

THE STRATEGIC ROLE OF BIOGAS PLANTS IN AGRICULTURE, LIVESTOCK FARMING, ENERGY AND THE LOCAL ECONOMY

A compendium of benefits, without attempting a comparative analysis of drawbacks

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*"To the extent that we intervene in nature,
we must rigorously ensure that its balance is restored."
Heraclitus of Ephesus (c. 540–480 BC)*

1. Integrating biogas plants into a community's economic activity makes it possible to create a **closed-loop economy** in which nutrients and lignin are recovered and reused. Nitrogen, phosphorus, potassium and other macroelements (Ca, K, Na, Mg, P, S, Cl) and trace elements (Co, Fe, I, Cu, Mn, Mo, Se, Zn, Li, B) extracted from the soil by crops are recovered at the biogas plant and returned to the biological cycle. Local farmers therefore avoid having to purchase costly mineral fertilisers, which are generally produced far from their farms, often in other countries.

Without **closing this cycle**, the development of agriculture would not have been possible. (The word "agriculture" comes from the Latin "agri", meaning field, and "cultura", referring to cultivation.) Agriculture is our most ancient cultural activity, the mother of all cultures, encompassing growing, processing and enjoying food. In modern civilisation, slurry, manure and organic waste are routinely removed from the biological cycle and regarded as waste rather than by-products of enormous value to local agriculture. In the past, a large manure heap beside a farmer's house was a sign of wealth because it demonstrated the farmer's capacity to cultivate the land.

Compared with mineral fertilisers, digestate, as an organic product, helps form a permanent humus layer, which is essential for soil health and fertility. This allows soils to recover their natural condition: their biological richness and their ability to absorb and retain rainwater. The latter is particularly important for the conservation and recharge of aquifers. Agricultural land near a biogas plant benefits from these improvements, resulting in better and more competitive production of vegetables and cereals in both the short and long term. In addition to the benefits for agriculture and livestock farming, this brings significant advantages at local, regional and national levels. Historically, the domestication of animals such as goats, sheep and cattle was crucial to the development of agriculture because their manure improved soils and increased crop yields. This is the role that a biogas plant plays today, which is why it could aptly be compared to a genuine "technological cow".

Closing the nutrient cycle also means closing the solar-bioenergy cycle. Solar energy stored biochemically in plants through photosynthesis is released when the long-chain compounds previously formed using that same energy break down. This process produces methane.

By producing nutrients and bioenergy, biogas plants increase the competitiveness of agricultural and livestock farms and **reduce their exposure to geopolitical risks** affecting fertiliser supplies. Greater independence from fertiliser imports, together with reduced purchases of natural gas on volatile markets, lowers the outflow of foreign currency to third countries. These are among the reasons why biogas plants are considered strategically important in Spain and in many local communities. The main producers of phosphate rock are China (accounting for around 44% of global production), Morocco (which holds the world's largest reserves), the United States, Russia, Jordan, Saudi Arabia and Egypt; **Spain has no phosphate mines of its own** and depends entirely on imports [2]. This concentration is reflected in prices: over the past two decades, phosphate rock has risen from around US\$44/t (2006) to approximately US\$150–170/t at present, with peaks of US\$400–450/t in 2008 and US\$300–320/t in 2022, a cumulative increase of more than 250% [3]. This far exceeds the increase in Brent crude oil over the same period (from around US\$54/barrel in 2005 to approximately US\$69–80/barrel in 2024–2025, or around 25–30%) [4].

2. Biogas plants help reduce the consumption of natural resources such as natural gas and oil and, above all, phosphate. As noted in the previous point, phosphate is a scarce macronutrient at the Earth's surface and must be imported from a handful of producing countries, many of which experience high levels of instability.
3. Biogas plants reduce atmospheric emissions of ammonia (NH_3), a harmful, highly volatile compound. They also reduce emissions of fatty acids associated with strong odours, as well as nitrous oxide (N_2O) and phenols. Applying digestate instead of untreated slurry and manure therefore **avoids odour nuisance and improves hygiene**.
4. There is considerable debate about residents' exposure to odours. Most existing small and medium-sized plants are located very close to towns and cities, often no more than 100 metres away. The **anaerobic digestion process itself does not generate odours** because it necessarily takes place in hermetically sealed tanks. When odours do occur, they generally result from incorrect storage of the organic feedstocks, particularly solid feedstocks from the food industry. Liquid feedstocks should not produce odours because they are handled and stored in enclosed spaces. A well-designed biogas plant operating at full capacity produces energy for around 8,500 hours out of the 8,760 hours in a year. With such demanding operational requirements, feedstock losses through volatilisation cannot be tolerated because they would reduce biogas production.
5. Biogas plants create **wealth in rural areas** and thereby help retain the local population by generating local jobs. Rather than merely managing organic waste, they produce energy and recycle nutrients in keeping with a **circular economy**. Livestock farmers and crop farmers who use, for example, municipal organic waste as a co-substrate can diversify their activities and take on a new socioeconomic and cultural role in rural areas. Biogas plants can therefore be said to **improve the future prospects of livestock farming and agriculture**, sectors that have been particularly hard hit by globalisation. In Spain, 69,487 agricultural holdings and 50,869 livestock holdings closed between 2018 and 2020 [1] [5]. The trend has continued: between 2020 and 2023, the number of agricultural holdings fell by a further 12.4%, and

livestock holdings by 10.5% [6]. Every farm that closes further reduces the country's food independence and, above all, the security of supply in times of crisis.

6. The digestate obtained from organic waste such as slurry is a better fertiliser than the undigested material. This is because complex organic compounds (fats, proteins and carbohydrates) are naturally converted into methane: nutrients (N, P, K, etc.) are mineralised into forms more readily available to plants (such as ammoniacal nitrogen), and the C/N ratio falls. Digestate can therefore be used as a **fast-acting fertiliser** and top dressing for growing crops, reducing the risk of nutrient leaching, particularly nitrogen, when it rains. When applied to leaves, it strengthens the plant and increases its resistance to parasites. Micronutrients are not lost during digestion, and lignin is preserved; the latter is important for the formation of permanent humus in soils. Microorganism populations increase in these soils, making them more porous and permeable to rainwater. In other words, the soil gains water-retention capacity, which helps recharge aquifers. Biogas plants can therefore be said to play an important role in **aquifer formation** and in the supply of high-quality drinking water.
7. In addition to saving on fertilisation costs, using digestate improves the health of the **soil biota (edaphon)**. Healthy soil biota improves plant health and can substantially reduce expenditure on plant-protection products. Organic soil amendments improve the soil's capacity to regenerate. This benefits not only soil and plant health but also the health of farm workers who apply plant-protection products and of consumers of agricultural produce.
8. It improves the soil year after year: digestate adds **organic matter** and **humic and fulvic acids** that mineral fertilisers do not contain. More humus means greater water retention, increased microbiological activity and healthier, more living soil. Living soil, populated by woodlice, centipedes, millipedes, springtails, mites, earthworms and microorganisms, is more resistant to harmful bacteria.
9. The development and dissemination of **highly innovative technologies** are encouraged, driving the creation of technically demanding jobs in civil, industrial, chemical, electronic and computer engineering and their integration with biology, microbiology and the skilled trades.
10. Sustainable management of agricultural and livestock farms improves the company's brand image.
11. Preventing nitrate leaching into aquifers increases the **legal certainty** of agricultural and livestock operations under the "polluter pays" principle of the Environmental Liability Act.
12. The digestion process significantly reduces the **germination capacity of weed seeds** present in the feedstocks, improving the agronomic quality of digestate. Mesophilic digestion temperatures (35–37°C) are already sufficient to stop most of these seeds from germinating, while thermophilic and hyperthermophilic temperatures (52–60°C) provide even greater protection against their spread. This reduces the risk of introducing and spreading weeds on agricultural land when digestate is applied, unlike what may happen with untreated manure or slurry.
13. The digestion process in biogas plants substantially improves **health and hygiene safety** compared with other methods of managing organic waste by reducing the

number of pathogenic organisms (particularly coliforms and salmonella). Process conditions adversely affect numerous pathogenic organisms, viruses, fungi, parasites and, especially, bacteria. High process temperatures (up to 40°C in mesophilic plants and up to 60°C in thermophilic and hyperthermophilic plants), the anaerobic environment, stress caused by pH changes and sudden temperature variations during hydrolysis cause many pathogens to die off or be displaced by organisms better adapted to those conditions.

14. As solar and wind power account for a growing share of Spain's **energy mix**, weather-related shortfalls need to be covered by **dispatchable energy**, mainly from combined-cycle power plants. The operating costs of these plants are very high because they must remain available throughout the year while generating very little electricity, coming online for only a few hours. All biogas plants have storage capacity that can be used when the electricity grid operator requires additional power because wind or solar generation is insufficient. They can reach **full availability** within just a few minutes, faster than a gas-fired power plant. In other words, new investment in gas-fired power stations would not be needed if there were enough biogas plants, as is the case, for example, in Germany. Certain anaerobic digestion processes make it possible to **increase or decrease biomethane production** easily and very quickly. Biogas plants are therefore the perfect complement to solar and wind energy, helping stabilise the electricity grid and mitigate insufficient transmission and distribution grid capacity.
15. Although the vast majority of biogas plants being built today are intended to produce biomethane, until a few years ago they were mainly designed to generate **electricity and heat**; in fact, most plants currently operating in Europe still serve this purpose. Electricity and thermal energy are produced using an engine-generator set and by recovering its waste heat.
16. Under certain weather conditions, surplus solar and wind generation can also be converted into **green hydrogen**. Once produced, the hydrogen can be converted within the anaerobic digester itself, without additional investment and at almost no incremental cost, increasing methane production by up to 35%. The resulting methane can then be readily used through the extensive existing natural gas infrastructure, avoiding substantial new investment.
17. Upgrading biogas to biomethane also enables straightforward capture of **high-purity, biogenic CO₂**. This can be reused, for example, in carbon-dioxide fertigation in greenhouses or in the food and beverage industry, replacing fossil-derived CO₂ and putting 100% of the by-products generated during waste treatment to use. Biogas and biomethane plants thereby achieve the comprehensive recovery of agricultural and livestock waste.
18. Biogas plants vary enormously in size, from facilities consuming 100 tonnes of feedstock per year to the largest ones, which process 3 million tonnes annually. The vast majority fall within the range of 50,000 to 200,000 tonnes per year, a range also representative of Spain. Germany, with some 10,000 installed plants, produces approximately 32 terawatt-hours (TWh) per year, equivalent to around 5.4% of its electricity consumption. Most feedstocks are sourced within a radius of approximately 25 km, although small quantities may occasionally come from farther away. Energy output typically ranges from 20 to 100 GWh of thermal energy annually.

19. Rare earth elements (neodymium, dysprosium, praseodymium, etc.) are used in the manufacture of biogas plants, although in **negligible quantities** compared with other renewable energy technologies. These elements are mainly used in the permanent magnets of direct-drive wind turbine generators and in electric vehicle motors [7]. A biogas plant's engine-generator set, driven by an internal combustion engine, uses conventional synchronous or asynchronous generators that do not require rare earth magnets. Their presence is therefore largely limited to traces in chips and control electronics. Nor does this technology require the critical minerals characteristic of photovoltaic solar energy, such as the silver and copper used in crystalline-silicon cells or the tellurium and indium used in thin-film panels. According to International Energy Agency data, an onshore wind farm requires around 10 tonnes of critical minerals per MW installed, and an offshore wind farm up to 15.5 tonnes, compared with much smaller quantities in technologies using conventional generators, such as biogas [8]. Avoiding this dependency is no minor matter: rare earth mining and refining are highly geographically concentrated—China produces around 70% of the world's rare earth ore [9]—creating **dependence on foreign suppliers, outflows of currency** to pay for imports and exposure to geopolitical decisions by third countries. There is also a significant environmental footprint: these minerals are often found alongside radioactive thorium, and their processing has generated toxic waste that has contaminated water and soil at sites such as Bayan Obo (China) and Bukit Merah (Malaysia) [10].
20. **Recovery of municipal and food-industry waste:** in addition to agricultural and livestock by-products, biogas plants can treat the organic fraction of municipal solid waste (OFMSW) and food-industry by-products that are unsuitable for consumption. This reduces the amount of organic matter sent to landfill—where it would generate methane uncontrollably—creates additional revenue for local authorities and businesses, and strengthens integrated waste management at the local level.

21. **Access to financing and alignment with European regulations:** by contributing to the decarbonisation, waste-management and circular-economy objectives of the European Green Deal and national energy and climate plans, biogas and biomethane projects can qualify for dedicated European grants and funding schemes, facilitating their development and improving the profitability of the farms that undertake them.

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