Defining a sustainable way of producing biomethane

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Air Liquide Biogas Solutions and WWF France collaboration

FOREWORD AND INTRODUCTION

Charles-Henri DES VILLETTES,
Vice-President
Air Liquide Biogas Solutions

“Since its inception, Air Liquide has envisioned its biogas business as an essentially sustainable one. To better demonstrate this through an actionable and holistic framework, we decided to develop our own charter to measure and track our progress on sustainability metrics. The charter had to be practical and flexible enough to encompass both current and future activities, and at the same time sound and resolute enough to be recognized by all as a robust pledge. Air Liquide Biogas Solutions’ teams have been thrilled to count as a major partner WWF France in this endeavour, and are very appreciative of their contributions to this end. The charter will guide us as a compass supporting our growth ambitions, and we call for the entire biogas sector to join us in this pioneering journey.”

Marie-Christine KORNILOFF,
Corporate Engagement Director,
WWF France

“As part of its mission to mitigate climate change, WWF calls for an acceleration of the energy transition aiming to significantly reduce our energy demand as quickly as possible and to reach 100% of the energy consumed from sustainable renewable sources. Biogas is one of the many options available to reach that goal. In this context, WWF France has brought its expertise and has contributed to establish sustainability criteria for the development of biomethane projects. It is now in Air Liquide Biogas Solutions’ hands to implement these principles through a charter, and ultimately have a broader impact in the sector.”

This document presents a summary of the work carried out as part of a collaboration between WWF France and Air Liquide Biogas Solutions, which brought together several other contributing experts from different organisations, among which the RE-SOURCE LAB from the University of Ghent (Prof.Dr.Erik Meers and Çağrı Akyol, PhD), the European Biogas Association (Secr. General Giulia Cancian) and United Experts (Board members and experts Filip Raymaekers and Lies Bamelis). They have worked together for a year in a collaborative spirit, to establish sustainability principles, criteria and indicators for the development of biomethane production projects to be used by Air Liquide Biogas Solutions. This content does not constitute WWF’s official position on biogas or anaerobic digestion.

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Executive summary

All energy production assets can have both positive and negative impacts on the environment and the production of biomethane is no exception. However, biomethane from anaerobic digestion (AD) is much more than renewable energy. It can participate in effective waste management, incorporate agricultural feedstock and even produce a biofertiliser[1]. **It forms a strong link between the energy, waste management and agricultural sectors.**

Digestion is a biological process; and life science triggers complexity, uncertainty and risk. Moreover, biomethane production projects are hence diverse and have to cope and be adapted to local conditions, especially regarding biomass as a feedstock and digestate spreading. These projects can impact the environment far beyond the production site perimeter. Therefore, investing in sustainable biomethane production **requires a clear understanding of the potential externalities and risks** (e.g. on food/feed competition, competition for land for carbon sequestration, soil health, water stress, biodiversity, etc.) **and a deep dive into the specificities of each project for adequate risk mitigation and performance monitoring.**

Considering the potential of biomethane and the numerous pledges made for its development, **several regulations** in the European Union (EU) and in the United States (US) currently exist to encourage growth in the sector but they **have yet to properly address the multifunctionality aspect of AD and its sustainability in a challenging way.**

Therefore, **Air Liquide Biogas Solutions and WWF France joined forces back in September 2022** to design a first set of principles, criteria and indicators to **frame what “sustainable biomethane production” means beyond existing regulatory frameworks.** The objective is for Air Liquide Biogas Solutions to methodically understand, measure, report and monitor the sustainability characteristics of its current operations. In order to build a reliable framework, **several internal and external experts were involved,** focusing, through dedicated workshops, on the different aspects of biomethane production, namely (i) feedstock, (ii) digestate management and (iii) asset design and operations.

The first deliverable of this collaboration is this public synthesis, which aims at increasing the awareness of biogas and biomethane projects’ potential impacts, and engaging further collaboration with the sector towards more efficient sustainability frameworks. It lists four main principles:

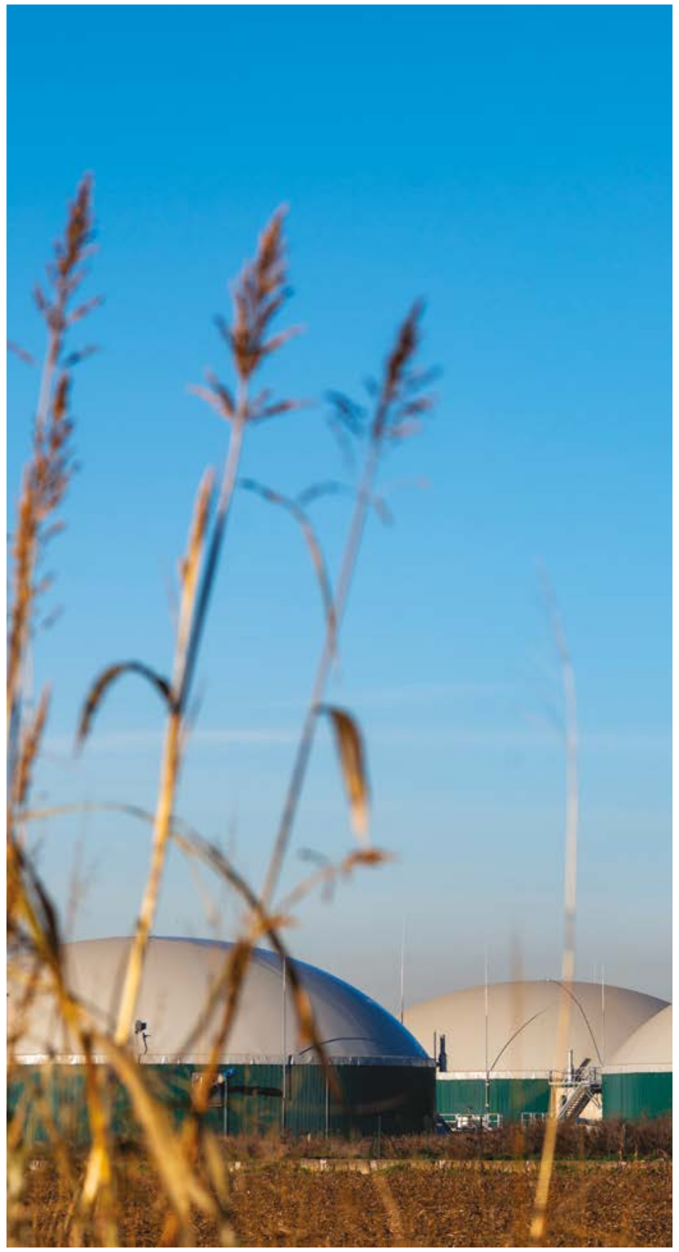
1. Contribute efficiently to the **energy transition**
2. Be a lever for **agroecological practices**
3. Maximise benefits for **local ecosystems** and promote a **circular economy**
4. Prevent **risks on the environment** and preserve **biodiversity**

The second deliverable is an internal charter, listing criteria and indicators allowing a concrete sustainability assessment for any new biomethane production projects to be presented to Air Liquide Biogas Solutions’ investment committee.

While this project has defined generic guidelines, they have to be adapted and completed by a specific analysis of each project / plant impacts . Indeed, **biomethane production from AD are deeply rooted in their local environments.** Their success and actual sustainability also depend on their capacity to leverage on local partnerships to **realise benefits for an entire ecosystem.**

Through this collaboration, a voluntary sustainability framework has emerged. The intention is that the framework is a live document continually being discussed and improved or used by other players in the biogas field. Thus, this initiative should not be seen as a ‘fait accompli’ but rather a humble contribution toward the development of more sustainable practices and a call for further collaborative work.

Air Liquide Biogas Solutions and WWF France welcome any contributions and feedback on the principles presented here and hope to contribute to initiatives pushing forward the adoption of such a framework.



> “This initiative should not be seen as a ‘fait accompli’ but rather a humble contribution toward the development of more sustainable practices and a call for further collaborative work.”

[1] In the United States, it is also common to valorise solid digestate as animal bedding on dairy farms.

Overview of sustainable biomethane production principles

4 MAIN SUSTAINABILITY PRINCIPLES

Sustainable feedstock | **Plant design & operations** | **Digestate management**

Contribute efficiently to **the energy transition**

Maximising plant efficiency: adapted hydraulic retention time, energy efficiency, tight follow-up, etc.

Avoiding the use of fossil energy: transport sobriety, heat digesters from waste heat or biogas, renewable electricity produced locally or from the grid.

Limiting GHG emissions on the whole value chain: reduced use of chemical fertilisers, monitoring and reduction of methane losses, adapted storage and spreading practices.

Be a lever for **agroecological practices**

Supporting farm efficiency and resiliency: avoidance of food and feed crops...

... and reduced dependance towards chemical fertilisers and water irrigation.

Facilitating agroecological transition: opportunity for diversification, organic cultivation...

... and more sustainable spreading practices.

Maximise benefits for **local ecosystems** and promote a **circular economy**

Involving local stakeholders in the governance: trustful and balanced partnerships rather than short-lived contracts and transparent exchanges with the local population from the very beginning of the project.

Respecting waste hierarchy: minimised food and feed competition.

Developing local and circular projects: local feedstock sourcing...

... and local use of digestate.

Prevent risks on the environment and **preserve biodiversity**

Safety first and operational excellence: safety culture and adapted technologies with the control and monitoring of key waste and process parameters.

Preventing soil, water and air pollution: robust traceability system, sourcing quality, adapted technologies and follow-up.

Protecting biodiversity: impact studies, landscape integration, chemicals reduction.

**Actual sustainability depends on the adaptation to the localisation while sharing benefits with an entire ecosystem.
Each plant thus must be designed and tailored according to its specific context.**

1. Methodology overview

1.1. Collaboration inception and objectives

Air Liquide Biogas Solutions and WWF France joined forces back in September 2022 to design a first set of principles, criteria and indicators to **frame what "sustainable biomethane production" means beyond existing regulatory frameworks,** in a pragmatic and easily usable format. The objective is for Air Liquide Biogas Solutions to methodically understand, measure, report and monitor the sustainability characteristics of its current operations and future projects in order to maximise their positive impacts and limit both risks and negative externalities.

This one-year project targeted the release of **two main deliverables:**

- This **public synthesis, to increase awareness on biogas and biomethane projects' potential impacts, and to engage further collaboration** with the sector towards more efficient sustainability frameworks for renewable gases production, either voluntary or regulatory.
- An **internal charter, for Air Liquide Biogas Solutions to assess the sustainability of any new projects** presented to their investment committee based on (i) **clear and thorough criteria** considered as "sustainability fundamentals" for selection purposes and (ii) **key sustainability indicators** combined into an overall "sustainability score" for comparison purposes.

[2] While farmers are key stakeholders for every AD-based biomethane production project, time constraints hindered the direct involvement of a farmer's association or representatives on the whole project. Any additional ex-post contribution will be more than welcome.

In order to meet this purpose, a core team was assembled, and welcomed contributions mostly from the following organisations[2]:

PARTNERS	EXPERTISE
Air Liquide	AD-based biomethane project developer and operator
WWF France	NGO focusing on the protection of biodiversity and the development of sustainable renewable energies
Ghent University	Department of green chemistry and technology, RE-SOURCE LAB. Expertise in research on biogas, digestate and manure
EBA European Biogas Association	Sector organisation for biogas and biomethane in Europe
United Experts Group	Consultancy company with broad expertise in the waste and biogas sector

Figure 1: partners participating to the development of the sustainability framework

Our guiding principles for this collaboration were to be:

- **Time-bound -** Actionable deliverables had to be produced in the frame of a year.
- **Scientifically robust -** An extensive literature review was performed, and experts from academia (namely Ghent University) and internal Research & Development teams were involved.
- **Collaborative -** Air Liquide Biogas Solutions and WWF France leveraged their networks to involve experts from the ecosystem during in-depth workshops.
- **Field-proof -** Iteratively throughout the project, Air Liquide Biogas Solutions Operations Managers were mobilised to test the understandability, actionability and relevance of the outcomes.
- **Pragmatic -** The team's effort focused on the most critical sustainability factors only, and with the imperative to remain actionable and not too complex.
- **Iterative -** The charter is designed to be a living tool. Experience from its implementation and dialogue with the sector will ensure it continues to evolve.

1.2. Approach

The collaboration focused on three critical steps in the biomethane value chain covering the whole process and set-up of a biomethane production site:

- **Feedstock,** including production, collection and storage.
- **Digestate management,** including post-treatment and storage.
- **Asset design and operations** from feedstock incorporation to biomethane final production.

The question of the most suitable valorisation paths for the biomethane was not part of the discussions.

This overview summarises the main topics discussed within the project during the dedicated workshops. It resulted in a framework for actionable best practices to support more sustainable development activities and operations. This framework led to the construction of the internal charter mentioned above.

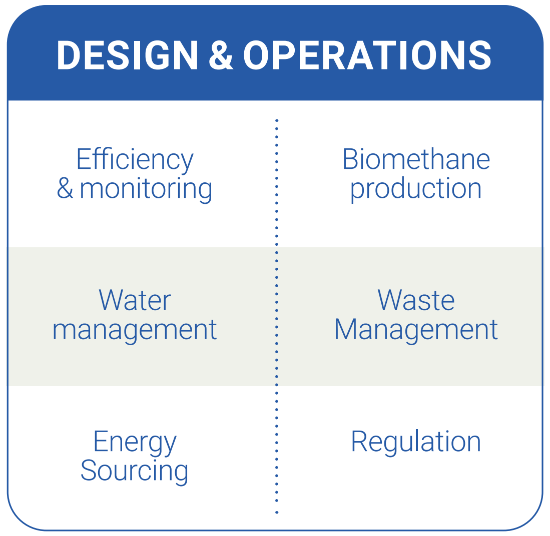


Figure 2: overview of the topics discussed in the workshops

This initiative shall be seen as a proposal to frame holistically and consistently the main impacts generated by the development and operations of AD-based biomethane production plants by an industrial stakeholder. It tries to take into account the numerous challenges the biogas industry faces to develop truly sustainable projects in a complex environment but does not pretend to cover the sustainability topic exhaustively.

2.
Biomethane production from anaerobic digestion: state-of-play

2.1. Beyond energy: multifunctionality of AD-based biomethane production sites

Anaerobic Digestion (AD) is a biological process through which microorganisms break down organic material in an oxygen free environment, leading to the production of biogas (valorised as bioenergy) on one hand and digestate (valorised as biofertiliser) on the other. AD is therefore a key component of organic wastes' circular economy, **at the crossroads between energy, waste management and agriculture.**

Energy

Biogas and biomethane produced from AD are versatile energy vectors that are valorised depending on local circumstances and needs. Biogas - mostly made of CH_4 and CO_2 - can directly feed an onsite cogeneration unit to produce electricity and heat or be purified to obtain biomethane and CO_2. Biomethane is chemically identical to natural gas, with the same primary uses. In its gaseous form, it can be used locally by industries and in transportation, or injected into gas grids leveraging the existing infrastructure. It can also be liquefied for more efficient transport to remote locations without direct access to gas grids. When upgrading biogas to biomethane, the residual CO_2 can be captured as a by-product. This CO_2, considered as "biogenic", can then be used in industrial processes or in the food industry as a renewable material.

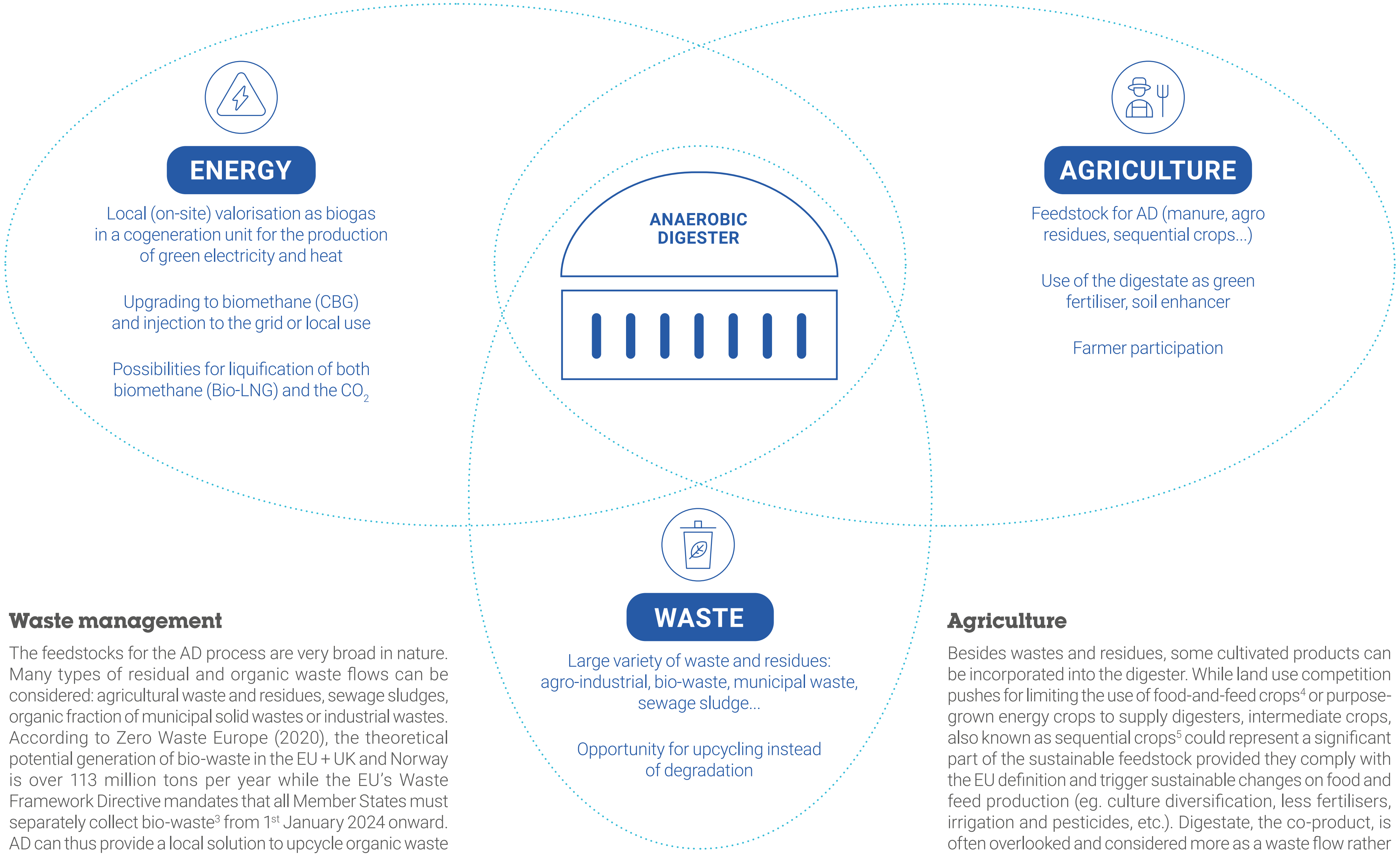


Figure 3: schematic overview of the role of AD-based production site in the circular economy

Waste management

The feedstocks for the AD process are very broad in nature. Many types of residual and organic waste flows can be considered: agricultural waste and residues, sewage sludges, organic fraction of municipal solid wastes or industrial wastes. According to Zero Waste Europe (2020), the theoretical potential generation of bio-waste in the EU + UK and Norway is over 113 million tons per year while the EU's Waste Framework Directive mandates that all Member States must separately collect bio-waste[3] from 1st January 2024 onward. AD can thus provide a local solution to upcycle organic waste for farmers, industries and municipalities.

Agriculture

Besides wastes and residues, some cultivated products can be incorporated into the digester. While land use competition pushes for limiting the use of food-and-feed crops[4] or purpose-grown energy crops to supply digesters, intermediate crops, also known as sequential crops[5] could represent a significant part of the sustainable feedstock provided they comply with the EU definition and trigger sustainable changes on food and feed production (eg. culture diversification, less fertilisers, irrigation and pesticides, etc.). Digestate, the co-product, is often overlooked and considered more as a waste flow rather than a sustainable resource, despite containing some organic carbon and the necessary nutrients to support agricultural activities. Depending on the project, digestate can be directly spread on land without any further treatment, or be further processed before its application.

[3] According to the EU's definition, 'bio-waste' means "biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants" (Directive 2008/98/EC).

[4] Food-and-feed crops are defined in the Directive (EU) 2018/2001, so-called RED2 as "starch-rich crops, sugar crops or oil crops produced on agricultural land as a main crop excluding residues, waste or ligno-cellulosic material and intermediate crops, such as catch crops and cover crops, provided that the use of such intermediate crops does not trigger demand for additional land".

[5] According to the EU's definition, intermediate crops are crops "such as catch crops and cover crops that are grown in areas where due to a short vegetation period the production of food and feed crops is limited to one harvest and provided their use does not trigger demand for additional land and provided the soil organic matter content is maintained" (Draft Delegated Act amending Annex IX to Directive 2018/2001, 2023). The implementation of sequential cropping leads to reconsideration and diversification of the whole rotation and depends strongly on local conditions.

2.2. Approaching production sites' impacts holistically

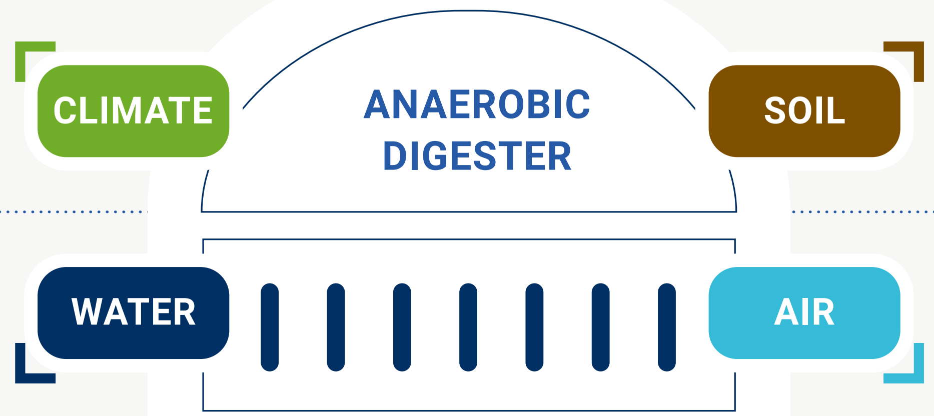
Given its multi-functionality, **an AD-based biomethane production site can generate a wide range of externalities and is not inherently virtuous**. A systematic and specific understanding of a site's footprint is necessary to realise its full benefits and to limit its potential downsides. The figure below provides a generic overview of **the potential environmental impacts and risks on climate, soil, air and water** (effect on biodiversity is considered as an indirect repercussion and thus not specifically mentioned).

Several studies (among others: European Biogas Association, 2023 and Environmental Protection Agency of the United States, 2024) highlight the other potential positive externalities triggered by this multifunctionality such as the positive impact on farm revenues (as long as the project is adequately designed, well managed and the added value fairly shared), the reduction of odours from manure, the development of local job opportunities in rural areas or energy independence and security. While this potential is increasingly under the spotlight, governments are progressively seizing the opportunity to push and frame the development of this industry.

> "A systematic and specific understanding of a site's footprint is necessary to realise its full benefits and to limit its potential downsides."

Avoided GHG emissions, due to :
- Replacement of fossil fuels and chemical fertiliser
- Induced changes in agricultural practices
- Controlled processing of bio-waste
- Possible valorisation of bioCO_2.

Induced GHG emissions (CO_2, CH_4 and N_2O) on all the value chain, from feedstock production and collection (including indirect land use change) to biomethane and digestate valorisation.



Support soil carbon storage, due to the application of digestate on land as a soil enhancer or as a lever for conservation agricultural practices, such as precision farming and minimum tillage. Sequential cropping systems reduce soil erosion.

Support soil nutrients management, due to the changes in agricultural practices and application of digestate on land as a fertiliser.

Risk of disturbing the soil microbiological equilibrium with digestate spreading.

Risk of contaminant distribution when working with inadequate input flows and quality checks.

Improved water management, through proper digestate application and cover crops that:
- improve water retention of the soil
- reduce local water contamination (caused by landfilling) and risk of eutrophication (caused by excess of nitrogen).

Risk of contamination of water in case of misapplication of the digestate and lack of traceability.

Increased water consumption can be needed for the production of (sequential) crops (additional irrigation or impact on useful soil water reserve).

Avoided ammonia emissions, due to induced changes in agricultural practices.

Induced ammonia emissions, mostly at digestate storage and spreading stages.

Figure 4: overview of the main environmental externalities of AD-based biomethane production sites (non-exhaustive list of potential benefits and risks)

2.3. Public authorities' will to develop sustainable biomethane could further address multifunctionality

Biomethane potential is substantial[6] and its actual development is triggered by public support and private investments. Major economies have defined ambitious production goals that also include some sustainability criteria or incentives. However, these do not fully comprehend the mutltifunctionality of biomethane production from anaerobic digestion (AD).

In Europe, the REPowerEU Plan set in 2022 a target for an annual production of 35 billion cubic metres (bcm)/year by 2030, up by 17 bcm from the previous Fit for 55 package. The plan calls for further development and mid-term policy actions regarding the actual sustainability of biomethane production, and already mentions that "*the production of sustainable biomethane should be waste-based, avoiding the use of food and feed feedstocks that would lead to land use change problems*" (European Commission, 2022). **Several directives and regulations frame this sustainable development, among which:**

- The **Renewable Energy Directive or RED** which provides sustainability criteria for the cultivated products and sets thresholds for greenhouse gas (GHG) emissions. However, biomethane sustainability is modelled on biofuel challenges and thus envisioned from its usage as fuel only.
- The **EU Taxonomy regulation**[7] mentions several activities related to AD and/or biogas/biomethane under the objective of Climate Change mitigation or Circular Economy[8] and lists mandatory criteria related to sustainability, such as the monitoring of methane leakage or the proper use of digestate. On the other hand, it suffers from some flaws such as highlighted by the European Biogas Association (EBA, 2023).
- The **Fertilising Products Regulation,** the **Nitrate directive** modification - to include RENURE (REcovery Nitrogen from manURE) criteria (JRC, 2020) - or the **Soil Monitoring and Resilience Directive** should facilitate an efficient use of the digestate.

In the US, the **Inflation Reduction Act of 2022 (IRA)** sets a framework to support the development of clean energy production, including biomethane, in order to strengthen long term growth (Public Law No. 117-169, 2022). Pending final rule implementation, the IRA supports the further development of the biogas sector by providing various tax credits. It complements the **Renewable Fuel Standard** (RFS - Federal level) and the **Low Carbon Fuel Standard** (LCFS - State level, currently active in four states and developing in some others) regulations which promote low carbon projects based on the so-called reference scenario. The approach is very flexible, it maximises renewable energy generation and highly subsidises those farms which had the highest GHG emissions prior to the biomethane project, targeting a significant reduction in methane release relative to the reference scenario. However, in this framework, **the use of very competitive natural gas in the operation of the AD-based biomethane production site is permitted and economically favoured**, the emissions associated being considered in the carbon intensity of the produced biomethane.

> Biomethane from AD is at the crossroads of several fields and overlaps many domains. Whereas supportive and stable regulations are necessary to bring long-term visibility to the industry, approaching impacts holistically is a difficult exercise for policy makers. Voluntary initiatives that promote more ambitious environmental legal frameworks are thus welcome to move the industry in the right direction; adequate regulations should then follow to implement a level-playing field.

[6] According to the International Energy Agency (IEA), worldwide sustainable biomethane production potential reaches 880 billion cubic metres (bcm) equivalent to about 20% of today's worldwide natural gas demand and sustainable feedstock excludes energy crops (IEA, 2020).

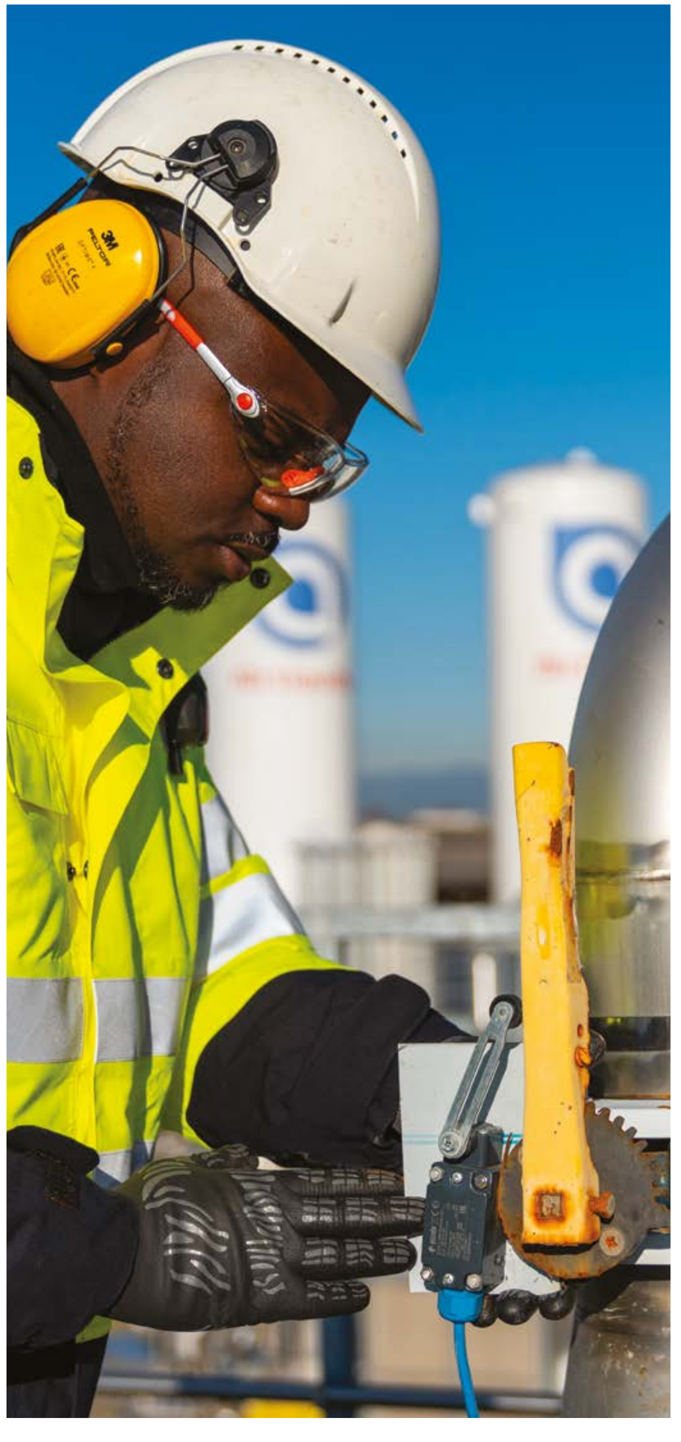
[7] "The EU Taxonomy is a classification system that helps companies and investors identify "environmentally sustainable" economic activities to make sustainable investment decisions. Environmentally sustainable economic activities are described as those which "make a substantial contribution to at least one of the EU's climate and environmental objectives, while at the same time not significantly harming any of these objectives and meeting minimum safeguards" (European Commission, 2024).

[8] Main ones are: Anaerobic digestion of bio-waste (CCM 5.7), Manufacture of biogas and biofuels for use in transport and of bioliquids (CCM 4.13) and Recovery of bio-waste by anaerobic digestion or composting (CE 2.5).

3. Main principles for a sustainable biomethane

Echoing the multifunctionality of AD, several guiding principles have emerged from the collaborative work. Project developers and installation operators can use them as a compass should they aim to increase the sustainability of their investments or operations. Such principles are, within Air Liquide Biogas Solutions, further detailed into criteria and indicators in order to support investment processes and increase the sustainability of current operations.

3.1. Principle 1: contribute efficiently to the energy transition



The energy transition seeks to progress towards a secure, affordable and climate friendly energy system. While biomethane participates in securing the supply of local and easily storable energy, and is therefore considered as an important and valuable alternative to natural gas, **attention should be paid on its actual positive impact on climate change.** On the level of the AD-based biomethane production plant, this is achieved by enhancing the overall efficiency on the production sites, avoiding the use of fossil fuel and limiting as much as possible GHG emissions and particularly methane losses.

Maximising plant efficiency

Optimising plant efficiency first goes by the **maximisation of biogas production out of the feedstock.** Proper measures shall be taken to preserve the biochemical methane potential from feedstock collection to soup incorporation (shorter and/or appropriate storage). **Preferential routes (shortcuts) inside the digester must also be limited** (e.g. through several-step digestion process, adequate mixing) and the **hydraulic retention time (HRT)**[9] **must be adapted** to the feedstock and the operational temperature. Measuring regularly the Residual Methane Production (RMP) of digestate at the outlet of the last heated and gas-tight tank allows checking the actual digestion of the material as well as evaluating the biogas plant efficiency over time.

Second, **energy efficiency is key**. Appropriate tank isolation with gasholders made of multiple membranes particularly contributes to limiting direct heat losses. Heat recovery from compressors and outgoing digestate participates also substantially in limiting heat consumption.

Electricity needs shall also be minimised particularly by investing in efficient mixing and biogas upgrading units.

Last, a **tight follow-up shall be in place** with both online (e.g. methane sensor in the biogas upgrading unit venting line, energy efficiency per equipment, flaring, etc.) and offline (e.g. biochemical and residual methane potential, etc.) analysis.

While it meets several limits, particularly considering the multifunctionality of AD-based biomethane production, calculating the **Energy Return on Investment (EROI)**[10] of the biomethane production allows to assess the overall plant efficiency.

Avoiding the use of fossil energy

While some local regulations ban fossil fuel consumption (e.g. In France, heating must be supplied either by biogas / biomethane production or from waste recovery), other incentive structures and market conditions make it economically prohibitive to use biogas/biomethane onsite.

Adequate regulations must thus be implemented to support the operators in moving from fossil fuels and incentivize electricity consumption from renewable sources (e.g. self-consumption with solar panels or grid-sourced electricity supply coupled with Guarantees of Origin - GO).

[9] Actual HRT must take into account progressive sedimentation and possible dead zones.

[10] EROI can be defined as the ratio of energy produced over the energy used to create it.

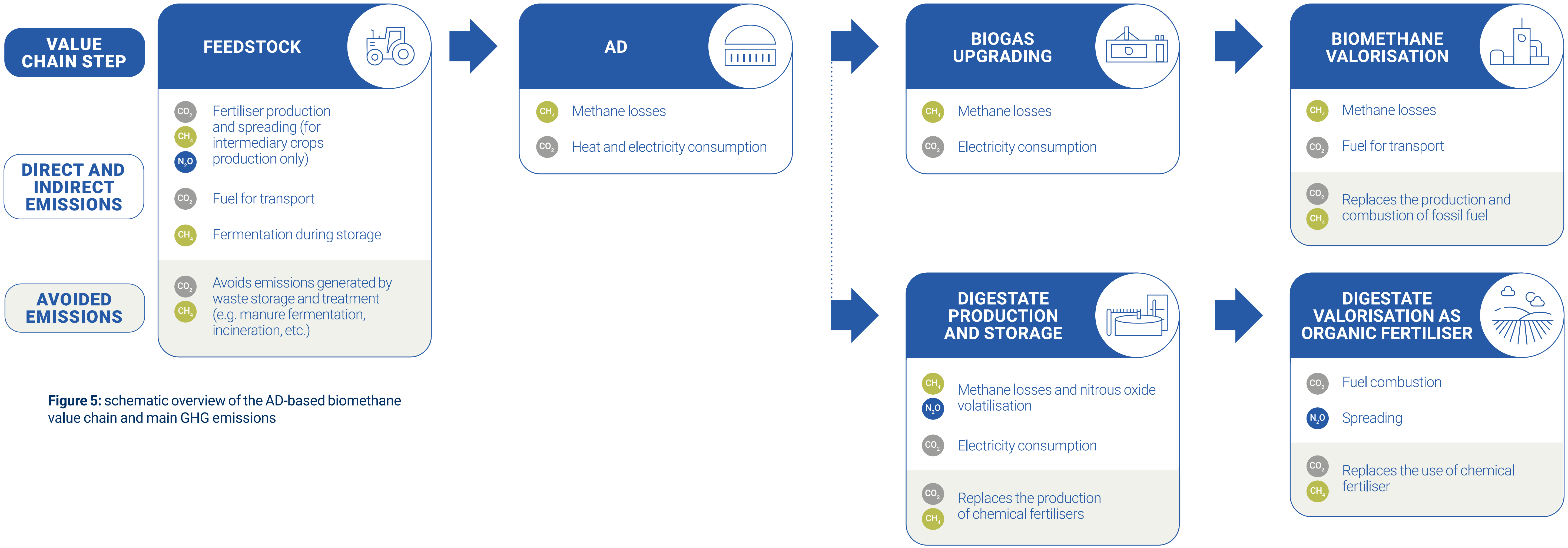


Figure 5: schematic overview of the AD-based biomethane value chain and main GHG emissions

Limiting GHG emissions on the whole value chain

Biomethane contributes to avoiding GHG emissions by replacing the use of natural gas, changing agricultural practices or diverting organic wastes from landfill. On the other hand, the **AD-based biomethane value chain can lead to emissions of CO_2, CH_4 or nitrous oxide (N_2O)[11] .** While the overall contribution to climate change is generally very beneficial, it's important to limit as much as possible these emissions whether they occur at the AD-based biomethane production site, upstream or downstream.

As CO_2 emissions can be limited thanks to the measures detailed above and N_2O is difficult to monitor for the site operator, **a strong focus shall be made on potential methane losses.** Several studies have highlighted the main measures for design and operations (among others: EBA, 2023 and IEA, 2017), which are:

- a design preventing emissions during the digestate storage (whether it occurs on-site or at farm level[12]) and the feedstock incorporation (avoid open mixing tank with digestate recirculation),
- a tight monitoring of critical sensors to optimise continuously the biogas upgrading extraction rate and limit the use of the security flare and the losses through the pressure relief valve.

It is also recommended to perform regular leaks identification campaigns although they cannot catch intermittent and diffuse losses.

Possible framework to contribute efficiently to the energy transition[13]

- The heat is supplied by renewable sources (or recovered).
- The methane losses are prevented with appropriate design (e.g. hydraulic retention time > XX days according to feedstock, losses at the Biogas Upgrading Unit vent < X% with reliable online sensors, biogas storage > X hours of max production, hydrolysis tank or premixing tank gas-tight covered, etc.).
- The methane losses are prevented with appropriate operations (e.g. regular detection rounds, digestate residual methane potential closely followed-up, methane holistic identification measurement campaign every X years, etc.).
- The biomethane carbon footprint is minimised or lower than X gCO_2eq/MJ.
- The Energy Return On Investment (EROI) is maximised or higher than X.
- The residual methane potential of the digestate is measured twice a year to catch seasonality.

[11] According to the Sixth Assessment Report of Intergovernmental Panel on Climate Change (IPCC), Global Warming Potential over 100 years (GWP100) of the biogenic methane is 27.2 ±11 while GWP100 of the N2O is 273 ±130.

[12] The Directive (EU) 2018/2001, so-called RED2, in its current version, does not directly tackle methane losses issues except by setting GHG emissions savings threshold with lower default values for gas-tight digestate storage. This latter does not incentivise longer hydraulic retention time nor tackle the case of remote open digestate storages.

[13] This proposed framework aims at listing ideas of criteria or indicators. "X" and "XX" represent theresholds to be set appropriately by the stakeholders.

3.2. Principle 2: be a lever for agroecological practices

The energy transition should promote active partnerships with farmers and other local stakeholders to make sure that the development of AD-based biomethane production is, at least, not detrimental to the agroecological transition, and, at best, a lever for the latter.

According to the Food and Agriculture Organization of the United Nations, **agroecology is "an integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems.** It seeks to optimise the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system" (FAO, 2018). AD-based biomethane production projects can be significant levers for agroecology provided that they increase farm efficiency and resilience, promote culture diversification and limit the risk of industrial intensification.

Supporting farm efficiency and resilience

Beyond the financial resilience that an AD-based biomethane production project might bring to farmers thanks to recurring revenues, a **project should be an opportunity for the local farmers to reduce their dependence on chemical fertilisers and water irrigation.** Digestate can strongly contribute to farm autonomy by replacing some part of their needs for chemical fertilisers while storing carbon; digestate should be thus valorised locally as much as possible.

The implementation of sequential crops can optimise the system efficiency, maximising the biomass produced per hectare and per unit of fertiliser. However, **intensification of the system should prevent further dependency on chemical fertiliser and water; both shall be monitored over the whole farming system (taking into account the entire rotation cropping and cattle).** Further support should be given to farmers to help them design resilient crop rotations with locally adapted varieties having low fertiliser and water needs, while maintaining sufficient yield to be economically viable. Additionally, **food-and-feed crops shall be avoided.**

Transition facilitation

Projects using sequential crops should be **an opportunity for agricultural diversification** (e.g. introduction of legumes, auxiliary plants, multi-species plots, etc.) **and for climate change adaptation** by rethinking the crop production and its rotation. Using digestate as a fertiliser can be a good opportunity for **organic cultivation** as long as the digestate meets the requirements[14]. Lastly, it is recommended to take the opportunity to **switch to more sustainable digestate spreading to preserve nutrients,** using specific material adapted to local needs, waiting for proper weather conditions and burying digestate within a few hours[15].

The implementation of, **AD-based biomethane production projects should also limit the risk of agro-intensive industry protraction** (e.g. indirect support to heavily industrialised farms in facilitating new regulations compliance, cattle headcount expansion, fertilisation and pesticides increase, etc.). As much as possible, the environmental and social impacts shall be assessed beyond the projects' borders, considering their consequences on a local (e.g. biomass fluxes) and on a global scale (e.g. climate) as highlighted by the WWF France (2020).

Possible framework to be a lever for agroecological practices

- **The project does not trigger any additional irrigation from tap or groundwater for crop cultivation (compared to the reference scenario and considering the whole farm system on a yearly basis).**
- **The project does not trigger any additional demand for chemical fertilisers for crop cultivation (compared to the reference scenario and considering the whole farm system on a yearly basis).**
- **The project does not incorporate any food-and-feed crops[16].**
- **The digestate is used as organic fertiliser / soil improver and complies with certain contaminant/pollutant limits.**
- **The project does not contribute to agro-intensive industry protraction (e.g. cattle headcount increase, increase in fertilisation / other inputs, reduction of grazing, etc.).**
- **The project contributes to agriculture diversification (e.g. intercropping, introduction of legumes, auxiliary plants, multi-species plots, etc.).**
- **The % of feedstock in weight which fits for use in the food or feed chain (e.g. crop residues, beet pulp, etc.) is minimised or lower than X.**

[14] E.g.: in Europe, digestate from industrial farming manure (definition varying as a function of the country) cannot be valorised in organic farming.

[15] For more information, refer to AgroParisTech consortium, The use of digestates in agriculture. Good practices to be implemented, 2021 (French only).

[16] As defined above, footnote n°4.

3.3. Principle 3: maximise benefits for local ecosystems and promote a circular economy

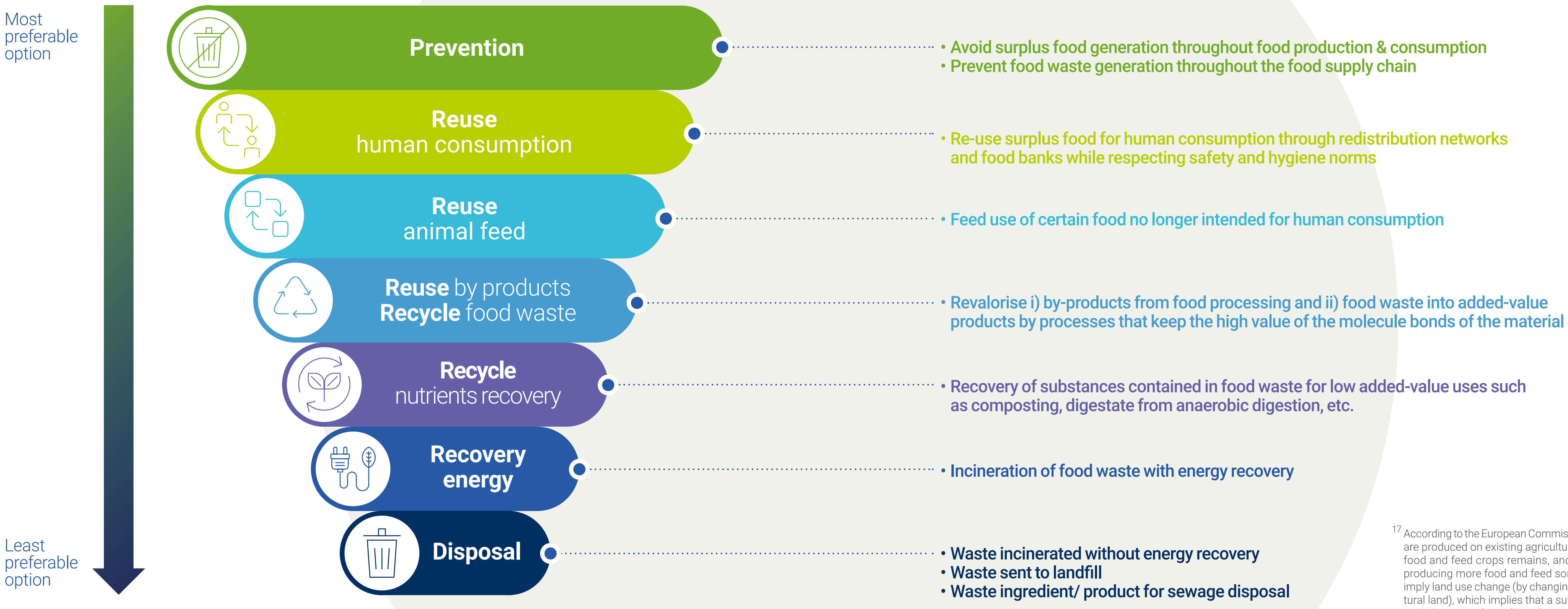
AD participates in diverting organic waste flows from landfill, for energy and nutrients valorisation. To maximise the benefits for the local ecosystem, the waste hierarchy should be respected, developing circular projects anchored locally.

Respecting waste hierarchy

Within the spirit of a circular economy, **waste must be minimised in the first place.** Residual flows must then be adequately valorised, by **merit order of the food waste hierarchy** (see figure 7 below). A feedstock specific evaluation is useful to assess its best application, and can generate new valorisation routes for local feedstocks; as food/feed competition can be difficult to assess, evaluation based on the reference scenario is recommended. This evaluation thus prevents any risk of indirect land use change (ILUC)[17].

On the other hand, it must be acknowledged that food/feed/carbon sequestration competition is a matter that requires investigation beyond the projects' borders and is quite difficult to anticipate on the lifespan of the unit and the agricultural dynamic.

Figure 6: practical application of the waste hierarchy for food (source: the European Commission's Knowledge Centre for Bioeconomy, 2020)



[17] According to the European Commission (EC), "when biofuels are produced on existing agricultural land, the demand for food and feed crops remains, and may lead to someone producing more food and feed somewhere else. This can imply land use change (by changing e.g. forest into agricultural land), which implies that a substantial amount of CO_2 emissions are released into the atmosphere" (EC, 2024).

Developing local and circular projects

Both the feedstock and the digestate use must be adapted to specific local features. **As much as possible, the digestate should be spread locally.** Oversizing a site might lead both to feedstock competition and digestate exports over long distances. The radius of supply (and spreading) shall thus be limited and can be set in relation to the theoretical biochemical methane potential of the feedstock in order for transport energy to remain a small percentage of the energy produced by the feedstock.

While most AD-based biomethane production projects are inherently circular, this circularity can often be improved by minimising and valorising any waste (mostly activated carbon or used oil), reducing water consumption (digestate recirculation and use of rainwater) and valorising the biogenic CO_2 from the vent as a product for the industry.

Involving local stakeholders

A sustainable AD-based biomethane production project may involve a large number of stakeholders, the first ones usually being the local farmers, for feedstock supply and/or digestate offtake. In the long term, they rely more on **trusted and balanced partnerships rather than short-term contracts.** Farmers and other local stakeholders can be involved in the governance of the facility and participate in the development of a sustainable and systemic vision and multi-year roadmap. **The implication of the local population from the very beginning of the project is also the best way to alleviate potential opposition** by understanding fears and expectations to be able to adapt the project accordingly.

For major industrial companies like Air Liquide, such close relationships help to comply with their duty of vigilance[18] and facilitate the implementation of good practices. Upstream, dialogue with farmers can support animal welfare practices, discussions with growers can contribute to system transition (rotation change, diversification, no-till farming, climate change adaptation measures, investment in new machines, etc.) and exchanges with bio-waste suppliers can improve sorting at source. Downstream, digestate offtakers should be incentivized to adopt more sustainable spreading practices (e.g. dedicated clause in the offtake contract). Finally, the additional income generated in the AD-based biomethane production project should play a part in financing these transitions.

Possible framework to maximise benefits for local ecosystems and promote a circular economy

- The average ratio of energy consumed for feedstock transportation vs energy content of the transported feedstock is minimised or lower than X%.
- The % of feedstock / digestate (in weight) secured locally with long-term contracts is maximised or higher than X.
- The distance between the further feedstock / digestate offtake and the AD-based biomethane production unit is minimised or lower than X km.
- The processed water consumption is minimised or lower than X / ton of feedstock.

> "Oversizing a site might lead both to feedstock competition and digestate exports over long distances."

[18] As a French company, Air Liquide has to comply with the "Duty of Vigilance Act" adopted in France in 2017. According to this act, companies like Air Liquide "must establish, publish, implement and monitor a "Vigilance Plan" to identify and prevent risks of severe violations of human rights and fundamental freedoms, health and safety of people and to the environment in their entire sphere of influence, subsidiaries and subcontractors when "an established commercial relationship" exists, which represents tens or even hundreds of thousands of companies for a single French group" (Conseil Général de l'Économie Evaluation, 2020) .

3.4. Principle 4: prevent risks to the environment and preserve biodiversity

As an industrial asset with gases present on-site, risks on **human safety from explosions or intoxications** are also inherent to this activity. Moreover, because it is at the crossroads between energy, waste management and agriculture, an AD-based biomethane production project inevitably presents some **risks on soil, water or air pollution, with possible repercussions on local biodiversity.** It is of **prime importance to understand and monitor all these risks in order to prevent accidents.**

Safety first and operational excellence

Safety is a licence to operate and an integral part of Air Liquide's operational excellence and culture. Air Liquide is committed to efficiently, and under all circumstances, reduce the exposure of its employees, customers, subcontractors, suppliers and local communities to professional and industrial risks with one ambition: zero accidents. Developing biomethane production projects is thus seen as an **opportunity to act as a change maker,** supporting farmers and other stakeholders in adopting industry standards with regards to safety (Personal Protective Equipment, required qualifications for working in potentially explosive atmospheres, pressurised equipment and electrification, adoption of standard procedures, etc.).

Besides, operational excellence requires the control and monitoring of key waste and process parameters, both manual and automatic with appropriate alarms. It shall ensure the optimal process-technical implementations combined with the economic constraints of the plant.

Soil, water and air pollution prevention

Soil and water pollution risks occur both upstream (feedstock production) and downstream (spreading practices). Indeed, the digestion process is conservative (for nutrients, contaminants or pollutants). It is thus recommended to implement a **robust traceability system** (with proper source segregation for biowaste), checking feedstock and digestate quality and efficiency, and to communicate their main characteristics to the offtakers (e.g. dry and organic matter content, pH, nitrogen, phosphorus and potassium content, contaminants, etc.).

Tight and long-term partnerships with local stakeholders enable feedstock quality enhancement and to implement appropriate digestate storage and spreading practices. Besides, while biowaste is an actual source of plastic pollution and contaminants, efficient technologies of deconditioning/separation shall be implemented upstream and/or downstream of anaerobic digestion to guarantee minimal diffusion in the environment. **Intensive efforts shall be focused on source sorting quality (packaging, bags, education)** in partnership with the suppliers, as biowaste treatment will not remove all possible pollutants.

Biomethane production units may also produce several polluting particles (ammonia, hydrogen sulphide, volatile organic compounds or dust) or generate problematic odours. The main risks occur during feedstock and digestate storage. Ex-ante impact studies allow the anticipation of the risks and the implementation of appropriate technologies and processes (e.g. adsorption, biofilter, air-tight trailer, etc.). The immediate incorporation of potentially emissive or odorful feedstock and a cover for the digestate storage (AD-based biomethane production site and farm level) are important preventive measures. Lastly, appropriate spreading practices can limit substantially the volatilisation of nitrogen.

Biodiversity protection

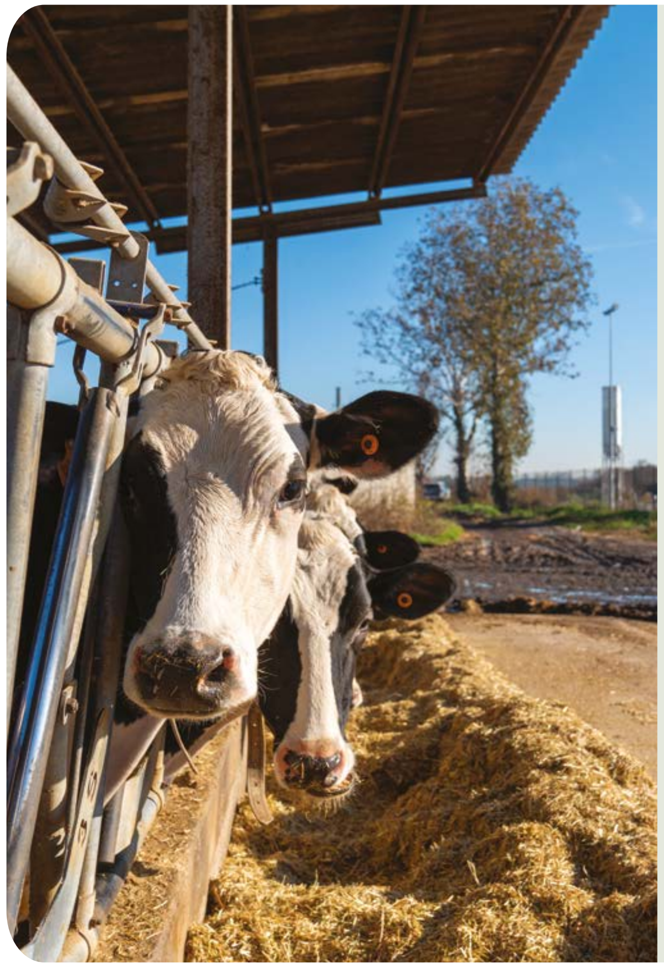
The development of an AD-based biomethane production project should be a lever for increased biodiversity at the farm level by adopting agroecological practices and infrastructures especially: more complex rotations, associated crops, hedges, less pesticides, less tillage, etc.

This issue should also be considered while designing the AD-based biomethane production plant and it can be integrated with the work on landscape integration. The latter is particularly important for relatively big sites and even more when they are close to urban or more frequented areas.

Finally, biodiversity is also a matter of microbiology. **"The impact of digestates on the soil biology is actually poorly known"** (Battle Karimi et al., 2022). Thus, investigations should be performed on fields to measure and better understand the impact of digestates on soil activity so that practices can be adjusted accordingly.

Possible framework to prevent risks to the environment and preserve biodiversity

- The design of the unit limits nitrogen losses (e.g. liquid/raw digestate covered with storage > X months).
- Appropriate technologies are implemented to keep levels of emissions to the air below predetermined thresholds.
- The flared volumes vs. production volumes and/or number of pressure relief valve openings are minimised or lower than X.
- The % of nitrogen or methane losses are minimised or lower than X.
- The monitoring and control of key parameters are anticipated or included (e.g. pH, ammonia, residual methane potential, hydraulic retention time, digestion tanks operating temperature, liquid and foam levels, pressure relief valve opening, flared volumes, electricity, heat and water consumption, etc.).
- The soil structure and composition where the digestate is spreaded is analysed on a yearly basis for impact assessment (% of organic matter, fauna and flora, etc.).



Regardless of the generic principles set out here, it is worth mentioning that AD-based biomethane production sites are deeply rooted in their local environments. Their success and actual sustainability depend on their adaptation to their local environment and how effectively they share benefits with the entire ecosystem. Moreover, safe and sustainable operation relies on human resources in the field. They are key to ensure an actual and efficient implementation of these principles and also participate in a continuous improvement process. This requires the provision of appropriate training and getting regular feedback from the operational team.

3.5. Moving forward

Developing the biogas industry in a truly sustainable way relies today mostly on voluntary actions, the present initiative being one of them. It would benefit from a more encompassing regulatory framework for sustainability, implementing a level-playing field among actors and incentivizing the most sustainable projects. Developing such a framework requires a sufficient level of transparency and trust between the biogas industry and the regulatory bodies. Air Liquide Biogas Solutions and WWF France welcome any contribution and feedback on the principles presented here, and will aim to contribute to any initiative pushing development forward for the implementation of ambitious industry standards.

4.
About us

4.1. Air Liquide Biogas Solutions

Air Liquide is a world leader in gases, technologies and services for Industry and Health. Oxygen, nitrogen and hydrogen are essential small molecules for life, matter and energy. They embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902.

With ADVANCE, its strategic plan for 2025, Air Liquide has opened a new chapter of its history by inseparably linking growth and a sustainable future. Together with CO_2 capture and hydrogen, biomethane is part of the Group's portfolio of energy transition solutions to support the emergence of a low-carbon society.

Leveraging proprietary technologies and core expertises in gas separation, Air Liquide has entered the biomethane market in the early 2010's, focusing on biogas upgrading. The company has now developed competencies throughout the whole biomethane value chain via its 100 % subsidiary Air Liquide Biogas Solutions. It operates in three continents, and has integrated upstream processes such as anaerobic digestion to control the molecule up to its upstream production, where major environmental stakes are concentrated. With an installed capacity of 1.8TWh/y across 26 biomethane production plants in 2023, our teams are proud to contribute everyday to the advancement of a low-carbon society.

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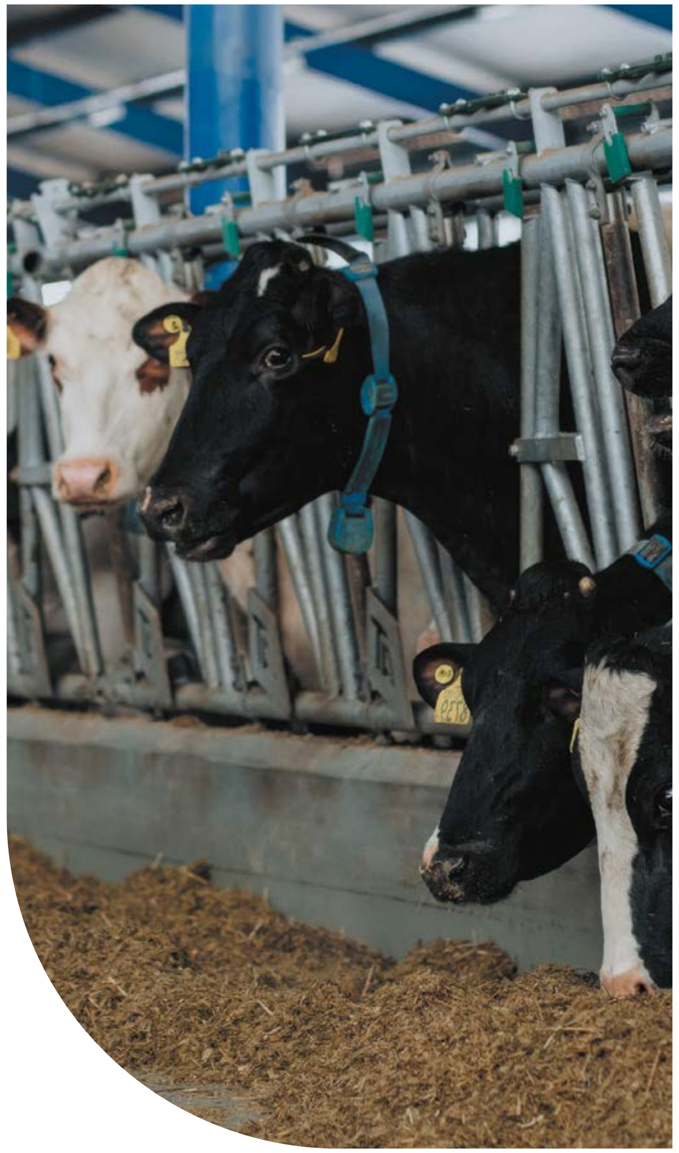
4.2. WWF France

WWF is one of the world's largest and most experienced independent conservation organisations. Its mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, with a philosophy based both on dialogue and action. WWF France has been working since 1973 to conduct concrete actions to safeguard natural spaces and species, promote sustainable lifestyles, inform decision-makers, support companies in the reduction of their ecological footprint and educate the youth.

As part of its transformational work with the private sector, WWF France has broadened its knowledge on biomethane since 2018 and more particularly on agricultural anaerobic digestion thanks to a partnership with GRDF. This collaboration enabled WWF France to develop a sustainability framework to guide the development of this sector. By leveraging further collaborations, WWF France brings its expertise in order to extend this framework to industrial projects and calls for a sustainable production of biogas to reach its objective of 100% sustainable renewable energy by 2050.



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CONTACT US

35-37 rue Baudin
93310 Le Pré-Saint-Gervais
www.wwf.fr

75 quai d'Orsay
75321 Paris Cedex 07
www.airliquide.com

WWF

Air Liquide