applied **additional selection modalities** for the 1,238 articles resulting from the first search.
- The final selection phase consisted in **reading 113 articles** in full. We got **a final tally of 73 articles** (38 in English and 35 in French).
- All of these steps are summarized on a **PRISMA** (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) **flow chart**.



PRISMA flow chart of the literature study (© Philippe Hamman and Aude Dziebowski. Source: PRISMA 2020 flow diagram. Page MJ, *et al*. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. This work is licensed under CC BY 4.0.).

3. Materials and Methods

3.3. Literature Synthesis

In the 3rd phase, the papers were categorized **using a matrix** to identify the main results and debates and to compare the 2 language corpora.

6 main themes appear, connecting the papers' findings:

1) The initial **positions of farmers** and the **industrial evolutions**.
2) The **typology of business models** of farms and biogas plants.
3) **Contextual and regulatory tools & barriers**, with a focus on the role of public subsidies and their evolutions.
4) The **economic viability** of biogas and the problem of its limited returns for farmers.
5) Its contributions (or absence of contribution) to **local rural development**.
6) **Scenarios** and futures studies.

→ **I'll try to sum up these interconnected issues.**

3.3.1. Identification of Key Contributions from the French-Language Social Sciences Literature on AAD

References	Empirical paper / Review	Farmer, farming and evolutions	Typologies and business models	Regulatory frames and public support	Economic viability of methanization	Local rural development	Scenarios and future studies	Considered areas/ EU countries
French-language corpus								
Amand *et al.*/2015	E	X	X		X	X		France
Anzalone, Mazaud/2021	E	X	X			X		France
Attarça, Lassalle de Salins/2013	E	X	X	X				France
Béline *et al.*/2012	E			X				France, Germany, Denmark
Béline *et al.*/2013	E			X				Germany, Denmark, France, Italy
Berthe, Grouiez, Dupuy/2018	E	X			X			France
Berthe *et al.*/2020	E	X	X		X		X	France
Berthe, Grouiez, Fautras/2022	E	X	X		X		X	France
Bioteau *et al.*/2013	E					X		France
Bolzonella, Fatone, Cecchi/2013	E			X				Italy
Bourdin/2020	E			X				France
Brühne, Tempel, Deshaies/2015	E					X		Germany
Camguilhem/2018	E					X		France
Carrière/1984	E			X	X		X	France
Condor/2019	E	X	X			X		France
Couturier/2013	E		X		X			France
Delhoume, Caroux/2014	E	X	X					France
Garambois *et al.*/2022	E	X		X	X	X	X	France
Grouiez/2021	E	X	X	X	X	X		France
Jayet, Sourie/1983	E			X	X		X	France
Jutteau, Lacquement/2019	E	X		X		X		Germany
Laboubée *et al.*/2020	E	X	X			X	X	France
Levasseur *et al.*/2011	E				X			France
Mazaud, Pierre/2019	E	X				X		France
Moraine *et al.*/2019	E	X	X			X		France
Raffin, Dormoy/2021	E					X		France
Rakotovao, Godard, Sauvée/2021	E	X	X					France
Sánchez Sáez/2005	E			X		X		Spain and the EU
Sourie/1980	E			X	X		X	France
Vue, Garambois/2017	E	X	X	X		X		Germany
Weiland/2013	E			X				Germany

3.3.2. Identification of Key Contributions from the English-Language Social Sciences Literature on AAD

References	Empirical paper / Review	Farmer, farming and evolutions	Typologies and business models	Regulatory frames and public support	Economic viability of methanization	Local rural development	Scenarios and future studies	Considered areas/ EU countries
English-language corpus								
Alan, Köker/2023	R	X			X	X		Worldwide
Bertolino *et al.*/2023	E	X		X				Italy, Brazil
Bischoff/2012	E	X	X					Germany
Bluemling, Mol, Tu/2013	R	X				X		Worldwide
Brémond *et al.*/2021	R				X		X	Germany, Denmark, Sweden, France, Italy
Burg *et al.*/2021	E				X		X	Switzerland
Cadiou, Aubert, Meynard/2023	R						X	France
Chodkowska-Miszczuk *et al.*/2020	E			X		X		Poland, Slovakia, Czech Republic
Darnhofer/2005	E					X		Autriche
Gava *et al.*/2017	E	X	X					Italy
Horschig *et al.*/2020	E	X		X				Germany
Igliński et al./2020	E		X	X				Poland
Karlsson *et al.*/2017	E		X		X			Sweden
Kriechbaum *et al.*/2023	E	X			X		X	Austria
Lyytimäki *et al.*/2018	E	X		X	X			Finland
Lyytimäki *et al.*/2021	E	X		X	X			Finland
Magnani/2012	E	X				X		Italy
Martinát, Cowell, Navrátil/2020	E	X				X		Wales
Mateescu, Dima/2020	E			X	X			Romania
Mol/2013	E		X				X	Worldwide (especially EU–Asia)
Navrátil *et al.*/2021	E	X						Czech Republic
Nevzorova, Kutcherov/2019	R	X	X	X	X			Worldwide (32 countries)
Niang, Torre, Bourdin/2022	E	X				X		France
Panoutsou *et al.*/2022	E	X				X		18 EU countries
Pestalozzi *et al.*/2019	E	X						Germany
Piwowar/2020	E	X		X				Poland
Plieninger, Bens, Hüttl/2006	R	X		X		X	X	Germany
Puupponen *et al.*/2022	E	X		X	X			Finland
Sheer *et al.*/2024	R		X					Worldwide
Sorda, Sunak, Madlener/2013	E			X		X	X	Germany
Stürmer *et al.*/2021	E			X				Switzerland, Germany, Austria
Sutherland, Peter, Zagata/2015	E	X		X				Germany, Czech Republic, United Kingdom

4. Results: A European Model Based Primarily on Farmers and Public Subsidies?

4.1. From an Agricultural to an Industrial Model?

- **Farmers as the initial impulse:** AD emerged from agricultural practices—with Germany as a pioneer in the 90s—with local projects based on manure and crop residues (Horschig *et al.*, 2020).
- **A distinctive renewable energy source:** Unlike wind, solar or hydraulic energy, biogas is embedded in the social structures and practices of rural areas → its inputs come from agricultural systems, not natural elements (Bluemling *et al.*, 2013).
- **Sector restructuring and the rise of biomethane injection**: The increasing adoption of the **energy transition discourse** in biogas production has changed the initial emphasis on farmers and local ties → closer interactions emerged between farmers and industry, starting upstream with biomass supply (Plieninger *et al.*, 2006; Grouiez, 2021) .
- **"Energy farmers" and agricultural differentiation**: Some farmers adopt entrepreneurial, multi-partner approaches. But this evolution benefits mainly capital-intensive farms, and reinforces structural inequalities by favoring those best able to adapt to modernization dynamics (Anzalone & Mazaud, 2021; Amand *et al.*, 2015).

4. Results: A European Model Based Primarily on Farmers and Public Subsidies?

4.2. Towards Mixed Business Models?

Differentiated farmer roles and trajectories:

- Berthe *et al.* (2020) classify plants by ownership and farmer autonomy:
  - **Industrial units**, managed by agribusiness firms or waste management companies → farmers serve only as input suppliers;
  - **Territorial units**, funded by local authorities → biogas is part of a broader local energy strategy;
  - **Mixed-ownership units**, in which farmers share governance with private investors, thus gaining easier access to funding but losing decision-making autonomy;
  - **Exclusively agricultural units**, managed solely by farmers, often following a cooperative model, ensuring them total control of plant management.

→ ***Shows a spectrum from cooperative control to dependence on external capital.***

- Rakotovao *et al.* (2021) identify 4 farmer postures in collective projects:
  - **"Leaders"**: strategic, governance-focused;
  - **"Driving forces"**: cooperative and operational;
  - **"Entrepreneurs"**: profit-driven;
  - **"Passive actors"**: reluctant or marginalized.

→ ***These typologies highlight the heterogeneity of roles and power relations, and how collective AD projects are embedded in territorial and relational dynamics.***

4. Results: A European Model Based Primarily on Farmers and Public Subsidies?

4.3. The Dependence on Regulations and Public Subsidies: A Variable-Speed Model?

- **Across Europe, the rise of biogas is strongly correlated with public policies and subsidies.**
- National contexts vary greatly in regulatory stability, types of economic instruments, and growth potential ➔ Comparative data show high output in Germany, but also highlight divergent challenges: investment costs, bureaucracy, substrate availability, legal uncertainty, etc. (Table based on Gustafsson & Anderberg, 2022).

	Germany	France	UK	Sweden	Netherlands	Denmark	Austria	Italy
Biogas output (MWh per inhabitant), 2020-21	1	0.1–0.3	0.1	0.25	0.3	0.2	0.15	0.1
Economic instruments at the disposal of farmers	Investment subsidies, feed-in tariffs and green certificates	Investment subsidies, feed-in tariffs, tax bonuses and cuts	Investment subsidies (bidding), feed-in tariffs and green certificates	Investment subsidies, tax cuts	Investment subsidies, feed-in tariffs and tax cuts	Investment subsidies, feed-in tariffs and tax cuts	Investment subsidies (bidding) and green certificates	Investment subsidies, feed-in tariffs
Regulatory framework	Stable, favourable policies	Recent but favourable framework	Regulated support framework	Robust regulation	Strong regulation, fiscal challenges	Ambitious regulations	Changing legislation	Less structured legal framework
Main challenges	Technological lock-in, production costs	Lack of long-term support, slow adoption	Setting up costs, subsidy dependence	Lack of agricultural substrates, high costs	Bureaucratic complexity, limited market	Rigid regulation	Lack of infrastructure	Weak public support, high costs
Medium-term growth potential	Very high, emphasis on innovation	Growth expected, particularly in the use of agricultural by-products	Moderate growth, with targeted support policies	Stable growth, but limited by market size	Moderate growth with fiscal challenges	High potential but bureaucratic challenges	Moderate potential, increased use of agricultural by-products	Slow growth, but increasing attention to organic waste

4. Results: A European Model Based Primarily on Farmers and Public Subsidies?

4.3. The Dependence on Regulations and Public Subsidies: A Variable-Speed Model?

Ambivalent effects of subsidies and the risk of structural dependence:

- **Substantial subsidies have enabled biogas development, but also created dependency** → questions the economic & social viability of the sector (Garambois *et al.*, 2022).
  - In Western and Central Europe alike, local actors recognize their dependency and are aware that legal frameworks and funding mechanisms are fragile and subject to political change (Sutherland *et al.*, 2015; Chodkowska-Miszczuk *et al.*, 2020).

- **As support policies become more harmonized across Europe, biogas networks scale up** —e.g. biomethane injection into (inter)national grids → **Mol hypothesizes a "governance paradox":**
  - **Territorialized governance allows direct intervention**: projects are mainly developed at state or regional level → regulation is feasible and targeted;
  - **Globalized biomethane networks complicate regulation**: expansion through gas grids increases scale and reduces political control;
  - **Yet stronger oversight would be needed**, the growing role of large industrial actors raises sustainability concerns (Mol, 2013).

5. Discussion: How Viable are the Biogas and Biomethane Supply Chains in Europe?

- **The main appeal of biogas for farmers rests on an economic rationale**, i.e. the fact that it is a source of additional income or can secure the profitability of their farms (for example : in France, Amand *et al.*, 2015; in Switzerland: Burg *et al.*, 2021; in Poland: Igliński *et al.*, 2020).
- **There are several barriers to profitability:**
  - Biogas plants require **high investment costs**, including the cost of building the digester, buying the necessary equipment, hiring technical staff, transporting the inputs, to which can be added the **costs of managing and maintaining the units**.
  - **Biogas is more expensive than natural gas**, which can dissuade end users, concerned about having to pay more (Nevzorova, Kutcherov, 2019).
  - Camguilhem (2018) points out **farmers' dependence** on support programs, as mentioned before.
- These concerns can account for the fact that **cogeneration units have been losing ground in Europe.** The biogas sector has had to face **a paradigm shift, with biogas being transformed into biomethane** to a greater extent across Europe (Brémond *et al.*, 2021; in Austria: Kriechbaum *et al.*, 2023; in Finland, Sweden & Denmark: Lyytimäki *et al.*, 2018 & Karlsson *et al.*, 2017; in France: Grouiez, 2021).

6. Discussion: Scenarios Studies

- Many future studies support the development of AD.
- An analysis reveals **a connection between the priorities developed in the studies and the institutions they spring from** → Cadiou *et al.* (2023) compare 16 possible biogas development scenarios in France, exploring the influence of farm-fed AD by 2030–2050:
  - The 7 least concerned with agri-sustainability come from energy-related institutions → mostly focus on decarbonization.
  - The 3 most committed to agri-environmental sustainability were led by a non-profit NGO, specialized in agricultural issues.
- **Competing narratives on biomethane** → the Austrian case (Kriechbaum *et al.*, 2023):
  - **"Greening of gas"**: biomethane is given a key role in the energy transition → a large-scale production required;
  - **"Champagne of the energy transition"**: doubts about feedstock availability & high costs involved → biomethane only justified if no better low-carbon option exists;
  - **"Energy farmer 2.0":** narrative centered on local job creation and rural economic activity.

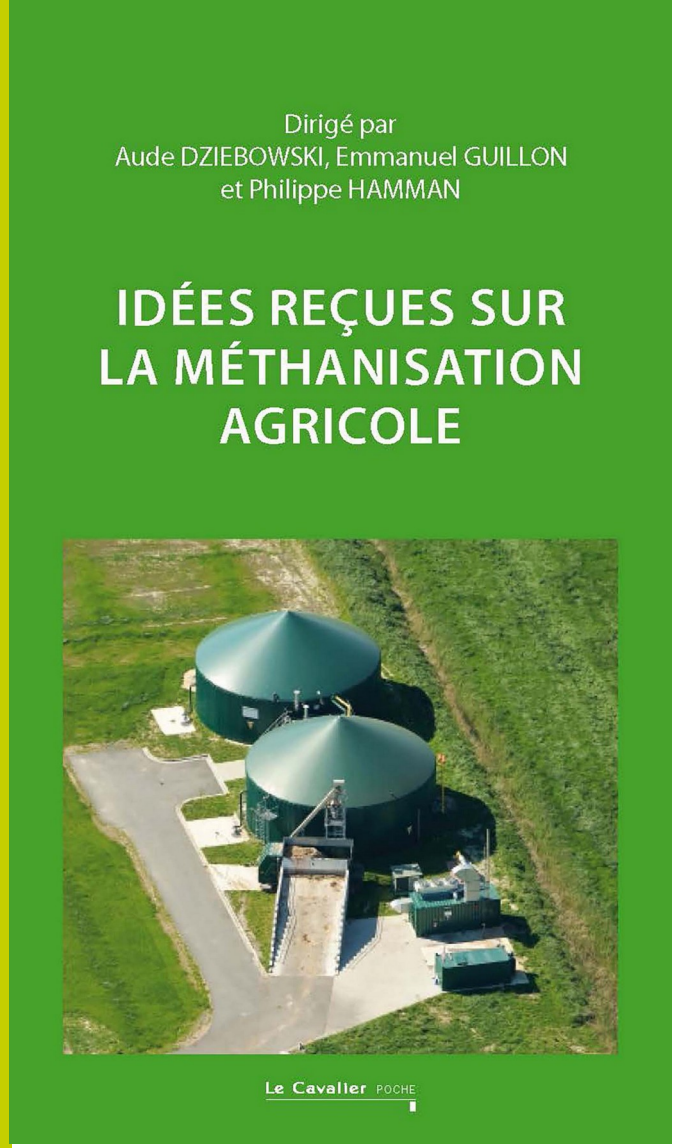
→ *The coexistence of these 3 narratives prevents the adoption of a unified strategic frame—which should remind us of the ever-changing nature of the socio-technological foundations upon which thought and action are based.*

7. Conclusion: A European Model? Key Features

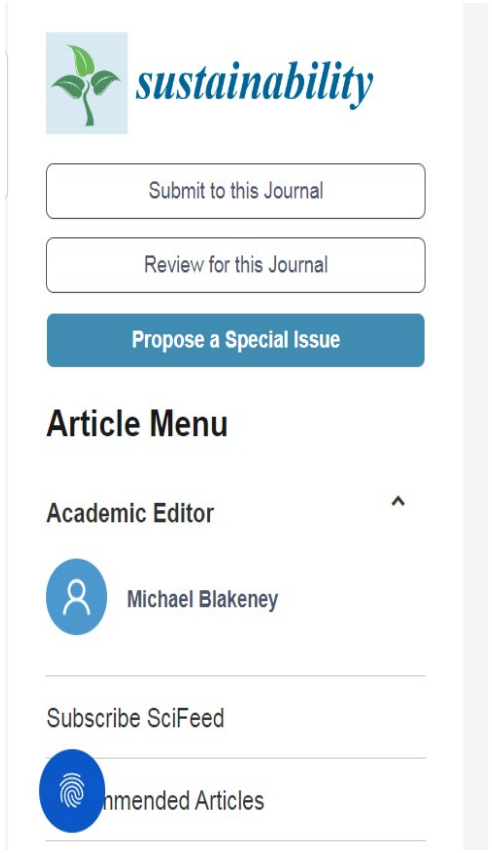
Even though different priorities taken over time, **it is possible to identify a European model for farm-fed AD**, characterized by:

- the **primacy given to energy transition goals** over objectives related to the agricultural and ecological transition,
- and **a central tension** between the prominence given to farmers and localized references *vs.* a process of industrial supply chain building and the rise of a more globalized model.

➔ This dynamic interpretation expresses ever-ongoing interactions and processes.



A collective work published in October 2023 by Editions du Cavalier Bleu



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Thanks for your attention!

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