Biogas Outlook 2023

Production and use of biogas in Denmark 2022-2035

Biogas Danmark

Preface

The Biogas Outlook 2023 focuses on the expected development and effects of biogas production and use towards 2035.

Biogas Outlook 2023 provide a comprehensive insight into the development of production and use of biogas based on available bioresources, including the potential of utilizing captured CO_2 from biogas for CO_2 storage (CCS) and Power-to-X (CCU).

The publication also conveys a significant amount of data and factual information about the derived effects of biogas regarding climate, agriculture, nutrient recycling, aquatic environment, economy, and market.

Biogas Outlook 2023 is not intended to be read from start to finish but rather as a book of reference for essential facts and data about the biogas sector in Denmark.

The focus on biogas is rapidly increasing, emphasizing the need for basic facts about biogas production and use. Biogas Outlook 2023 is an essential contribution to this.

Biogas Outlook 2023 is available in Danish and English versions under “fakta" on www.biogas.dk. Additionally, the website Biogas Data Online provides access to historical and current data on biogas production, gas consumption, the status of gas storage, stock exchange value, etcetera.

The scenarios in Biogas Outlook 2023 are based on the forecasts for biogas production and gas consumption in the Danish Energy Agency's Analysis Assumptions 2022 (AF22), and data from Aarhus University, University of Southern Denmark, Energinet, Evida, and several other sources.

The opportunities are described in two scenarios:

1. "The Danish Energy Agency scenario" based on the Danish Energy Agency’s forecast for biogas production and the expected gas consumption described in AF22.

2. " Biogas Danmark scenario" describes the consequences of Biogas Danmark's proposal to shift from a subsidy scheme driven to a market pull policy.

The shift in framework conditions is proposed to be implemented from 2025 in the form of increased CO_2 reduction obligations in the transportation sector and CO_2 tax refunds for biogas delivered via the common gas grid.

Best regards!

Henrik Høegh
Chairman

Frank Rosager
CEO

Biogas Danmark

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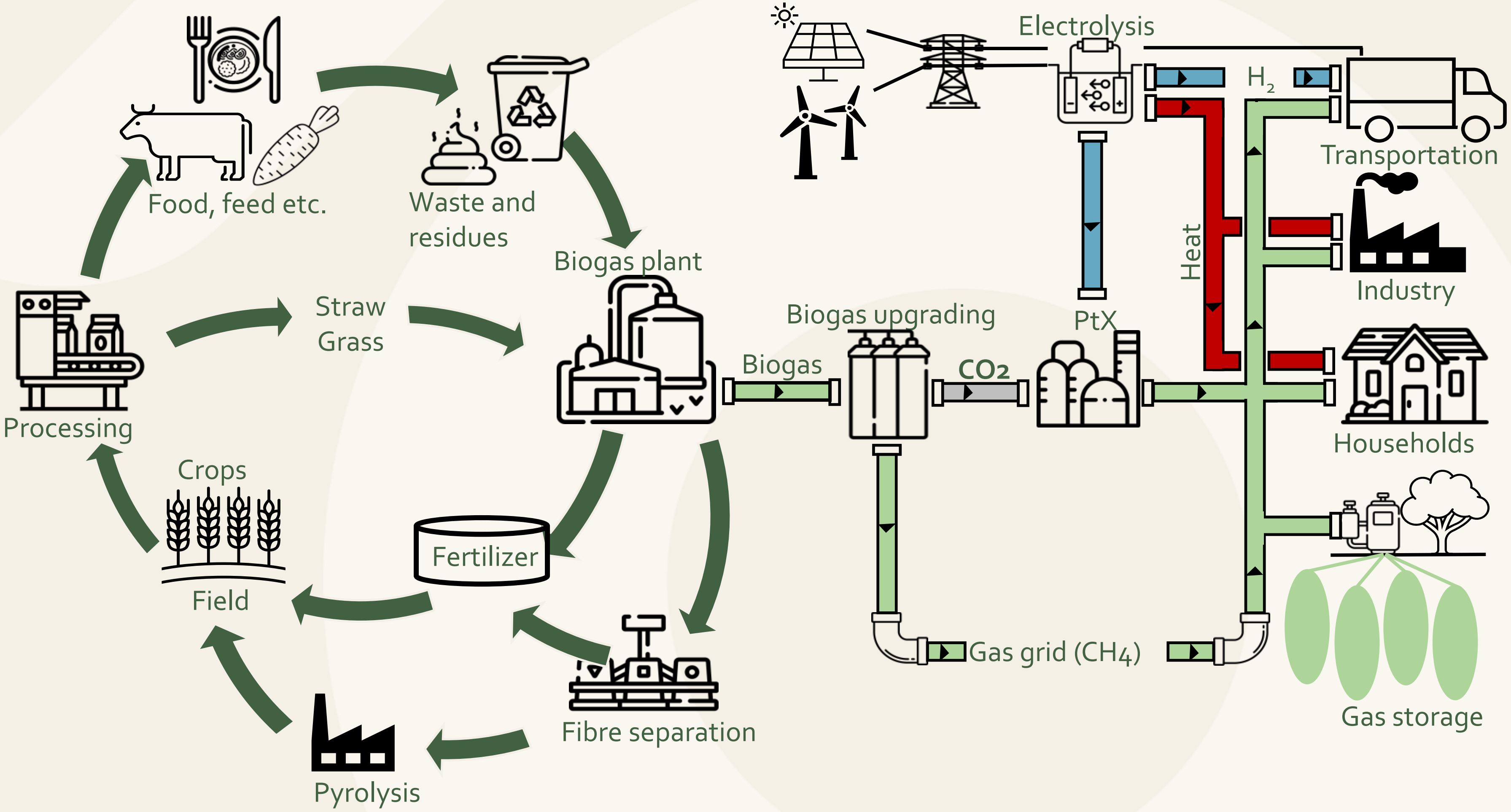
Biogas supply chains

Biogas is circular economy in practice

The Danish biogas plants play a crucial role in handling livestock manure and residues from households, industry and agriculture. The biogas plants ensure that nutrients in waste and residues are recycled and reused as fertilizers in agriculture.

At the same time, the energy content in the biomasses is utilized to produce biogas, which substitutes for fossil fuels.

Before injecting the biomethane into the gas grid, the biogenic CO2 is separated. The sector is actively developing the use of this CO2 for the production of Power-to-X fuels and CO2 storage.



The Danish biogas sector is a strong example of circular economy in practice.

The biogas is injected as biomethane in the gas grid. In addition the biogenic CO2 can effectively substitute for electricity in PtX fuels

Summary

Biogas Danmark: From subsidy schemes to market pull

A comprehensive package consisting of four initiatives.

In spring 2023, Biogas Danmark proposed a package of several initiatives to shift the development of biogas production from being based on subsidies to being driven by market demand:

1. The biogas tenders that have been agreed upon should be implemented as fast as possible with the aim of completing them by 2024. At the same time, the timeframe should be shortened from 20 to 10 years, meaning that the subsidy will end in 2035.

2. The CO_2 reduction obligation for the transportation sector should be increased, and the sustainability criteria (ILUC requirements) should be tightened.

3. CO_2 tax refunds should be guaranteed for unsubsidized biogas delivered via the gas network and documented with origin guarantees.

4. No CO_2 tax should be imposed on livestock manure when it is anaerobically digested in biogas plants.

The proposal is expected to significantly increase the production of unsubsidized biogas, reaching 17 PJ in 2030 and 30 PJ in 2035.

Agreed subsidy and Biogas Danmarks proposal

New subsidy (million DKK)	2024	2025	2026	2027	2028	2029	2030	2031-2050	Total
Planned biogas tenders	**200**	**120**	**0**	**75**	**75**	**90**	**88**	**10.047**	**12.960**
Annual subsidy	200	320	320	395	470	560	648		
Proposal from Biogas Denmark	**172**	**303**	**172**	**0**	**0**	**0**	**0**	**1.944**	**5.832**
Annual subsidy	172	476	648	648	648	648	648		
Reduced subsidy	31	-159	-328	-253	-178	-88	0	8.103	**7.128**
New biogas (PJ)									
Planned biogas tenders	**2,9**	**1,7**	**0,0**	**1,1**	**1,1**	**1,3**	**1,3**	**189**	**231**
Annual production	2,9	4,6	4,6	5,7	6,8	8,1	9,4		
Proposal from Biogas Denmark	**2,5**	**4,4**	**2,5**	**0,0**	**0,0**	**0,0**	**0,0**	**200**	**260**
Annual production	2,5	6,9	9,4	9,4	9,4	9,4	9,4		

The rows "Planned Biogas Tender" and "Proposal from Biogas Danmark" indicate the years from which the subsidies will be paid out. Support will be provided for 20 years from the initial payment.
Biogas Danmark propose to change the tenders giving a much faster growth in the biogas production. Shortening the subsidy period to 10 years can save a total of 6.5 billion DKK. This can compensate for the lower CO_2 tax revenue when tax refunds are given for climate-neutral biogas.

Summary

Two Scenarios - Danish Energy Agency and Biogas Danmark

This section outlines the basic assumptions and main outlines for the two scenarios.

Danish Energy Agency Scenario (AF22)

The Energy Agency Scenario is based on the Energy Network Analysis Assumptions 2022 (AF22). These reflect the Energy Agency's expectations for future gas consumption.

The development in gas consumption is based on AF22. (1)

This Scenario involves a development in biogas production based on the Energy Agency's forecasts for both the existing subsidy scheme and the planned biogas tenders until 2030 (2).

As the Danish Energy Agency's (DEA) forecasts only include details on the use of livestock manure, Biogas Danmark has depicted the use of other available bioresources. This feedstock composition is based on data from the most recent reporting to the DEA of feedstock used in Danish biogas plants. (2)

Biogas Danmark has estimated the effect on climate, potentials for CO_2 storage, Power-to-X, pyrolysis, etcetera.

Biogas Danmark scenario

The Biogas Danmark Scenario is based on the Energy Agency's forecast on gas consumption.

The development in biogas production is based on Biogas Danmark's policy proposals to bring forward and shorten the upcoming biogas tenders and simultaneously strengthen the framework conditions for the sale of unsupported biogas. This approach will contribute to faster growth in biogas production.

Due to high gas prices in the coming years, Biogas Danmark expects faster production capacity utilization capacity at existing biogas plants and new framework conditions, especially in the transport market, which can lead to increased production and use of unsupported biogas from 2027.

The development in gas consumption in the Biogas Danmark Scenario is based on the intensified focus on phasing out gas consumption in both the heating supply and industry.

Summary

Effects of biogas growth

Increased biogas production give significant climate and environmental benefits

Both scenarios for expanding biogas production show significant benefits in substituting fossil gas, reducing Denmark's climate footprint, reducing the leaching of nitrates to the aquatic environment and increasing the recycling of nutrients.

The Biogas Denmark Scenario assumes the same reduction in gas consumption up to 2035 as the Energy Agency Scenario but assumes faster growth in biogas production. From 2027, production will exceed gas consumption by existing gas customers, and the increased production is supposed to be used in heavy duty transportation.

At the same time, captured biogenic CO_2 from the biogas can enable the storage of large amounts of surplus electricity via Power-to-X or provide an additional climate effect of up to 2.2 million tons of CO_2 if this CO_2 is stored underground via CCS.

Environmentally, there is a basis for reducing nitrate leaching to aquatic environments by 1,600 tons of N, and recycling 8,000 tons of phosphorus from waste and residues in addition to the 29,000 tons recycled in livestock manure. A total of 37,000 tons of phosphorus, which is both a scarce and vital resource.

Effects of biogas expansion	Danish Energy Agency		Biogas Danmark	
	2022	2030	2030	2035
Biogas production, PJ	**29**	**52**	**57**	**60**
Share of biogas in the gas grid, pct	32	100	100	100
Gas consumption, PJ	**77**	**52**	**57**	**60**
Of which from the gas grid	70	43	37	29
Of which outside the gas grid	6	7	3	1
Of which available for transport and export	1	2	17	30
PtX potential, PJ				
E-methane	15	30	36	40
E-methanol	8	16	19	21
Net climate effect (mil. tonnes of CO_2-eq)	**1,8**	**4,4**	**5,3**	**5,9**
Of which fossil substitution	1,8	3,1	3,8	4,5
Of which pyrolysis gas	0,2	0,4	0,4	0,4
Of which reduction in agriculture	0,2	1,0	1,1	1,2
Of which biochar	0,1	0,3	0,3	0,3
Of which methane emissions and own consumption	-0,5	-0,4	-0,4	-0,4
Reduction potential (mil tons of CO_2-eq)				
CCS potential	0,8	1,7	2,0	2,2
PtX e-methane potential (transport)	1,1	2,2	2,7	2,9
PtX e-methanol potential (transport)	0,6	1,2	1,4	1,6
Circular economy				
Reduced nitrogen emissions, tonnes N	400	1.475	1.600	1.650
Phosphorus content in digested biomass, tonnes P	18.224	35.230	37.450	37.450

Biogas Danmark

Summary

Denmark's GHG reduction deficit

In its 2023 evaluation, the ´Danish Council on Climate Change highlights that Denmark will not meet the EU's climate requirements.

In its annual evaluation of the government's climate initiatives, Klimarådet concludes that even if both the 2025 and 2030 targets are met, Denmark will still lack a reduction of over 6 million tons of CO2e to meet EU requirements for reductions of greenhouse gases outside the ETS sector and LULUCF from 2021 to 2030. (3)

The Council on Climate Change also finds it unlikely that Denmark's climate target for 2025 can be met.

The table on the right shows the Climate Council's expected shortage in GHG reduction to fulfil Denmark's national climate targets in 2025 and the EU requirements for reductions in the non-ETS sector.

The national 2025 climate target is the average for 2024 to 2026. The shortfall indicates how much Biogas Danmark's policy proposals can reduce the shortfalls estimated by the Climate Council.

Biogas Danmarks policy proposals can close the gap

Climate Council calculation	Danish target	EU requirements 2021-2030	
Million tonnes of CO_2	2025	Accumulated Non-ETS	Accumulated ETS
Reduction target 50%, 2025*	**0,9**	**6,9**	
Reduction target 54%, 2025*	**4,0**	**6,1**	
Effects of Biogas Danmark's proposal			
CO_2 reduction obligations +2%**	0,7	5,6	0
Faster implementation of tender pools	0,2	0,5	0,5
CO_2 tax refund	0,4	1,2	1,2
In total	**1,3**	**7,3**	**1,7**

*The Danish Council on Climate Change status report 2023

** Agreement on green conversion of road transport

The Danish Climate Council's forecast in its 2023 evaluation is a shortfall in meeting Denmark's climate targets in 2025 and the EU's requirements for reductions in the non-ETS sector. The 2025 target is an average from 2024 to 2026.

The shortfall indicates how much Biogas Danmark's policy proposal can reduce the shortfalls estimated by the Climate Council.

Biogas Danmark

Summary

Production potential and demand of biogas in Denmark

The potential for biogas production in Denmark exceeds the current demand.

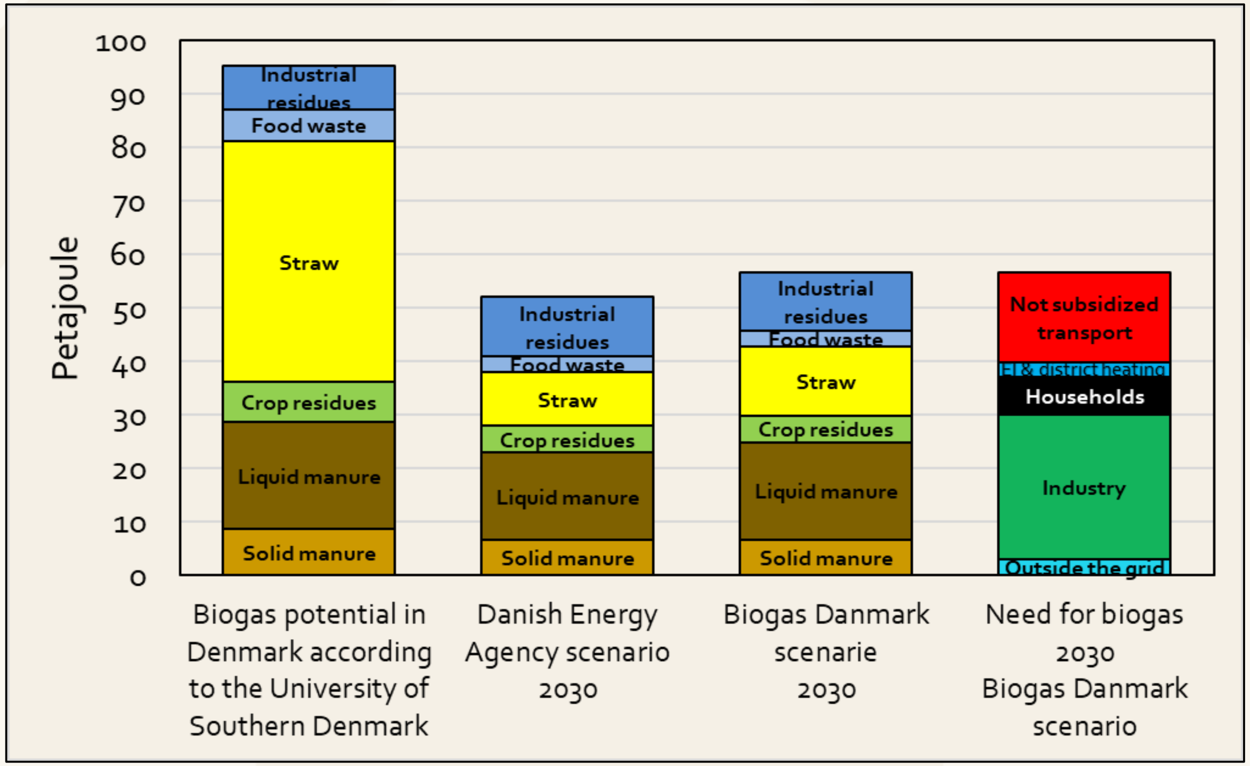
Biogas can be produced from bioresources such as livestock manure and residues from households, industry, and agriculture. The University of Southern Denmark has, in an expert report for the Danish Energy Agency (5), estimated that the biogas potential in these resources is 94 petajoules (PJ).

The abundant available resources in residues therefore exceed the Danish Energy Agency's expected biogas production of 52 PJ in 2030 and Biogas Danmark's policy proposal, which is expected to lead to a total biogas production of 57 PJ in 2030 and 60 PJ in 2035.

Currently, only a minor part of the straw from cereal production is utilized. New resources may become available in the future, such as grass from fields converted from cereal production.

The Biogas Danmark scenario makes it possible to meet the expected gas consumption, including 17 PJ of biogas for heavy duty transportation in 2030 and 30 PJ in 2035.

Biogas potentials, bioresources, and the need for biogas in 2030



The left column shows the biomass potential for biogas production estimated by the University of Southern Denmark (5). The two middle columns show the feedstock in 2030 in the Danish Energy Agency and Biogas Danmark scenarios, respectively. The right column shows the use of the produced biogas in the Biogas Danmark scenario.

Biogas Danmark

Summary

Development in biogas production and bioresource

Biogas Danmark's expectations to future feedstock

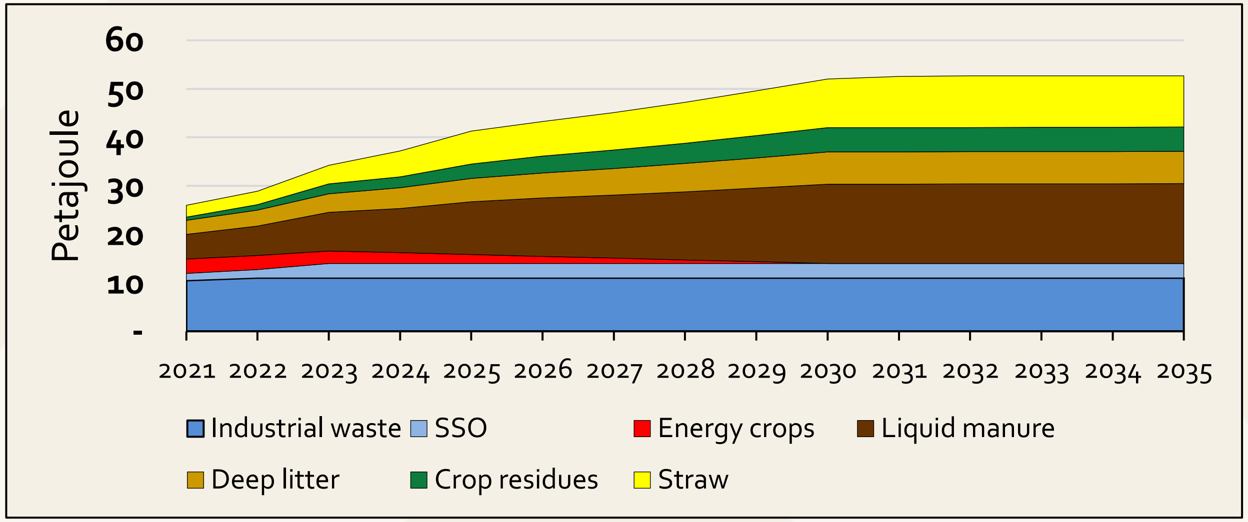
The Danish Energy Agency predicts that Danish biogas plants will produce 52 petajoules (PJ) in 2030 and that biogas production development will stabilize on his level.

Biogas Danmark assumes that 52 PJ will be produced from 2027 due to high gas prices and the progress of the biogas supply.

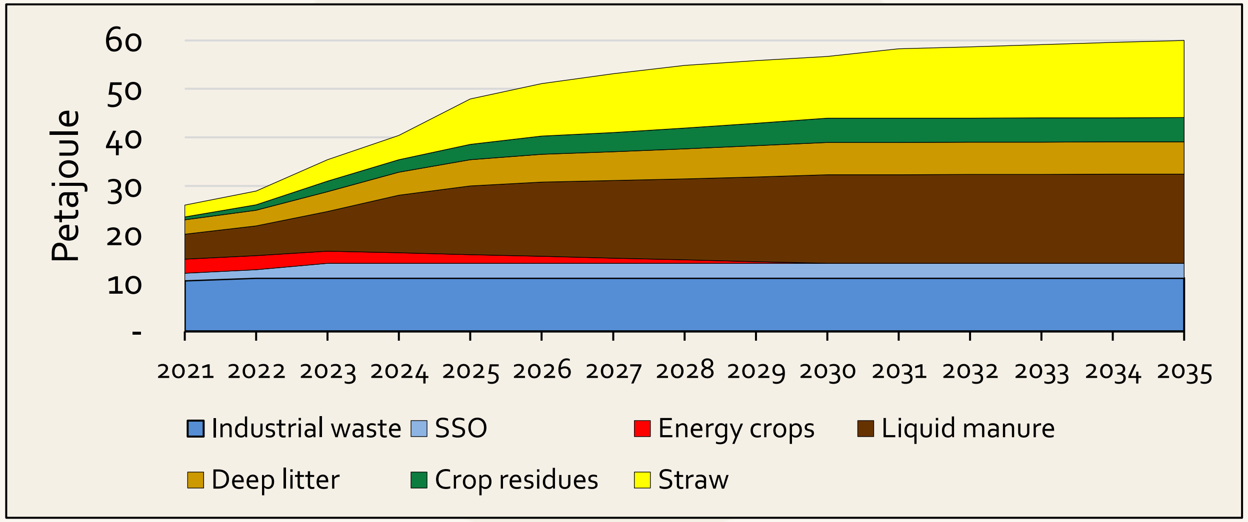
In both scenarios, the increase in biogas production leads to increasing use of livestock manure and crop residues from agriculture as feedstock. Especially in the Biogas Danmark scenario, there is also an increasing use of straw as feedstock.

Food waste from households, the service sector, and retail (SSO) and industrial waste are expected to be fully utilized by 2025, while energy crops are expected to be phased out by 2030.

Biogas production split on bioresources in PJ - Energy Agency Scenario



Biogas production split on bioresources in PJ - Biogas Danmark Scenario



Summary

Share of renewable energy in the gas system

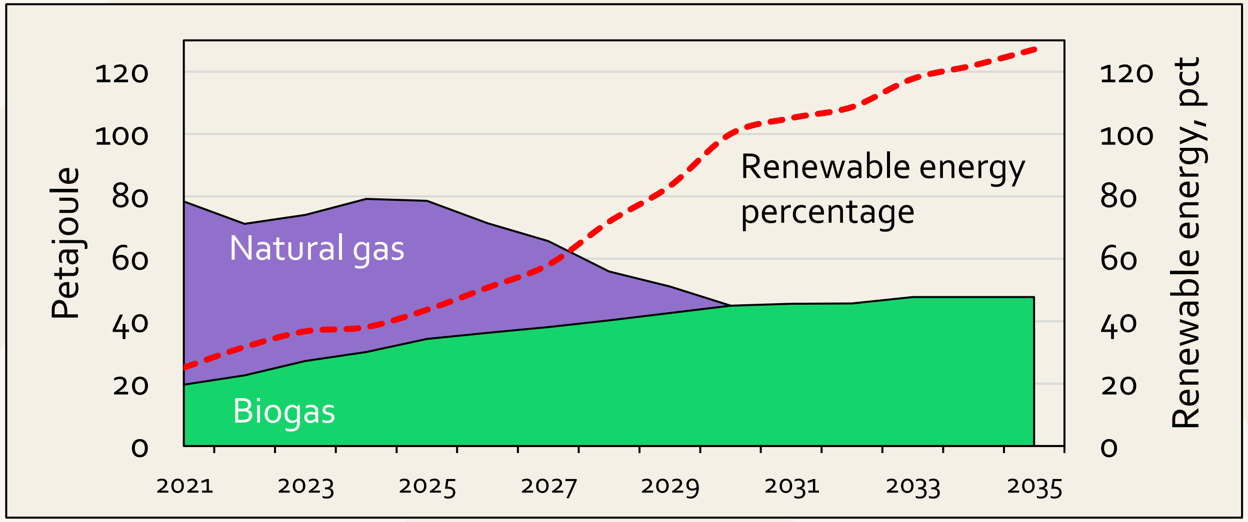
100 per cent renewable energy in gas grid from 2027 in Biogas Danmark's scenario

The increase in gas consumption is based on AF22 in both scenarios.

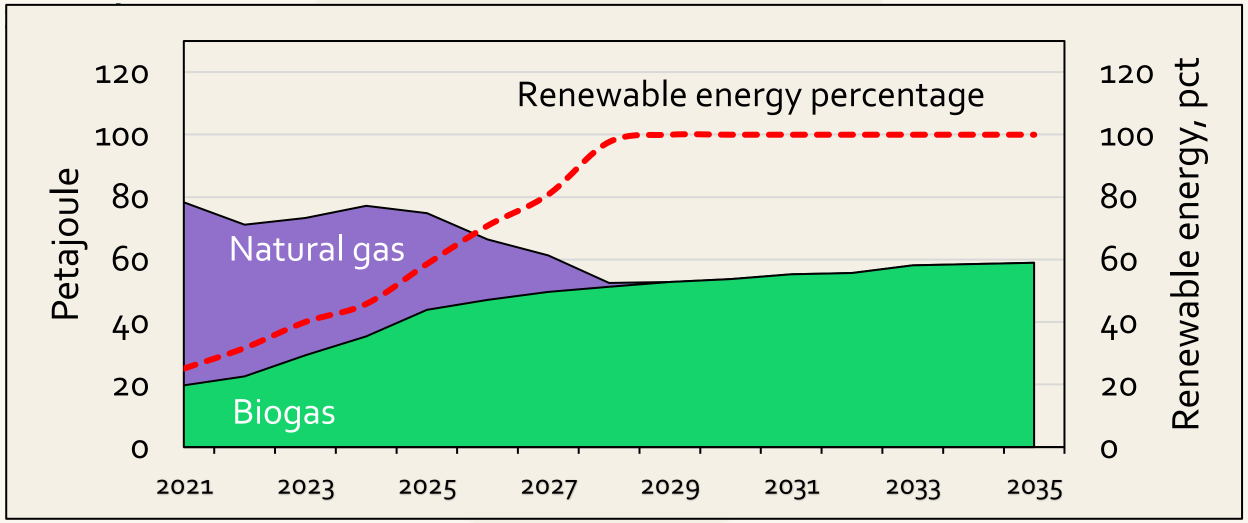
The Danish Energy Agency's scenario results in 52 PJ biogas in the gas grid from 2030, covering the entire Danish gas consumption. From 2030 onwards, there is an increasing surplus of biogas, which is expected to be exported.

In the Biogas Danmark scenario, the share of renewable energy in the gas system reaches 100 percent as early as 2027, giving independence from fossil gas three years earlier than the Danish Energy Agency's forecast. From 2027 onwards, an increasing volume of biogas will be used for the green transition of heavy duty transportation.

Future gas consumption and biogas supply in grid - Energy Agency Scenario



Future gas consumption and biogas supply in grid - Biogas Danmark



The consumption of gas will decrease in the coming years and within this decade biogas will cover the demand.. The share of biogas in the total gas consumption is shown with a dotted line.

Biogas Danmark

Summary

Climate effect of biogas

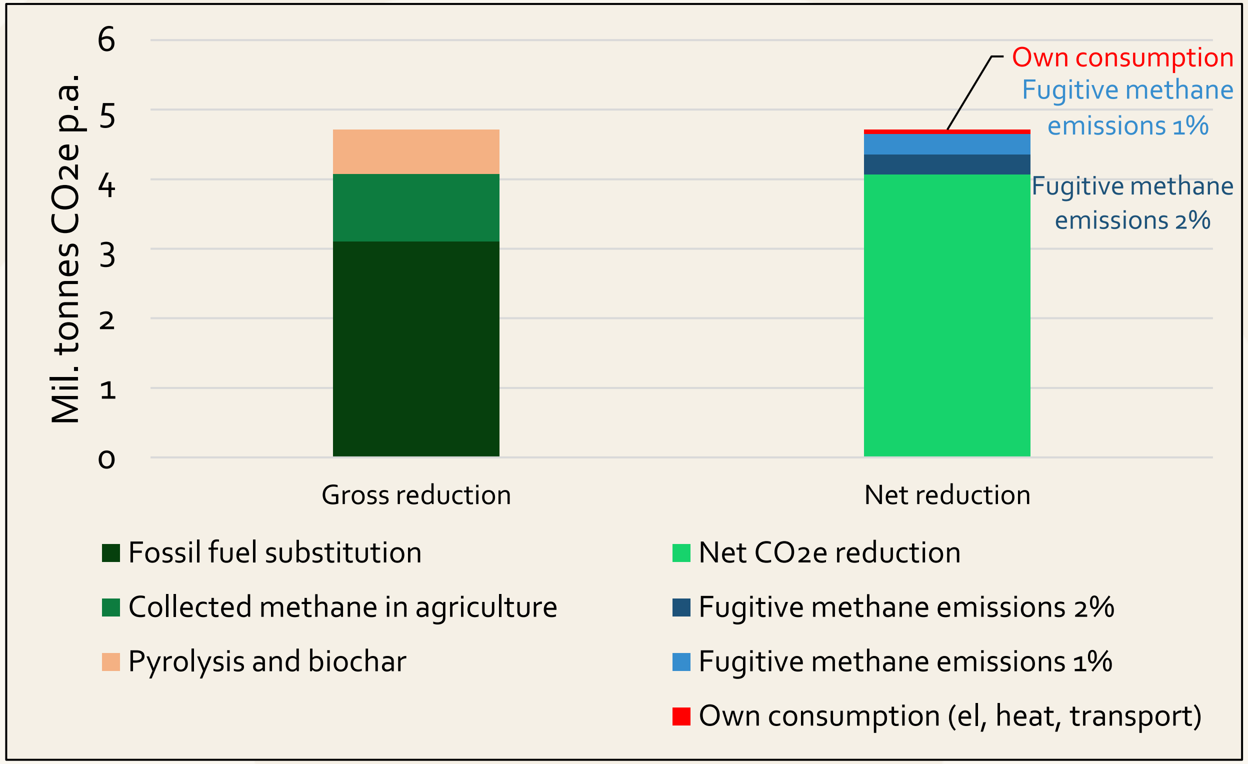
The net climate effect of biogas is greater than the CO_2 reduction from substituting fossil fuels.

Substitution of natural gas with biogas reduces the emission of CO_2. In addition, the methane emission from the storage of livestock manure is reduced when the manure is digested anaerobically in biogas plants. Biogas production does, however, also give greenhouse gas emissions due to methane leakage and energy consumption for process energy and the transport of feedstock and digestate.

The net climate effect is calculated when subtracting the CO_2 emissions from the biogas plants' energy consumption and methane leakages from the gross climate effect. The net climate effect is shown in the figure with methane leakages of 1 and 2 per cent.

In the Energy Agency scenario, the production of 52 petajoules of biogas in 2030 will reduce the CO_2 emission from the substituted fossil fuels with more than 3 million tons of CO_2 and reduce the methane emissions in agriculture by about 1 million tons of CO_2e. Biogas production therefore leads to a net reduction of about 4.1 million tons of CO_2e at a methane loss of 2 percent. Therefore, the use of biogas is climate-neutral.

Gross and net climate effect of biogas in 2030 - Energy Agency Scenario



The gross and net greenhouse gas reductions for the Energy Agency scenario show that biogas that substitutes fossil gas is net climate-neutral at a methane loss of 2 percent.

A new regulation to control and minimize fugitive methane emission came into force by January 1st 2023 aiming to reduce the leakage to 1 per cent. In a survey in 2020-21 it was measured to be on average 2 per cent in agricultural biogas plants [7]

Biogas Danmark

Summary

Climate footprint gas and electricity in Denmark

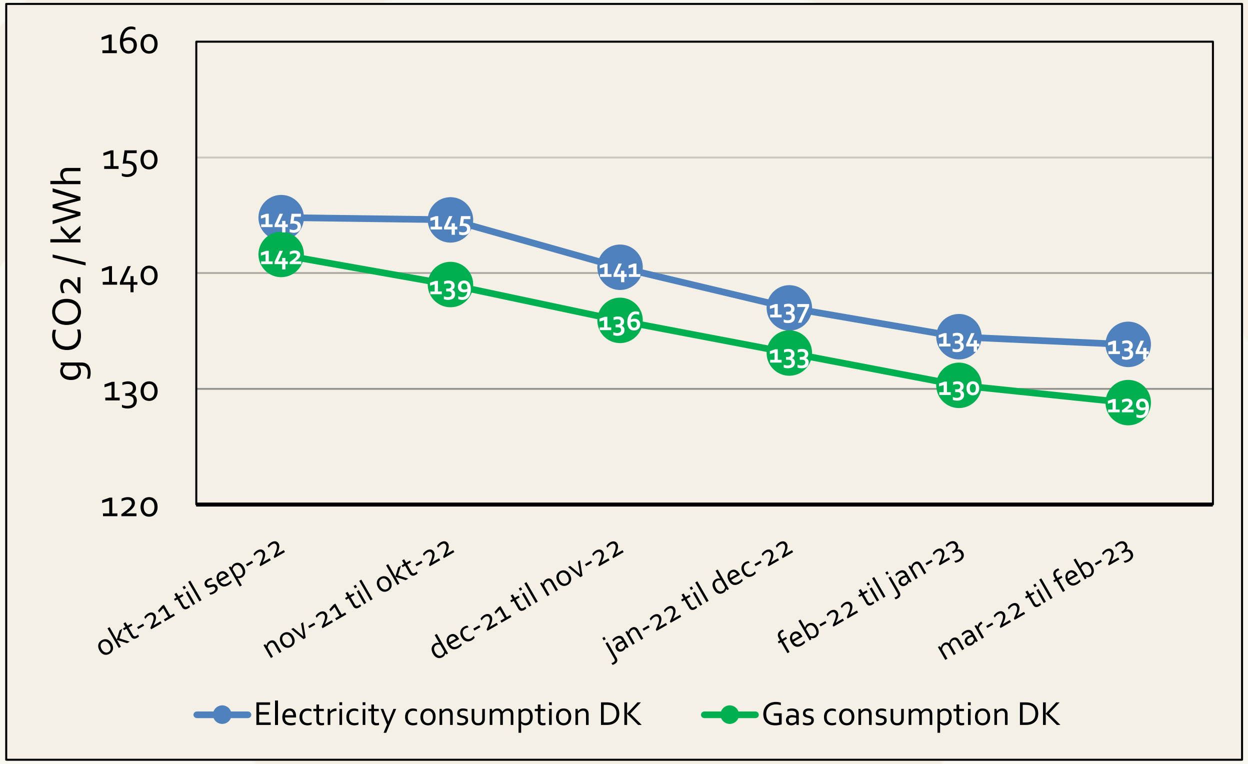
In Denmark the gas and electricity consumption has roughly the same carbon footprint.

For more than a year, the climate impact of Danish gas and electricity consumption has been less than 150 grams of CO_2/kWh. For each month, the footprint is calculated as an average over the previous 12 months. (8, 9)

Gas consumption has decreased due to high gas prices and political initiatives, while biogas production is steadily increasing. This leads to a constant decrease in the climate impact of Danish gas consumption.

The climate impact of electricity consumption is less constant, as it is affected by water resources for Norwegian hydroelectric power plants, wind and solar resources in Northern Europe, and especially gas, coal, and CO_2 quota prices.

Accumulated climate footprint for gas and electricity consumption in 2022-2023.



The figure shows the CO_2-intensity of gas and electricity consumption. For each month shown, the intensity indicates the average for the previous 12 months period. For electricity, data is calculated and provided by Energinet (8, 9), while Biogas Danmark has calculated the climate impact of gas consumption based on data for the gas system supplied by Energinet. (10)

Biogas Danmark

Summary

Market value of biogas delivered through the gas grid

Development of market value and subsidy costs.

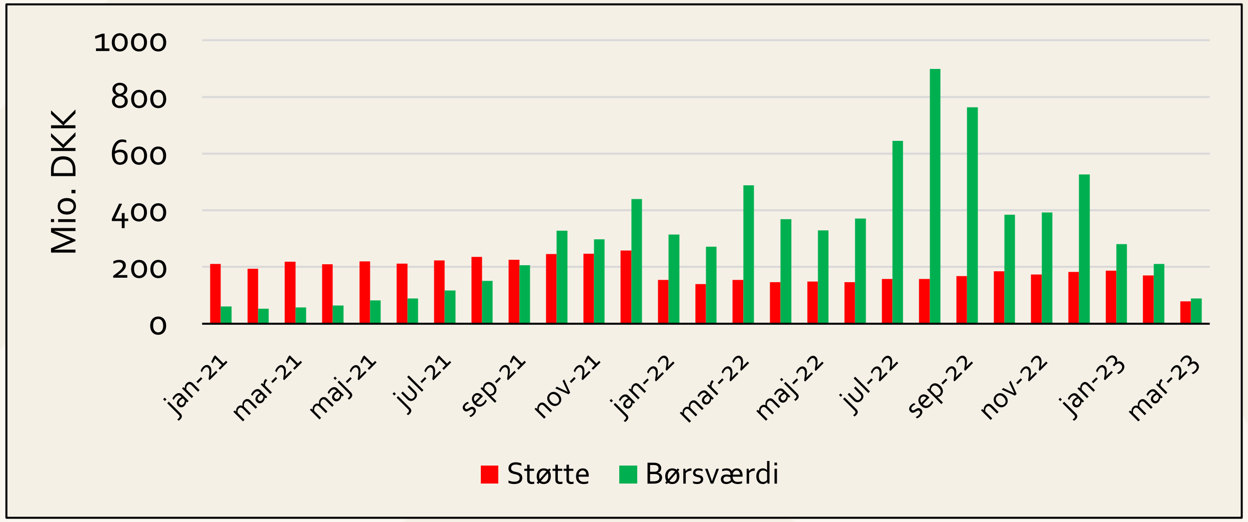
Due to the reduced gas supply from Russia to Europe in 2022, the gas prices on the European stock exchanges increased significantly. As a result, the value of the biogas delivered to the gas grid in 2022 substituting, fossil natural gas, had a value of DKK 5.7 billion. When the value of the biogas production used off grid is included, the value increases to almost DKK 8 billion.

The market value of biogas is volatile, but stock exchange prices remain significantly higher than before, and forward prices are expec-ted to remain high in the coming years. Gas prices are expected to remain high for some time, and subsidies will, therefore, likely stay low.

Since the delivery of natural gas from Russia is diminished, money has not been channelled out of Denmark or the EU to Russia. Instead, it has created value for biogas producers and, most importantly, for the many customers who have contracted with biogas producers for a fixed price.

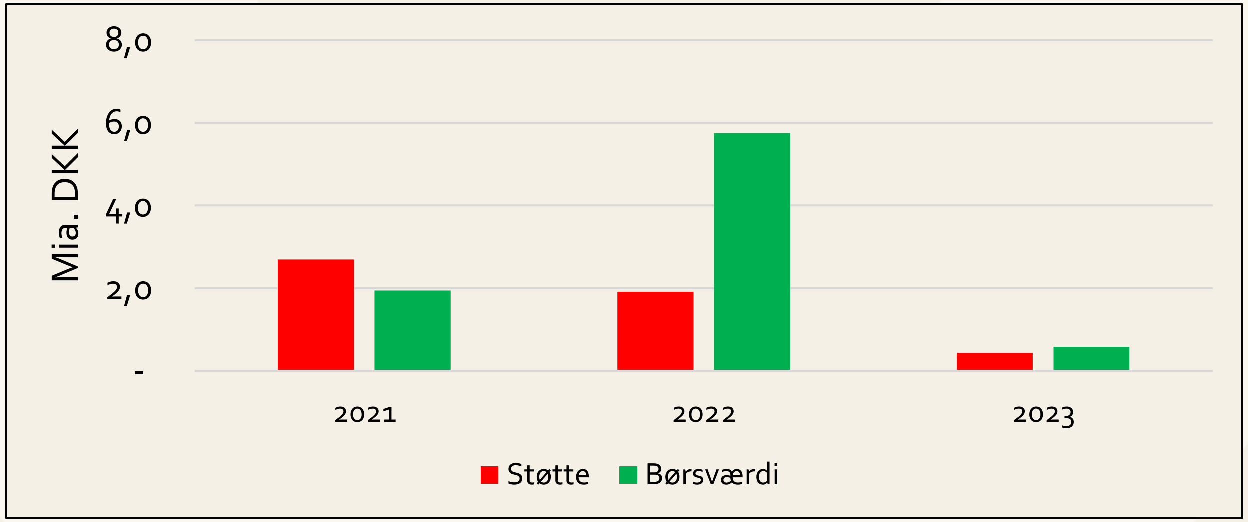
Due to the high gas prices the value of the biogas exceed the subsidies..

Market value of natural gas substituted by upgraded biogas in Denmark.



Since October 2021, the subsidy for biogas has been lower than the gas exchange value of the natural gas that biogas substitutes in the gas system. Sources: Energinet (biogas delivered to the gas grid) (10),Danish Energy Agency (subsidy) (11), and EEX Gas Market Data (exchange value) (12).

Market value of natural gas substituted by biogas in Denmark since 2021.



Gas consumption

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Gas consumption

Future gas consumption

Gas consumption is significantly decreasing.

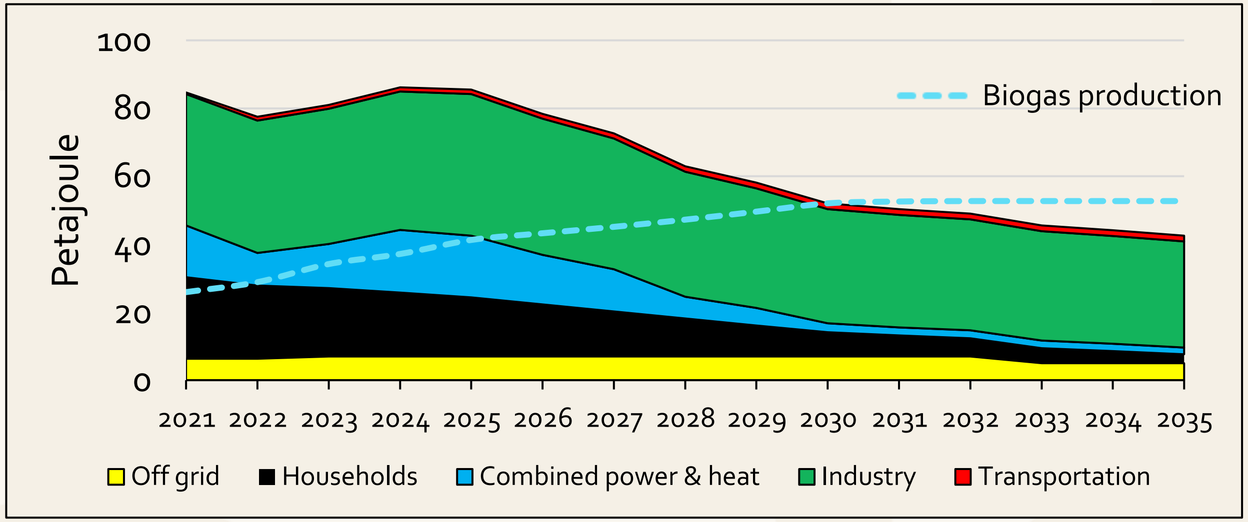
Gas consumption is predicted to decrease by about 30 petajoules (PJ) by 2030 and another 10 PJ by 2035, according to the Danish Energy Agency's forecast in AF22 (1).

This decline is due to political initiatives, such as support schemes and upcoming CO_2 taxes, aiming to phase out gas in private homes, district heating, and industry.

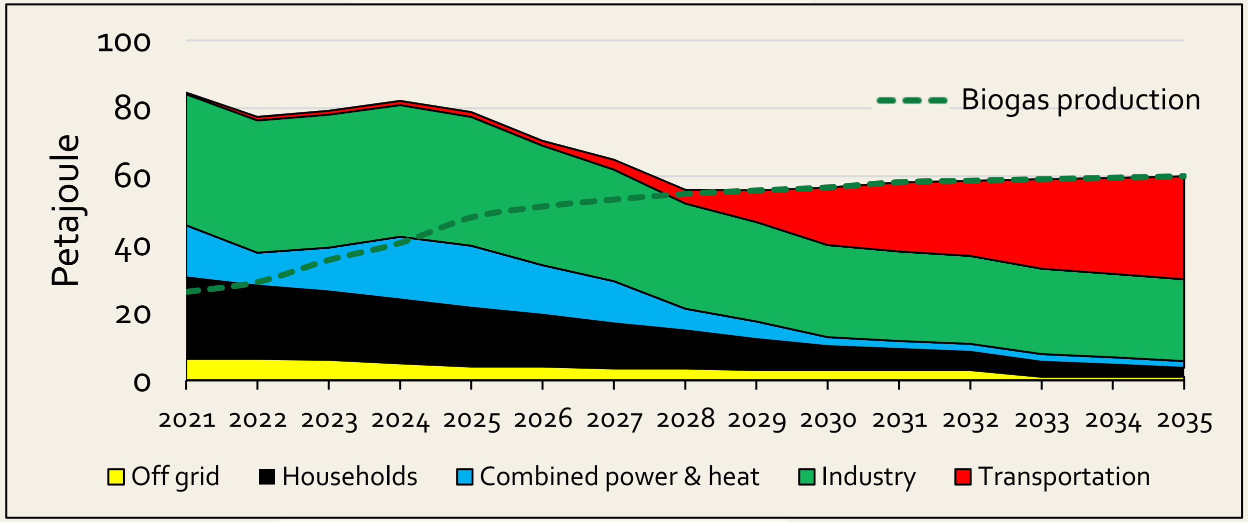
With the Energy Agency's forecast for biogas production, biogas will cover 100 percent of the expected gas consumption in 2030.

In the Biogas Danmark scenario, the gas consumption will be covered 100 percent with biogas from 2027. Increasing volumes of unsubsidized biogas will be delivered to the transport sector driven by increased CO_2 reduction obligations.

Future gas consumption and biogas production - Energy Agency scenario



Future gas consumption and biogas production - Biogas Danmark scenario



Biogas Danmark

Gas consumption

Need for energy storage

With the gas storage infrastructure biogas can meet the fluctuating gas demand between seasons.

There is a close correlation between ambient temperature and gas consumption fluctuations throughout the year (top figure). During the winter months, December to February, extra cold weather led to high daily gas consumption of 80-100 GWh. During the warm period from May to November 2022, the gas consumption was low: less than 50 GWh per day.

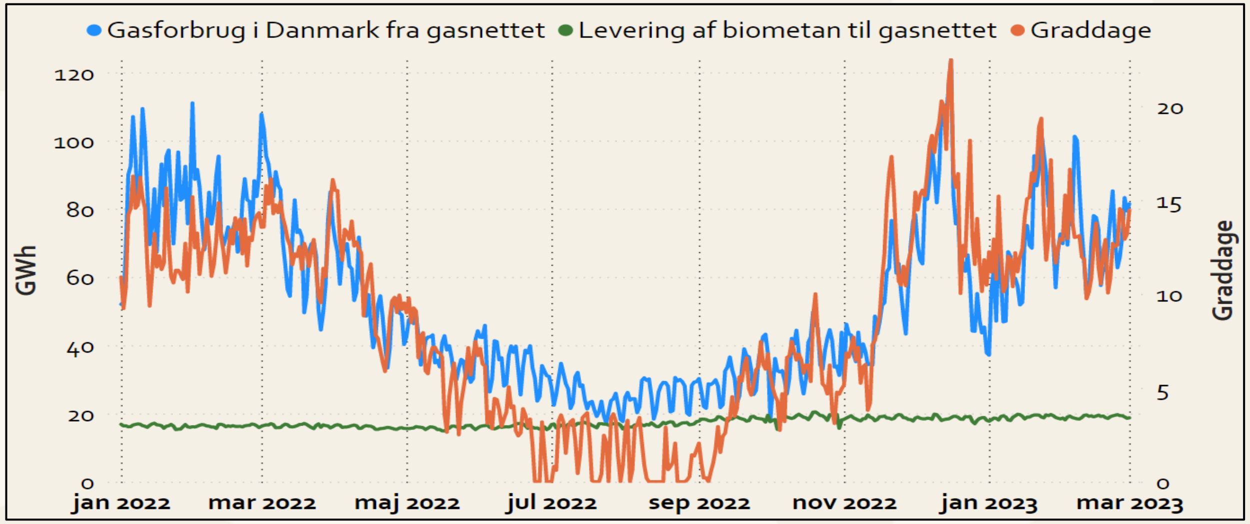
The ambient temperature and gas consumption fluctuations emphasize the need for a flexible energy system that can significantly increase and decrease energy deliveries throughout the year, as shown in the bottom graph. During cold periods, large amounts of energy were exported from gas stores, while energy was stored in the gas stores during warm periods.

Degree days measure how cold it has been and how much energy is used for heating. A degree day is defined as a difference of 1°C between the indoor temperature set at 17°C and the daily average outdoor temperature.

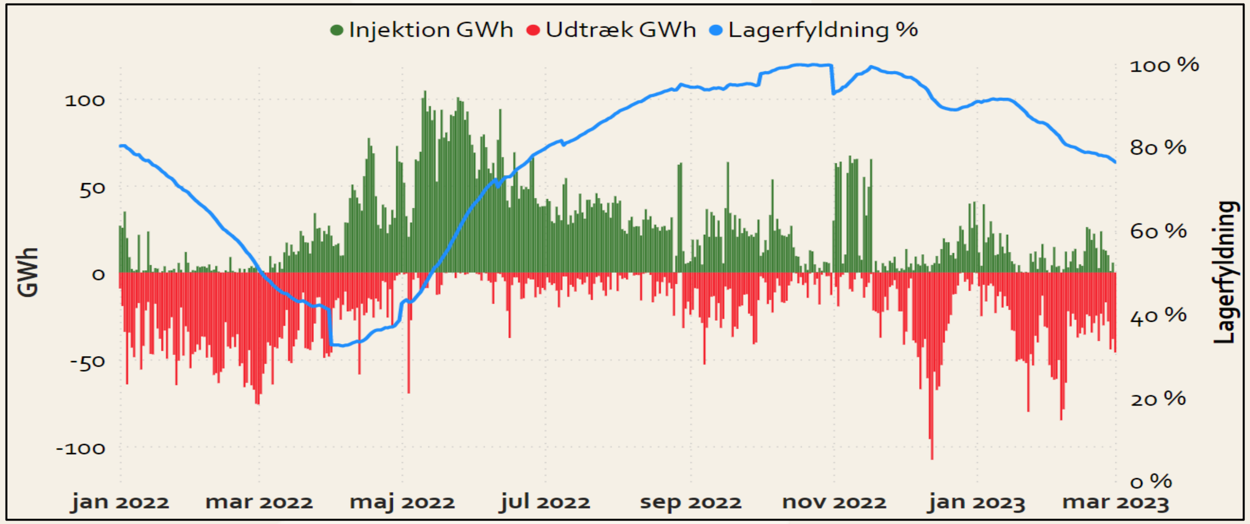
For more details, please visit Biogas Data Online at biogas.dk/biogas-data-online.

Biogas Danmark

Relation between degree days and gas consumption from Jan 2022 to Jan 2023 (13)



Withdrawals and injections in gas storage facilities from Jan 2022 to Jan 2023 (13)



Both figures are from Biogas Data Online

Gas consumption

Heavy-duty transportation

Biogas can enable a fast green transition.

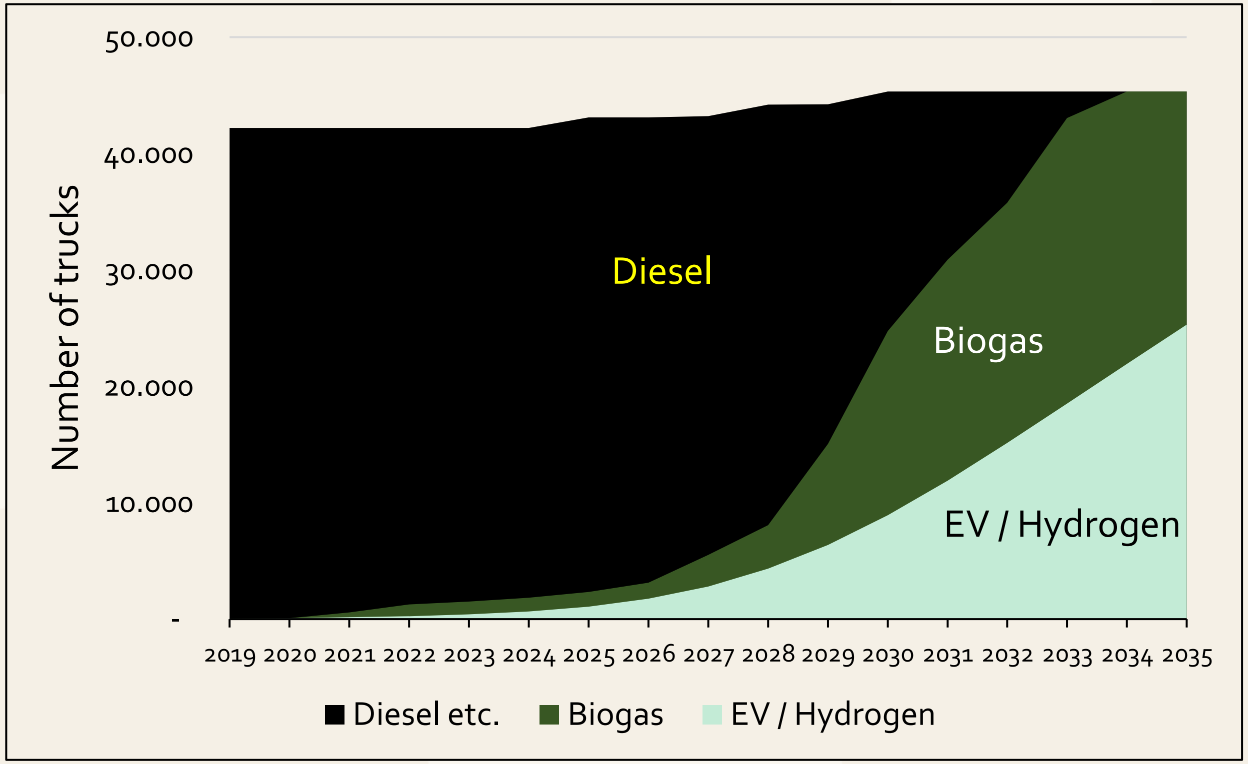
In recent years, there has been a gradually increasing interest in Denmark for converting trucks from fossil diesel to biogas. From January 1, 2022, it has been possible to deliver unsubsidized biogas as a transportation fuel due to an update of the Danish legislation, including the introduction of a CO2 reduction obligation.

According to an analysis of the transport sector by Green Power Denmark, from 2022, electric and hydrogen fuel cell trucks will only account for half of the total number of trucks by 2035. An extra effort is therefore needed to ensure the green transition of heavy transportation, especially in the heavyweight classes.

Biogas Danmark's analysis shows that Danish biogas plants can deliver 17 PJ of unsubsidized biogas to the transport sector in 2030 and 30 PJ from 2035. As the Danish Energy Agency expects an energy consumption of around 23 PJ for trucks in 2030, biogas can cover a large part of the energy consumption in the heaviest weight classes, and 2035 deliver a significant surplus of biogas to the maritime and aviation sectors.

This development requires an increase in the CO2 reduction obligation, and Denmark – in line with neighboring countries - will allow for a refund of the CO2 tax for biogas delivered by the gas grid.

Potential for biogas in road freight transport in Denmark.



According to an analysis from Green Power Denmark (14), approximately half of the Danish trucks are expected to be electric and hydrogen fuel cell trucks by 2035. There is plenty of biogas production potential to fuel the remaining fossil diesel trucks with un-subsidized biogas from 2030 until the electric and hydrogen fuel cell trucks are matured. According to the Danish Energy Agency's Climate Status and Projection 2022, diesel trucks are still expected to account for 79 percent of the truck fleet in 2035.

Biogas Danmark

Energy production and use of bioresources

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Energy production and use of bioresources

Biogas potential and production in the EU

Biogas is expected to contribute significantly to EU energy security in the REPowerEU plan

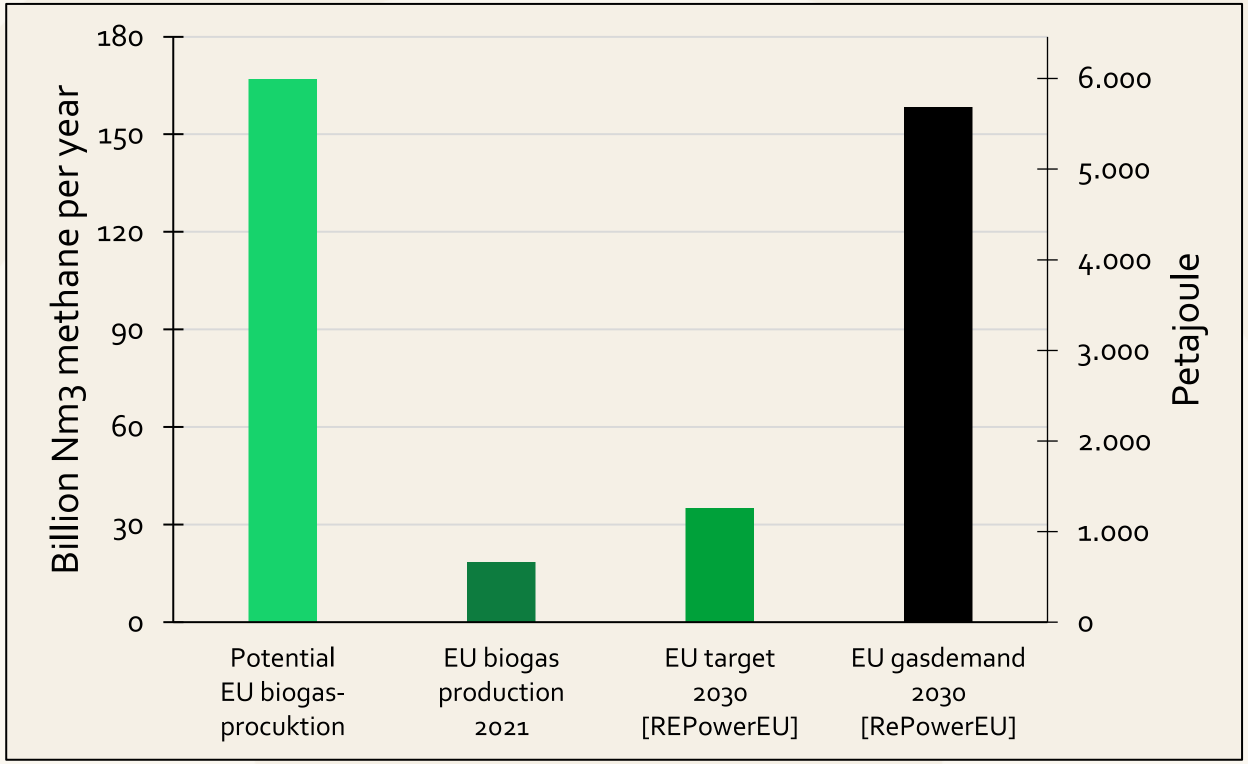
The European energy supply crisis has highlighted the necessity to reduce the European gas consumption and significantly increase biogas production.

According to an analysis by The European Biogas Association, the total European biogas production potential is 167 billion cubic meters. (15)

According to the REPowerEU plan, it is possible to reduce the gas consumption by 52 percent in 2030 to just under 160 billion cubic meters of biogas annually. (16) Theoretically, it is possible to cover the entire European gas consumption with biogas in the long term.

The European Union has set a target to increase the biogas production to 35 billion cubic meters of biomethane in 2030. (16)

Biogas production, potential, and demand in Europe



** EBA Statistical Report 2022* (15)
*** REPowerEU* (16)

Energy production and use of bioresources

Biogas production potential and demand in Denmark

Biogas can meet the gas demand

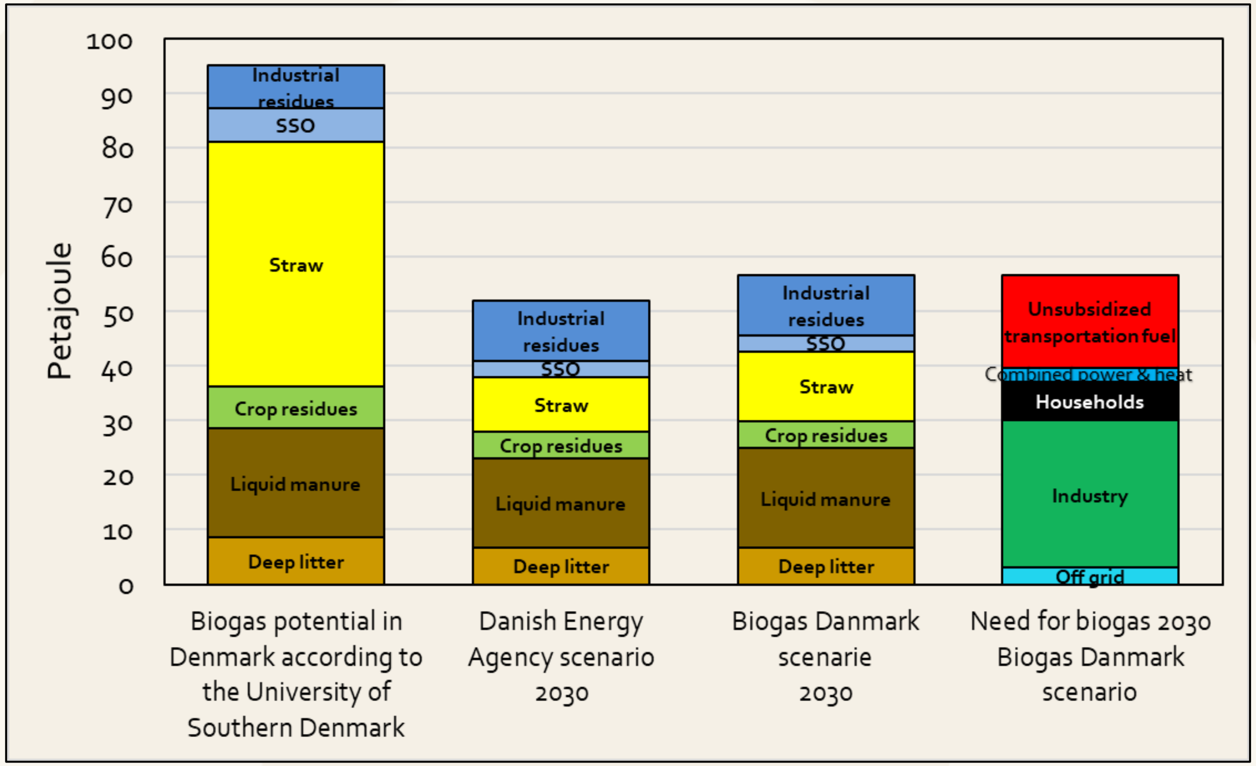
Bioresources such as livestock manure and residues from households, industry, and agriculture can be utilized in biogas plants. According to an analysis made by the University of Southern Denmark for the Danish Energy Agency. (5). the energy production potential in these resources is 94 petajoules (PJ .

There is therefore ample resources to meet the expected biogas production. Both the Danish Energy Agency's expectation of 52 PJ in 2030 and Biogas Danmark's expectation of 57 PJ in 2030 and 60 PJ in 2035.

Currently only a tiny fraction of the straw resource is utilized. In addition, new resources may become available in the future – such as from fields converted from cereal production to grass.

Biogas Danmark's recommendation makes it possible to cover the expected gas consumption, including 17 PJ of biogas for heavy duty transportation in 2030 and 30 PJ in 2035.

Biogas production potential in residues, and the need for biogas in 2030



The left column shows the available production potential for biogas as estimated by the University of Southern Denmark. (5) The two middle columns show the biomass input split into different feedstocks in 2030 in the Danish Energy Agency and Biogas Danmark scenarios, respectively. The right column shows the use of the biogas in the Biogas Danmark scenario.

Energy production and use of bioresources

Development in biogas production

Significant growth in the Danish biogas production from 2015

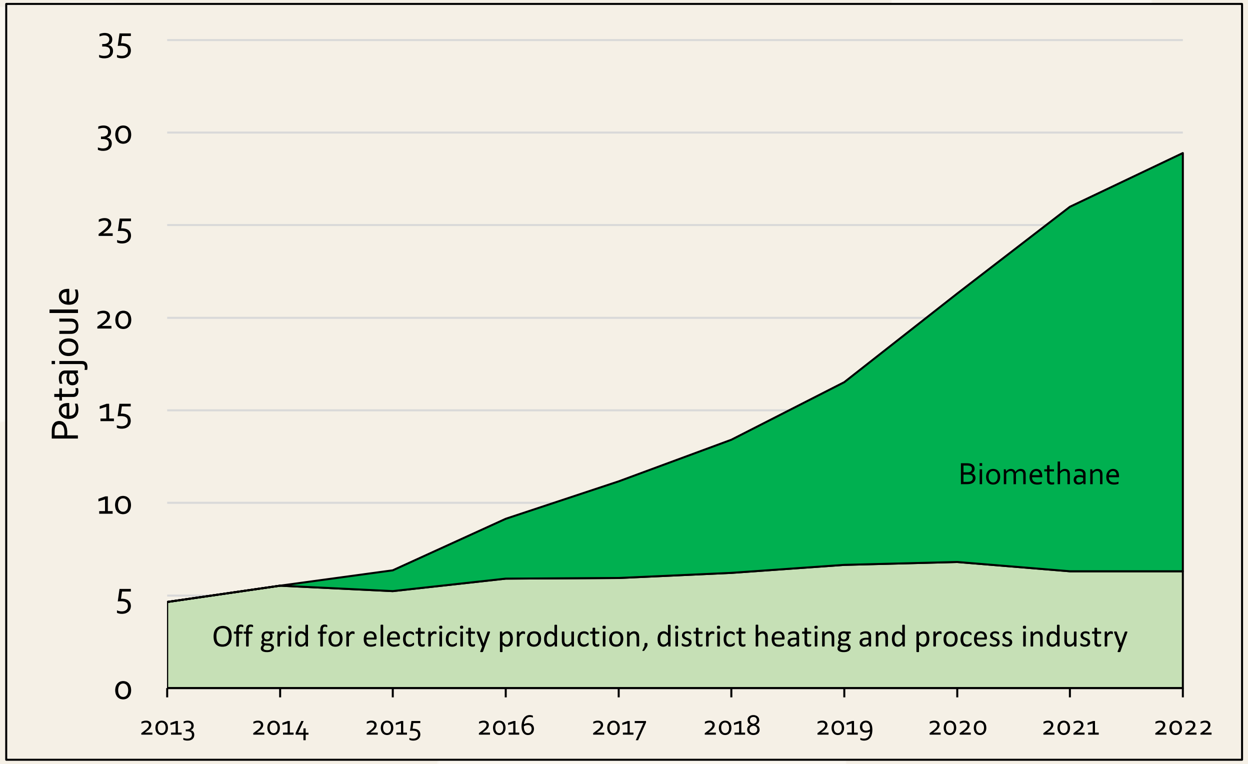
In 2012, a new subsidy scheme allowed biogas producers to inject upgraded biogas (biomethane) into the gas grid. (17)

Since then, biogas production has continuously grown from 5 petajoules in 2014 to 29 petajoules in 2022, where biogas accounted for approximately 40 percent of the total gas consumption.

In 2023 upgraded biogas is expected to account for 40 per cent of the gas consumption delivered through the gas system (27 PJ). In addition, an off grid production of approximately 6 to 7 petajoules of biogas is expected to be used directly for combined heat and power production and process energy in industry.

Overall, it is realistic that biogas's share of the grid-based gas consumption (excluding bottled gas) will exceed 45 percent in 2023 and reach 50 percent by the end of 2024.

Development of biogas production in Denmark since 2013



There are approximately 180 biogas plants in Denmark.

- 100 agriculture-based biogas plants, of which 55 upgrade to biomethane
- 49 wastewater treatment plants, of which 2 upgrade to biomethane
- 7 industrial biogas plants, of which 1 upgrade to biomethane
- 27 landfills where biogas is collected

Plants without upgrading typically produce power and heat in CHP plants or in industry

The overview of biogas plants in Denmark in 2022 by the Danish Energy Agency :
https://ens.dk/sites/ens.dk/files/Bioenergi/liste_over_biogasanlaeg_i_dk.pdf (18)

Biogas Danmark

Energy production and use of bioresources

Biogas production by biomass resources – DEA*

One-third of the biogas is produced from livestock manure

While livestock manure accounts for about three-quarters of feedstock for the biogas plants in tonnes, it only delivers about one-third of the gas.

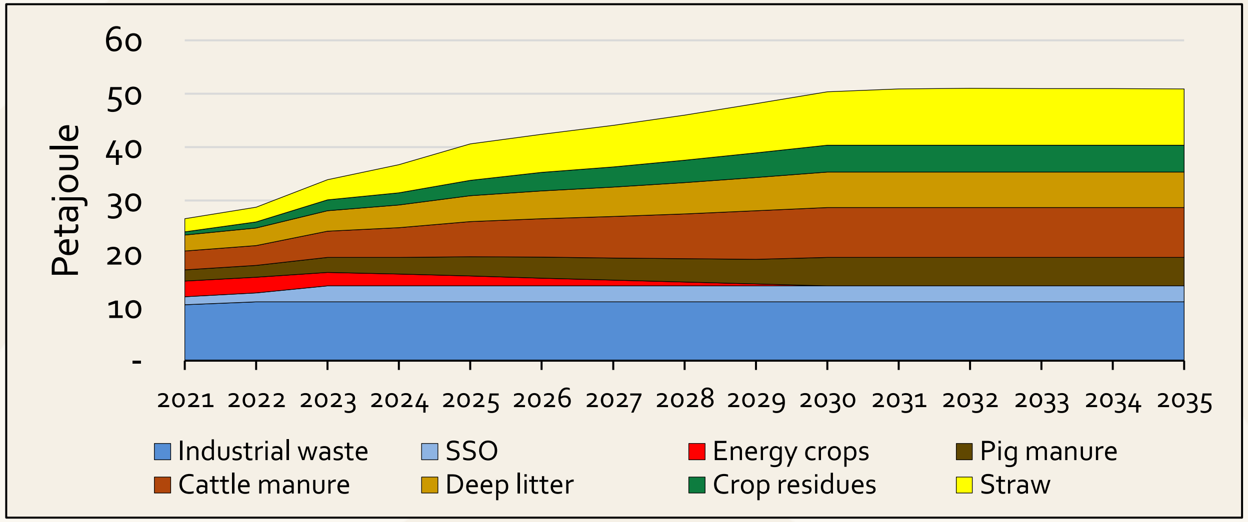
The biogas is produced by anaerobic digestion of the organic matter in the feedstock. Therefore, the biogas yield is lower per tonne of fresh weight feedstock than drier biomasses such as deep litter, straw, industrial residues and household food waste.

Pig slurry delivers about 10 percent of biogas production. Energy crops will be completely phased out by 2030.

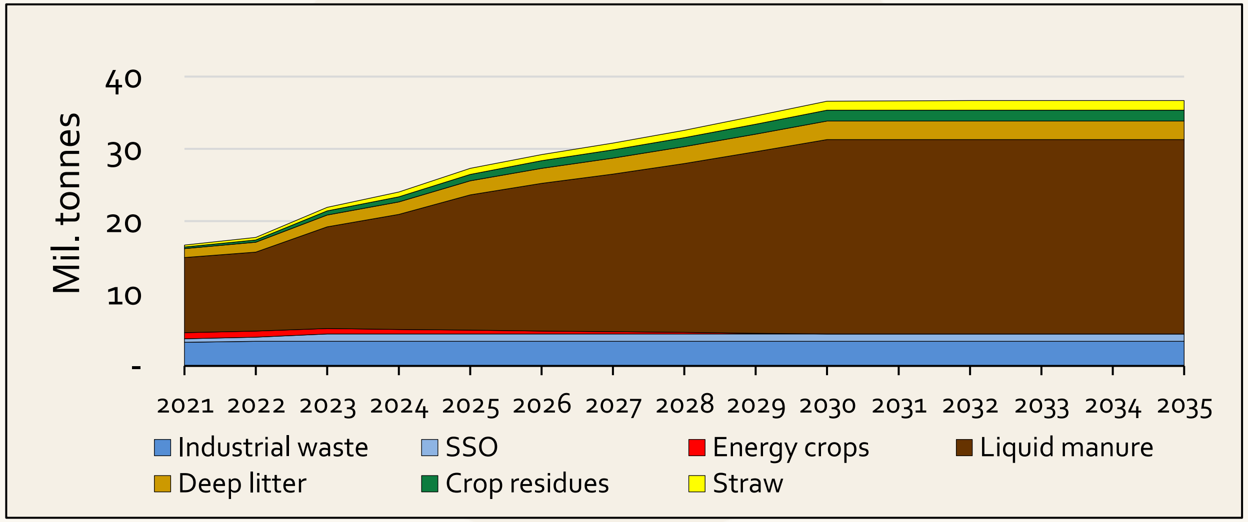
Three-quarters of produced biogas has its origin in biomasses delivered directly from agriculture. As organic waste from industry and source separated household waste (SSO) also originates in agriculture, agriculture is the prime source for the total biogas production.

*Danish Energy Agency

Biogas Production by biomass resources - Danish Energy Agency scenario



Biogas production by biomass resources in tons - Danish Energy Agency scenario.



Biogas Danmark

Energy production and use of bioresources

Biogas production by biomass resources - Biogas Danmark

More biogas from livestock manure and straw.

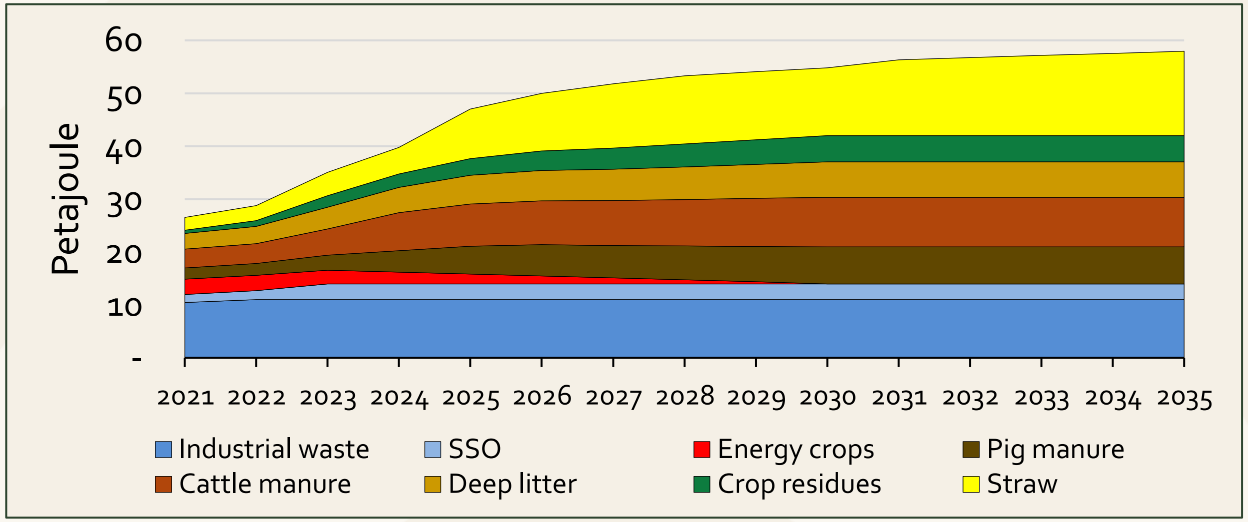
The Biogas Danmark scenario involves a significant and faster increase in the biogas production. The available resources for this growth are primarily straw, and livestock manure, as food waste and industrial waste are assumed to be fully utilized after 2025.

In 2035, livestock manure accounts for three-quarters of feedstock and delivers one third of the biogas in the biogas. Straw accounts for about 4 percent of input but about 22 percent of the biogas.

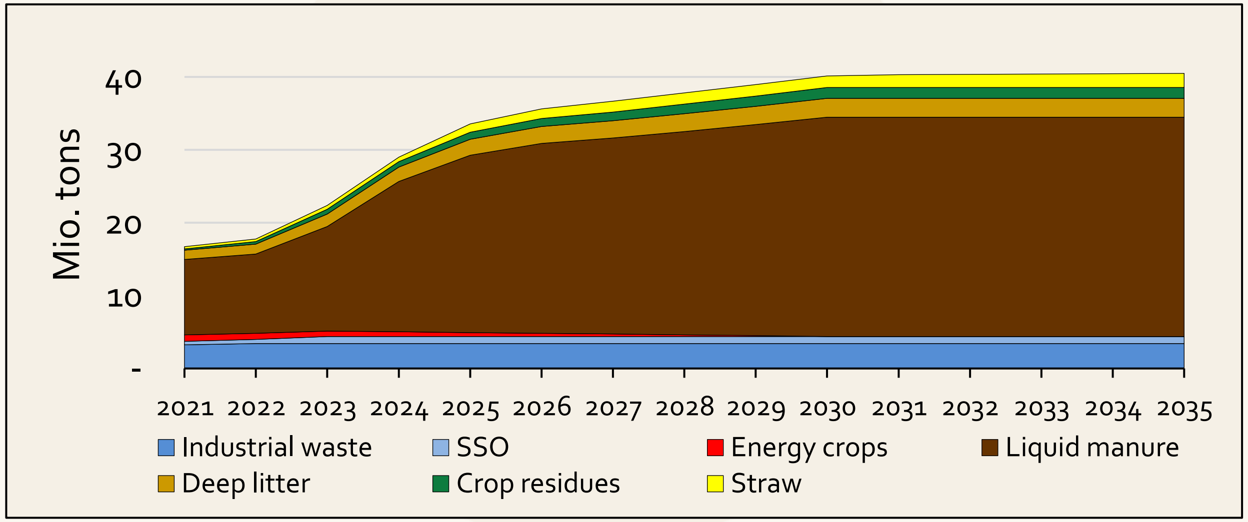
Pig slurry will provide 12 percent of biogas production in 2035.

The sharp increase in the use of straw as feedstock requires further development of methods and technologies for the effective digestion of straw. As it will also lead to a higher content of undigested fibres in the digestate, it is expected that an increasing share of the digestate will be separated, resulting in the production of designer fertilizer tailored to the recipient's needs.

Biogas production by biomass resources in PJ - Biogas Danmark scenario.



Biogas production by biomass resources in tons - Biogas Danmark scenario.



Biogas Danmark

Energy production and use of bioresources

Anaerobic digestion of livestock manure and straw

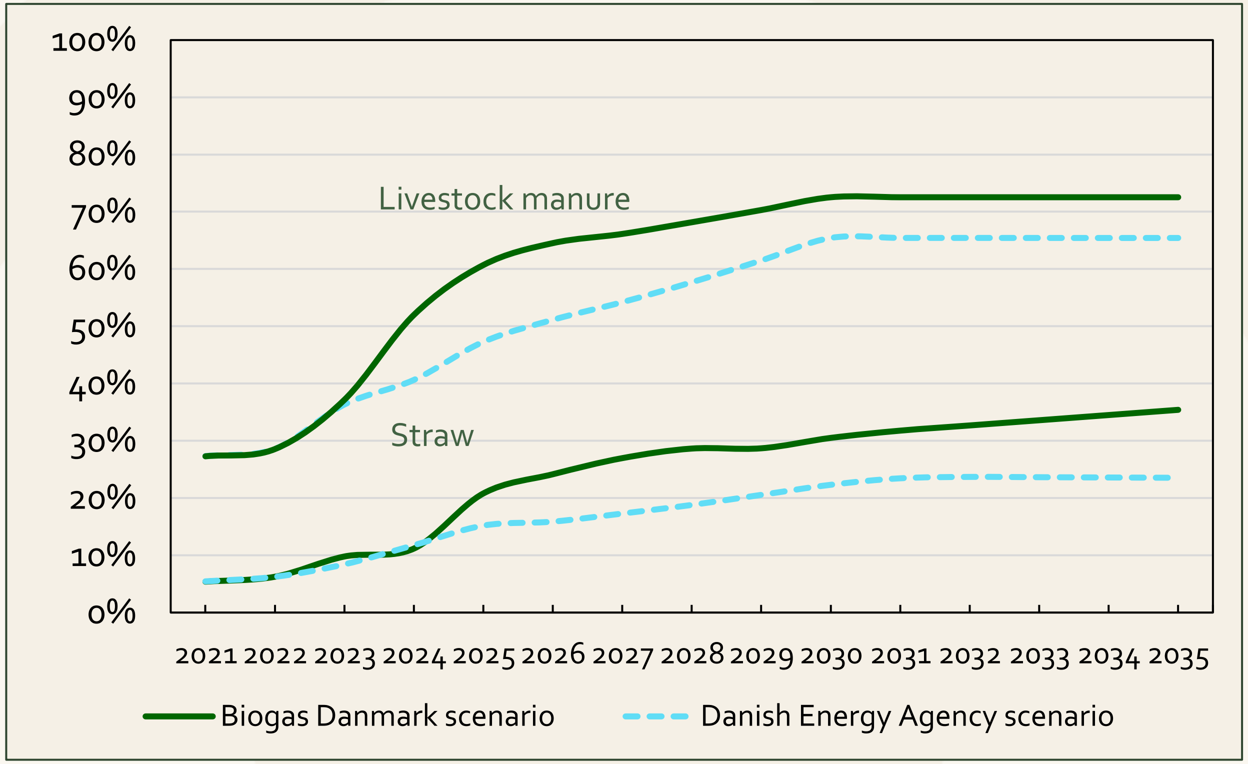
Huge potential, especially in straw.

Although the Biogas Danmark scenario involves higher shares of livestock manure and straw being digested in biogas plants compared to the Danish Energy Agency scenario, there will still be a significant unutilized resource of, especially straw.

The Danish Energy Agency scenario assumes that 65 per cent of livestock manure will be digested in biogas plants in 2030. The Biogas Danmark scenario depicts the digestion of 70 per cent of the livestock manure, as the total biogas production in this scenario is increased to 60 petajoules.

For straw, the Danish Energy Agency scenario requires that about 20 percent of the straw resource be used for biogas in 2030. In the Biogas Danmark scenario, 25 percent of the straw will be anaerobically digested in biogas plants in 2030, increasing to 36 percent in 2035.

Utilization of the potential available livestock manure and straw for biogas



The proportion of the total resources of livestock manure and straw that is utilized for production of biogas in the two scenarios.

Research shows that when straw and deep litter are digested in biogas plants, most of the slowly degradable carbon is recycled to the agricultural soils. Therefore, the same quantity of carbon is stored in the long term as if the straw is incorporated directly into the soil. (19)

Biogas Danmark

Energy production and use of bioresources

Simultaneous wind power production in Northern Europe

Huge demand for backup during calm wind periods

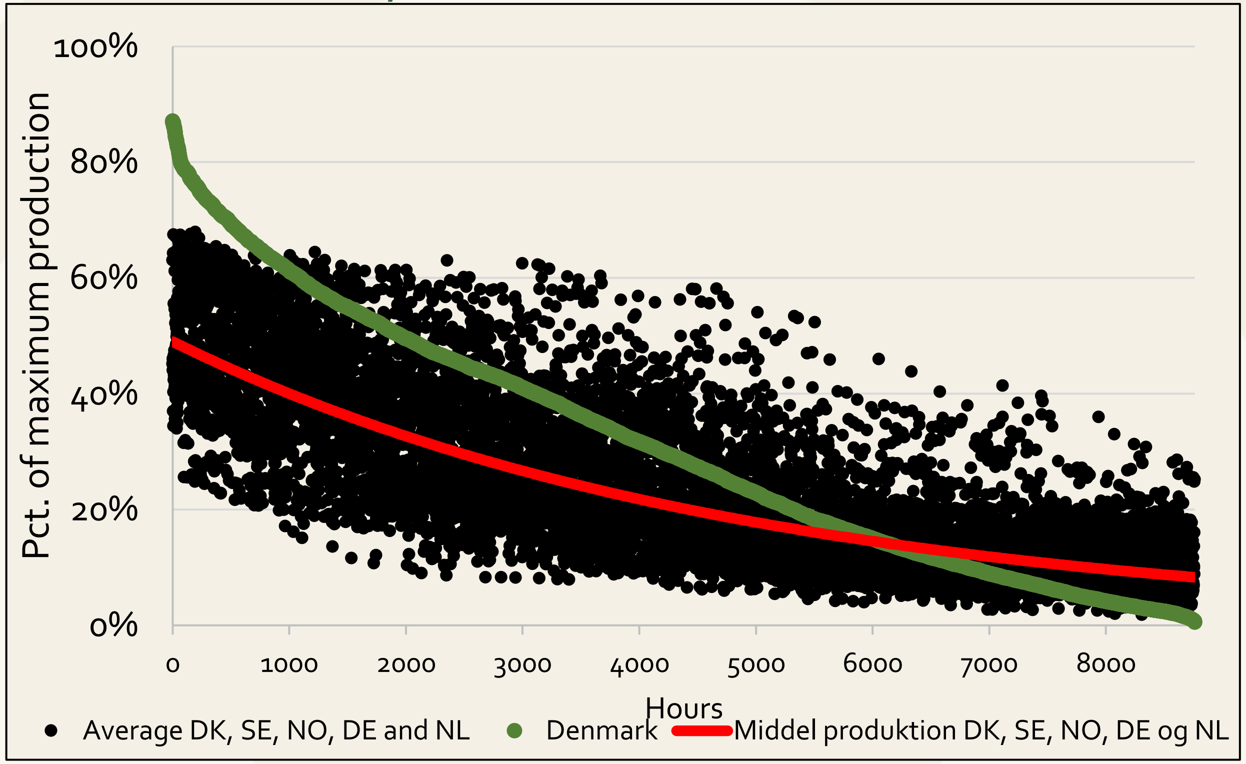
During periods of low wind power production in Denmark, neighboring countries also tend to experience low wind power production.

Conversely, when wind power production is high in Denmark, it also tends to be high in the whole region. Hence, wind power can not become a constant energy source for base load, even with significant expansion of international connections.

A major expansion in wind power capacity is required to cover a large percentage of the electricity consumption during the 3000 hours per year with the lowest wind power production. However, this would result in electricity production exceeding consumption for the rest of the year by at least three times the amount needed during the 2000 hours with the highest wind power production.

Therefore, a combination of backup sources during calm periods and new utilizations for Power-to-X (PtX) when wind power is at its maximum must be introduced to balance electricity production.

Duration curves for electricity production in Denmark and neighboring countries simultaneously.



The share of the installed capacity that delivers power is plotted for each hour. The green curve represents the Danish wind power, with the hours with the highest utilization of the installed capacity to the left and decreasing towards calm at the right. The dots show electricity production in wind areas in neighboring countries, and the red line shows the average trend in these areas.
Source: entsoe.eu - Actual Generation per Production Type´ [20]

Biogas Danmark

Energy production and use of bioresources

Potential for balancing the power grid with PtX production

The CO_2 from biogas can store electricity

The biogenic CO_2 that every day is captured in the upgrading facilities on biogas plants can be utilized in at least five different ways:

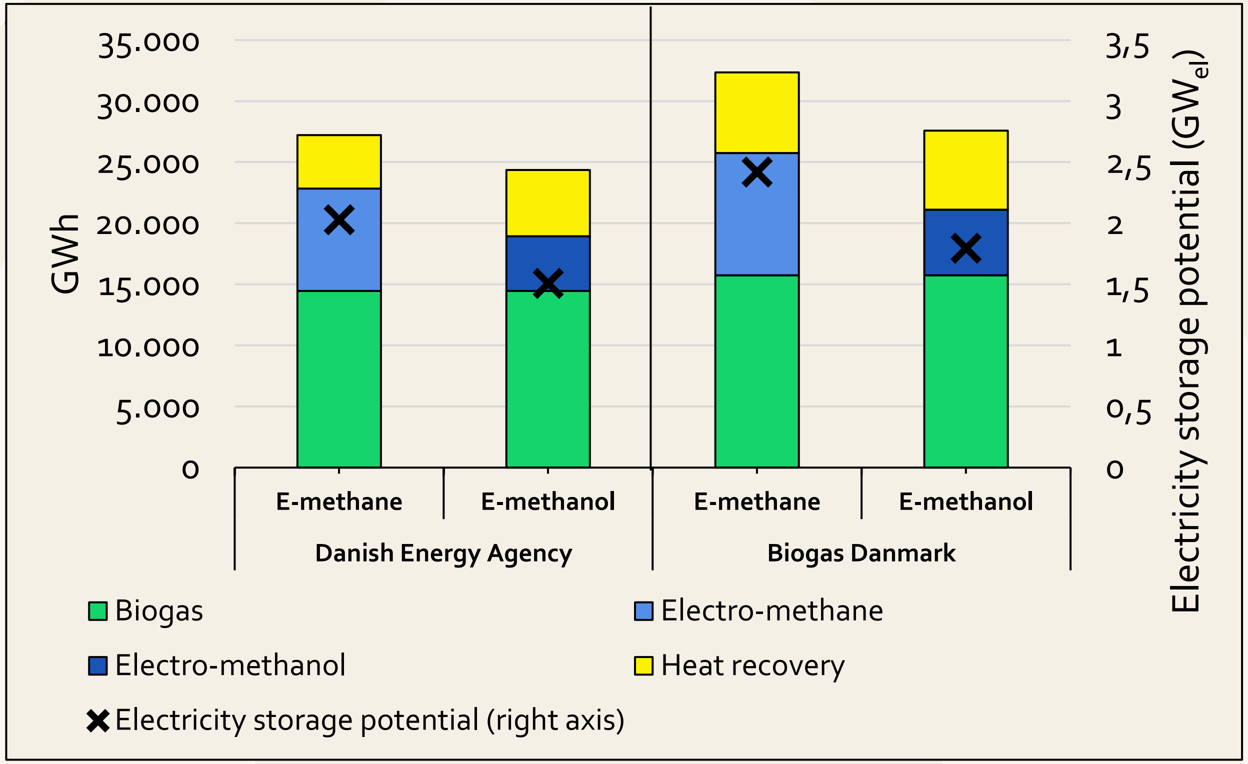
1. Replace industrial CO_2 currently produced from natural gas
2. Deposition by Carbon Capture and Storage (CCS)
3. Produce electro-methane (e-methane) through methanation utilising hydrogen from renewable electricity [21]
4. Produce electro-methanol (e-methanol) utilising hydrogen from renewable electricity [21]
5. Produce biogen carbon-based plastic and textile production replacing hydrocarbons of fossil origin.

Solution 1 is implemented at several facilities without subsidies. Solution 5 is the long-term solution, as the world needs these products even in a fossil hydrocarbon independent future.

The figures compare the capacity to balance electricity from wind and solar panels via PtX and CCS in the two scenarios.

The most straightforward solution is to switch between PtX and CCS depending on the need for balancing electricity hour by hour.

Electricity storage potential via CCUS in 2030 with CO_2 capture at the biogas plants – Biogas Danmark scenario



The black crosses indicate how much electric power can continuously be converted to PtX fuels per hour. The blue show the electro-fuel (e-methane or e-methanol) production potential by utilising the CO_2 content of the biogas production (green). The yellow indicates the heat recovery from the electrolysis process that delivers the hydrogen. The scenarios require large storage facilities of either CO_2 or hydrogen.

Biogas Danmark

Energy production and use of bioresources

CO_2 from biogas enables large-scale production of PtX fuels

Storage of surplus electricity from solar and wind

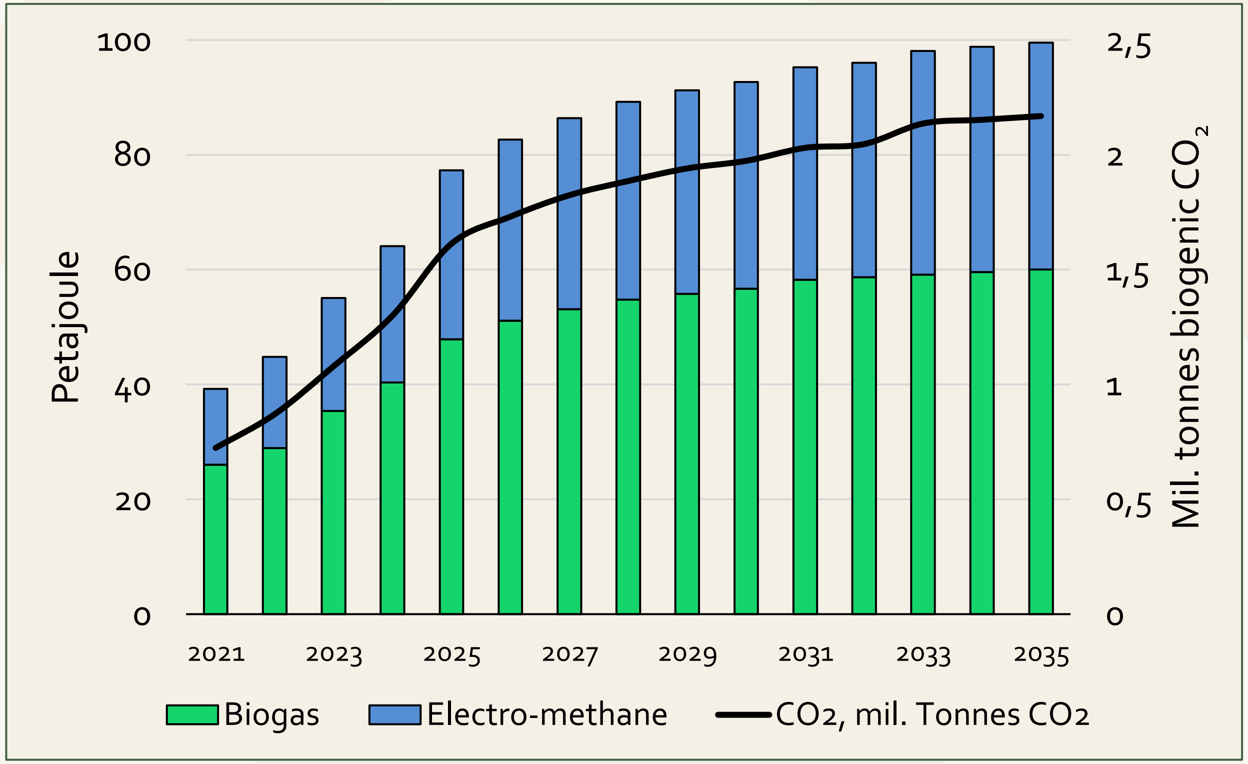
Biogenic CO_2 removed when the biogas is upgraded to biomethane is easily accessible for producing Power-to-X fuels (methane or methanol) utilizing hydrogen produced by electrolysis based on electricity from windmills or solar panels.

Hence, biogenic CO_2 can be utilized to store surplus electricity as easily usable electrofuels, such as e-methane or e-methanol.

The e-methane production potential if all captured biogenic CO_2 from the biogas production in the Biogas Danmark scenario is shown in the graph. This would, however, require huge storage facilities. Either for CO_2 in the hours without a surplus of electricity production from solar and wind. Or for hydrogen during the hours with a considerable surplus of electricity from solar and wind.

Surplus electricity from solar and wind can occur when electricity production exceeds consumption or the capacity of the electric grid.

E-methane production potential - Biogas Danmark scenario



The black line shows the annual CO_2 content that can be captured when the biogas is upgraded to biomethane that is injected into the gas grid (green). The blue columns show the e-methane production potential if all the captured biogenic CO_2 reacts with hydrogen.

Biogas Danmark

Climate effect

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Biogas Danmark

Climate effect

Overall climate effect of biogas

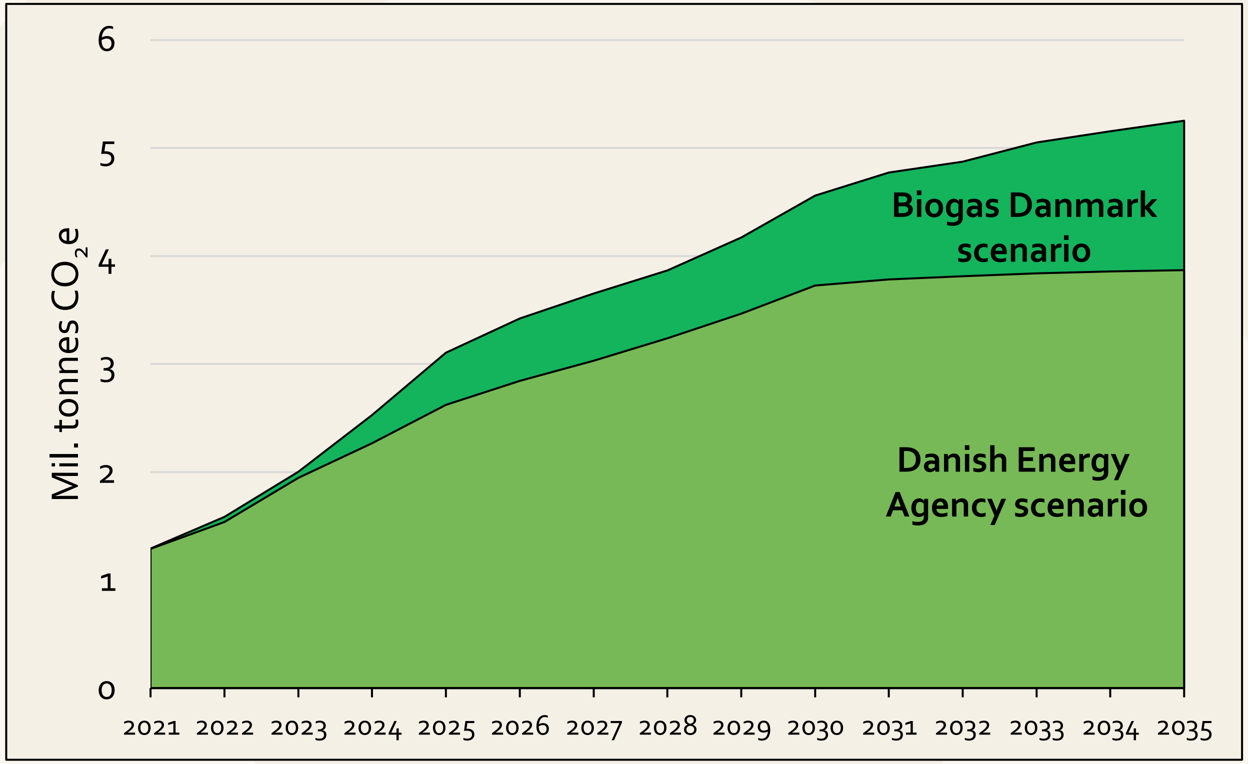
Biogas is a powerful greenhouse gas tool

The increasing biogas production contributes significantly to Denmark's ability to reach the 70 per cent climate target for 2030.

According to the Energy Agency scenario, biogas can reduce greenhouse gas emissions with 2.6 million tons of CO2e in 2025 and 3.7 million tons of CO2e in 2030.

Biogas Danmark's policy proposal can increase the greenhouse gas emission reduction to 3.1 million tons of CO2e in 2025 and 4.6 million tons of CO2e in 2030.

Annual net CO_2e reduction by biogas production in the two scenarios



In the Danish Energy Agency scenario, biogas can reduce greenhouse gas emissions with 3.7 million tons of CO2e in 2025. In the Biogas Danmark, this can be increased to 4.6 million tons CO2e.

Climate effect

Climate effect of biogas

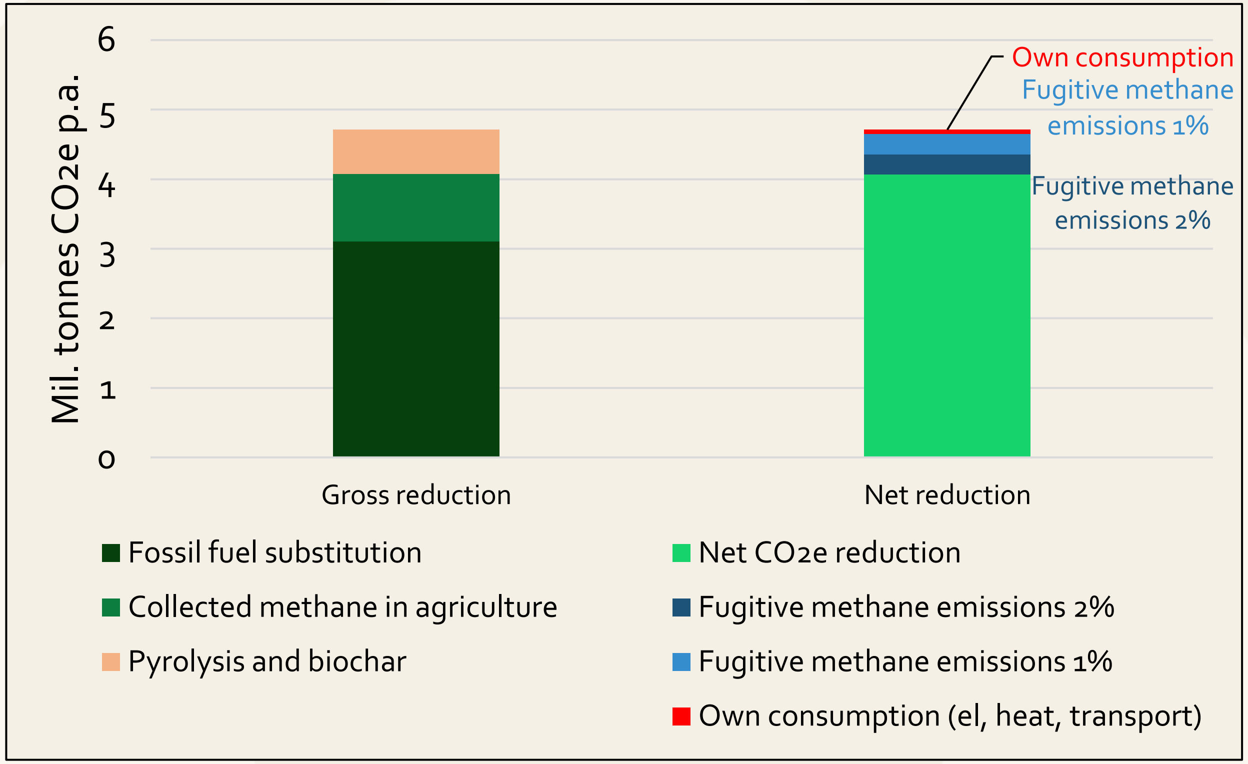
The net climate effect of biogas is greater than the CO_2 reduction from substituting fossil fuels.

Substitution of natural gas with biogas reduces the emission of CO_2. In addition, the methane emission from the storage of livestock manure is reduced when the manure is digested anaerobically in biogas plants. Biogas production does, however, also give greenhouse gas emissions due to methane leakage and energy consumption for process energy and the transport of feedstock and digestate.

The net climate effect is calculated when subtracting the CO_2 emissions from the biogas plants' energy consumption and methane leakages from the gross climate effect. The net climate effect is shown in the figure with methane leakages of 1 and 2 per cent.

In the Energy Agency scenario, the production of 52 petajoules of biogas in 2030 will reduce the CO_2 emission from the substituted fossil fuels with more than 3 million tons of CO_2 and reduce the methane emissions in agriculture by about 1 million tons of CO_2e. Biogas production therefore leads to a net reduction of about 4.1 million tons of CO_2e at a methane loss of 2 percent. Therefore, the use of biogas is climate-neutral.

Gross and net climate effect of biogas in 2030 - Energy Agency Scenario



The gross and net greenhouse gas reductions for the Energy Agency scenario show that biogas that substitutes fossil gas is net climate-neutral at a methane loss of 2 percent.

A new regulation to control and minimize fugitive methane emission came into force by January 1st 2023 aiming to reduce the leakage to 1 per cent. In a survey in 2020-21 it was measured to be on average 2 per cent in agricultural biogas plants (7)

Biogas Danmark

Climate effect

Denmark's GHG reduction deficit

In its 2023 evaluation, the ´Danish Council on Climate Change highlights that Denmark will not meet the EU's climate requirements.

In its annual evaluation of the government's climate initiatives, Klimarådet concludes that even if both the 2025 and 2030 targets are met, Denmark will still lack a reduction of over 6 million tons of CO2e to meet EU requirements for reductions of greenhouse gases outside the ETS sector and LULUCF from 2021 to 2030. (3)

The Council on Climate Change also finds it unlikely that Denmark's climate target for 2025 can be met.

The table on the right shows the Climate Council's expected shortage in GHG reduction to fulfil Denmark's national climate targets in 2025 and the EU requirements for reductions in the non-ETS sector.

The national 2025 climate target is the average for 2024 to 2026. The shortfall indicates how much Biogas Danmark's policy proposals can reduce the shortfalls estimated by the Climate Council.

Biogas Danmarks policy proposals can close the gap

Climate Council calculation	Danish target	EU requirements 2021-2030	
Million tonnes of CO_2	2025	Accumulated Non-ETS	Accumulated ETS
Reduction target 50%, 2025*	**0,9**	**6,9**	
Reduction target 54%, 2025*	**4,0**	**6,1**	
Effects of Biogas Danmark's proposal			
CO_2 reduction obligations +2%**	0,7	5,6	0
Faster implementation of tender pools	0,2	0,5	0,5
CO_2 tax refund	0,4	1,2	1,2
In total	**1,3**	**7,3**	**1,7**
*The Danish Council on Climate Change status report 2023			
** Agreement on green conversion of road transport			

The Danish Climate Council's forecast in its 2023 evaluation is a shortfall in meeting Denmark's climate targets in 2025 and the EU's requirements for reductions in the non-ETS sector. The 2025 target is an average from 2024 to 2026.

The shortfall indicates how much Biogas Danmark's policy proposal can reduce the shortfalls estimated by the Climate Council.

Biogas Danmark

Climate effect

Klimarådet*: Denmark can not meet its EU obligations

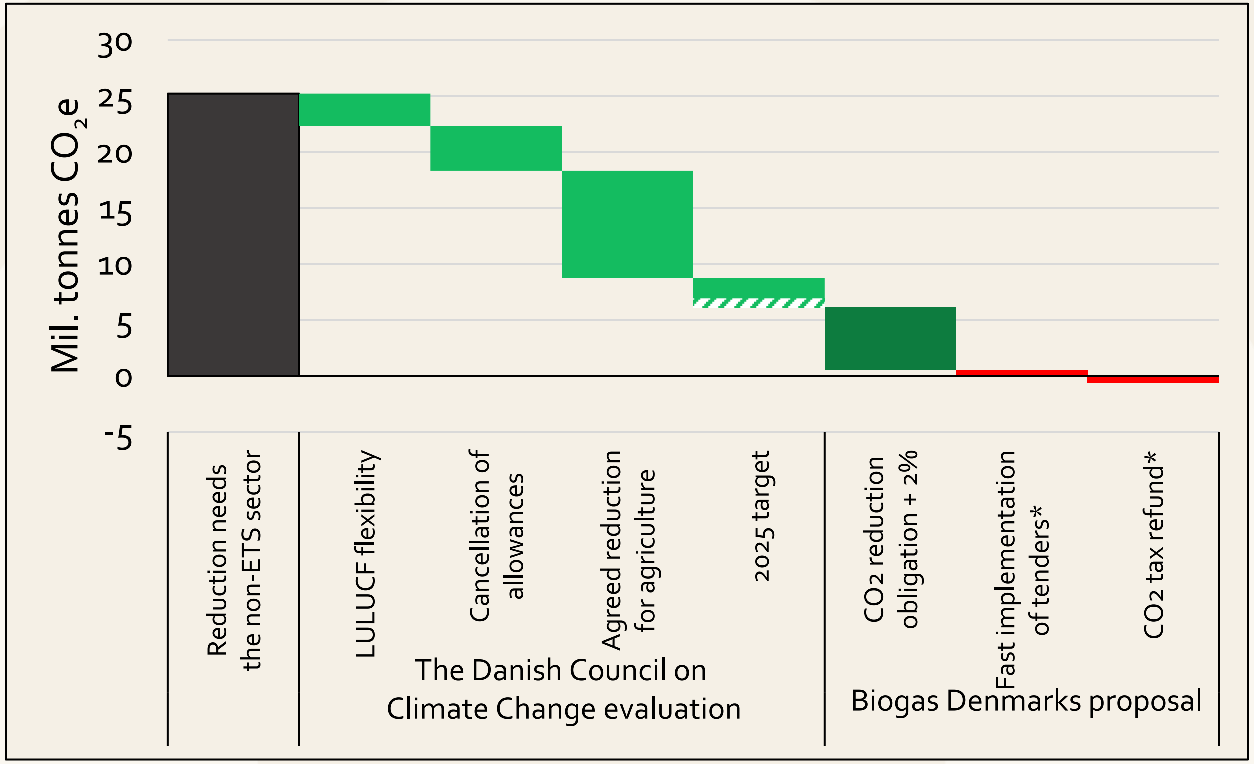
Klimarådet points out in their 2023 evaluation that Denmark cannot meet the EU's climate obligations

According to the 2023 annual status report from Klimarådet, Denmark is on track to meet its climate goals by reducing greenhouse gases by 54 per cent and 70 per cent in 2025 and 2030, respectively. However, miss the EU’s obligation to reduce non-ETS greenhouse gas emissions by 50 per cent and LULUCF between 2021 and 2030. (3)

Klimarådet estimates it is necessary to reduce greenhouse gas emissions by 25.2 million tons of CO2e. LULUCF flexibility, CO2 quota cancellation, reduction in agriculture and compliance with Denmark's 2025 goal are inadequate to meet the EU's requirements. There remains a gap of between 6 and 7 million tons of CO2e.

Biogas Danmark's policy proposal can significantly contribute to closing the gap, as demonstrated in the accompanying figure. Klimarådets scepticism towards several greenhouse gas reduction tools underline the importance of Biogas Danmark's proposal.

Reduction gap and biogas' contribution to EU goal fulfillment



The black column to the left is Denmarks deficit in meeting the EU requirement to reduce greenhouse gas emissions outside the quota sector and in LULUCF (land use, land use change, and forestry), according to Klimarådet. The bars on the right-hand side illustrate how Biogas Danmark's policy proposal can contribute substantially to closing the gap. The climate impact of fast implementation of the biogas tenders and CO2 tax refund is estimated to influence the emissions from both the non-quota and quota sectors.

*Klimarådet is The Danish Council on Climate Change

Biogas Danmark

Climate effect

Climate effect of production and use of biogas

Biogas significantly reduce greenhouse gas emissions

The Energy Agency scenario predicts an annual net greenhouse gas emission reduction from 2030 through 2035 of 4.5 million tons of CO2e.

The Biogas Danmark scenario increases the reduction to 5.3 million tons of CO2 equivalents in 2030, rising to 6 million tons in 2035.

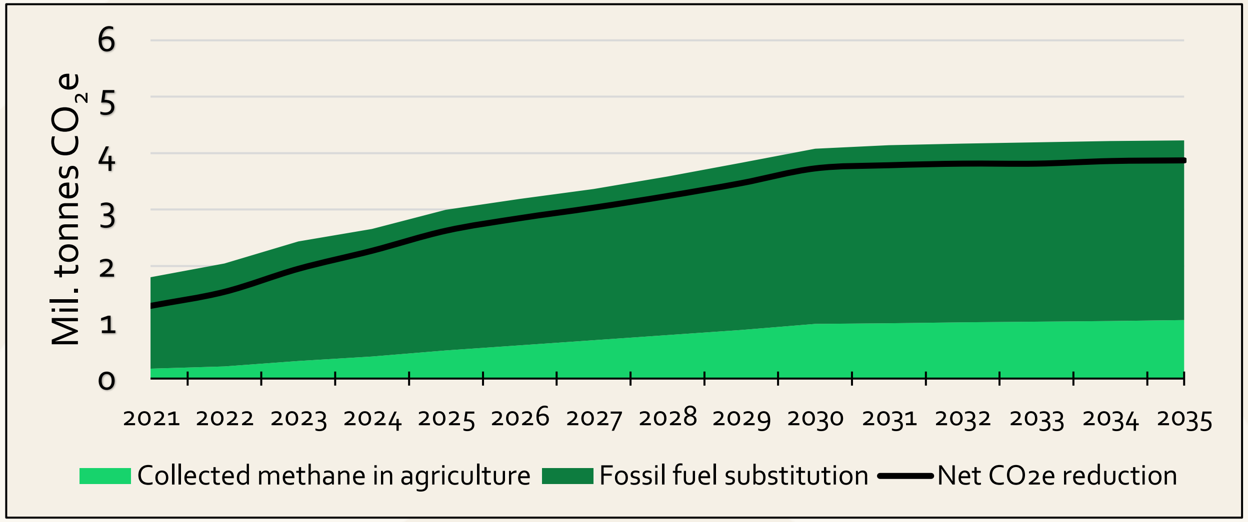
The net climate impact is calculated as the reduced emission of methane from livestock manure in agriculture and the substitution of fossil fuels. In addition, CO2 emissions from the transport of biomass and fertilizers, as well as energy consumption and methane losses at the biogas plants, are subtracted.

Installation of heat pumps is expected gradually to reduce the CO2 emissions from biogas plants' energy consumption.

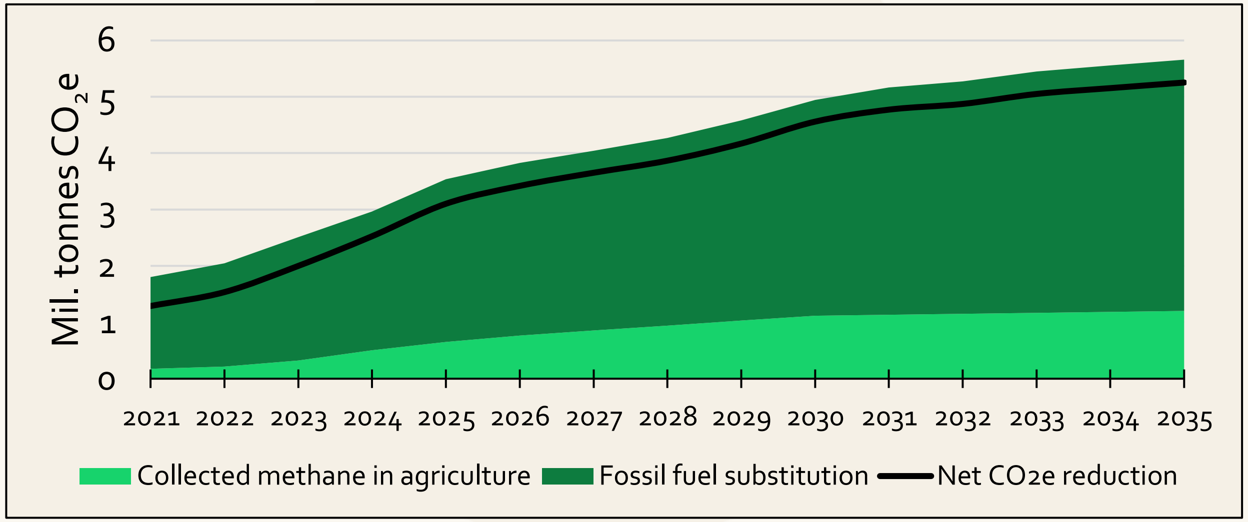
The methane leakage of 2.1 per cent in 2021 is expected to be reduced to 1 per cent from 2024 due to the mandatory methane leakage control obligation that came into force from 2023 (7).

Biogas Danmark

Climate effect of biogas production and use - Energy Agency scenario



Climate effect of biogas production and use - Biogas Danmark



Net greenhouse gas reduction is after deducting methane loss and energy consumption for process and transport on the biogas plant.

Climate effect

Climate impact of gas and electricity consumption

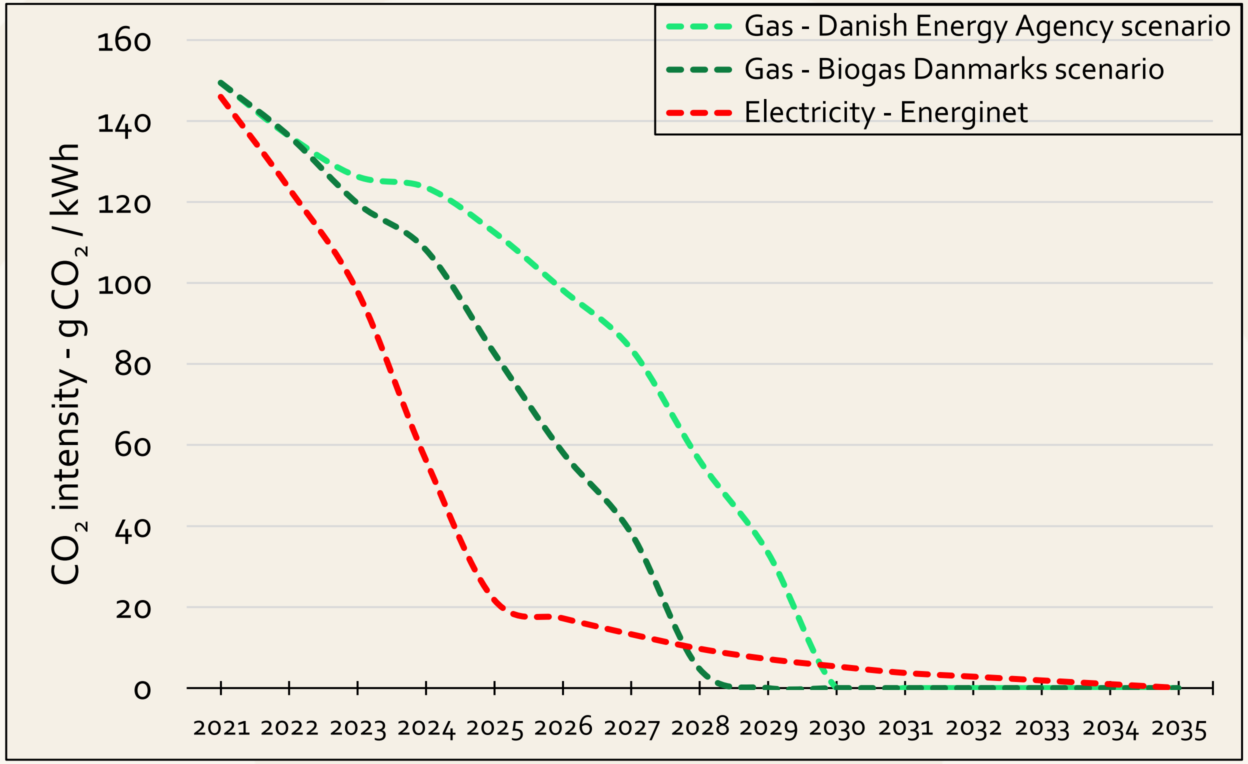
The carbon footprint of gas and electricity consumption can be drastically reduced by 2030.

The Danish gas and electricity consumption currently have the same climate footprint expressed as the CO2-intensity.

If Biogas Danmark's policy proposal is implemented and the politically decided offshore wind farms are established, the carbon footprint from both electricity and gas consumption will be close to climate neutrality by 2028.

If the Danish Energy Agency's biogas production and gas consumption forecast is met, the carbon footprint of the gas consumption will also be diminished, but with a few years' delay. A Carbon neutral gas consumption will not be achieved until 2030.

Future carbon footprint of gas and electricity consumption in Denmark



The forecast of the carbon footprint in electricity consumption is made by Energinet [22]. Biogas Danmark has calculated the carbon footprint of the gas consumption, partly based on the Danish Energy Agency's expectations for the future biogas production and partly based on the Biogas Danmark scenario.

Climate effect

Optimal climate effect through utilization of the captured CO_2

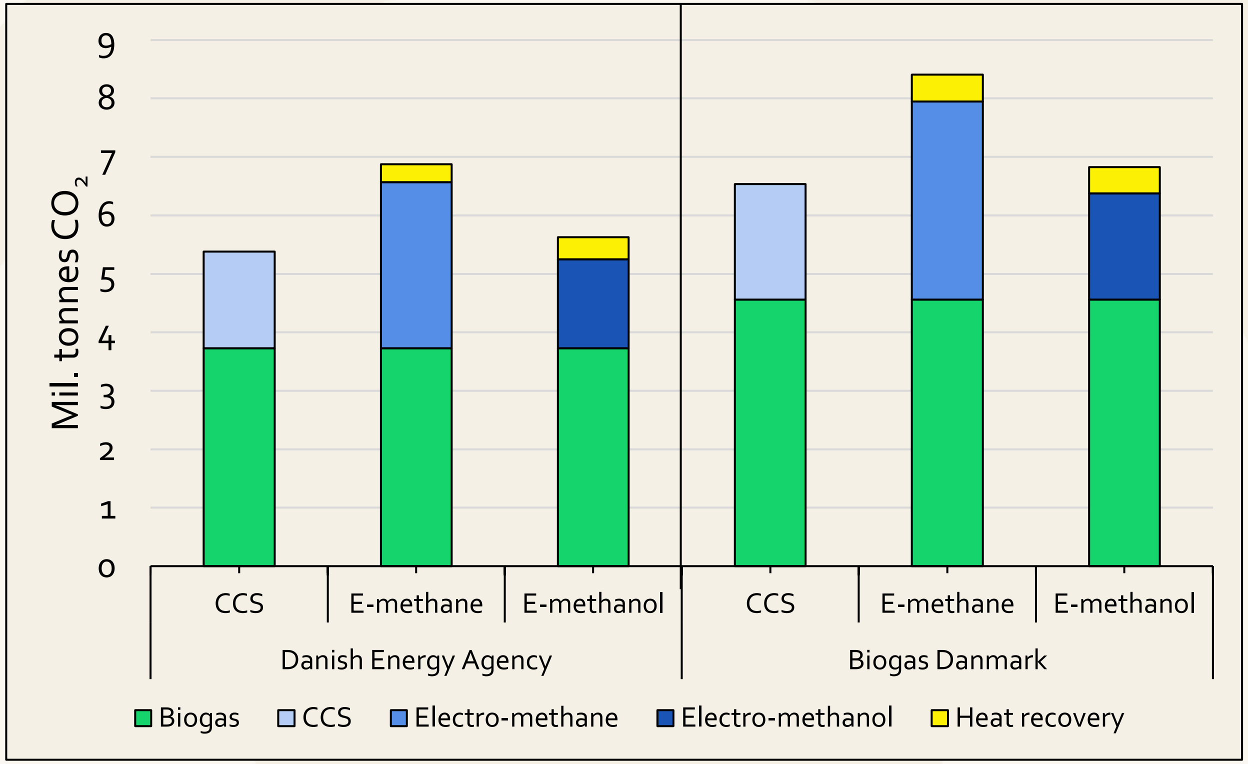
Biogenic CO_2 collected at biogas plants upgrading facilities can be utilized in five ways:

1. Deposition by Carbon Capture and Storage (CCS)
2. Produce electro-methane (e-methane) through methanation utilising hydrogen from renewable electricity [21]
3. Produce electro-methanol (e-methanol) utilising hydrogen from renewable electricity [21]
4. Replace industrial CO_2 currently produced from natural gas.
5. Produce biogen carbon-based plastic and textile production replacing hydrocarbons of fossil origin.

Option 4 is the most obvious and has the potential for the highest contribution to reducing climate change, but data for it are not yet available. In 2023, industrial demand and prices will increase due to a natural gas shortage.

E-methane has the highest greenhouse gas reduction potential as it can bind more energy from RE-electricity.

Potential for reduced greenhouse gas emission in 2030 through CO_2 capture at biogas plants - Energy Agency scenario



Methanation of the CO_2 from biogas captured at the upgrading facilities reduces greenhouse gas emissions more than *CCS or the production of e-methanol. The PtX pathways enable the possibility of balance the renewable electricity production.*

Climate effect

Climate effect of liquified biogas

Green transition of heavy duty transportation

Liquified biogas (LBG) cooled to minus 160°C has a higher energy density and lower volume than compressed biogas (CBG).

LBG is, therefore, a better fuel for ships and long-haul trucks. On the European market, there has been an increasing demand for gas trucks equipped with tanks for liquefied gas, which provides a range of 1,000 to 1,500 kilometers.

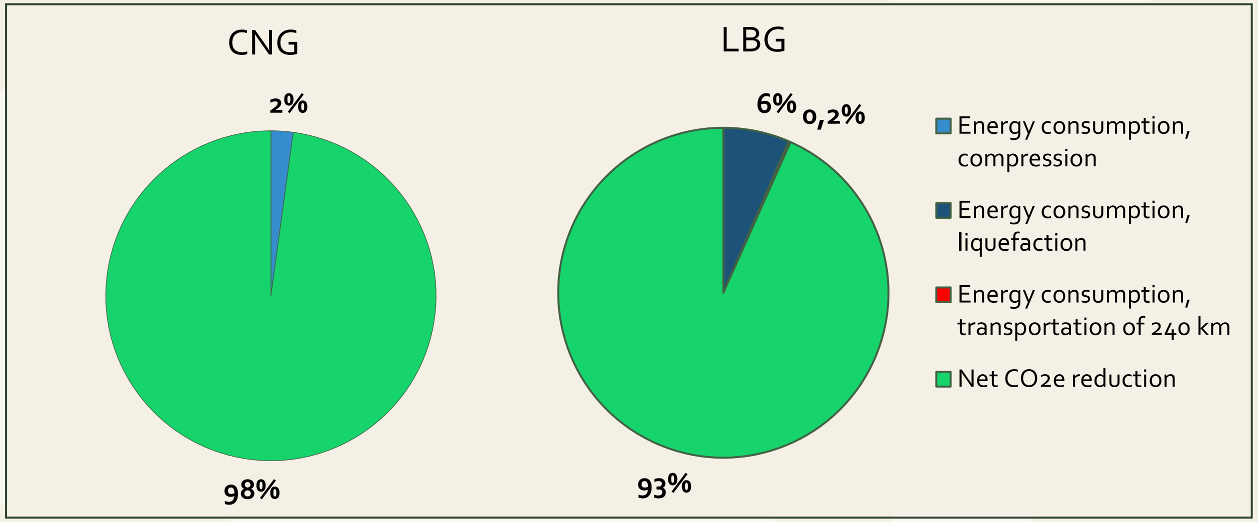
The demand for LBG for these trucks is rapidly increasing in neighboring countries. In Denmark, it could significantly contribute to the green conversion of the heaviest weight classes in road freight transport and shipping if the CO_2 reduction obligations for the transport sector are increased, as proposed by Biogas Danmark.

The top figure shows that 93 percent of the energy content of the biogas can be utilized after liquefaction. Approximately 7 per cent of the energy content in the biogas is consumed for compression and distribution (240 kilometers).

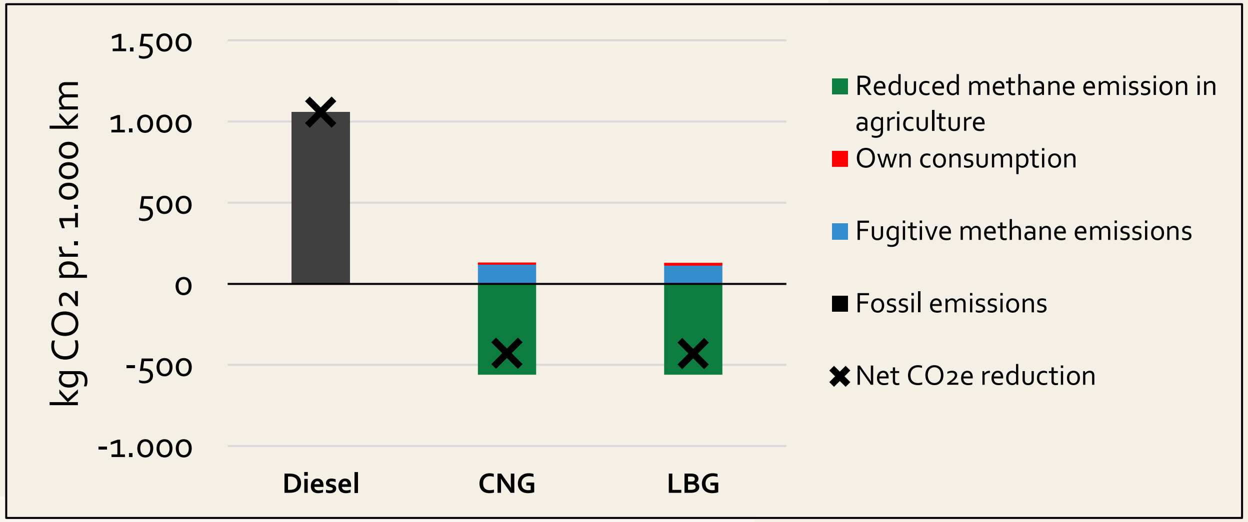
The bottom figure shows that the reduction in greenhouse gas emissions when biogas produced from livestock manure substitute fossil diesel far exceeds the avoided emission from fossil diesel. Thus, biogas is a climate-neutral fuel.

Biogas Danmark

Energy efficiency in the production and distribution of LBG in Denmark



Greenhouse gas emission of fossil diesel and compressed and liquified biogas substitution of diesel with LBG



Climate effect

Biogenic CO2 from biogas

There is significant potential in using CO2 from biogas for PtX or CCS.

CO2 from biogas is called biogenic as it originates from plants that have assimilated CO2 from the air through photosynthesis. This CO2 would be recirculated into the atmosphere through the natural degradation of the dead plants.

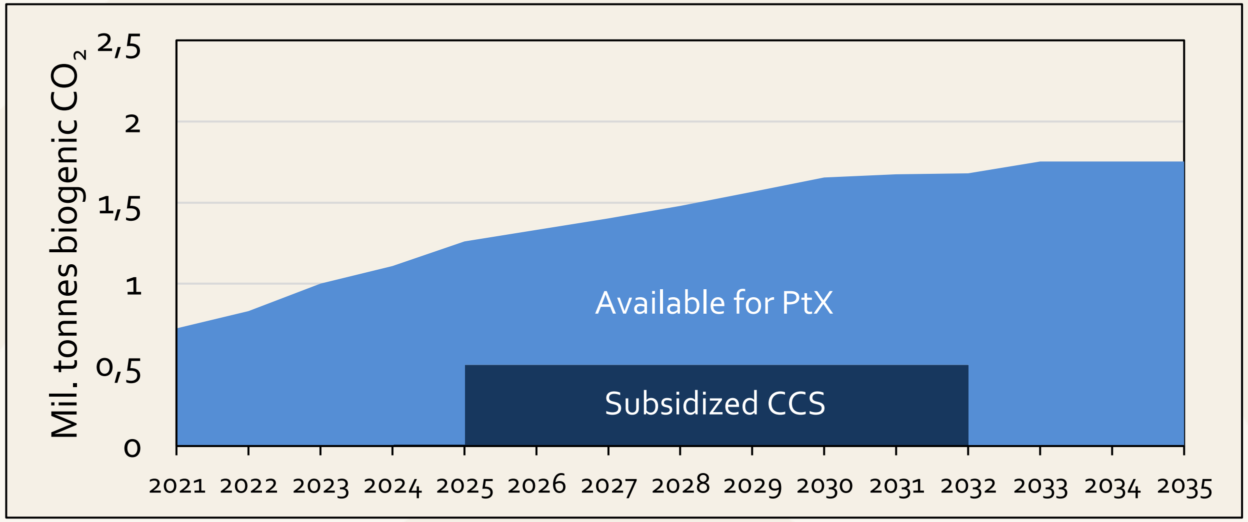
Biogas typically contains 60-65 percent biomethane and 35-40 percent biogenic CO2. In order to meet the quality requirements to inject the biomethane into the gas grid, the CO2 is segregated from the biogas at the upgrading facilities on the biogas plants. The biogenic CO2 is, therefore, readily available at biogas plants.

There is a huge potential in utilizing this CO2 for either CO2 storage (CCS), Power-to-X (PtX), or substitution of fossil-based CO2 in industry.

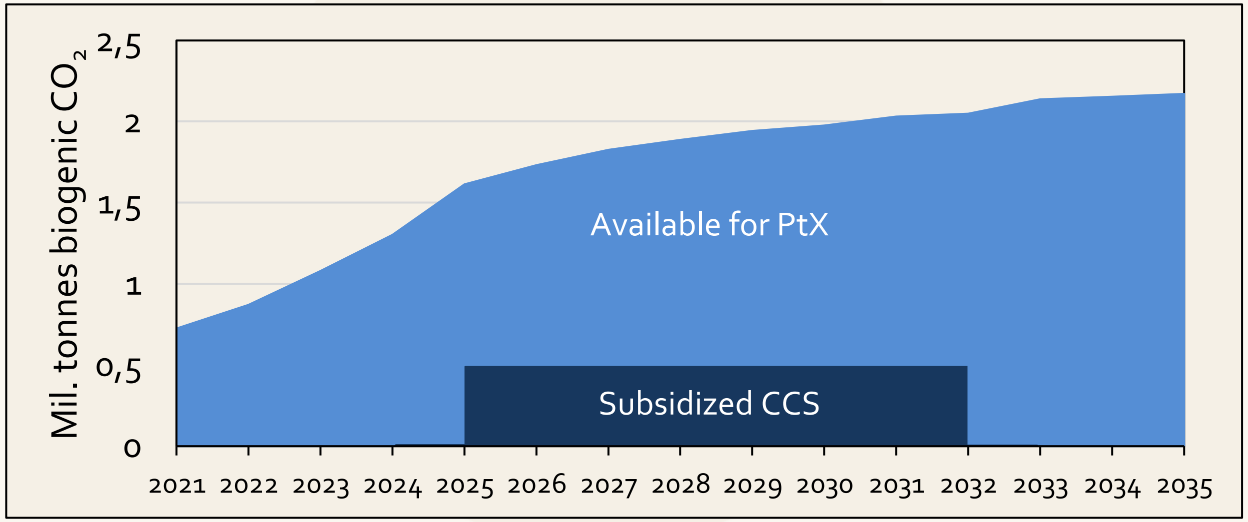
In the Energy Agency scenario, the available CO2 potential is 1.7 million tons annually, but Biogas Danmark's scenario provides an available potential of more than 2 million tons annually in 2030. A subsidy scheme has been adopted that makes it possible to store biogenic CO2 in the period 2024-2032. The subsidy scheme makes it possible to store a total of 4 million tons of biogenic CO2.[23]

Biogas Danmark

Available CO2 for PtX and CCS – Danish Energy Agency scenario.



Available CO2 for PtX and CCS - Biogas Danmark scenario.



Climate effect

Climate impact in agriculture

Huge synergies between biogas and frequent discharge and cooling of livestock manure.

Like the rest of the society, agriculture faces a significant climate challenge. Agriculture is the only sector with a mandatory greenhouse gas reduction obligation of 55-65 per cent in 2030. The climate agreement for agriculture from 2021 requires frequent flushing of manure from existing stables for slaughter pigs and all new pig stables from January 1, 2023. (24)

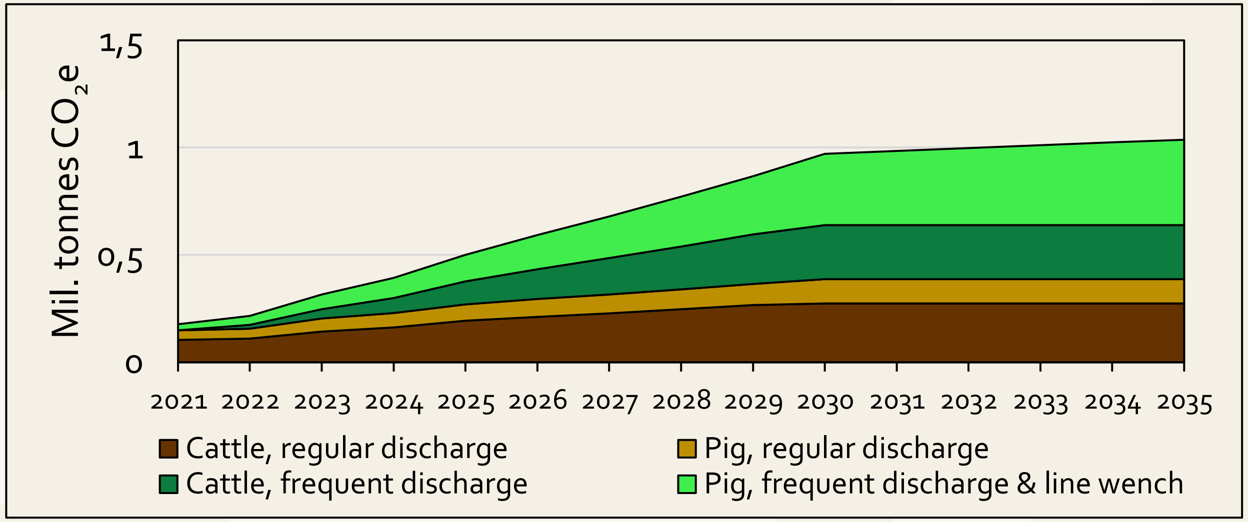
The Danish Agricultural Agency has previously financed a project to assess the climate impact of frequent discharge of liquid manure from pig stables delivered to biogas plants. 400 farms participated.

There was an effect in most existing stables, but it will be even higher in new stables, where frequent discharge with weekly pumping of manure or daily in stables with line winch is established.

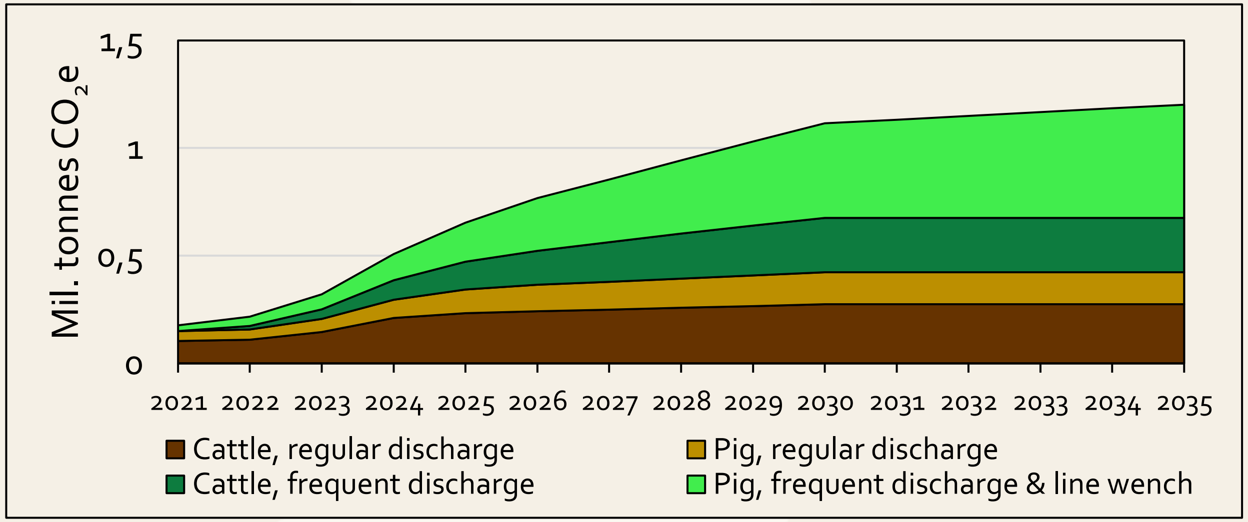
Thus, the anaerobic digestion of livestock manure has an additional climate effect, as methane emission from stables and manure storage is reduced. In addition, the produced biogas substitutes fossil natural gas and thereby reduces the emission of CO2

The total climate benefit is about 4.4 million tons of CO2e in the Energy Agency scenario and almost 6 million tons in the Biogas Danmark scenario, of which about 1.2 million tons are in agriculture.

Climate impact of frequent discharge or cooling of slurry- DEA scenario.



Climate impact of frequent discharge or cooling of slurry - BD scenario.



Biogas Danmark

Climate effect

Climate impact of manure management

Frequent discharge and anaerobic digestion of livestock manure reduces climate impact.

When livestock manure is stored beneath the slattered floors in the stables or in the outside liquid livestock manure storage tanks, there is a natural production and emission of the greenhouse gas methane. When the manure is anaerobic digested in a biogas plant, this methane is collected, thereby reducing the greenhouse emissions in agriculture. In addition, the produced biogas can substitute fossil energy and reduce overall CO2 emissions.

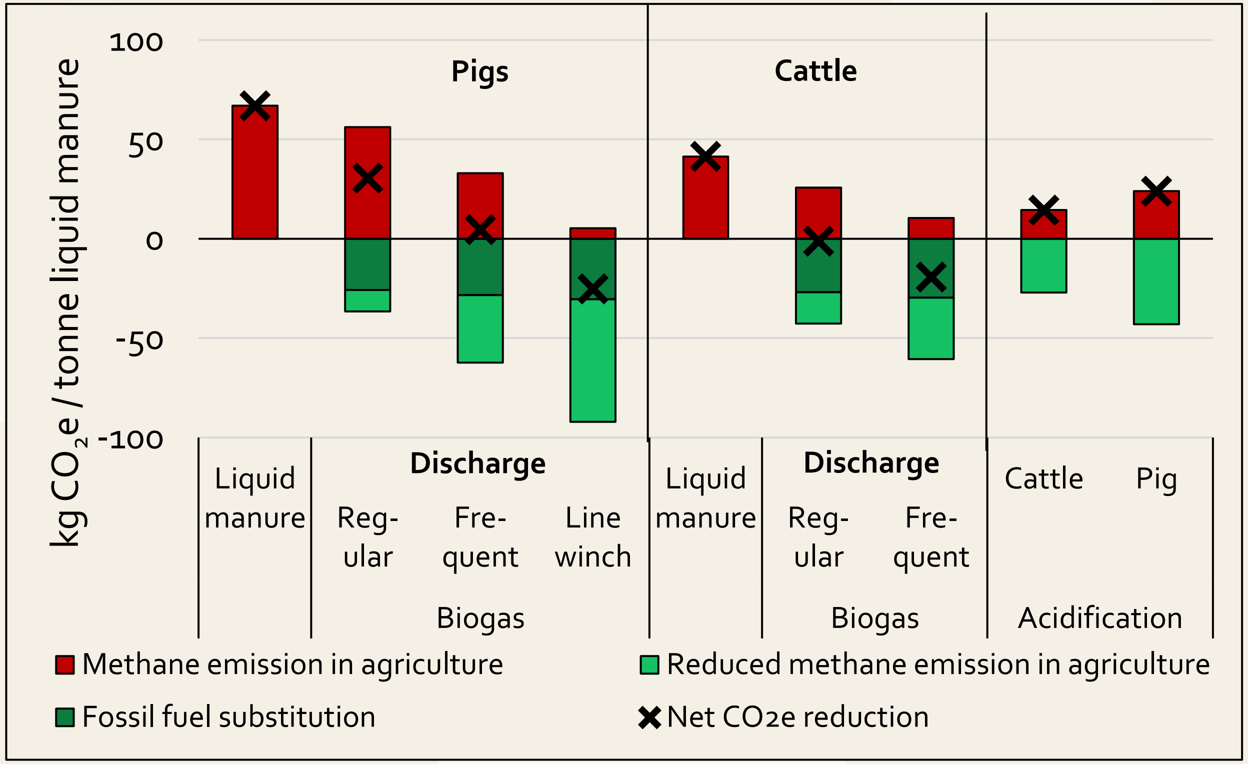
The climate benefit can be optimized by faster delivery of the livestock manure from the stables to the biogas plant, either by pumping once a week or daily via a line winch system.

Proper management of the stables, combined with biogas, can significantly reduce the climate impact of livestock manure.

Alternatively, the farmers can reduce the methane emissions by acidification of the livestock manure with sulfuric acid, but then it cannot be utilized to the same extent in biogas plants.

Acidification does not have the double climate effect of biogas, and therefore both the climate effect in agriculture and the overall net CO2 reduction are smaller with acidification than with biogas.

Climate benefits from different manure management practices (25, 26).



The figure shows the climate effect of different manure management strategies and technologies. The red is GHG emissions in agriculture. The light green is avoided methane emission in agriculture, while the dark green shows the climate effect of substituting fossil natural gas and diesel with biogas. The black crosses show the net climate effect. In pig production, the most effective technology is line winches with a net climate effect of -25 kg CO2 per ton of manure, while frequent discharging is most effective in cattle with a net climate effect of about -20 kg CO2 per ton of manure.

Biogas Danmark

Climate effect

Climate impact in husbandry

Biogas eliminates GHG emissions from livestock manure especially when combined with pyrolyses.

Anaerobic digestion in biogas plants is an efficient tool for reducing methane emissions from livestock manure.

It has the potential to almost eliminate the emissions. The benefits are illustrated for two typical farms: one with 400 cows with weeners and another with 1,100 sows fattening all the piglets.

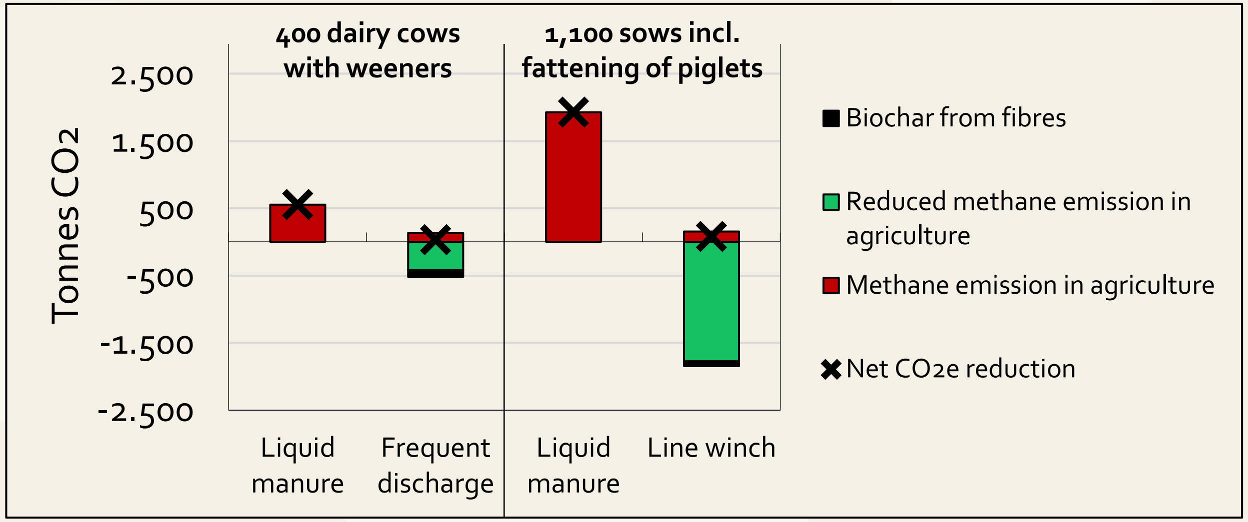
Anaerobic digestion in biogas plants can significantly reduce the methane emissions from livestock manure from cattle and pigs. In both cases, the reduction is up to 95 percent when the manure is delivered fast from the stables to the biogas plant.

An additional climate effect can be achieved if the digestate is separated and the fibre fraction is delivered to a pyrolysis plant.

The pyrolysis oil and gas can substitute fossil energy, and the biochar can long time store the CO_2 absorbed for a longer time.

The reduced methane emission through the anaerobic digestion of animal manure in biogas plants is an essential tool in reducing the climate impact of agriculture.

Climate impact of frequent discharge combined with biogas and pyrolysis of fiber fraction in two typical animal farms.



Climate effects measured per animal farm and per ton of manure.

Climate effect of biogas, frequent manure discharge, CCS, pyrolysis, and biochar		
Tonnes of CO2e per typical farm	**Dairy cows with weeners**	**Sows with piglets**
Emissions from stable and storage for liquid manure	553	1.926
Emissions after frequent liquid manure discharge, biogas, and biochar	33	80
Overall on-farm reduction	**520**	**1.846**
Climate effect in agriculture of frequent manure discharge for biogas and pyrolysis of fibre fraction		
kg CO2e per tonne of liquid manure	**Cattle**	**Pigs**
Emissions, liquid manure	41	67
Emissions, digestate	10	5
Effect of biogas	**-31**	**-62**
Biochar from fibres	-8	-3
Reduced emission of greenhouses gases	**-39**	**-64**
Reduced emission of greenhouses gases, per cent	**-94**	**-96**

Biogas Danmark

Climate effect

Overall climate impact of optimal management

Significant GHG emission reduction with frequent discharge to biogas plants and pyrolysis.

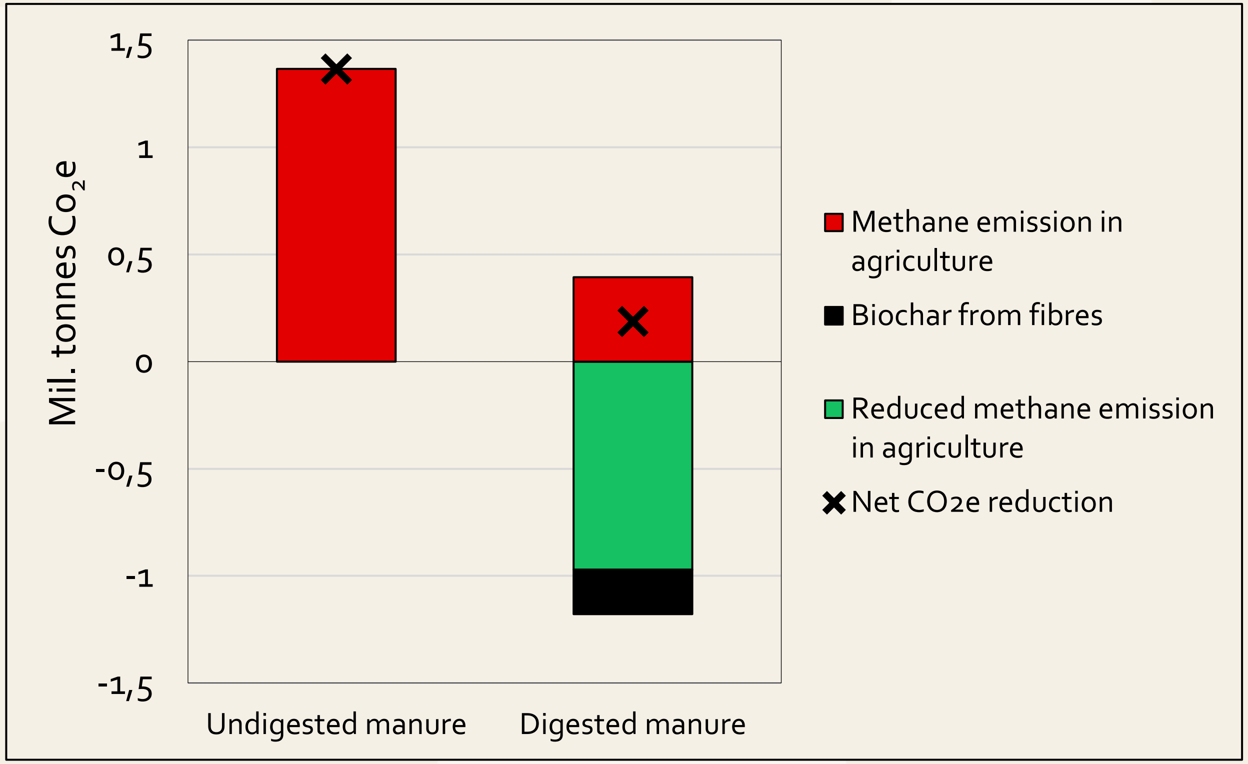
According to the Energy Agency's scenario, 65 per cent of the livestock manure will be delivered to biogas plants by 2030.

With frequent discharge in all these stables and the liquid livestock manure, therefore, is delivered to the biogas plants within a week, and the digestate is separated and the fibre fraction delivered to a pyrolysis plant. Then, methane emissions from agriculture can be reduced by about 1 million tons of CO2e in 2030.

The reduction will be even more significant if all the animal manure is treated this way.

Therefore, the potential for reducing agriculture's carbon footprint by exploiting the synergies between biogas production and pyrolysis is significant.

Overall climate impact in agriculture when 65 per cent of the livestock manure is handled in an optimal way – Energy Agency scenario.



In the Energy Agency scenario, the greenhouse gas emissions can be reduced with 1 million tonnes of CO2e if the livestock manure is flushed frequently out of the stables and delivered to biogas plants and the digestate afterwards is separated, and the fibre fraction goes to a pyrolysis plant. The crosses indicate the net emissions for both treated and untreated livestock manure.

Climate effect

Potential climate effect of pyrolysis and biochar

Significant synergies between biogas and pyrolysis.

There is great potential to improve the climate performance of agriculture by exploiting the synergies between biogas production and pyrolysis.

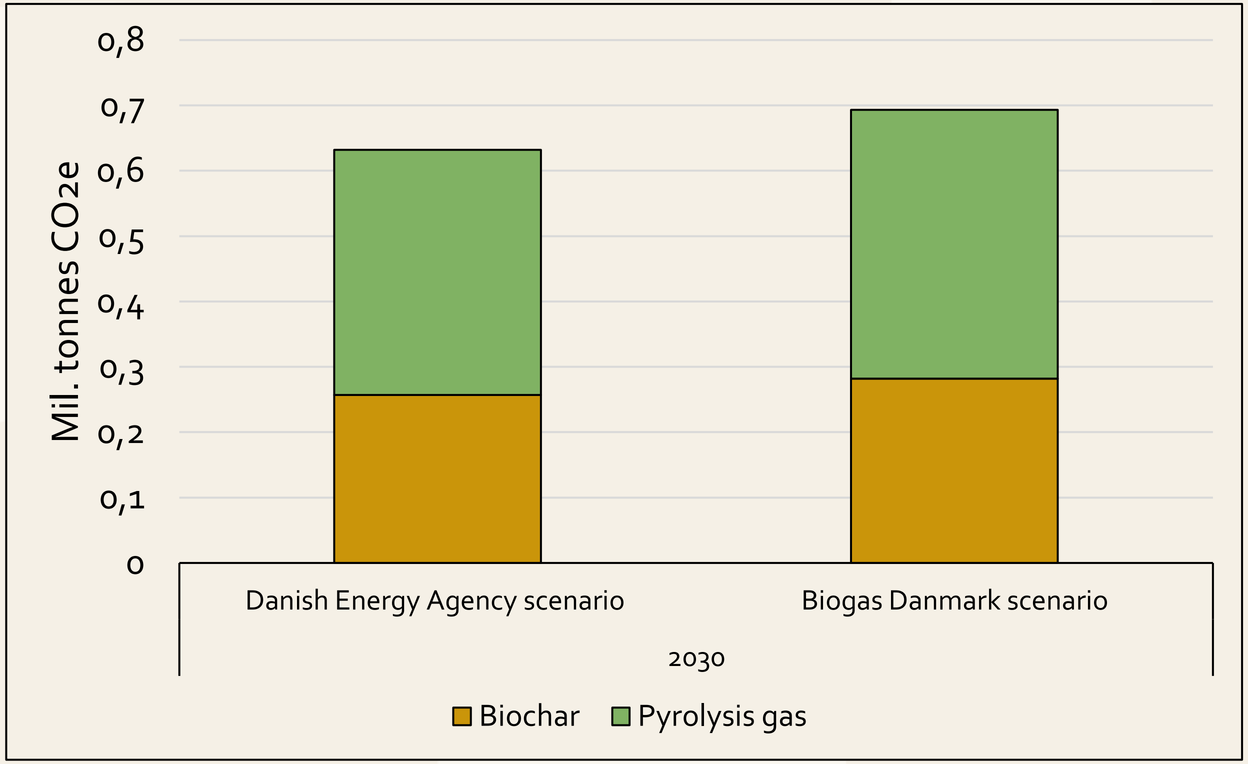
The digestate can be separated into a liquid fraction and a fibre fraction.

The liquid fraction contains most of the plant-available nitrogen and is, therefore, an attractive fertilizer. The fibre fraction can either be used as a fertilizer and soil improver or in a pyrolysis plant.

In a pyrolysis plant, the fibres are heated to several hundred degrees. In this process, pyrolysis gas is emitted, and the solid fraction is turned into biochar. The pyrolysis gas is used as process energy to dry the fibre fraction before pyrolyzation. The heat from the drying process can be reused as process energy in the biogas plant's upgrading units.

The carbon-rich biochar can be incorporated into the soil on farms where the carbon is stored for a long time.

Potential climate impact of pyrolysis gas and biochar produced from the fiber fraction of digestate based on livestock manure [27].



The Energy Agency scenario has a greenhouse gas reduction potential of 0.6 mill. tons if the digestate is separated and the fibre fraction goes to a pyrolysis plant. In the Biogas Denmark scenario, the potential is around 0.7 million tons. The climate effect of pyrolysis gas is calculated based on its ability to reduce gas consumption, thereby substituting more natural gas. For biochar, a 100 per cent long-term effect is assumed.

Climate effect

Life cycle analyses of climate impact from pyrolysis & biogas

Significant CO2 reduction from pyrolysis and biogas

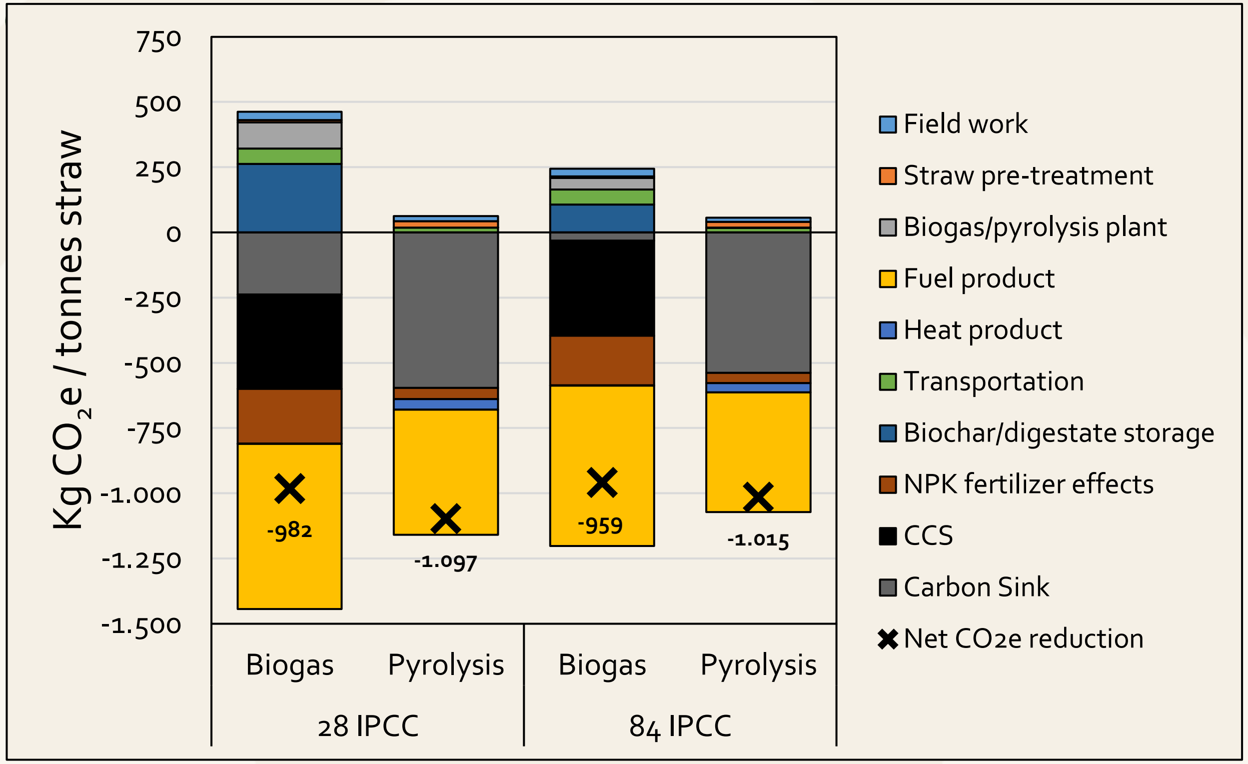
A certified life cycle analysis shows that using straw in combination with manure for biogas production combined with pyrolysis is environmentally beneficial. (28)

Pyrolysis plants convert straw into fuel and biochar. Biochar can ensure longtime storage of carbon in the soils. Biogas plants, on the other hand, convert straw and livestock manure into upgraded biogas and CO2, where the CO2 can be stored (CCS). The analysis accounts for factors such as process energy consumption and transport of biomass, among others.

Based on the analysis, both technologies significantly impact the climate and are comparable. The most optimal solution is to digest the straw in a biogas plant, after which the fibre fraction obtained by separating the digestate is sent to the pyrolysis plant.

The first full-scale plants are scheduled to be built in 2023 at a biogas plant in Jutland.

Comparison of carbon footprint from pyrolysis of straw and biogas with



In a life cycle analysis, the use of straw for biogas in combination with manure (including CO2 storage) was compared with the direct pyrolysis of straw. The red markings indicate the total reduction of greenhouse gases in kg CO2 equivalents per ton of straw at a methane emission factor of 28 (100-year period) and 84 (20-year period). (28)

Climate effect

Overall climate potential of biogas, CCS, and pyrolysis

Full utilization of the potential for CCS and pyrolysis significantly increases the climate impact of biogas

Biogas plants efficiently reduce methane emissions from animal manure in agriculture. In addition, the produced biogas can substitute fossil fuels in the energy sector, industry and heavy-duty transport.

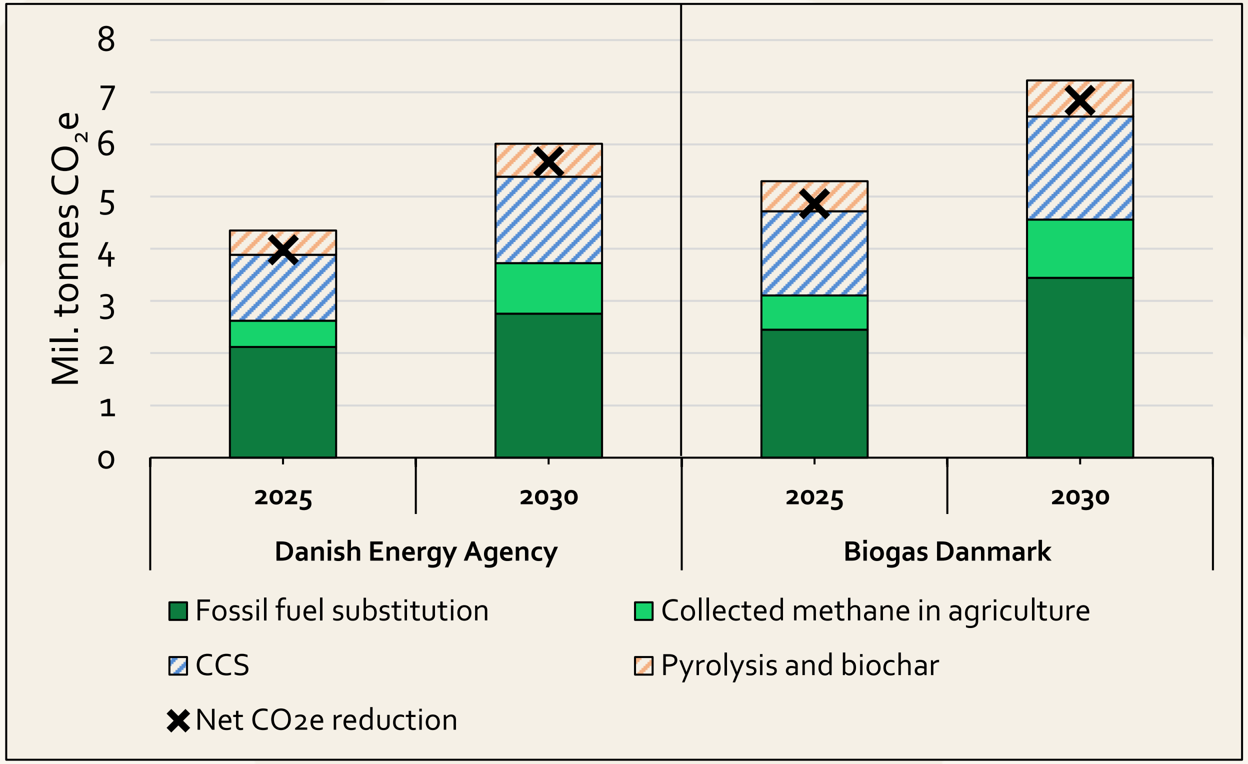
The climate impact can be significantly enhanced by storing the biogenic CO2 from biogas and treating the residual fibres in a pyrolysis plant. The pyrolysis plant produces pyrolysis gas and biochar. The pyrolysis gas can be used to produce process heat for the biogas plant, and the biochar can be stored in agricultural soil.

According to the Energy Agency scenario, the climate effect will be increased from 3.7 million tons to 6.0 million tons of CO2e by 2030 if the potentials in CCS and pyrolysis are fully utilized.

In the Biogas Danmark scenario, the climate effect can be further increased to 7.2 million tons of CO2e by 2030 if the potentials in CCS and pyrolysis are fully utilized.

Biogas Danmark

Potential climate impact of biogas, CCS, and pyrolysis in 2025 and 2030



The diagram illustrates the potential climate impact of biogas, CCS and pyrolysis combinations. The dark green represents the climate impact of replacing natural gas and diesel with biogas. The light green indicates the reduced methane emissions from livestock manure due to anaerobic digestion in biogas plants. The shaded areas represent the potential climate impact of CCS and pyrolysis gas and biochar. The climate impact of net CO2 reduction, marked with the black crosses, considers methane leakage and energy consumption involved in biogas production and transportation.

Circular economy and effects in agriculture.

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Biogas Danmark

Cirkulær Economy

Phosphorus recycling

Biogas plants recycle scarce resources.

In biogas plants, significant volumes of residues from agriculture, households and industry are digested, ensuring the recycling and reuse of the content of nutrients as fertilizer.

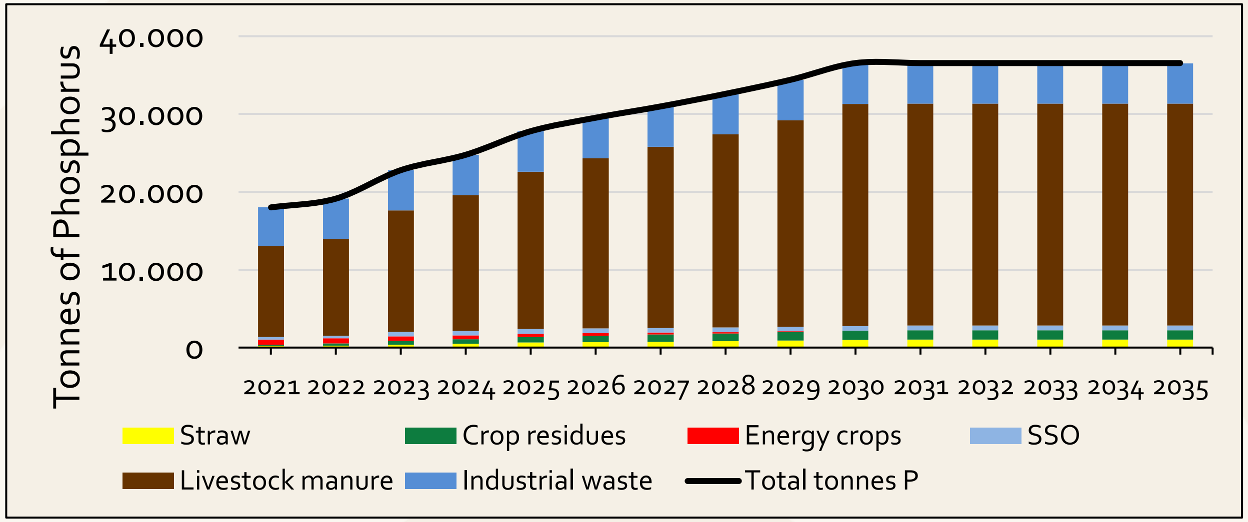
The most considerable quantities of phosphorus in the feedstock are in livestock manure, but significant amounts of phosphorus are also recycled from residues from industry and food waste from households.

According to the Danish Energy Agency scenario, biogas plants will recycle approximately 36,000 tons of phosphorus in 2030, of which almost 5,800 tons will come from industrial residues and food waste. About 2,200 tons of phosphorus will also be recycled from straw and agricultural crop residues.

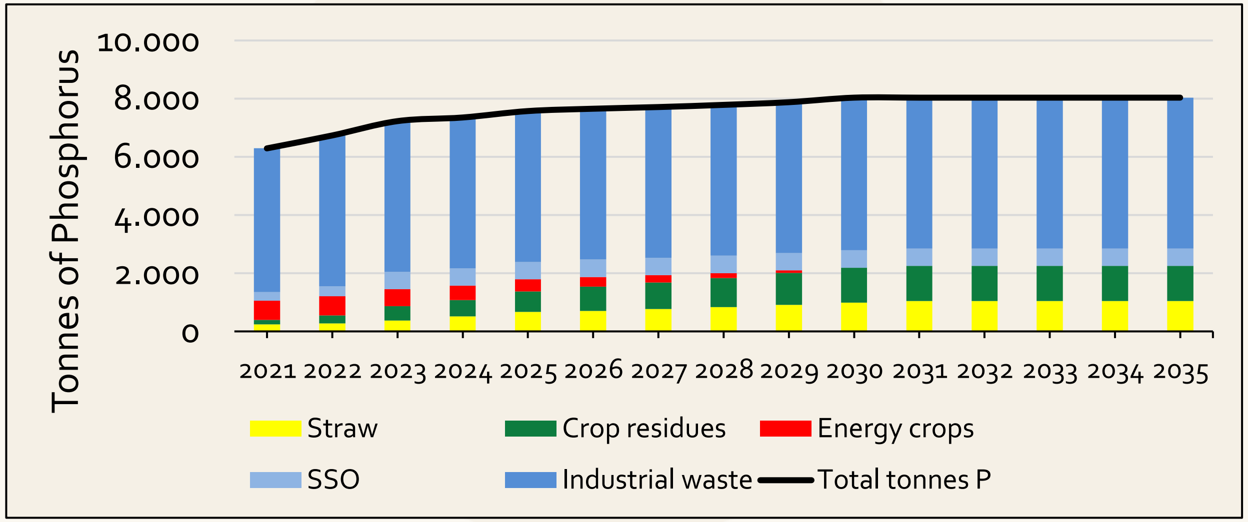
In comparison, 13,500 tons of phosphorus is applied to Danish crops in commercial fertilizers.

Both figures relate to the Energy Agency scenario.

Phosphorous handled in livestock manure and industrial waste via biogas plants



Recycled phosphorus via Biogas plants.



Biogas Danmark

Effects in agriculture

Reduced nitrogen leaching to the aquatic environment.

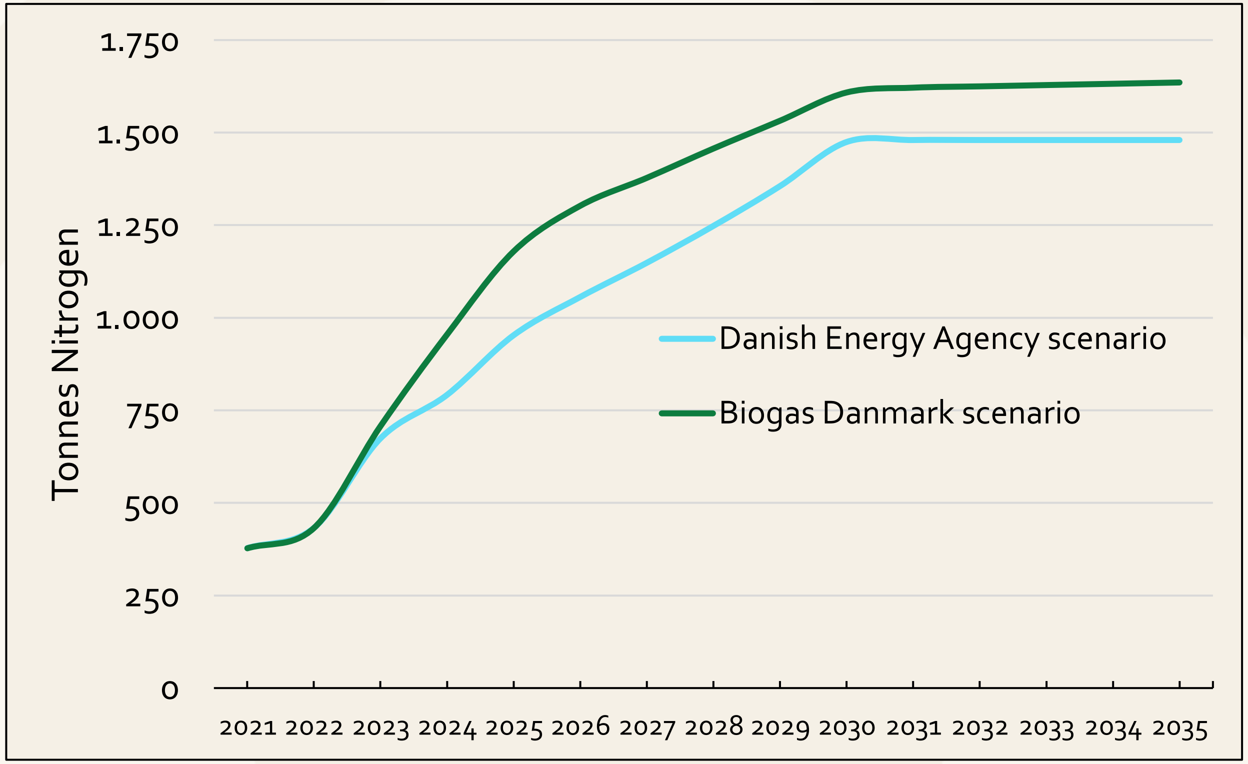
Biogas plants can contribute to the agricultural agreement's goal of lower nitrogen emissions.

When livestock manure is digested in biogas plants, the nitrogen is converted into a form that crops can readily utilize as a natural and efficient source of fertilizer. This results in improved plant growth, increased yields, and a reduced risk of nitrogen leaching into the aquatic environment.

In the 2021 agricultural agreement, the Parliament has set a target to reduce nitrate leaching by 10,400 tons by 2027 (24) to meet the European Union water quality goals. The production of 52 petajoules of biogas in the Energy Agency scenario, where 65 per cent of the livestock manure is digested in biogas plants, will reduce the leaching with approximately 1,200 tons of nitrogen per year by 2027.

If the biogas tenders are forwarded to 2024-2025, the increased and earlier digestion of livestock manure will reduce nitrogen leaching by 1,400 tons per year in 2027. This highlights the potential benefits of accelerating biogas production and its role in sustainable agriculture, meeting the environmental targets.

Annual reduction in nitrogen leaching through digestion of livestock manure.



According to the Energy Agency scenario, anaerobic digestion of 65 per cent of the livestock manure by 2030 could reduce the nitrogen leaching by nearly 1,500 tons. If the biogas production is increased according to the Biogas Danmark scenario, nitrogen leaching could be further reduced to almost 1,600 tons annually by 2030. [31]

Effects in agriculture

Synergies between biogas and organic farming

Biogas plants can support organic agriculture.

Recycling nutrients from food waste and agricultural and industrial residues via biogas plants can enhance the political objective of doubling the organic acreage.

According to SEGES Innovation, the conversion of 300,000 hectares to organic farming is dependent on 60,000 hectares of clover grass, which can collect nitrogen from the atmosphere. [32] If there is no market for clover grass as feed, it can be utilized in biogas plants to produce energy and fertilizer. Compared to ploughing it down, the anaerobic digestion of the biomass in the biogas plants reduces the risk of nitrogen leaching and greenhouse gas emissions.

1.4 million tons of clover grass silage from 60,000 hectares can produce nearly 5 petajoules of biogas. In the years to come, bio-refineries extracting protein for feed and food from grass are expected to be developed. This will generate significant quantities of by-products that can be used for feed or biogas production. If the fibres are used as cattle feed, there is a biogas potential of around 0.9 peta joules in the liquid residue. If both the fibre and liquid residues are utilized in biogas plants, it produces in 3.8 petajoules of biogas.

Biogas potential from approximately 60,000 hectares of organic clover grass.

In organic farming, the cultivation of clover grass is essential to supply crops with nitrogen. The clover grass can be utilized in biogas plants if it cannot be used as feed for ruminants. In the future, it can probably be utilized in bio-refineries that extract protein from which the residues, fibre and brown juice can also be used for biogas and feed production. Source: SEGES Innovation. [32]

Effects in agriculture

Biogas and biorefineries

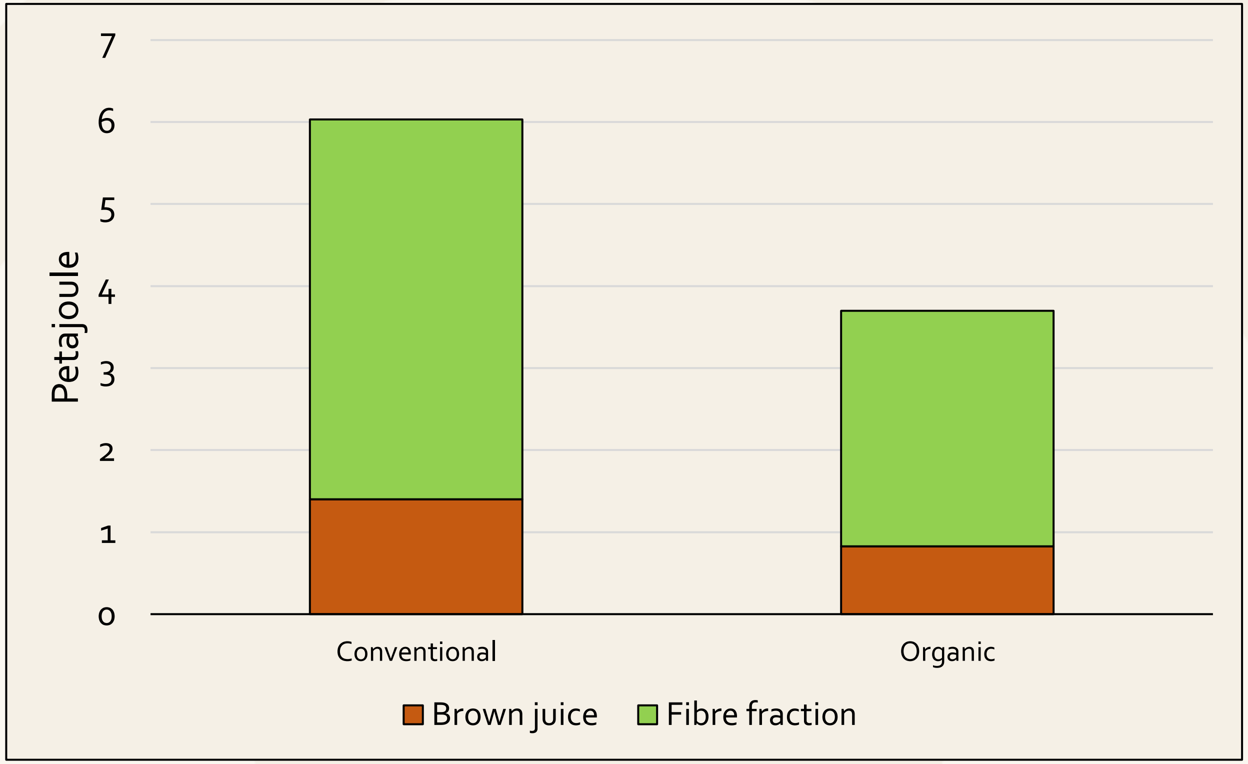
Biogas plants supports green biorefineries.

There is a growing interest in replacing imported protein with domestically produced protein from biorefineries that extract protein from green crops. In the coming years, the Ministry of Food, Agriculture and Fisheries will implement a subsidy scheme for feasibility studies and the establishment of biorefineries. The focus is on synergies between biorefining and biogas, which can ensure sustainable utilization of by-products for energy and fertilizer.

SEGES Innovation has assessed the biogas potential in the by-products from biorefineries, which yielded 50,000 tons of conventional and 30,000 tons of organic protein, respectively. The production of such quantities requires 56,500 hectares of organic clover grass and 74,000 hectares of conventional grass, respectively.

If both the brown juice and fibre fraction are utilized for biogas production, the total biogas potential is estimated to be 9.7 PJ. If only the brown juice is anaerobically digested in biogas plants, the biogas potential would be 2.2 PJ.

Biogas potential from biorefineries handling grass from 74,000 hectares of conventional clover grass and 56,500 hectares of organic clover grass.



Source: Seges Innovation. [32]

Denmark imports approximately 700,000 tons of crude protein annually. In addition, 30,000 tons of protein are imported annually for organic feed, which can be substituted with Danish grass protein. [33]

Biogas Danmark

Economy and market

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Biogas Danmark

Economy and market

Guarantees of origin

Guarantees of origin document the delivery of biogas through the gas grid.

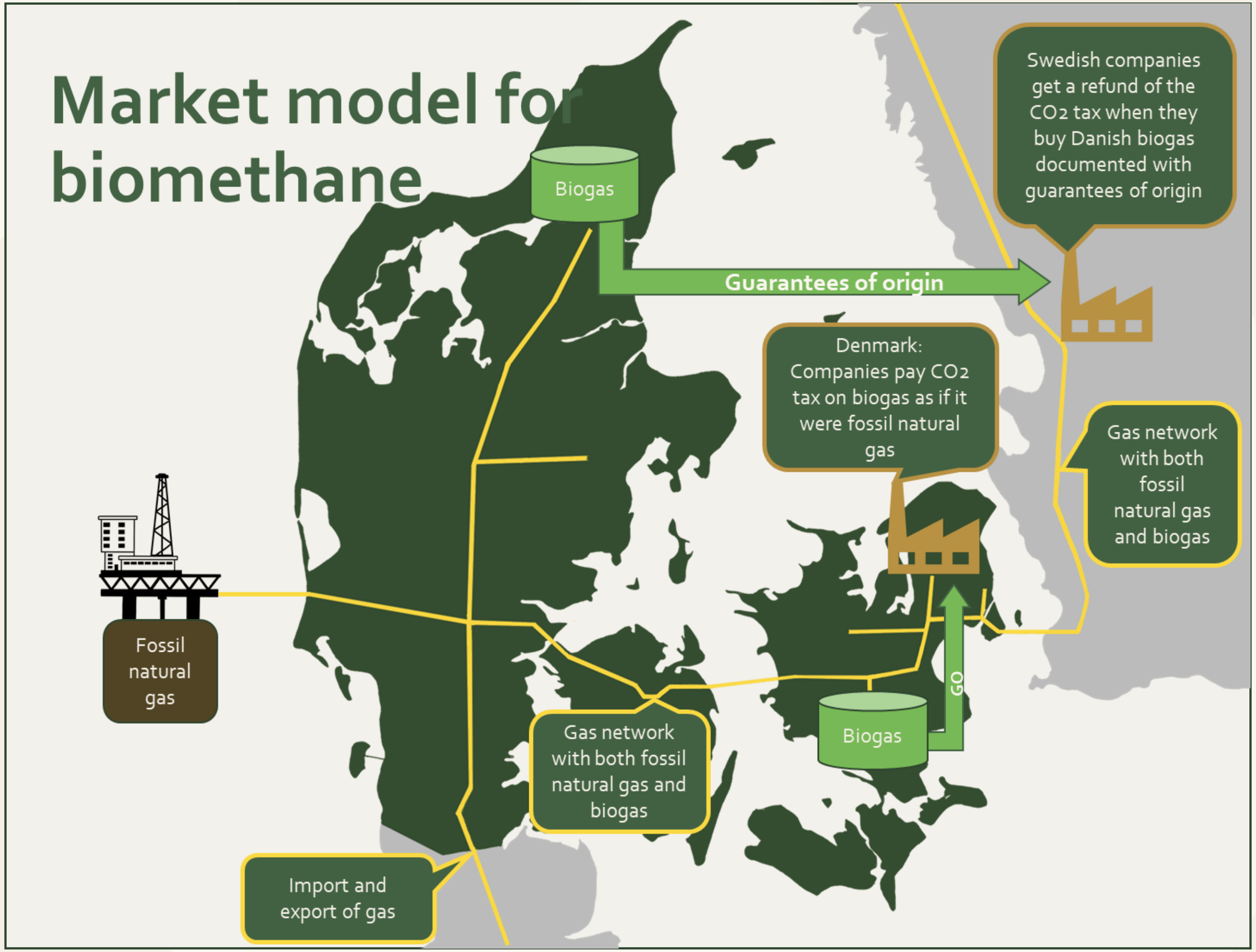
Biogas producers sell upgraded biogas via the gas networks to customers in Denmark and internationally. The independent organization, Energinet, owned by the Ministry of Climate and Energy, is responsible for issuing guarantees of origin (GO) for every 1 MWh of biogas injected into the gas grid.

To make a green choice, gas customers have to buy the GO in addition to buying the gas. The specific GO is then cancelled in Energinet's register, verifying that the gas has been utilized and cannot be resold.

In Germany and other countries, the authorities recognise GOs as a basis for CO_2 tax refunds in case of unsubsidized biogas.

In Denmark, GOs are recognized in CO_2 quota purchases but are not yet recognized for tax refunds.

Flow of biogas and related guarantees of origin and national differences in CO_2 tax refund.



Biogas Danmark

Economy and market

Guarantees of origin and sustainability certification

Guarantees of origin documents the origin - sustainability certificates declare sustainability.

The biogas market utilizes guarantees of origin to document the origin/producer of the biogas and ensure that it has only been sold once. On the other hand, sustainability certificates document that the sustainability criteria in the Renewable Energy Directive are fulfilled for the utilized feedstock. The sustainability certificates are issued by EU-accredited organizations such as ISCC, RedCert, or similar bodies.

The market price of the guarantees of origin depends on the sustainability certification.

Customers of biogas receive:

1. A receipt from Energinet, which confirms the transfer and cancellation of guarantees of origin from a specific producer, along with information on its subsidy status.

2. A sustainability declaration for the delivered gas containing information regarding its climate footprint. The climate footprint is typically determined based on standard values outlined in the RED II directive, based on the "Cradle to Grave" principle.

Sustainability Statement - Biomethane

Company Name	
Contact Name and telephone number	
Customer	
Production site	
Item Short Name and name	
Batch number	

The product that was delivered to the costumer complies with requirements in EU Renewable Energy Directive 2009/28/EC "RED"

GHG Emission CO_2eq/MJ – values and savings have been calculated according to the methodology in Directive 2009/28/EC.

The reference GHG value in RED/Directive 2009/28/EC for fossil transport fuel is equal to 83,8 g CO_2eq/MJ.

An example of a sustainability certificate section is where the carbon footprint is certified according to EU-approved certification systems and by approved auditors.

Economy and market

Market-driven subsidies

High gas prices and demand for biogas delivered through the gas network reduce subsidy needs.

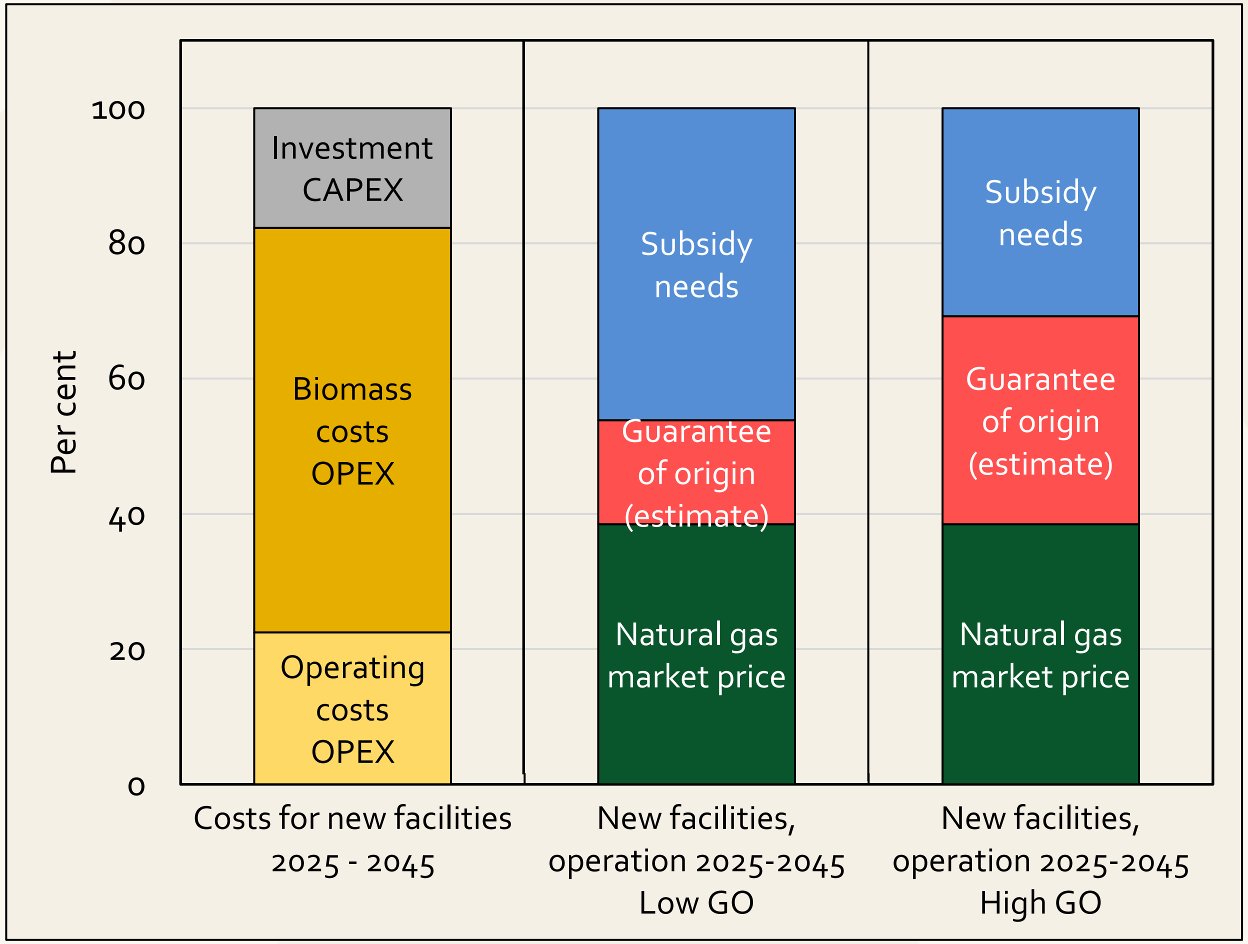
The production costs of biogas plants differ significantly from those of windmills and solar panels in that investment costs do not dominate them, but operating costs, with the expenses for biomass acquisition and handling being the most significant.

The economy of scale benefits has reduced larger biogas plants' investment and operational costs.

Consequently, the need for subsidies is primarily driven by revenue from sales in the market. The market prices of natural gas play a critical role. There is a growing willingness to pay a premium price for biogas delivered via the common gas grid, as demonstrated by purchasing guarantees of origin.

The prices of guarantees of origin for unsubsidized biogas are so high that they can cover production costs without subsidies because of the CO_2 reduction obligations in the EU's transportation fuel market.

Costs, revenues, and necessary subsidies for biogas plants.



The figure illustrates the fundamental correlation between production costs (34), market revenues, and need of subsidy for biogas delivered via the gas grid. The basic price fluctuates with the market prices for gas. On the contrary, the cost of the guarantees of origin (GO) depends on the biogas's climate footprint, as indicated by the accompanying certificates, and whether the biogas has received subsidies. Unsubsidized biogas has highest value in the market.

Biogas Danmark

Economy and market

Climate effect of biofuels according to the RED II

Are used in the market to comply with CO_2 reduction obligations

The European Union has, in the Renewable Energy Directive II (RED II), adopted a list of standard values to be used for the sustainability certification of transportation fuels.

These values are referred to as cradle-to-grave values, as demonstrated by the emission value for diesel being 94 kg CO_2 per GJ, which is higher than the CO_2 content of diesel. This approach accounts for upstream emissions. Another example is the negative value assigned to biogas produced from livestock manure, as anaerobic digestion in biogas plants reduces methane emissions in agriculture. (35)

These values are particularly relevant in countries that have implemented CO_2 reduction obligations. For instance, biogas produced from manure can displace nearly five times more CO_2 per GJ than biodiesel.

If a company overfills their CO_2 reduction obligation, they are eligible for a CO_2 ticket that can be sold to other companies that cannot meet the requirement. As such, these tickets offer a significant economic incentive for choosing sustainable fuels.

Climate effects according to the RED II directive and the Sustainability Ordinance

RES II Directive [kg CO2eq/GJ]	GHG emissions [Diesel]	GHG emissions [Default value]	GHG emissions [CCS]	Emission savings compared to diesel	Emission savings in per cent
Biogas:					
Manure	94	-100	-37	**231**	**245%**
Organic waste	94	14	-37	**117**	**124%**
Maize	94	30	-37	**101**	**107%**
Biodiesel:					
Waste oil (HVO)	94	15		**79**	**84%**
Rendered animal fat	94	20		**74**	**79%**
Rapeseed (1.gen.)	94	50		**44**	**47%**
Emmelev (1.gen.)	94	20		**74**	**79%**

The table summarizes selected standard values for climate impact and greenhouse gas emission reductions according to the RED II for calculating CO_2 emission reduction in the transportation sector. (35) Companies can use other values, provided they are certified under the RED II. Biogas Danmark estimated the carbon footprint for CCS. The self-consumption of fuel for transportation and storage, estimated to be about 7 kg CO_2e per GJ, is not included in the calculations.

Biogas Danmark

Economy and market

CO_2 reduction obligations in the transport sector

Differences in climate ambitions between Denmark and Germany hamper Denmark's carbon footprint.

CO_2 reduction obligations for transportation fuels came into force in Denmark by January 1, 2022. Only unsubsidized biofuels like biogas can fulfil the obligation.

Germany has adopted much stricter standards for transportation fuels. Consequently, diesel prices are much higher in Germany than in Denmark.

Therefore, German drivers preferably fuel their trucks in Denmark, deteriorating Denmark's carbon footprint and diminishing the impact of Germany's ambitious CO_2 reduction obligations.

Several Danish biogas producers have discovered it is economically attractive to export liquefied biogas (LBG) to Germany delivered via truck. This leads to a further deterioration of Denmark's carbon footprint.

Biogas Danmark therefore propose to increase Denmark's CO_2 reduction obligation by at least 2 percentage points from 2025, which will reduce the Danish CO_2 emission with 0.7 million tons in 2025 and the years to come.

Legislation to reduce CO_2 emissions in the transport sector in Denmark and Germany.

CO_2e reduction obligations (pct.)	2023	2025	2030
Denmark	3,4	5,2	7,0
Germany - current	8,0	10,5	25,0
Germany - new law proposal	8,0	9,25	25,0
ILUC requirement - limit for 1G (percent)	**2023**	**2025**	**2030**
Germany - new law	4%	2%	0%
Germany - ILUC non-food factor value	2	2	2
Denmark	None	Pending	Pending

The table displays the transport sector's CO_2 displacement requirements for Denmark [36] and Germany [37]. While Denmark has decided to introduce ILUC requirements in 2025, implementation has yet to be determined. The German ILUC requirements mandate that the climate impact of non-food-based biofuels be multiplied by a factor of 2. Additionally, there is a limit to the proportion of the CO_2 displacement requirement that may be fulfilled using first-generation biofuels.

According to the Green Road Transport Agreement of 2020 [4], the Danish Parliament has agreed to introduce ILUC regulation in 2025 aiming to reduce the use of food-based biofuels. Germany has already addressed this through a factor system and an absolute cap. Biogas Danmark proposes introducing ILUC requirements in Denmark from 2024.

Economy and market

CO2 tax refunds on biogas delivered via the gas grid

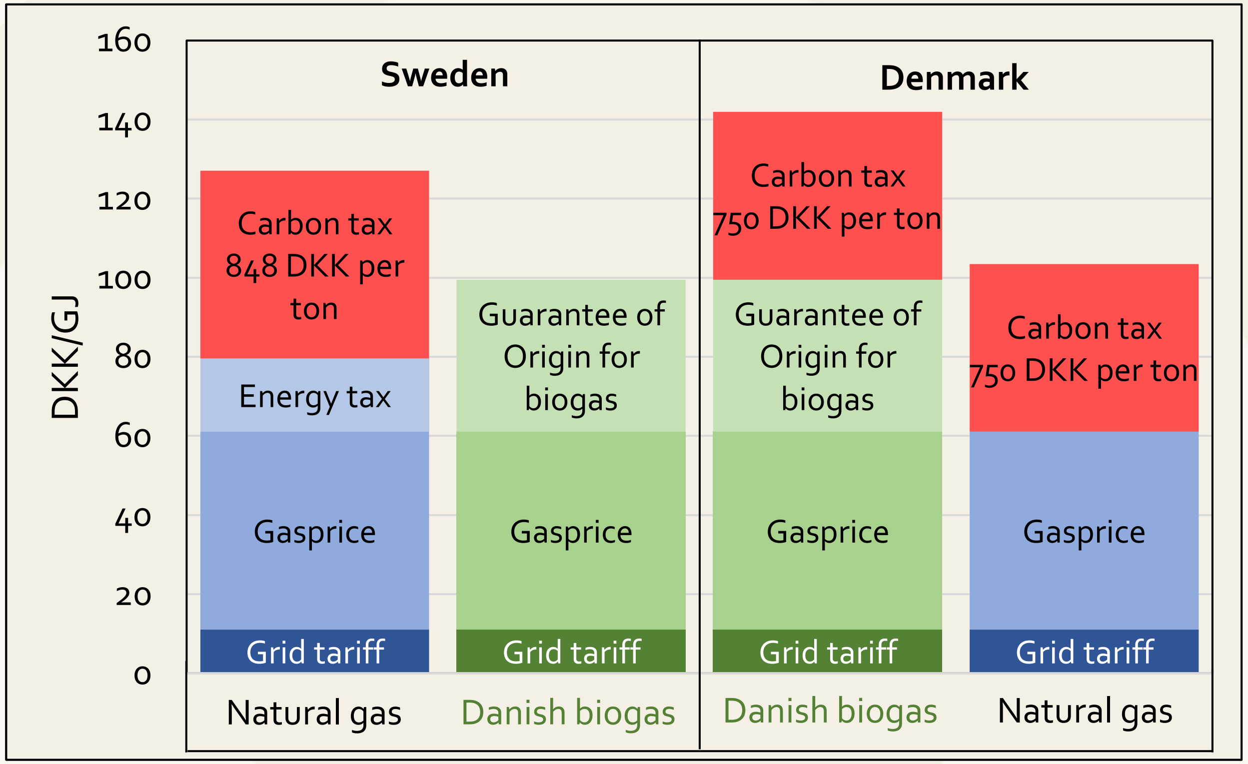
Tax refunds give foreign companies an advantage.

The Danish tax system differs significantly from that of both Germany and Sweden, and this is the main reason why a large part of the biomethane produced on Danish biogas plants is exported.

In Denmark, gas consumers are charged the same taxes for climate-neutral biogas as they are charged for fossil natural gas. In Sweden, industries have to pay significantly higher CO_2 taxes on natural gas than their Danish counterparts, but they have been able to achieve full tax refunds when purchasing biogas documented with guarantees of origin from Denmark. The European Court of Justice has rejected the Commission's state aid approval of the Swedish tax exemption for subsidized Danish biogas. However, this does not change the considerations for unsubsidized biogas.

In an agreement on green tax reform from June 2022, the Danish Parliament has agreed to analyze the possibilities of introducing a CO_2 tax refund for unsubsidized biogas delivered via the gas network documented via guarantees of origin. This would provide a level playing field with biogas delivered directly from biogas plants to industry.

Gas costs for ETS-based industry in 2030.



Swedish process industries have a strong tax incentives to choose climate-neutral Danish biogas compared to natural gas. In Denmark, however, the process industry has no tax incentives to choose biogas unless there is an opportunity for CO_2 tax refunds for biogas delivered via the gas grid documented with guarantees of origin.
The figure shows the difference in expected energy costs and taxes for Danish and Swedish companies in the non-ETS sector in 2030, depending on whether they purchase Danish biogas or fossil natural gas.

Biogas Danmark

Economy and market

Export of Danish biogas

80 percent of biogas exported in 2022.

For several years, a significant part of Danish biogas has been purchased by foreign companies, with Sweden and Germany dominating the market. According to a 2022 assessment, 81 per cent of biogas was bought by foreign companies. [38]

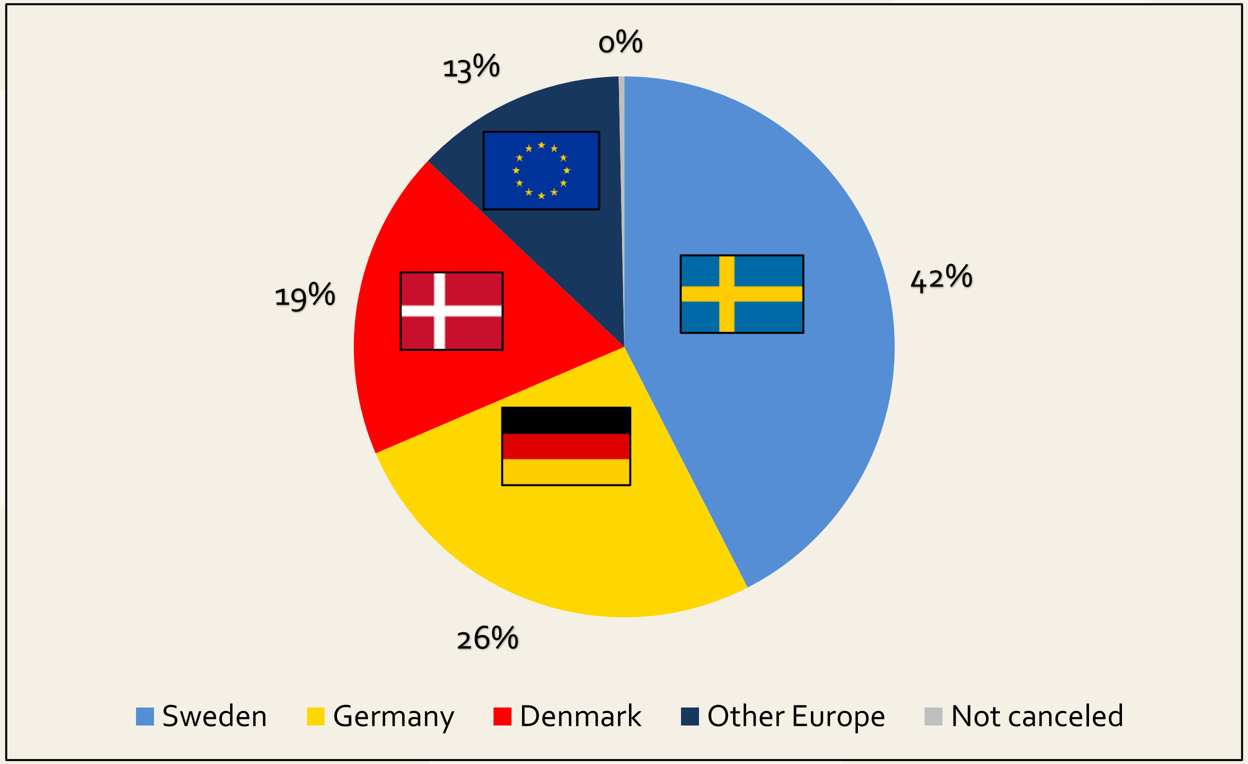
The main reason for the high export of Danish biogas is the tax authorities in Sweden and Germany accepting that guarantees of origin issued according to the Renewable Energy directive can be used to obtain refunds for the high CO_2 taxes in their respective countries.

On the contrary, Danish companies have no incentives to choose climate-neutral biogas over fossil natural gas due to the lower CO_2 taxes and no tax refunds for biogas delivered through the gas network.

However, due to a political agreement of a green tax reform, the Parliament is positive towards tax refunds for unsubsidized biogas delivered through the gas network and documented with guarantees of origin, thus increasing the demand for unsubsidized biogas.

To fully exploit the potential for unsubsidized biogas in Denmark, it will require that the CO_2 reduction obligation for transport is at the same level as Germany or that there are requirements to phase out food-based biofuels.

Export of Danish biogas in 2022



More than 80 per cent of guarantees of origin issued to upgraded biogas injected into the gas grid in Denmark was purchased by foreign consumers in 2022. [38]

The climate effects stay in Denmark.
Despite the export of biogas via guarantees of origin, the climatic effect of biogas production is still counted in the national Danish greenhouse gas inventory. Guarantees of origin provide companies abroad with the opportunity for tax refunds and to market green energy consumption. Revenues from the sale of guarantees of origin contribute to reducing the subsidies for biogas production.

Biogas Danmark

Economy and market

CO_2 taxes on livestock manure

Consequences at different levels of CO_2 taxes.

Late in 2023, the Danish expert committee for the green tax reform [40] will issue a recommendation regarding a future CO_2 tax on biological emissions from agriculture as requested by the government. The government has stipulated that a CO_2 tax on agriculture must not result in job losses or CO_2 leakage from Denmark.

In light of this, Biogas Danmark has analyzed the potential consequences of implementing a CO_2e tax on methane emissions from livestock manure, using the CO_2 tax levels defined in the "Agreement on Green Tax Reform for Energy and Industry".

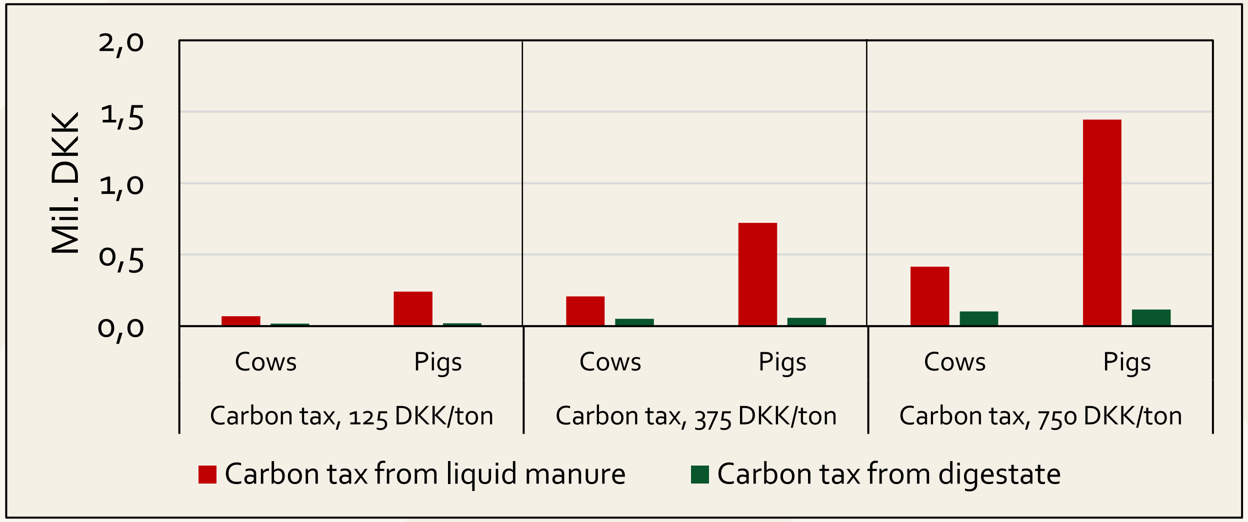
The red bars indicate the CO_2-tax of livestock manure handled without delivering to a biogas plant. In contrast, the green bars illustrate the CO_2-tax if the manure is frequently flushed from the stables and delivered to a biogas plant for anaerobic digestion.

The top figure shows the potential impact on a dairy farm with 400 cows with calves fed up to 6 months and a farm with 1,100 sows that raise all piglets to slaughter. The bottom figure shows the overall tax burden for agriculture in the Energy Agency scenario, where 65 per cent of the livestock manure is digested in biogas plants.

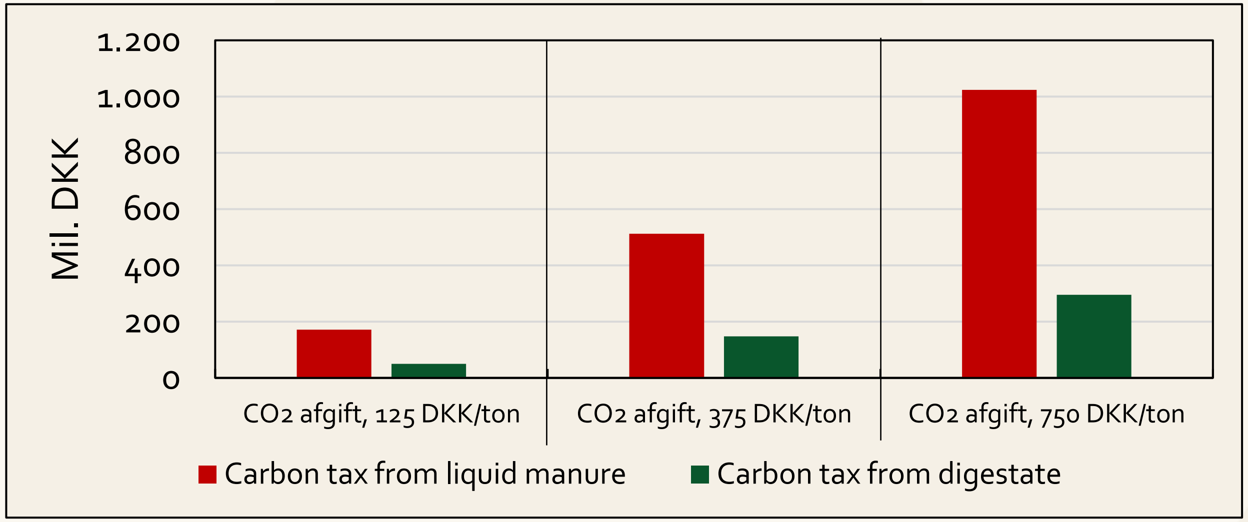
The calculation of CO_2 taxes for the total production is based on the assumption of frequent discharge, among other factors, assumed in the Energy Agency scenario.

Biogas Danmark

CO_2 taxes per farm based on different manure management methods.



CO_2 taxes for total livestock production in Denmark with and without optimal manure management for the Energy Agency scenario.



Economy and market

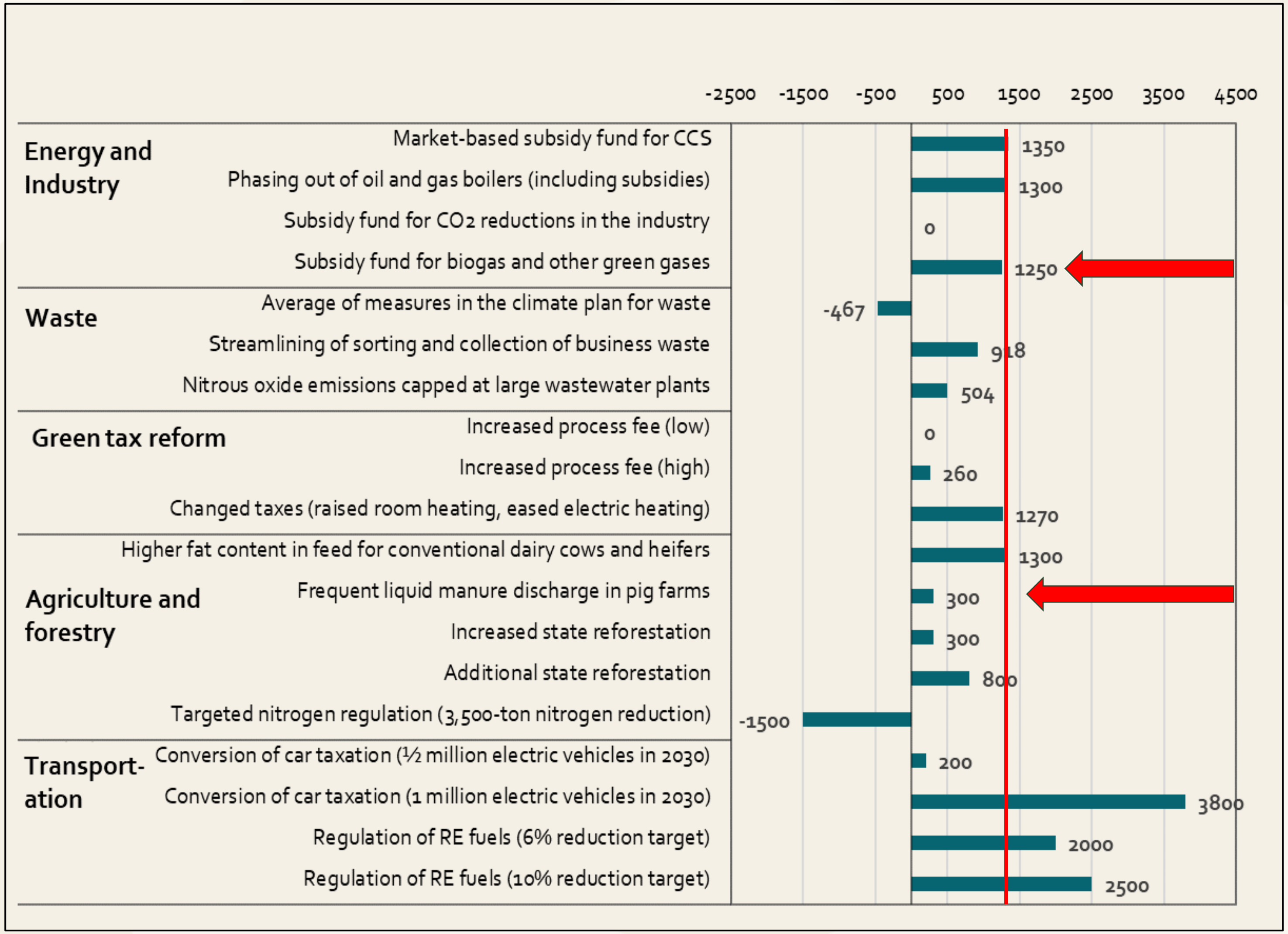
CO2 shadow costs for biogas

Low shadow costs for biogas compared to other initiatives to reach the 70 percent goal.

As stated in the government's Climate Program 2020, the forthcoming biogas subsidies entail a CO_2 shadow cost of 1250 DKK per ton of CO_2. [41]

Consequently, biogas presents a relatively low CO_2 shadow cost compared to other initiatives adopted thus far, specifically those within the transport sector.

CO_2 shadow costs according to the Government's Climate Program 2020 [27].



This is how we did it

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This is how we did it

Data foundation and assumptions

Biogas Outlook 2023 is based on the forecast for biogas production and gas consumption in Analyseforudsætninger for Energinet 2022 (AF22) [1] by the Danish Energy Agency. The Energy Agency provides data on the development of biogas production and the amount of manure [41] that is digested but does not provide further information on which biomasses are expected to be used in biogas production. Therefore, Biogas Denmark has made assumptions on the biomass distribution based partly on the annual biomass reports to the Energy Agency [40] and partly on Syddansk Universitet's calculation of the biomass potential [5]. KF22 includes an expected distribution of cow and pig manure [41].

AF22 and KF22 also do not provide a detailed forecast for implementing of frequent manure removal from barns to biogas plants. Meanwhile, the Energy Agency has not yet incorporated the Agricultural Agreement's [24] decision to introduce frequent manure removal in pig barns from 2023. Therefore, for the period up to 2030, Biogas Denmark has made assumptions based on data on frequent manure removal from Aarhus University.

Moreover, it is assumed that the methane loss will decrease from approximately 2% to 1% in 2024, based on the Climate Agreement for Green Power and Heat from June 2022 [7]. The agreement decided to introduce regulation of fugitive methane emissions from 1 January 2023. While the Energy Agency's scenario follows the biogas forecast in AF22, the Biogas Danmark scenario shows how biogas production develops with an acceleration of the planned tenders and by creating conditions for increased sales of unsubsidized biogas to the transport sector. Based on this, Biogas Danmark has made assumptions for biomass distribution with higher biogas production.

This leads to higher biogas production and more significant methane reduction in agriculture.

Reductions in nitrogen leaching are calculated based on research from Aarhus University [31]. Phosphorus recycling is calculated based on typical values from Seges [29].

The market value of biogas is calculated using data from the Energy Agency [9], EEX Gas Market Data [10], and Energinet [11].

CO_2 storage and Power-to-X calculations are primarily based on the Energy Agency's technology catalogues [22]. The CO_2 content is calculated based on the distribution of CO_2 and methane in biogas. The market value of biogas is calculated using data from the Energy Agency [9], EEX Gas Market Data [10], and Energinet [11].

This is how we did it

Parametres and standard values

Tabellerne på denne side viser de centrale værdier for gasudbytte for forskellige biomasser [2, 42] samt de anvendte værdier for energiindhold i massefylde, klimaeffekter, metantab, fremskrivning af hyppig udslusning mv.

Biomass	Dry matter [%]	Volatile soil (VS) [%]	Gas yield Nm3 CH4/ kg VS	Gas yield Nm3 CH4/ tonne biomass
Cattle manure	8	6	0,25	15
Pig manure	5	4	0,35	15
Deep litter	30	24	0,27	65
Energy crops	31	29	0,33	96
Crop residues	30	29	0,32	92
Straw	84	80	0,29	228
Industrial waste	22	20	0,45	90
SSO	23	20	0,43	84

Overview of Parameters		Unit
Calorific value and density		
Methane, lower calorific value	35,9	MJ/Nm^3
Natural gas, lower calorific value	39,6	MJ/Nm^3
Density, methane	0,72	MJ/Nm^3
Density, carbon dioxide	1,98	MJ/Nm^3
CO_2e emissions		
CO2 emission, natural gas	55,5	kg CO_2/GJ
CO2 emission, diesel	74,10	kg CO_2/GJ
CO2 emission, diesel RED II	94	kg CO_2/GJ
CO2 emission, electricity production	Energinet projection	
Own consumption		
Pretreatment and biogas production	26 - 36	kWh/tonne biomasse
Upgrading of biogas	0,1 - 0,6	kWh/Nm_3 CH4
CO2, transport of biomass	1.080	tonnes CO_2 / PJ biogas
Upstream emission, natural gas	3.000 - 6.700	tonnes CO_2 / PJ biogas
Fugitive methane emission	2,1 → 1	%
Projection of frequent discharge	7	%, new stables
	9	%, old stables
PtX		
CH4/CO2 ration in biogas	60 / 40	%
PtX, elektromethane	35	%, Efficiency
PtX, methanol	48	%, Efficiency

Biogas Danmark

References

Note no.	Subject	Reference
1	Analysis assumptions for Energinet	Analyseforudsætninger for Energinet
2	BiB analysis, 2021	BiB-analyse, 2021
3	Climate Council status report 2023	Klimarådet statusrapport 2023
4	Agreement on green conversion of road transport	Aftale om grøn omstilling af vejtransporten
5	Energy crop analysis	Energiafgrødeanalysen
6	Methane emissions at Danish biogas plants 2021	Metantab på danske biogasanlæg 2021
7	Methane regulation	Metan regulering .pdf
8	Energinet, CO2 in the electricity grid	Energinet, CO2 i elnettet
9	Energinet, CO2 in the electricity grid	Energinet, CO2 i elnettet
10	Energinet, amount of biogas in the gas grid	Energinet, mængde biogas til gasnettet
11	Energistyrelsen, Subsidy rates 2022	Energistyrelsen, Støttesatser 2022
12	Spot market data	Spot market data
13	Biogas Danmark Data Online	Biogas Danmark Data Online
14	Green Power Denmark	Green Power Denmark
15	EBA Statistical Report 2022	EBA Statistical Report 2022
16	REPowerEU	REPowerEU
17	Subsidy scheme 2012	Støtteordning 2012
18	List of biogas plants in Denmark, 2021	Liste over biogasanlæg i Danmark, 2021
19	Digested biomass maintains soil carbon	Afgasset biomasse opretholder jordens kulstof
20	Electricity production by type	Elektricitetproduktion fordelt på type
21	Technology catalogue for renewable fuels	Teknologikatalog, fornybare brændstoffer
22	Energinet, Environmental report 2021	Energinet, Miljøredegørelse 2021

References

Note no.	Subject	Reference
23	Agreement for CO2 capture	Aftale for CO2-fangst
24	Agreement on green conversion of Danish agriculture	Aftale om grøn omstilling af dansk landbrug
25	Effects of normal and frequent discharge	Effekter af normal og hyppig udslusning
26	Seges Gris, note	
27	Knowledge synthesis of biochar in Danish agriculture	Knowledge synthesis of biochar in Danish agriculture
28	LCA Biogas and pyrolysis	LCA Biogas og pyrolyse
29	Phosphorus regulation	Fosforregulering
30	Phosphorus in Danish agriculture	Fosfor i dansk landbrug
31	Climate and environmental effects + nitrogen leaching	Klima og miljøeffekter + kvælstofudvaskning
32	Seges Innovation, notes	
33	Aarhus University on protein	Aarhus Universitet om protein
34	Production costs and own consumption	Produktionspriser og eget forbrug
35	RES directive, 2018	VE-direktivet, 2018
36	RES requirement Denmark	Fortræningskrav Danmark
37	RES requirement Germany	Fortræningskrav Tyskland
38	Energinet on origin guarantees	Energinet vedr. oprindelsesgarantier
39	Climate program 2020	Klimaprogram 2020
40	Climate agreement on green electricity and heating 2022	Klimaaftale om grøn strøm og varme 2022
41	Climate status and projections, 2022	Klimastatus- og fremskrivning, 2022
42	Article on gas yield from biomass	Artikel om gasudbytte af biomasser

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Danmark

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