SCALING LAND-BASED MITIGATION SOLUTIONS IN THE NETHERLANDS

LAND-BASED MITIGATION NARRATIVES

JIN & BIOCLEAR

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1. Co-design of LMT scenarios

1.1 Introduction

This report includes a description of a generic nation-wide transition scenario for the implementation of land-based mitigation technologies and practices for the AFOLU sector (agriculture, forestry, and other land use sectors) in The Netherlands.

To co-develop these scenarios a broad range of information/literature sources, and stakeholder consultations have been conducted. Land-based mitigation technologies (LMTs) includes a broad range of carbon farming options and/or nature-based solutions for emission reduction and carbon removal, such as peatland rewetting, BECCS, biochar, agroforestry, and afforestation. It is the intention of this report to serve as input for economic and land use simulation modelling to estimate (quantify) the impacts of nation-wide scaling up of a series of LMT solutions.

The combination of LMT solutions ('National LMT portfolio') described in this report has been selected (short-listed), after consultation with several stakeholders. Key selection criteria included policy relevance, technological feasibility, and scalability.

The Dutch climate agreement states that the Dutch AFOLU sectors will have to be climate neutral by 2050. This implies that deep cuts in GHG emissions are needed, and to compensate for any residual/remaining emissions a certain amount of carbon removals will also be needed.

A portfolio of land-based mitigation solutions for agriculture and land use sectors

We consider a mixture of the following key reduction and removal solutions:

1. Peatland management (rewetting and paludiculture)
2. Agroforestry (grasslands trees outside forests)
3. Afforestation (land converted into forest land)
4. Bio-energy carbon capture and storage (BECCS) and recycling of nutrients and organic carbon

Peatland management

CO_2 emissions due to the drainage of peat(y) soils within The Netherlands are responsible for about 3-4% of the national GHG emissions. On top of that the oxidation of peat causes significant soil subsidence in large areas of the country. There are already many pilot initiatives that experiment with different technologies for rewetting peat(y) soils in an effort to limit soil subsidence and retain the soil carbon. These pilot initiatives mostly are executed in relation to dairy cattle farming, where grass is cultivated in peat meadows and used as animal feed. In addition, a more limited set of pilot projects are experiments with different crops and vegetation that thrive better in wet conditions (paludiculture). To date, the total acreage of pilot rewetting projects has been rather limited. While the pilot projects show promising results, nationwide scale-up of rewetting comes with a series of challenges. For example, the business model for rewetting for the dairy cattle farmer is still too weak (in most cases the dairy cattle farmer will have to accept or switch to another form of land-use). On top of that the national water management systems (run by regional water boards) that serves different land use functions (farming, housing, industry) will become much more decentralised/localised and difficult to manage to guarantee water safety, quality, and quantity.

Afforestation and agroforestry

While the total area of forest cover (about 10% of total land surface area) in The Netherlands is limited, the forest sector is a significant carbon sink. While forest cover in The Netherlands gradually increased since the 1970s, but after 2013 rapidly declined again to 1990 levels. The trend in deforestation has nearly come to a halt in the past few years. A key cause for deforestation were a range of nature restoration initiatives that resulted in forest land being converted back into other (more open) forms of nature landscapes. There are increasing ambitions to expand the forest area outside the already existing nature areas. This can be sone either by means of afforestation, or by planting more trees outside forest, such as through agroforestry (e.g., food forests or reintroducing landscape elements such as hedgerows). In most cases the expansion of the forest / agroforestry area will come at the expense of land used for agricultural purposes.

Bio-energy carbon capture and storage/utilization and recycling or organic carbon

Bio-energy carbon capture and storage/utilization (or BECCS/U) is considered one of the key options for carbon removal internationally. Also, within The Netherlands, BECCS/U is considered a serious climate change mitigation option, with significant potential. However, most BECCS studies and scenarios for The Netherlands assume that large amounts of biomass will be imported from abroad, where after combustion the biogenic CO_2 will be captured and stored in underground geological formations. Within this scenario study we analyse BECCS/U, where the bioenergy stems from the anaerobic digestion (AD) of (liquid) animal manure, and where the excess biogenic CO_2 from the biogas is captured and stored/used.

The main advantage of animal manure is that it is available domestically in large quantities. Currently, only about 5-10% of the total annual domestic production of animal manure is processed or treated. The biogas production potential is significant (reduction)[1], as well as the potential for reducing methane emissions from manure management (reduction) and associated ammonia emissions (NH3) from stable systems. The captured CO_2 can be either stored underground (removal) or used in several industries as feedstock (reduction). On top of that the AD of manure results in a digestate, that can be further processed and converted into an organic fertilizer. Organic fertilizers have the potential to replace chemical fertilizers (reduction) as well as aid in the accumulation of soil carbon (removal).

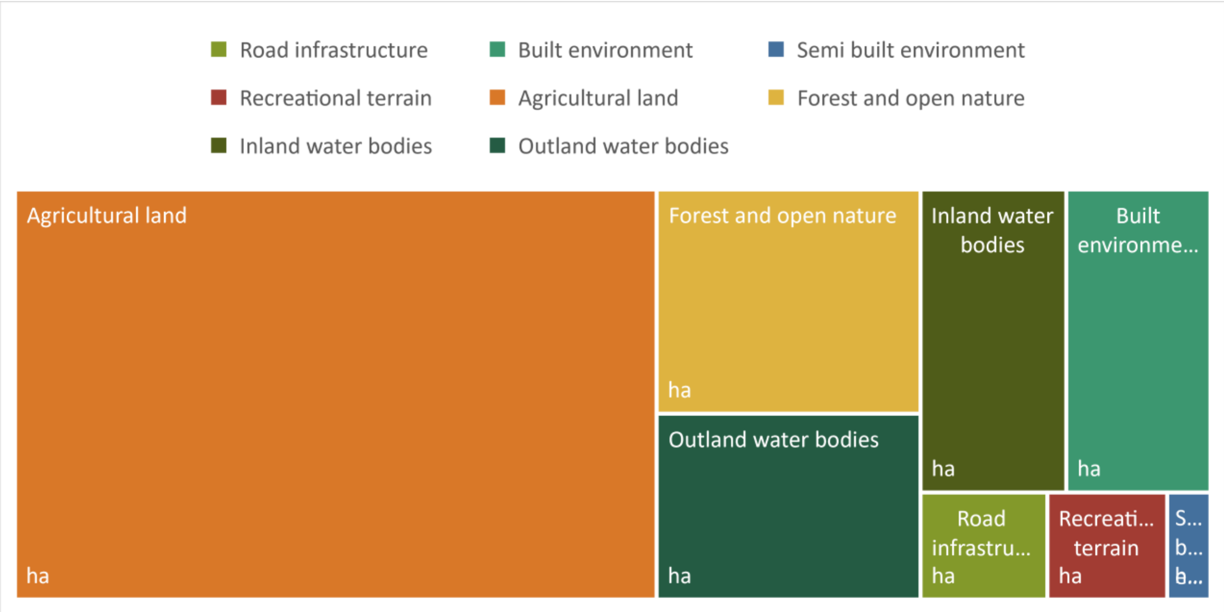
The impact of scaling up the LMT portfolio

[1] Biogas can be used directly for co-firing, or be upgraded to be injected into the gas grid or upgraded to transport fuel (bio-CNG or bio-LNG).

Scaling up of these different LMTs to the national level will be highly challenging for a small, and densely populated country like The Netherlands. The transition in the AFOLU sector, will likely have a broad range of spatial, socio-economic, and environmental impacts that are difficult to predict.

To be able to co-design more realistic scaling up scenarios for the selected LMT portfolio to be able to meet the set climate sectoral 2050 net-zero climate target, we also must consider a range of other relevant (policy) developments and targets that have an (in)direct impact on the GHG emissions within this sector.

Figure 1-1: Land use in The Netherlands (2017 data)



Source: CBS, 2021

Within the agricultural sector, livestock farming in The Netherlands has a large claim on the use of scarce land. In 2022, about 2,2 mln. ha of land (or 54% of total land use) was used for agricultural purposes. A sizeable part of this arable land 1,16 mln. ha (54%) was used as grassland and cultivation of other feed crops for cattle (e.g., fodder maize). Both the cattle sector and pig sector are key contributors to national NH_3 and CH_4 emissions. This livestock farming practice is no longer considered to be sustainable in the long-run due to several environmental (e.g., biodiversity, soil subsidence, GHG/NH3 emissions) and social (e.g., animal/human health, housing shortage, land scarcity and flood risks) issues).

As a result, a transition strategy is needed for (dairy) cattle and pig farmers to make better, more sustainable end/or alternative use of their land, livestock, and biomass resources to reduce their negative impacts on the environment, while at the same time contributing to a range of social, economic, and environmental goals.

We propose three transition storylines or scenarios:

1. **Base case:** dairy cattle and pig farming remain at the same level of productivity and do not switch away from traditional (intensive) livestock farming practices. This will entail a continuation of existing livestock management practices with associated negative environmental and social impacts (e.g., emissions and future costs of soil subsidence and further environmental decline).
2. **New 1 - scaling nature-based solutions:** Planting additional trees outside forests (as agroforestry or as afforestation) and rewetting organic soils will be implemented. The subsequent land claim for scaling these nature-based solutions could be synergetic with the envisioned deliberate (planned/forced) reduction of the livestock sector. Such reduction of livestock herds will automatically reduce the related NH_3/CH_4 emissions. Both rewetting and tree planting will reduce the land available for feed (grass / maize) production or will lower the overall yields per hectare, requiring more extensive livestock management practices for cattle (or additional feed imports).

   Business case: the business case for rewetting is uncertain as nationwide rewetting maybe implemented without clear plans for farm compensation. Also, the business case for agroforestry and afforestation is still marginal and risky, particularly in the start-up phase of around 5 years, and because new supply chains and market demand for new bio-based products are not well established. Also, the valorisation strategy (which incentives to pick and combine) is unclear. Rewetting practices are most suitable in the lower lying Northern and Western parts of The Netherlands with higher shares of organic/peat(y) soils, while tree planting (for agroforestry or afforestation) is more suitable in the Southern and Eastern parts of the country with higher shares of sandy and clay type soils.
3. **New 2 - scaling engineered solutions:** Anaerobic digestion of animal manure and post-treatment of digestate is used to reduce CH_4, NH_3 emissions from livestock, to produce renewable energy (biogas), liquid CO_2 and organic fertilizers to replace fossil equivalents. The scale of deployment (manure availability) will largely depend on the expected size of the dairy and pig herds. The current political debate considers planned reductions (even with possible forced buyouts) of the livestock sector ranging from 10-50%.

   Business case: Currently, the business case for biogas-CCUS is highly uncertain within the political landscape which intends to proactively reduce the size of the livestock sector, and fragmented policy regime for valorisation. In this situation the expected decline in domestic food production may be dampened.

We anticipate that a most plausible scenario will entail a combination of the above three scenarios, where certain highly productive regions, where soil subsidence is less of an issue, and no Natura2000 zones are nearby will retain intensified cattle/pig farming (***Base case***). Other regions could retain a certain level a semi-intensive (dairy) cattle farming, which can be combined with anaerobic digestion of animal manure (***New 2 – scaling engineered solutions***). This would also free up land to build additional houses and infrastructure but may limit land available for expansion of natural areas (e.g., afforestation). Other areas may switch to a more extensive type of livestock farming system to limit environmental issues, expand land available for rewetting and tree planting (***New 1 – scaling nature based solutions***).

Within the Chapter 2 we discuss a diverse range trends and (policy) developments and targets that have a significant (in)direct impact on the scaling up of the presented LMT portfolio.

2. Policy developments

There are several ongoing policy processes that are relevant for the AFOLU sector, and for driving the implementation and scale up LMTs.

2.1 Climate and renewable energy policies / strategies

Given the inherent exposure to naturally occurring processes, such as oxidation, photosynthesis, and mineralisation, the agricultural sector is unlikely to be able to reduce their sectoral GHG emissions to zero by 2050. Some 'hard-to-abate' residual emissions (e.g., N2O, CH4) in agriculture are likely to remain (IPCC, 2023). As a result, this sector will have to rely on the use of a certain amount of carbon removals to be able to achieve net zero emissions by 2050. For most sectors specific GHG emission reduction targets are set. However, national level or sector level carbon removal targets are not (yet) determined. The extent to which carbon removal measures have to be implemented largely depends on the success and efforts made on reducing emissions.

In the interim period towards 2030, there are several energy, land use and climate policy initiatives relevant for the LMTs included in our portfolio (summarised in). These policy processes run in parallel. The main ones include:

- The regional energy strategies (RES)
- The peat meadow strategy (VWS)
- The forest strategy (BS)
- Blending obligation for green gases (BV)

Regional energy strategies

The regional energy strategies aim to decarbonise the electricity and heating system in the different regions. There are 30 so-called 'RES-regions' which formulate their own strategies and implementation plans for reducing energy related CO_2 emissions. The combined efforts (and pledges) of the RES-regions will have to add up to meeting the set national climate and energy targets for 2030. The primary focus of this nationwide participatory policy process up until now has been on ensuring that by 2030 an additional total of 35 TWh of renewable electricity is produced. This would require a land claim of about 5.000 ha (estimated range between 4.500 and 6.700 ha) to meet the target.

An evaluation of the RES 1.0-strategies by (PBL, 2021) shows that the regions have pledged to produce 55 TWh of renewable electricity. However, (PBL, 2021) estimates that based on several implementation challenges (e.g., grid capacity shortages, grid congestion, environmental permitting) that a realisation of 35 to 46 TWh (with middle value of 41 TWh) is realistic. This increase in capacity for renewable electricity production will mainly comprise onshore wind, and solar pv (rooftop and/or field). This expansion will have significant spatial implications due the additional land use claim. This will interact with the scale up of the different LMTs in our portfolio. With agroforestry/afforestation, the expansion of onshore wind/pv can compete for the same land. Also given the announced reduction of the Dutch livestock sector, the economics of an LMT versus, for example, an onshore solar park will become a relevant factor in determining future land use.

Peat meadow strategy

In the Dutch Climate Agreement (Government D. , 2019) it is anticipated that measures for managing peat meadow areas (i.e., increasing the groundwater level) will deliver 1 $MtCO_2$-eq. of emission reductions by 2030. This is roughly a 20% reduction relative to the 2019 peat meadow emissions reported in the Dutch National GHG inventory report (RIVM, 2021). The measures to achieve this target are elaborated in the so-called Peat Plan phase 1 (Dutch: “Veenplan 1e fase”) for the period 2020-2022 (LNV, 2020). The Phase 1, is considered a start-up phase, where the plan mainly focusses on learning experimental pilots, improving GHG monitoring, and preparing for the scale up of rewetting peat(y) soils up to 2030 and beyond.

Of the about 436.000 ha of organic soils, 274.000 ha are so-called peat(y) soils. Most of this land (207.000 ha) is used for agriculture. The other 162.000 ha (of which 130.000 ha is used in agriculture) generally have thinner peat layers (5-40 cm of peat in the top 80cm of soil). The areas where rewetting will likely be conducted, are those areas where soil subsidence is most significant. Soil subsidence due to decades of peat soil drainage is a major driver for current and future damages to houses and infrastructure for the coming decades.

Forest strategy

The National Forest Strategy (LNV, 2020) builds upon the agreements made in the National Climate Agreement (Government D. , 2019). It also aims to implement biodiversity policy in the scope of the EU Habitat and Birds Directives. the National Forest Strategy focusses on 1) increasing the national forest area by 10% from 370,000 ha in 2020 to 407,000 ha in 2030 (of which 18.000 ha in existing nature areas, and 19.000 outside nature areas), 2) the revitalization of forests, and 3) increase the number of trees outside forests (TOF). Especially, the expansion of the forest area and TOF outside of the already existing nature areas will most likely come at the expense of the land used for agricultural purposes.

Blending obligation green gas

The blending obligation for green gases aims to scale up the production of green gases (biogas, hydrogen) up to at least 1,6 bln. m^3 (current production around 220 mln. m3) by 2030 (EZK, 2022). This in turn is expected to result in a 2,9 Mton CO_2 emission reduction (1,8 – 4,9 Mton CO_2/y range estimate) by 2030. These estimated CO_2 savings exclude any potential emission reductions or carbon removal associated with the production and utilization of organic fertilizers (derived from AD digestate), as well as any CO_2 capture and reuse/storage at the biogas plants. As such the net CO_2-savings from AD of animal manure, combined with CCS/U and production of organic fertilizers could be significantly higher.

In a report (CE-Delft, 2022) commissioned by the Ministry of Economic Affairs exploring the impact of a blending obligation green gas, assumes a high reliance on AD of animal manure for meeting the set target. It is estimated that around 57% of the biogas will have to originate from animal manure (with 43% originating from other feedstocks). The report also assumes that the green gas production target (for animal manure derived biogas) can be achieved, assuming an assumed 20% (min) or 30% (max) reduction in the livestock population. This target will not likely be achieved by reducing the livestock population >30%. The discussion about the size of the Dutch livestock sector is very relevant, since within the current public/political debate regarding NOx and NH_3 emissions there are several political parties advocating reducing the livestock sector by about 50%.

Table 2-1: Overview of policy programs relevant for LMT portfolio

Policy	Blending obligation green gases	Regional Energy Strategies	Peat meadow strategy	Forest strategy
Target	1,6 bcm of green gas production in 2030, to be mainly supplied in to built environment	35 TWh of additional renewable electricity production by 2030 (pledge by RES-regions is 55 TWh)	-1 Mt CO2 emissions from peat soils in 2030 (is about 20% of national reported peat soil emissions in 2019)	A 10% increase in forest area, of which 18,000 ha to be realized in the NNN areas, 19,000 ha outside NNN network.
Expected climate target impact	-2,9 Mton CO2 emissions by 2030	A near zero-emission electricity sector by 2030	-1 Mton CO2 emissions from peat soils by 2030	0,4 Mton CO2 removed (ambition to go to 0,8 Mton CO2 removed), of which about 0,1 Mton CO2 for agroforestry
Challenge	To go from 220 mln. m3 renewable gases (in 2021) to 2.000 mln. m3 in 2030	To go from approximately 39 TWh net renewable electricity production in 2021 (+35 TWh) to 74 TWh in 2030	To reduce LULUCF peat soil emissions from 5,5 Mton CO2 in 2019 to 4,5 Mton CO2 in 2030.	To go from about 370.000 ha of forest to 407.000 ha of forests.
	About 900% increase in 9 years time.	About 200% increase in 9 years time.	About 20% decrease in 10 years time.	About 10% increase in 9 years time.
Link to / relevance for AFOLU sector	Increase in domestic green gas production potential is highly reliant (57%) on AD of animal manure digestion (already discounted for a 20% reduction of the livestock sector).	Land claim for onshore wind and solar parks (4500-6700 ha), likely taken from agriculture. Agricultural sector also is a key source for rooftop pv (on stables), and investor in renewable electricity production.	Rewetting of peat soils will mostly affect current of peat meadows used for cattle farming and nature areas	Additional land claim will most likely come at the expense of agricultural (grass/feed) land.
	Link 1 Link 2	Link 1 Link 2 Link 3	Link 1 Link 2 Link 3	Link 1 Link 2 Link 3

2.2 Other relevant policies / strategies / incentives

Aside from the energy and climate policies, there are a wide range of other policy processes running in parallel. The key ones affecting the implementation of the LMTs in our portfolio will be briefly discussed below.

- National Program Rural Area
- Common Agricultural Policy (CAP) reform
- Nitrate Directive – derogation
- Voluntary carbon market
- Meadow bird action plan
- National housing agenda
- Spatial planning – soil and water

National Program rural area

The National Program Rural Area (Rijksoverheid, 2022) acts as an umbrella policy program to integrate the different policy targets regarding nature, nitrogen (NH_3) emissions[2], agriculture, water, soil, and climate. Within this program there is a transition fund of around €24,3 bln. available up to 2035 to ensure that The Netherlands will become compliant with the national targets for nitrogen emissions, climate, and water. The targets set for nitrogen (N-related) emission reduction are the primary policy driver. For the rural area ambitious targets have been set to substantially reduce NH3 emissions with 39 kton NH_3 by 2030. This is on top of an already projected base scenario reduction (based upon existing policies) of 10 kton of NH_3 emissions relative to the chosen reference year 2018.

In 2018, agriculture was by far the largest emitter of NH3 emissions with 109 kton NH_3 emissions (or 87% of the national NH_3 emissions). Assuming a proportionate sectoral share for reducing NH_3 emissions, the agricultural sector at minimum would have to reduce 34 kton of NH_3 emissions (or about 31% of agricultural NH_3 emissions. The main reason for reducing NH_3 emissions is to reduce the nitrogen deposition in the environment, particularly in and around the more vulnerable, and protected habitats. The program is set up, so that each subregion can develop its own regional implementation strategy.

Common agricultural policy (CAP) reform

Eco-schemes are part of the new CAP 2023-27 (link). Eco-schemes provide an incentive (premium) for the agricultural sector when implementing certain eligible eco-activities. For 2023, eligible eco-activities in The Netherlands (link) include e.g., cover cropping, paludiculture, landscape elements, etc, thereby providing a possible financial incentive for two of our LMTs, agroforestry and peatland rewetting.

Nitrate directive – derogation

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[2] NOx emissions will be addressed through national level generic policy frameworks.

Under the EU's nitrate directive, The Netherlands is set to gradually phase out its derogation to the application of N from animal origin on soils. This derogation allowed the usage of higher levels of N from animal origin on soils. As per 2026 Dutch farmers can only submit a maximum of 170 N-manure to soils (link). The current debate is now, on whether this phase-out will result in a number of undesirable trade-offs (link), including:

- Increased manure surplus could lead to increased production costs for livestock farmers,
- Potential increased conversion of grasslands into cropland to ensure protein supplies for livestock, potentially leading to higher levels of N-leaching and worsening conditions for meadow birds.
- Potentially lower N-surplus (NH3 emissions) at farm level, which may result in some gains for biodiversity,
- Increased use of chemical fertilizers (and thus natural gas) to meet the needs of the highly productive cropping/farming systems in the country.

A relevant ongoing debate within The Netherlands and Europe relates to the possible production and application of recovered nitrogen from manure (RENURE). RENURE (link) could play a significant role in reducing the agricultural sectors' dependence of chemical fertilizers and promote more circular agricultural system (link). For the feasibility and scaling of our BECCS/U LMT (biogas-production systems) acceptance of RENURE fertilizers could provide an additional economic incentive. However, in light of the current phase out of the derogation it remains to be seen if RENURE will be seen and perceived as i) a circular and more sustainable way to replace chemical fertilizers and reduce natural gas use, ii) or a 'backdoor' to reinstate the lost derogation for applying animal manure on Dutch soils. Advanced manure treatment systems, that produce biogas, captured CO_2, as well as organic fertilizers can outperform chemical fertilizers in terms of overall climate impacts and sustainability. Moreover, such systems are also more likely to outperform the management usage and application or untreated liquid animal manure. A possible compromise to allow for extended derogation could be to ban, phase out or limit the usage of untreated liquid animal manure on soils and promote (or mandate) more advanced manure management and treatment systems, combined with biogas production. Continued uncertainty regarding derogation and RENURE will most likely negatively affect the feasibility of rolling out biogas production systems in The Netherlands.

Voluntary carbon market

Since 2019, a voluntary domestic carbon market (Stichting Nationale Koolstofmarkt; SNK) is operational within The Netherlands. SNK provides an incentive for a range of accepted project types relevant for AFOLU sectors (link). Approved methodologies exist for peatland rewetting, CH_4 reduction by applying feed additives, conversion of liquid fraction of digestate into replacement of chemical N-fertilizers, planting of trees outside forests, climate smart forest management, ash forest revitalisation, permanent grasslands on mineral soils, as well as hemp cultivation for long duration sequestration in materials. It has to be noted that SNK only provides a potential additional (or complementary) incentive for all four LMTs in our portfolio (*policy additionality*). This means that the voluntary carbon market should be considered as a last resort instrument in case existing and/or planned policies and incentives fail to deliver.

Meadow bird action plan

To preserve and support biodiversity in the country, and in particular meadow birds like the black-tailed godwit), there is a nationwide (link) meadow bird strategy. One of the measures promoted is to rewet bird breading grounds and meadows during breading season to provide a more suitable habitat for these birds. The strategy has a budget reservation of about EUR 70 mln. budget, which also aims to provide a premium for participating farmers to compensate for any economic damages / losses related to rewetting and/or other bird-friendly practices. However, due to an ongoing disagreement between the national government and provincial governments this fund remains mostly unused to date (link). As a result of this rewetting practices are slowing down and there is uncertainty added to novel more nature-inclusive and sustainable farming business models.

National housing & building agenda, and the circular building strategy

The Dutch national housing and building agenda (link) illustrates that by 2030 an estimated 900.000 new houses will have to be built to meet housing demand. From these 900.000 about 13% will replace outdated (to be demolished) houses, while 87% entails a net expansion of the housing stock. This net expansion will put an additional claim on the use of land, which in most cases will likely be agricultural land close to existing urban or rural settlements. Finding suitable locations for building new houses will be a challenge in a densely populated country, with already intensive forms of land use. Also making sure that new houses are built in locations that are sufficiently climate resilient (e.g., flooding areas, soil subsidence areas near coastal and river zones) requires a planned approach (link).

While the foreseen housing expansion may put additional claims on land, the net effect on land use competition with existing agricultural practices is likely to remain relatively modest. Alternatively, the Netherlands government has significant ambitions to promote the use of bio-based materials and circular building designs. The Policy agenda 'standardizing and stimulating circular construction' (link) aims for example to:

- Enhance and widen the scope for the minimum environmental performance of (new) buildings,
- Introducing minimum performance standards for CO2-emissions for material usage in buildings,
- Promote and incentivise the application of bio-based materials in buildings,

These policy ambitions could provide an alternative incentive for forest owners/managers and farmers to start cultivating or supplying biomass for the production and use of building materials. Such complementary business models or market opportunities could be synergetic with afforestation and agroforestry via construction or engineered wood products, rewetting of organic soils (e.g., cattail, miscanthus, hemp, straw based) insulation or plate materials (link), as well as anaerobic digestion and post-treatment or animal manure (manure digestate based building blocks - link).

Spatial planning – soil and water

A recent (November 2022) letter from Dutch the Ministry of Infrastructure and Water Management (link) on the role of water and soil/land in spatial planning is aiming to structurally increase ground water levels in areas with significant acreages of peat(y) / organic soils. Increasing or managing ground water levels is delegated to the regional water authorities throughout the country. As a result this (planned) policy could directly affect the viability ongoing (mainly cattle) livestock farming (higher costs of production, lower yields), peatland management / rewetting initiatives (e.g., meadow bird strategy, or voluntary carbon market projects). Without proper compensation or development perspective for potentially affected farming communities, uncertainty regarding the public acceptance of rewetting practices remains.

2.3 Greenhouse gas emissions, and emission reduction targets

The Dutch Climate Agreement (Government, 2019) states that the Dutch economy will have reduced its national GHG emissions by 49% in 2030, and at least 90% (95%) in 2050 relative to 1990 emissions. The known residual GHG emissions for 2030 and 2050, as well as the emission reduction efforts relative to 2020 GHG emissions per sector are indicated in Table 2-2 below.

Table 2-2: Residual emissions, 2020 emissions and reduction efforts per sector for 2030, 2050 (in Mton CO_2-eq.)

Sector	Residual emissions		Emissions	Reduction effort	
	2030	2050	2020	2030	2050
Electricity	12,4	?	32,6	20,2	?
Industry	35,7	?	53,4	17,7	?
Built environment	15,3	?	21,8	6,5	?
Transport	25	?	30,6	5,6	?
Agriculture and land use	28	0	27,1	-0,9	27,1
Total	116,4	11-23	165,5		

Sources:

- https://www.emissieregistratie.nl/data/overzichtstabellen-lucht/broeikasgassen
- https://www.klimaatakkoord.nl/klimaatakkoord/vraag-en-antwoord/wat-is-het-doel-van-het-klimaatakkoord
- https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/klimaatakkoord/maatregelen-klimaatakkoord-per-sector

For agriculture and land use sectors we can see that the 2020 recorded GHG emissions (27,1 Mton CO_2-eq.) are already slightly below to the projected residual 2030 emissions (28 Mton CO_2-eq). This would imply that up to 2030 no further GHG emission reduction efforts would be needed. However, only for this sector a 2050 target appears to be set. By 2050 climate neutrality will have to be reached, indicating that this sector will have to get to a net zero emissions level.[3] This suggest that within the 2020-2050 period the agriculture and land use sectors would have to reduce and/or remove an equivalent of 27,1 Mton CO_2-eq. relative to 2020 GHG emission levels. Key options within this sector to reduce emissions or remove CO_2 from the atmosphere from our LMT portfolio include a broad range of technological measures and nature-based solutions (see Table 2-3).

Table 2-3: Potential reduction and removal impacts from Dutch LMT portfolio

Reduction	Removal
Reduction of methane emissions from livestock (e.g. reduction of livestock, manure management)	Afforestation
Peatland rewetting	Agroforestry (planting trees outside forest)
Land management (No tillage, permanent grasslands)	Paludiculture (wet agriculture for building materials
Efficient or reduced use of nitrogen fertilizers	Harvested wood products

[3] *"Om te zorgen dat de landbouw en het landgebruik in 2050 klimaatneutraal zijn, moet er veel gebeuren. Een deel van de uitstoot van broeikasgas is namelijk niet te vermijden. Zo stoten koeien methaan uit. En veengebieden veroorzaken CO2-uitstoot als de grondwaterstand laag is. Daar staat tegenover dat planten CO2 opslaan. Bomen en gras doen dat bijvoorbeeld heel goed. Dit is gunstig om de CO2-uitstoot te verminderen."*

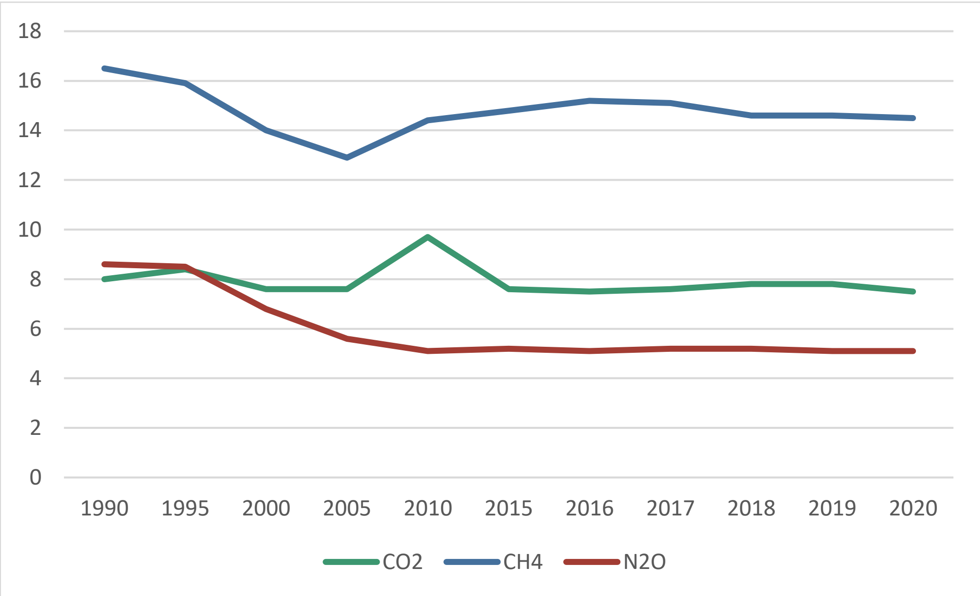
Avoided deforestation, reforestation	CO2 capture, and storage/re-use

To know which emission reduction or removal measures to implement in this sector to meet its 2030/50 climate targets will be good to know the origins of the agricultural and land use sector emissions.

2.4 Agricultural and land use sector (AFOLU) emissions

In 2020 the GHG emissions in these sectors represent 16,4% of total national CO_2-eq. emissions (see Figure 2-1). This mainly comprises the non-CO_2 GHGs, CH_4 and N_2O representing respectively 76,3% and 73,9% of total national CH_4 and N_2O emissions. CO_2-emissions from these sectors comprise only about 5,4% of total national CO_2 emissions.

Figure 2-1: GHG emissions in AFOLU sector in NL (1990-2020) in $MtCO_2$-eq.



If we take a closer look at the specific GHG emission and removal data from both the agriculture and land use, land use change (LULUCF) sectors we can see that the LULUCF sector not only includes emission sources, but also a few carbon sinks (removals). Within the National Inventory GHG reporting The Netherlands reports agriculture and land use, land use change and forestry (LULUCF) sector emissions and removals. In (RIVM, 2021) Chapters 5 (Agriculture) and 6 (LULUCF), more disaggregated GHG emission data is published.

Agriculture sector emissions

GHG emissions in agriculture mainly comprise CH4 and N2O emissions (see Table 2-4). The CH_4 emissions almost exclusively originating from the livestock subsector (enteric fermentation and manure management), while the N_2O emissions are mainly stemming from the application of inorganic and organic nitrogen (N-)fertilizers.

Table 2-4: GHG emissions in agriculture in The Netherlands

Year	Gas	1990	2018	2019
Total	**All**	**24,6**	**18**	**17,7**
	CO2	*0,2*	*0,1*	*0,1*
	CH4	*14,7*	*12,1*	*12*
	N2O	*9,7*	*5,8*	*5,6*
Enteric fermentation	**CH4**	**9,2**	**8,3**	**8,1**
Manure management	**All**	**6,3**	**4,6**	**4,6**
	CH4	*5,4*	*3,8*	*3,8*
	N2O	*0,9*	*0,8*	*0,8*
Agriculture soils	**N2O**	**8,7**	**5**	**4,8**
Liming	**CO2**	**0,2**	**0,03**	**0,03**
Urea application	**N2O**	**0**	**0,1**	**0,05**

Source: (RIVM, 2021)

For both CH_4 and N_2O emissions sources the total aggregate GHG emissions are largely dependent on the total size of the livestock sector. More/less animals (mainly cattle and pig) imply higher/lower enteric emissions (cattle) and manure management emissions (cattle and pig manure). At the same time more/less animals also increases/decreases the availability of organic fertilizers (animal manure), which to a certain extent could decrease/increase the application of inorganic N-fertilizers on agricultural soils.

LULUCF sector emissions

GHG emissions in the LULUCF sector mainly comprise CO_2 emissions stemming from the different land uses and land use changes. The LULUCF sector is one of the few sectors that includes both emission sources and carbon sinks (see Table 2-5).

Table 2-5: GHG emissions in LULUCF in The Netherlands

Year	Gas	1990	2018	2019
Total	**All**	**6,1**	**4,5**	**4,4**
	CO2	6	4,6	4,4
	CH4	0	0	0
	N2O	0,1	0,1	0,1
Forest land (total)	**CO2**	**-2**	**-1,9**	**-1,9**
Forest land remaining forest land	*CO2*	*-1,5*	*-1,4*	*-1,4*
Land converted to forest land	*CO2*	*-0,5*	*-0,5*	*-0,5*
Cropland (total)	**CO2**	**2,6**	**1,6**	**1,6**
Cropland remaining cropland	*CO2*	*1,2*	*0,5*	*0,4*
Land converted to cropland	*CO2*	*1,4*	*1,1*	*1,2*
Grassland (total)	**CO2**	**4,7**	**3,1**	**2,9**
Grassland remaining grassland	*CO2*	*5*	*3,3*	*3,2*
Land converted to grassland	*CO2*	*-0,3*	*-0,2*	*-0,3*
Wetlands (total)	**CO2**	**0,1**	**0**	**0**
Wetlands remaining wetlands	*CO2*	*0*	*0*	*0*

Land converted to wetlands	*CO2*	*0,1*	*0*	*0*
Settlements (total)	**CO2**	**0,8**	**1,5**	**1,5**
Settlements remaining settlements	*CO2*	*0,4*	*0,4*	*0,4*
Land converted to settlements	*CO2*	*0,4*	*1,1*	*1,1*
Other land (total)	**CO2**	**0**	**0,2**	**0,2**
Other land remaining other land	*CO2*	*0*	*0*	*0*
Land converted to other land	*CO2*	*0*	*0,2*	*0,2*
Harvested wood products (total)	**CO2**	**-0,2**	**0,1**	**0,1**

Source: (RIVM, 2021)

The primary CO_2 emission source for the LULUCF sector in The Netherlands is drainage of peat/peaty soils. In 2019 this contributed to 5,5 Mton CO_2-eq. emissions for mainly the grassland, cropland, and settlement land use subcategories. A large portion of the Dutch open land is being used to cultivate grass and fodder (maize) for the livestock sector. To sustain the agricultural use of land for agricultural purposes, and particularly the peat/peaty soils the groundwater levels are being controlled. Under the current water management regime this mainly results in active drainage of large peat(y) areas of land in the country resulting in oxidation of soil organic carbon. Within a changing climate proper management of ground- and surface water levels is increasingly challenging given the less predictable and more erratic/extreme precipitation patterns.

The main carbon sink in The Netherlands is forest land. In addition, grasslands also comprise a potential yet limited carbon sink. Within the grassland category, also the carbon removal from trees outside forest concepts (e.g., agroforestry, landscape elements with trees) are accounted. The relevance of sinks (removals) will be relevant for both the agriculture and land use sectors combined in their effort to reach the climate neutrality (or net zero) target by 2050. In this respect the accounting and allocation of carbon removals related to all kinds of raw (biogenic) materials for the bio-based economy, will become relevant. Within the current GHG accounting there is only a key focus on harvested wood products (HWP), but the agriculture and land use sectors could also provide raw materials for a broad range of bio-based products and materials (e.g., bio-plastics, biochemicals, bio-based insulation materials, hemp- or grass-based materials, organic fertilizers) with subsequent short- and long-lived applications. For 2019 HWP comprise a net emission source for the LULUCF sector of 0,1 Mton CO_2-eq. However, during the 1990-2019 period this fluctuated between -0,158 (removal) and 0,165 (emission) Mton CO_2-eq. This implies that downstream uses of biomass in other economic sectors originating from agriculture and land use sectors, any emissions, or removals (claims) will be accounted within these two sectors.

3. LMT Portfolio

The scope of the Dutch LMT portfolio focuses on the shortlisted LMTs that have been narrowed down by literature review and a few interviews with relevant experts. These four shortlisted LMTs are considered for further analysis including their potential to store carbon and reduce GHG emissions (with the help of model simulations). Before such an assessment can be done a narrative or storyline for each of the selected LMTs needs to be developed. The following sections provide the qualitative narratives of the four LMTs for the Netherlands.

- Peatland management (see section 3.1)
- Forestry (see section 3.2)
- Agroforestry (see section 3.3)
- CCS applied to AD based on animal manure & soil carbon enhancement with AD based digestate (see section 3.4)

3.1 Peatland management

3.1.1 Introduction

Peatlands in the Netherlands have already been faced with soil subsidence for a long time, mainly due to a systematic draining of the land to make it suitable for agricultural use. During the last 100 years, the process of soil subsidence has been increased due to improved pumping techniques that have been applied to meet the increasing requirements of agriculture. The draining of the peatland results in the peat drying out and oxidising – or 'burning' – under the influence of oxygen, which causes subsidence. Due to this subsidence, the groundwater level becomes closer to the ground level, which may hamper agricultural management. Hence the water authorities lower the water level even further so that agriculture can continue. This process ends up in a negative spiral. Apart from costs for adapting drainage to continue using the land for its current purposes, other problems arise as well, such as damage from subsidence of infrastructure and buildings; CO_2 emissions from peat oxidation, and the drying out of nature conservation areas (RLI, 2020). These problems are also cumulative and build up over time. This cumulative process can be stopped by reversing the adaption of the groundwater level from lowering into increasing it. However, there are some limitations of increasing the groundwater level as N2O and CH4 emissions arise when groundwater levels become too close to the ground level. Evidence from Germany and the UK shows that with groundwater levels over 20 cm below the ground level there are hardly any N_2O and CH_4 emissions (RLI, 2020).

3.1.2 Policy context

Climate Agreement and Peat Plan

Estimates of current annual carbon emissions of peatlands in the Netherlands vary from 4 to 7 $MtCO_2$-eq. (RLI, 2020). As total carbon emissions in the Netherlands have to be reduced to 11 $MtCO_2$-eq. by 2050, it goes without saying that peatlands have to contribute to the reduction effort. In the Dutch

Climate Agreement (Government D. , 2019) it is anticipated that measures for managing peat meadow areas (i.e. increasing the groundwater level) will deliver 1 $MtCO_2$-eq. of emission reductions by 2030. These measures are elaborated in the so-called Peat Plan phase 1 (Dutch: “Veenplan 1e fase”) for the period 2020-2022 (LNV, 2020). During this phase, the focus is on gaining more insight into the effectiveness of emission reduction measures and how these can be rolled out by setting up pilots, a National Research Programme on Emissions in Peat Meadow Areas (NOBV) and communities of practices. As emission reduction in peatlands cannot be considered in isolation from other activities, regional actors are asked to develop an integrated territorial peat meadow area strategy for their region by the end of 2020. In those strategies, regions have to indicate how they will achieve emission reductions while simultaneously taking account of the economic perspectives of farmers, nitrogen disposition, water management and biodiversity. For stimulating piloting with territorial measures aimed at increasing the groundwater level, a budget of €100 mln is available for peat meadow areas in five provinces. Within the scope of the research programme NOBV, a national network for measuring emission reductions of measures will be developed, that can be used for monitoring. It is expected that by 2022 the second phase of the Peat Plan can be started, aimed at scaling up and rolling out effective measures.

Numerous initiatives on peat soil subsidence

Apart from these activities aimed at implementing the emission reduction target for the peat meadow areas of the Climate Agreement, during the last decade, numerous initiatives have been set up for exploring solutions for problems arising from peat soil subsidence. These refer amongst others to five peat areas financed by the Intergovernmental Programme (IBP) on a Viable Countryside, a project on climate-smart agriculture on peat soils in Utrecht, so-called Region Deals for nature including agriculture and peat meadow areas in the Green Heart, farmers’ collectives on nature and landscape management, and a Green Deal on value for peat (Dutch: “VvV”) (Verhagen, Westerhof, & de Weerd, 2020). The experiences of actors participating in these initiatives may act as a useful knowledge source for LANDMARC in scaling up climate mitigation technologies and practices. However, the (RLI, 2020) observes a lack of upscaling of initiatives as pilots tend to stay in an experimenting phase and local actors are repeatedly trying to invent the wheel without pushing the process any further.

Combining public and private funds

Although there are public funds specifically labelled for emission reduction measures available from the Climate Agreement and the national government, additional funds are needed. These have to be derived from provinces, other policy fields and private actors. By doing so, it is hoped that public-private partnerships will manage to achieve various objectives by combining a mix of public and private funds. Other policy fields are amongst others the Common Agricultural Policy (CAP), fiscal policy, economic policy, environmental policy, nature policy and regional policy.

3.1.3 Current land use and potential land-use competition

In the Netherlands, organic soils amount to 436,000 ha, which is about 10% of the total area (Table 3-1). Depending on the depth of the peat layer, these soils are divided into peat soils (274,000 ha) and peaty soils (Dutch: "moerige gronden") (162,000 ha) (LNV, 2020). Over three-quarters of these organic soils are used by agriculture (resp. 76% of the peat soils and 80% of the peaty soils), mainly as grassland (279,000 ha) and to a lesser extent as cropland (67,000 ha). Grassland on organic soils is usually referred to as peat meadow area. Its typical Dutch landscape value is in general highly appreciated, nationally as well as internationally. The area of organic soils tends to decline because of oxidation, particularly in drained agricultural areas. In the years 1990-2017, this decrease amounted to over 60,000 ha.

Table 3-1: Land use on organic and mineral soils in the Netherlands, 1990-2017

Land use		1990	2004	2009	2013	2017
Forest land	Organic soils area (ha)	20,482	21,990	21,885	21,453	20,396
	mineral soils area (ha)	341,619	348,052	351,595	354,291	345,183
	% organic soils	6	6	6	6	6
Cropland	Organic soils area (ha)	108,979	85,117	80,816	75,967	66,842
	mineral soils area (ha)	910,373	854,500	844,046	868,373	803,468
	% organic soils	11	9	9	8	8
Grassland (non-TOF)[4]	Organic soils area (ha)	322,053	292,709	282,252	276,031	278,616
	mineral soils area (ha)	1,185,629	111,5356	1,109,236	1,069,678	1,128,425
	% organic soils	21	21	20	21	20
TOF	Organic soils area (ha)	2,216	2,237	2,221	2,132	2,120
	mineral soils area (ha)	18,590	19,970	19,872	19,443	19,120
	% organic soils	11	10	10	10	10
Other land uses	Organic soils area (ha)	45,142	61,999	64,440	66,082	68,718
	mineral soils area (ha)	1,196,416	1,349,571	1,375,136	1,398,050	1,418,613
	% organic soils	4	4	4	5	5
Total	Organic soils area (ha)	498,873	464,051	451,615	441,666	436,691
	mineral soils area (ha)	3,652,627	3,687,449	3,699,885	3,709,834	3,714,809
	% organic soils	12	11	11	11	11

Source: https://edepot.wur.nl/314315.

[4] Trees outside forest (TOF)

As the Climate Agreement and the Peat Plan focus on peat meadow areas, for the time being, we only consider organic soils used for grassland in the narrative. At a later stage, we can eventually extend the narrative to peaty soils. In the Netherlands, three clusters of peat meadow areas can be considered (RLI, 2020):

1. The western peat meadow areas in the provinces of South Holland and Utrecht;
2. The peat meadow areas in the province of North Holland;
3. The peat meadow areas in the provinces of Friesland and Overijssel.

These clusters greatly differ from each other due to, amongst others, the thickness of the peat layer, the extraction history, the drainage level, and the plot pattern. There are also differences when it comes to the relationship with other land uses in the area, such as housing, infrastructure, energy production, nature, and recreation.

Current land use competed by societal demands

Land use competition issues in the Dutch agricultural sector usually originates from land claims by other functions, in particular for settlement and infrastructure use, land use to accommodate the energy transition and land for nature and recreation. In the case of the peat meadow areas, however, current agricultural land use is competed by societal demands for increasing the groundwater level to reduce soil subsidence. Higher groundwater levels imply that current agricultural management practices have to be adapted to alternatives like less intensive management, nature including agriculture and wet cultivation.

Within LANDMARC the focus is on climate change mitigation technologies and practices. As such, rewetting peat meadows could be referred to as a practice to reduce GHG emissions. However, demands for increasing groundwater levels in the peat meadow areas in the Netherlands are not only related to achieving climate goals but to several other societal concerns as well (RLI, 2020):

- Due to soil subsidence, buildings and infrastructure subside as well and infrastructure cables in the soil can be blotted,
- Lower soils need water management adaptations like bigger pumps and higher quays and flood defences,
- The water quality deteriorates due to leakages from nitrates, sulphates, and phosphates from peat oxidation and salination from seepage water, which in turn has consequences for biodiversity,
- Adjacent nature areas are in danger of drying out as the water from these higher-lying areas drains to the lower-lying peat meadow areas.

Addressing these issues imply high societal costs, which can be prevented by stopping soil subsidence. Within this context, it can be argued that a transition to higher groundwater levels in peat meadow areas is rather a societally driven urgency than a voluntary choice by farmers.

3.1.4 Climate risks & sensitivities

Risks

For avoiding any further oxidation of peat and peaty soils, and thereby reducing GHG emissions, hydrological interventions, i.e., reverse drainage and re-wetting the area, are needed. A key condition for such water-based strategies is the continued and structural availability of sufficient water. However, climate-related disturbances, like increasing levels of annual rainfall and prolonged periods of (extreme) drought endanger sound water management due to fluctuations in water availability. Although in the last decade progress has been made to deal with extreme rainfall through temporary 'flooding areas' which allow for an overflow of excess water, prolonged drought periods seem more difficult to address. Droughts might result in drops in groundwater levels, which hamper proper drainage of the soil and thereby contributing to continued oxidation.

Sensitivities

Climate sensitivities of soil subsidence are related to the sea-level rise, which increases the danger of flooding the steady subsiding peat meadow areas. Technical solutions to protect the land from flooding cannot be realized without drastic measures and high costs. Hence this sensitivity can be considered as a plea for rewetting peat areas.

3.1.5 Economic implications

The consequences of increasing the groundwater level for agricultural management practices depend on the groundwater level before the increase and that after the increase (Daatselaar & Prins, 2020). Estimations of the costs of increasing the groundwater level in the peat meadow areas in the Green Heart show that an increase in the groundwater level from 100 cm below ground level to 80 cm below this level has hardly any effects on current practices. However, further increases closer to the ground level result in lower feed production and require adaptations in agricultural management like a lower livestock density per ha, feed purchases, less outdoor grazing, and lighter machines due to less load-bearing capacity of the soil. These adaptations result in higher costs per ha (Table 3-2). In the peat meadow areas outside the Green Heart costs will differ due to different plot sizes and permeability of the peat.

Table 3-2: Effect on CO_2 emissions and estimated additional costs with increasing groundwater levels in peat meadow areas in the Green Heart under various baseline situations.

	100→ 80 cm	80→ 60 cm	60→ 40 cm	40→ 20 cm	30→ 10 cm	Average
CO2 reduction (ton per ha)	8	8	8	8.1	8.2	8.1
Costs for farmer (euro per ha)	0	87	312	470	489	332
Costs per ton CO2 reduction (euro)	0	11	39	58	60	41

Source: (Daatselaar & Prins, 2020)

As current business models in peat meadow areas do not comply with increasing groundwater levels, farmers have to look for alternative business models, like:

- Less intensive dairy production,
- Wet cultivation (like cattail (Typha), reed (Phragmites), sphagnum moss (Sphagnum), wild rice (Zizania) duckweed fern (Azolla) (Smolders, et al., 2019);
- Energy/biomass production,
- Other activities on the farm, like milk processing, care and recreation,
- Nature including agriculture aimed at providing ecosystem services (landscape and nature management, CO_2 reduction, less soil subsidence etc.).

In particular, a business model derived from ecosystem services could be promising if the long term and sufficient payments for these services could be guaranteed. Such payments could originate from subsidies and private payments by, for example, firms buying certificates of CO_2 emission reductions. From Table 3-2 it can be derived that in the calculations for farmers in the Green Heart the price of a certificate for one ton CO_2 reduction has to amount to at least 41 euro to compensate for farmers' costs.

- Region Alblasserwaard-vijfheerenlanden: 15,000 ha out of which 4,000 ha are economic to apply pressure drainage (rewetting). This results in less soils subsidence and less CO_2 emissions (both reduced by 50-75%) (Paulin et al., 2022)
- "Greatest uncertainties in the cal-culations are the price for CO_2 that will be calculated in the future and the costs of installing and managing the pressure drainage system." (Paulin et al., 2022)
- Pressure drainage: "The average net present value per hectare for these locations is approximately €7,800/ha over a 30-year period. The analysis shows that the costs for the construction of pressure drainage mainly end up with the farmers (investment & maintenance costs of pressure drainage and loss of yield), the benefits of CO_2 reduction are shared by society." (Paulin et al., 2022)

3.1.6 Co-benefits and trade-offs

The main issue with stopping soil subsidence in peat meadow areas is the question of who has to pay for it: society or farmers? In the current situation of continuing soil subsidence, farmers benefit and society suffers. When groundwater levels are increased to stop soil subsidence, the opposite applies: farmers suffer and society benefits. Given the severe impacts of soils subsidence on costs for subsidence of buildings and infrastructure, costs for water management and climate change, the question is not whether groundwater levels in the peat meadow areas will be increased, but when and at which pace. Avoided societal costs can be considered as a financial benefit of increasing the groundwater level. Whether farming will continue in peat meadow areas with increased groundwater levels depends on the extent farmers manage to set up viable business models. Public/private payments for ecosystem services likely play the main role in such models.

Changes in agricultural production

On the whole, increasing groundwater levels imply less feed production per ha in peat meadow areas. This can result in less dairy production if the feed is not purchased from elsewhere. If farmers decide to change to less intensive dairy production or other types of production, like wet crops, a drop in dairy production occurs as well. This implies that the total Dutch supply of dairy products may decrease and that of wet crops increase. The extent of these shifts are yet unclear but could be explored in the LANDMARC model simulations.

Landscape changes

In a situation of increased groundwater levels in the peat meadow areas, farmers have broadly three options: to adapt their management practices, to stop their farming activities or to move their business to another area. Changing agricultural practices will result in changes in the landscape of peat meadow areas: it turns into a mix of wet grasslands and areas with wet cultivation, nature and water.

Biodiversity

Biodiversity may benefit from less intensively farming practices. Nowadays the peat meadow areas are an important habitat for meadow birds, that feed on wet soils. However, if areas become swampy due to groundwater levels close to the ground level, these areas are no longer suitable for meadow birds (RLI, 2020). Biodiversity in adjacent nature areas also benefits from increased groundwater levels in peat meadow areas as it lessens dehydration due to drainage of water

- Pressure drainage: "makes the area more attractive for farmland birds such as black-tailed godwits, lapwings and oystercatchers. Pressure drainage also offers other advantages, such as lower costs for water purification and water management. One disadvantage of the higher groundwater level is that less grass can be produced."(Paulin et al., 2022)

Nitrogen emissions

The achievement of the national nitrogen aim of reducing nitrogen depositions near nature areas can both positively or negatively be affected by increased groundwater levels in peat meadow areas. If farmers adapt their agricultural management practices by decreasing the number of livestock per ha, this results in fewer nitrogen emissions from ammonia. However, if farmers adapt by less outdoor grazing and feed purchases, nitrogen emissions increase as these are higher in stables than outdoor (Hoving et al., 2015).

Water quality

Peat oxidation is a substantial source of nutrients and dredging production that pollutes surface water (Smolders, et al., 2019). Moreover, the eruption of low-lying peat soils and seepage results in salination. These problems decrease at rising groundwater levels with positive effects on the water quality.

3.1.7 Risks associated with scaling up

The amount of land where groundwater levels can be increased to prevent soil subsidence is limited to the peat meadow areas. These areas equal about 15% of total Dutch agricultural land. The main risk refers to whether farmers manage to implement viable business models. The development of such models needs knowledge, time, and financial support. If farmers do not manage this transition, the main risk would be a drop in agricultural production and an increase in land abandonment.

3.2 Forestry

3.2.1 Introduction

Forests in the Netherlands cover about 340,000 ha, which is just over 8% of the total area (Table 3-3). About 55% of the forest (larger than 5 hectares) is owned by public organizations; the remaining is private forest property. This concerns both private individuals such as estate owners and organizations such as 'Nature Monuments' (Dutch: "Natuurmonumenten") (Rijksoverheid, 2014). A recent survey among forest owners revealed that almost 80% of them indicated that their forests were faced with increasingly natural and climate-related disturbances over the last decade (Sikkema, 2020). These disturbances were related to drought, storm damage, extreme temperatures and intense rainfall. On top of that, they experience increased insect damage (bark beetles, oak processionary caterpillar) and fungal diseases (ash dieback). Other disruptions refer to soil damage caused by wild pressure and acid nitrogen deposition. In particular, species like Norway spruce, native oak, ash, larch, Scots pine, beech and Douglas are affected by these disturbances.

3.2.2 Policy context

The National Forest Strategy (LNV, 2020) builds upon the agreements made in the National Climate Agreement (Government D. , 2019) and also aims to implement biodiversity policy in the scope of the EU Habitat and Birds Directives. As such, the emphasis is on the sequestration of CO_2 and reinforcing biodiversity. Broadly, the National Forest Strategy focusses on three areas:

a) increase in the forest area by 10% (from 370,000 ha in 2020 to 407,000 ha in 2030)

This increase has partly (18,000 ha) to be realized in the so-called Nature Network the Netherlands (NNN), which includes all Dutch Natura 2000 sites, and partly (19,000 ha) outside this network in forests that are private property. Afforestation outside the NNN could be realized using transition zones bordering the NNN, in and around towns and villages to enhance life quality and to decrease recreation pressure in other forests, along brooks and rivers, and by combining forests with other uses such as agriculture, house construction and wind energy.

b) revitalization of forests

Revitalization is intended to adapt forests to climate changes. First, it focuses on surrounding factors, such as reducing nitrogen deposition in forests, water retention in sandy soils, rejuvenation of forests, and improvement of corridors between forests. Second, revitalization intends to give forests a quality boost by aiming at self-regulating natural forests due to adaptations in structure, composition, and hydrology of forests. Third, revitalization must be realized by adjustment of forest management, an increase of natural forests, which are fully directed at reinforcing biodiversity and more attention for recreation forests.

c) increase in trees outside forests

> Trees in the countryside and towns and villages contribute to carbon sequestration, biodiversity, and quality of life. Increasing the number of trees outside the forests must be realized by an enhancement of the so-called 'blue-green veining' of the countryside through planting more woody landscape elements, by extension of agroforestry, by an increase of trees in each Dutch municipality by 1% p.a., and by support for planting trees by primary school children on the national tree day.

The National Forest Strategy is a cooperation of the national government and the 11 provinces in the Netherlands, as forest policy is part of nature policy, which is due to decentralization a common responsibility of the national government and the provinces. Other actors involved in forestry development are public/private forest organizations and forest owners.

The National Forest Strategy covers the period 2020-2030. There is a limited budget available from the so-called Nature Pact for the increase in trees within the NNN. For other actions, the budget must come from the general budget for nature policy, other policy fields, such as the Common Agricultural Policy (CAP) and from private partners. It is yet insecure whether these funds will be sufficient for realizing the ambitions of the National Forest Strategy.

3.2.3 Current land use and potential land-use competition

The Netherlands is a highly densely populated country. The pressure on land for new houses and transport infrastructure is high. Moreover, due to the high intensity of agricultural production, productivity per ha is high, which results in high land prices. So, it is doubtful whether sufficient land can be acquired for a substantial extension of forest area. Therefore, the National Forest Strategy focuses particularly on the extension of forests within the NNN and on smart combinations with other policies and ambitions. The NNN is public property, which consists mainly of nature area. A part of this area has a relatively low natural value and could therefore without much biodiversity harm be converted into a forest area. Combinations with other policies or ambitions refer amongst others to the reduction of the nitrogen deposition in nature areas, water retention, the Climate Agreement ambition of an increase in trees in and around villages and towns, the planting of hedgerows for increasing the green-blue vein of the countryside and agroforestry in the scope of the CAP.

Table 3-3: Area in the Netherlands, 2015

Sector	Size in % of total
Traffic area	2.8
Built area	8.7
Semi-built area	1.2
Recreation area	2.5
Agricultural area	53.8
Forests	8.2
Nature	3.8
Water area (internal and external)	18.9
Total area (million ha)	4.2

Source: CBS.

Prospects for combinations of forests/trees with other land use depend on its economic or intrinsic benefits. Planting and maintaining hedgerows on agricultural land is eligible for CAP support. Whether farmers decide to plant hedgerows depends on the extent these can be integrated into farm management and the ratio of income forgone and revenues of hedgerows. Support for agroforestry has for decades been included in the CAP, as a rather marginal measure. With the increasing attention for the circular economy nowadays, also the interest in circular agriculture increased in the Netherlands. This is often related to the concept of nature inclusive agriculture, which opts for sustainable agricultural production based on an integration of agriculture and the natural environment. Within this context, interest in agroforestry increased, either production forests or food forests. Planting trees on agricultural land contributes to CO_2 sequestration and enhancement of biodiversity. However, severe doubts can be raised on the business model of agroforestry. That is why the National Forest Strategy put in the years up to 2025 efforts in knowledge development, design of financial and fiscal instruments and support for pilot projects and agroforestry initiatives.

3.2.4 Climate risks & sensitivities

Existing forests – but newly planted forests as well - are threatened by climate-related disturbances such as drought, storm damage, extreme temperatures, and intense rainfall, which ask for climate adaptation measures. Within the National Forest Strategy, some revitalization measures to better cope with these disasters are foreseen.

3.2.5 Economic implications

In the Netherlands, the economic benefits of forest per ha land are relatively low compared with benefits from other land uses. So, it is unlikely that the market mechanism will bring about a considerable land-use change in the direction of an extension of forest area. Only if non-economic benefits like carbon sequestration, enhancing biodiversity and increasing quality of life, could be monetized by for example payments for carbon credits or ecosystem services, opportunities for forestry become more promising.

3.2.6 Co-benefits and trade-offs

Forests contribute to carbon sequestration, offer room for biodiversity, produce wood, and provide recreation opportunities. Often, the neighbourhood of trees or other ‘green elements’ increase real estate prices.

Trade-offs arise as land used for forestry excludes its use for other functions. Putting it simply: if the land is used for forestry, this land cannot be used for building houses or producing cereals. If the supply of houses or potatoes exceeds demand, this is not necessarily problematic. However, the opposite applies in cases of shortage. Smart combinations such as planting several trees in the garden of houses could be used to limit such trade-offs.

3.2.7 Risks associated with scaling up

It is likely that scaling up of forestation of the intended 10% in the National Forest Strategy to, for example, 50% or 100% will be mainly realized on agricultural land. Doubling the forest area would imply that forest area increases from over 8% of the total area to more than 16%. The Netherlands is the second agricultural exporter in the world. As such, a decrease in agricultural production due to less agricultural land would have consequences for the global food supply.

3.3 Agroforestry

3.3.1 Introduction

Agroforestry is a rather new concept in the Netherlands representing an interesting climate mitigation option. In a former publication about the current state of agroforestry in Europe, agroforestry is defined as "*the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land*" (Mosquera-Losada et al., 2009, p. 3). Agroforestry, therefore, aims at integrating woody structures with agriculture and livestock farming (Figure 3-1).

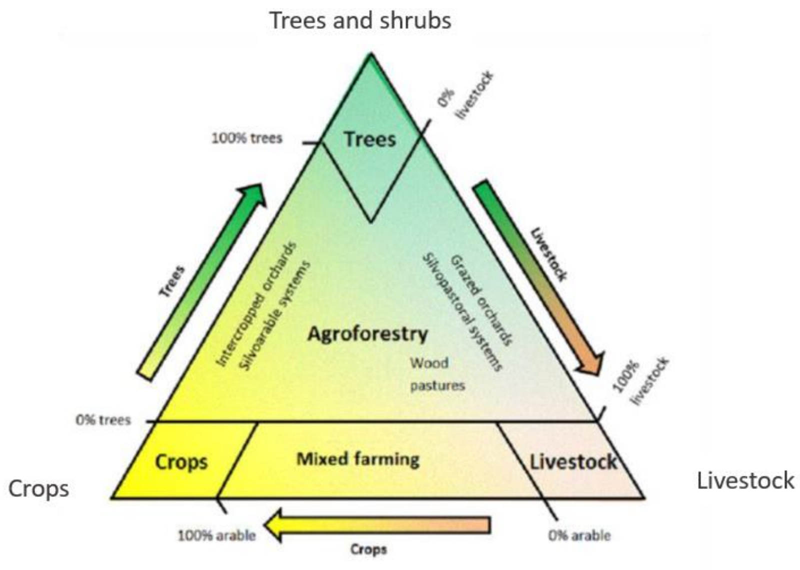


Figure 3-1: The agroforestry triangle shows the different agroforestry types which are combinations of crops, livestock and trees and shrubs (source: adapted from (Luske et al., 2020, p. 10))

The most prominent agroforestry types in the Netherlands are listed in the Dutch Agroforestry Masterplan (Luske et al., 2020):

- *Silvopastoral systems*: combinations of productive grassland and livestock with trees or shrubs (this also includes old cultural landscapes such as the Northern Frisian Woods and the Maasheggen area).
- *Silvoarable systems:* combinations of arable land, open field vegetable/fruit cultivation, and trees or shrubs.
- *Windbreaks* (NL: 'Windhagen'): combinations of grassland or arable farming with hedges to break the wind.

- *Food forests*[5]*:* cultivation systems consisting of multiple layers of vegetation to produce a range of fruit, nuts, seeds, vegetables, and herbs.

Similar to forestry, agroforestry supports the **sequestration of carbon** in the biosphere but also contributes to important **ecosystem services** such as improvements in biodiversity, pest control and reduced soil erosion (Kay et al., 2019) as well as economic benefits of a more diverse product range.

3.3.2 Policy context

In the Netherlands, using land for agroforestry aligns with objectives of multiple policies, such as the National Forest Strategy (Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020) and the transition to a more circular and nature-inclusive agriculture (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2018).

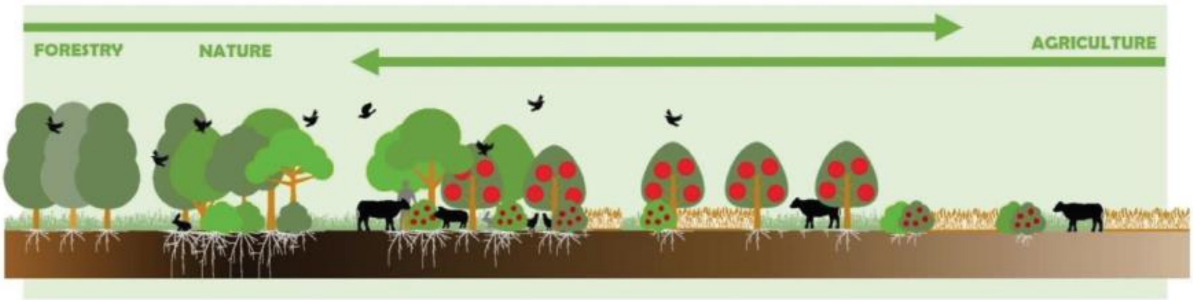


Figure 3-2: Agroforestry can be seen as a link between forestry and agriculture (source: (Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020, p. 37))

To facilitate agroforestry in the Netherlands, the Dutch key stakeholders in research, private and government sector, paved the way for specific policy and regulation in recent years. The integration of agroforestry in the Dutch Climate Agreement goals, even though with few specifications, can be seen as an important starting point (Ministerie van Economische Zaken en Klimaat, 2019). Further steps followed with the aforementioned Masterplan Agroforestry as well as the subsequently published official Dutch Forest Strategy (Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en

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[5] According to (Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020, p. 37), food forests are defined as follows:
"A productive ecosystem designed by humans after the example of a natural forest, with a high diversity of perennial and/or woody species, parts of which (fruits, seeds, leaves, stems, etc.) serve as food for humans. With presence from:
- a canopy of taller trees.
- at least three of the other niches or vegetation layers of resp. lower trees, shrubs, herbs, ground covers, underground crops and climbing plants.
- a rich forest floor life.

A food forest has a robust size, i.e. an area of at least 0.5 hectares in an ecologically rich environment; in a severely impoverished environment a minimum area of up to 20 hectares is required."

Voedselkwaliteit, 2020) providing more insights and concrete steps toward an expansion of agroforestry in the Dutch context.

As outlined in the Dutch Forest Strategy, the total climate impact of agroforestry is quantified as part of the sector goal "trees, forest and nature" **with 0.4 Mton CO2 and 0.8 Mton CO2 ('ambitious goal') in 2030**. However, it is not clear yet how much of the aimed GHG emissions are assigned to non-agroforestry in this sector such as landscape elements. According to (Lesschen et al., 2021), agroforestry could contribute to 0.1 Mton CO_2, however, assuming a more ambitious target of 25,000 ha in 2030 compared to 7,000 ha mentioned in the Dutch Forest Strategy (see section 3.3.3).

The current phase of Dutch policy development (2020-2024) focuses on a general evaluation of agroforestry including the development of knowledge, financial incentives and the elimination of implementation barriers (Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). In a first step, a task force consisting of provincial governments, water boards, municipalities and agricultural stakeholders has been established to identify policy barriers in 2021. The focus for the following period is planned to be on the application and upscaling of agroforestry.

In terms of **available funding**, the forest strategy mentions potential funding either via pillar I and/or II of the Common Agriculture Policy (CAP) of the EU, or funding from the Dutch Climate Agreement. The latter specifies the available funding with 51 MEUR ('climate funds') for, among others, the restoration of landscape elements/agroforestry, and a subsidy scheme for farmers planting forests on their land. How much exactly shall be accounted for in agroforestry has not been specified.

The former option of funding via the CAP so far limited the integration of tree structures in agriculture since so-called landscape planting is deducted from eligible agricultural for the calculation. As a result, planting trees on the agricultural ground would lead to a reduction of EU subsidies. However, the new CAP (2021-2027) is expected to provide more degrees of freedom for national governments to design subsidy schemes that could reward e.g., farmers for ecosystem services such as biodiversity. Still, in this context advisors to the respective Dutch ministry concluded that the **CAP alone is not sufficient for a solid agroforestry business case but needs to be complemented by national subsidies (Strootman et al., 2020).**

Strootman et al (2020) mention three examples for national funding: (1) the Transition Fund which still needs to be set up and would include a total funding budget of some 175 MEUR, (2) the 'nitrogen letter' from the Minister of Agriculture, Nature and Food Quality which offers financial opportunities to support companies in the reduction of nitrogen (which is a co-benefit of agroforestry), and (3) the subsidy scheme for Nature and Landscape Quality Impulse (SKNL) which supports the conversion of agricultural land to forestry by compensation of loss of economic value of the ground.

To conclude, there are multiple opportunities to incentivise the implementation of agroforestry. It requires more in-depth research to evaluate if/how these can be combined and if this is sufficient to stimulate agroforestry development.

3.3.3 Current land use and potential land-use competition

What is particular to the Dutch situation is that in policy documents specific goals are mentioned for so-called food forests (NL: 'voedselbossen') as one integral element of agroforestry.

This is an important distinction since there is a specific sub-target mentioned for food forests in both, the national forest strategy as well as the masterplan agroforestry. However, the speed of agroforestry deployment differs in the two documents. Whereas the masterplan agroforestry strives for **25,000 ha agroforestry in 2030, including 1,000 ha food forest** (Luske et al., 2020), the national forest strategy takes a more conservative approach by setting the contribution of agroforestry to the general forestry expansion to **7,000 ha in 2030, but supporting the goal of 25,000 ha for the long-term**.

Agriculture being with its over 50% land coverage the largest land user in the Netherlands will be most probably impacted by the described expansion plans for agroforestry, e.g. by requiring agricultural lands to partly integrate tree structures and/or by the land-use change to grasslands.

Concrete agroforestry cases in the history of the Netherlands are limited. One of the main reasons for the limited use of agroforestry lies in the high **land-use competition** with intensive agriculture. According to (Oosterbaan & Kuiters, 2009) many farmers due to high labour costs and land prices switched towards large-scale agricultural production to achieve as much production as possible, including intensive fertiliser and chemical use. An analysis of the European land use and land cover data by (den Herder et al., 2017) has shown that in 2015, livestock agroforestry was the largest form of agroforestry (27,800 ha), next to 3,700 ha grazed fruit, olive and nut tree area (belonging to the high-value tree agroforestry category) and no sizeable (>100 ha) arable agroforestry.

Next to the larger established parts, there are also plenty of **small-scale agroforestry projects** and experiments. (Oosterbaan & Kuiters, 2009) show a variety of 17 small-scale agroforestry experiments across several Dutch provinces (1-10 ha per experiment) to search for alternative ways of producing different crops (e.g. beet and maize) and growing trees (e.g. poplar and walnuts).

More recent experiences, experiments and projects at a small scale (<100 ha per test location) are published on various Dutch websites.[6] Most of the small tests are currently executed in the province of North Brabant (see Annex I: Additional information for the national narratives).

[6] References: https://www.agro-forestry.nl/projecten/
https://www.landbouwenvoedselbrabant.nl/landbouw+en+natuur/agroforestry+brabant/initiatievenkaart+agroforestry/default.aspx
https://www.landbouwmetnatuur.nl/initiatieven-agroforestry/

3.3.4 Climate risks & sensitivities

In general, climate risks and sensitivities for the agroforestry sector closely align with the forestry sector. The National Forest Strategy (Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020) specifies **salinisation in the low-lying parts of the Netherlands** as one specific risk that makes some places unsuitable for tree structures. This can be caused by rising sea levels, subsidence and more extreme periods of drought and their effect of freshwater displacement by brackish or saltwater.

Drought can also cause forests to become more prone to nitrous oxide, precipitation, diseases, and plagues.

Another limitation is **very wet and poorly drained soils** with increasing groundwater levels. Many species do not grow well under those conditions such as nut and fruit trees.

3.3.5 Economic implications

In general, it can be assumed that agroforestry is not economically viable based on regular income alone (Strootman et al., 2020). On the positive side, Strootman et al. mention the possibility of increased crop yield thanks to agroforestry, e.g., by protecting from wind leading to increases of 5-30% in the arable crop. Though, one has to note the provided additional economic value is usually not realised in the short-term in contrast to annual crops since trees and shrubs take some years to grow which poses a serious challenge to agroforestry. Also, a general barrier that many ecologically valuable options face is that the provided services to the ecosystem such as erosion control, reduced nutrient loss, and carbon storage cannot be monetized (Kay et al., 2019). The same research paper generally concludes that when societal values of ecosystem services and dis-services are priced, the profitability of agroforestry is higher than for non-agroforestry cases.[7] **Realised carbon prices of some 30 EUR/ton CO_2** favoured agroforestry in comparison to non-agroforestry cases.

In this regard, the Dutch National CO_2 market, which is a voluntary emission trading market, currently works on methodologies for providing certificates e.g. the plantation of new forests and different forest management.

Additional ways of financial support are also discussed in the National Forestry Strategy:

- Supporting advantageous tax schemes and available funding from the Circular Agriculture Conversion fund (NL: Omschakelfonds Kringlooplandbouw)
- Supporting research to monetize ecosystem services, possibly based on critical pressure indicators described in the national plan for recreating biodiversity

[7] The research paper's scope comprises of agroforestry and non-agroforestry profitability assessment of case studies in Atlantic and continental regions of Europe.

3.3.6 Co-benefits and trade-offs

Next to the positive effect of carbon sequestration in the biosphere, the implementation of agroforestry introduces various co-benefits but also some negative impacts on agriculture.

The more diverse product range of agroforestry is an advantage since it can help farmers to lower the risk of total income losses in the events of natural disturbances affecting their only product (e.g., silvoarable systems: flood damages conventional crops such as wheat but high stem fruit trees may be less affected). Other examples of co-benefits are provided in literature (Dollinger & Jose, 2018; Interprovinciaal Overleg & Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020; Kay et al., 2019; Lesschen et al., 2021; Luske et al., 2020; Strootman et al., 2020):

- **Ecosystem services** such as reduced nutrient and soil losses, enhanced soil organic matter (which affects soil biodiversity and associated soil biological functions), pest control in agricultural areas, water retention, pollination, biodiversity, and animal welfare (e.g., natural sun protection for cattle and poultry by trees).
- **Social benefits** such as savings on healthcare costs and positive effects on business climate and real estate value

What can generally be observed is the trade-off between these ecosystem and social co-benefits on the one hand and negative impacts on agricultural production on the other hand. The agricultural sector is negatively impacted by among others: (1) the incompatibility of trees with agricultural practices since trees can result in potentially lower harvesting efficiencies due to the heterogeneous composition compared to monocropping and thus an increase of labour costs, and (2) the reduction of available area for crops. Especially the latter can also result in increasing emissions somewhere else (Lesschen et al., 2021) e.g., due to land use conversion in a different country to agricultural land.

3.3.7 Risks associated with scaling up

Many risks for agroforestry in the Netherlands originate from the fact that it is a new concept that has not been accounted for in much of the Dutch agriculture and nature **policy**. The National Forest Strategy mentions the example of unclarity on how agroforestry parcels need to be registered in terms of land categories, crop codes etc.

Another risk for upscaling is that with fragmented or even without **financial** support for carbon sequestration and ecosystem services, the profitability of agroforestry is less in comparison to traditional agriculture. On top of that, parts of the incomes may be generated in the longer term which can be a disadvantage compared to the short-term income of annual crops.

A lack of knowledge is another risk for upscaling agroforestry. The combination of different sectors in agriculture and forestry comes with scattered knowledge over those sectors which can pose a barrier for agroforestry implementation.

3.3.8 Research gaps

Due to the just recent appearance of agroforestry in the national policy context, knowledge about agroforestry is limited and therefore needs to be developed and deepened to provide reliable qualitative and quantitative information.

Not just on a national level, but also on the EU level, there is a knowledge gap on effective measures to account for ecological and social benefits in the economic evaluation of projects (Kay et al., 2019).

3.4 CCS applied to AD based on animal manure and soil carbon enhancement with AD based digestate

3.4.1 Introduction

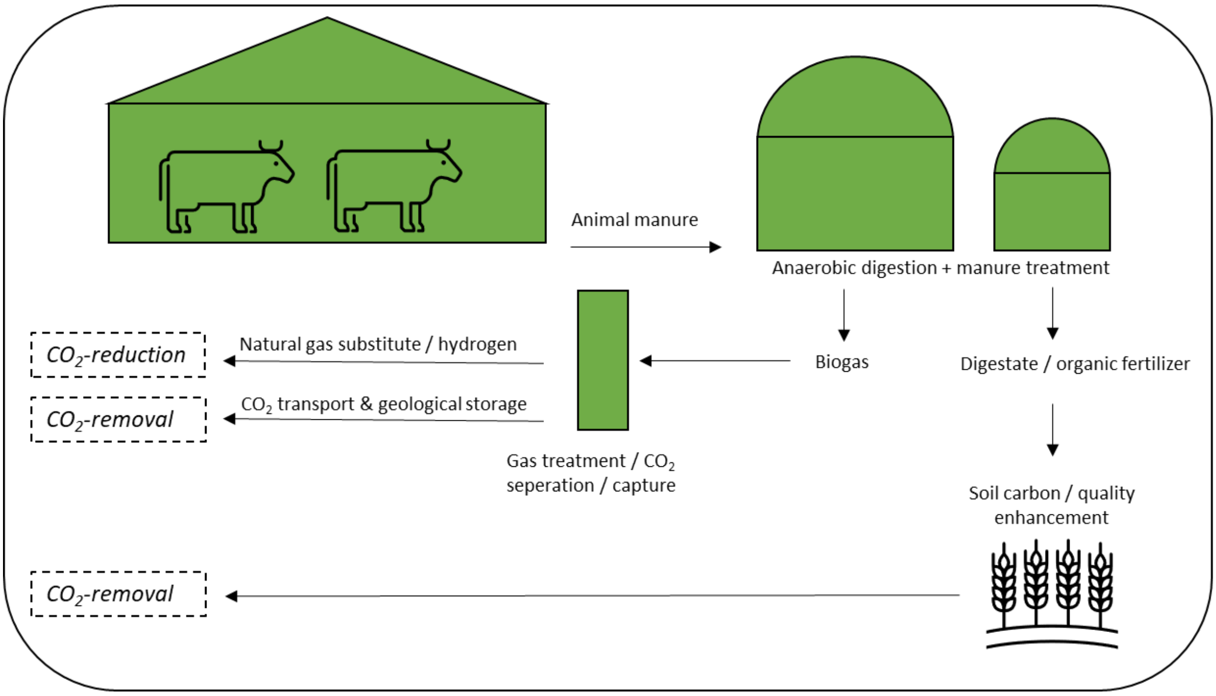
The historical developments, ongoing research activities and market initiatives in the field of CO_2 capture and geological storage within the Netherlands over the past two decades or so do not show a promising picture. Several CCS market initiatives and projects have been proposed and cancelled, and to date, no commercial-scale CCS projects have been developed. While great advancements have been made in post-combustion CO_2-capture technologies, and techno-economic assessments for CO_2-transport and geological storage infrastructure have been developed, CCS in The Netherlands is far from market implementation and meaningful scales. However, this picture is not unique to The Netherlands, similar delays in CCS market application can be observed in many other countries around the globe. This is despite the notion that most 1.5 and 2.0^{o}C compatible climate scenarios rely considerably on CCS deployment at scale. However, the basic geophysical and industry conditions for developing a viable CCS sector in The Netherlands are available. As a former top-3 exporter of natural gas in the EU (whose domestic gas production is now in considerable decline) there will be increasing opportunities to (re)use existing gas sector knowledge/expertise, and natural gas infrastructure for CO_2-transport and geological storage.

(Strengers B., 2018) provide a first estimate of the **technical potential** for **post-combustion CO_2-capture of 46-55 Mt CO_2 per annum** for the Netherlands for several different BECCS supply chain configurations. The resulting estimated **realistic potential** is considerably smaller with resp. **4.6 and 17 Mt CO_2 per year**. This is mainly due to a range of risks and uncertainties relating to the core technology, CCS: Among others, social resistance to onshore CCS projects, uncertainty about viable business cases and doubts about sufficiently available subsidies have so far blocked several CCS projects and still hamper the introduction of large CCS applications in the Netherlands (Akerboom et al., 2021).

Next to the concerns of CCS, the bioenergy component of BECCS raises another major question, namely if the Netherlands can secure the required volumes of biomass sustainably.

Side-effects of more irrigated biomass plantations are e.g., extra water stress in an already water-stressed world (Stenzel, Greve, Lucht, Tramberend, & Wada, 2021). Furthermore, all the BECCS supply chain configurations considered by (Strengers B., 2018) rely heavily on imported biomass. [8] While there are ample scenario studies about the international availability and future trade of biomass considering major global developments such as the energy transition, the circular economy, the bio-based economy, general population growth and food security, securing (future) supplies of imported and domestically available biomass will remain a continuous risk and challenge. (SER, 2020) recommend a phase-out of lower value biomass to energy applications, such as for electricity production, low-temperature heating systems and as fuel for light vehicles and to use biomass for (higher value) bioenergy applications - such as heavy road transport, shipping, and air transport – only as a temporary, or bridging option.

Figure 3-3: Outline of a possible AD BECCS + soil carbon enhancement supply chain in The Netherlands



Concerning this stress on biomass supply for bioenergy and CCS applications, animal manure is one of the few remaining and underutilized domestic sources of biomass within the Netherlands (Strengers B., 2018). The sizeable Dutch livestock sector (mainly dairy cattle and pig farming) produces a steady

[8] Post-combustion CO_2-capture configurations include: CCS applied to coal fired power plants using biomass as feedstock, CCS applied to the about 30 larger and smaller gas-fired power plants in the country that could be fuelled with biogas, CCS applied to the HIsarna process in the steel sector, CCS applied to solid biomass combustion in high temperature heat applications, CCS applied to waste incineration plants (biogenic fraction of waste).

annual supply of mainly liquid manure[9] that can be used to produce biogas, as well as organic fertilizers.

Biogas from animal manure results in avoidance (reduction) of CH_4 emissions (from manure storage) and CO_2 emissions (substitute fossil fuels), as well as in negative emissions (removals) through CO_2 capture and geological storage (from biogas treatment and CO_2-separation), and soil carbon enhancement by using manure derived digestate / organic fertilizers (see Figure 3-3). Other aspects to consider in the overall GHG balance include e.g., N_2O emissions from soils, CH_4 leakages, CH_4 emissions from enteric fermentation, manure management, potential CO_2 emission savings from reduced use of fossil fertilizers.

While there undoubtedly is a technical domestic potential for negative emissions concerning treatment and usage of animal manure, robust scenario studies on the realistic scaling potential of these negative emission solutions are scarce. (Strengers B., 2018) have excluded CO_2-capture at anaerobic digestion plants from their assessment, mainly due to the considerable infrastructure requirements for CO_2 transport but argue that in a possible future where large-scale centralised (manure)digesters will be built (>1000 m^3 per hour) then this BECCS option could become interesting. Marginal costs are estimated at EUR 70-80 per ton of CO_2 (including CO_2-transport costs). However, further risks and impact assessments, techno-economic analysis and scenario studies would be needed to determine the realistic potential.

In this study, we try to determine whether such a scenario for nationwide scaling-up of manure digestion with CCS and digestate reuse for soil carbon enhancement can be compatible with the net-zero emission ambitions for agriculture in 2050.

3.4.2 Policy context

The BECCS value chain finds itself in a complex situation of different policies and measures affecting both components (bioenergy and CCS) either separately or simultaneously. In this chapter, we briefly address CCS and bioenergy related policy items and go into more depth about the biomass supply which is crucial for BECCS to be implemented at scale.

CCS

For considering CCS alone, the **EU CCS directive (2009/31/EC)** is of importance that aims at the safeguarding of safety and health conditions for CCS applications, as well as minimum requirements for storage permits, liability and roles and tasks of CCS actors (Akerboom et al., 2021). The CCS directive finds its national implementation in **chapter 3 of the Dutch Mining Act**.

[9] In 2020 the annual production of liquid manure in the Netherlands was 71,642 mln. kg and 2704 mln. kg solid manure. Source: (Statline, 2021)

To support the **economic viability** of CCS, there are basically three policy measures on EU and national level impacting the CCS business case: (1) Avoided costs of the EU Emission Trading Scheme where e.g., actors that fall under this scheme can apply CCS to reduce emissions which otherwise may result in costs for additional allowances, (2) avoided costs by the Dutch carbon tax for industrial emissions, and (3) financial support by the Dutch SDE++ subsidy in form of a premium bridging the gap between installation costs and financial business case. More information about each option can be found in (Akerboom et al., 2021).

Bioenergy

On the matter of bioenergy, important points are mentioned in the Dutch Climate Agreement (Ministerie van Economische Zaken en Klimaat, 2019): (1) The green gas sector aims to realise some 3.6 Mt carbon dioxide reduction and a cost level of 100-150 EUR per avoided tonne of CO2 by 2030, (2) there is a reduction aim of 1-2 Mt by 2030 through **CCS and CCU in the green gas sector**, and (3) **a cascade of biomass use** primarily for soil fertilisation, human and animal feed, feedstock for materials and chemicals, and just lastly for energy production.

In this framework BECCS would apply to the second category, thus contributing to the green gas reduction aim of 1-2 Mt carbon dioxide by 2030. As to the question of where the required biomass for the generation of bioenergy and subsequent CCS can be sourced, this narrative focuses on manure from the domestic livestock sector.

(Ministry of Economic Affairs and Climate Policy, 2022):

- At least 2 bcm green gas in Netherlands annually from 2030 onwards
- The current green gas production capacity is approximately 220 million m3 per year, built up over a period of more than 10 years
- The current coalition has expressed itself through the Coalition Agreement in favour of an admixture obligation of 20%, or an expected 1.6 bcm, in the built environment by 2030 *equivalent to 2.9 Mton CO2 reduction per 2030*
- Scaling-up primarily in built environment
- The blending obligation will be fulfilled with administrative certificates, whereby the green gas is fed into the natural gas network. These can only be obtained, with the consent of the European Commission, on the basis of: green gas produced in the Netherlands. The Dutch Emissions Authority (the NEa) is the supervisory and enforcement authority for this certificate system.
- Blending obligation starting in 2025 with 150 mln. m^3
- Efforts to increase availability of unused biomass potential such as micro algae, seaweed and digestate.

Dutch legislation regarding the livestock sector

Next to the indirect contribution of livestock to the reduction aims of the green gas sector, it also directly contributes to climate change mitigation via more sustainable farming, e.g., by reducing methane and ammonia emissions (see able 3-4).

able 3-4: Overview of AFOLU sector measures stated in the Dutch Climate Agreement

Theme	Measure	Foreseen emission reduction in 2030 (Mton CO_2-eq.)	Finance / funding 2020-2030 (mln. EUR)
Livestock farming	- Precision fertilization dairy cattle farming - Low emission dairy cattle and pig stable systems - Extend productive life and genetic selection of dairy cattle - Integrated approach for reducing methane and ammonia emissions - Research on nitrification inhibitors - Sustainable stable systems in pig farming - Buy-out scheme for pig farming - Substitution of fossil fertilizers - Research & Development	1.2 – 2.7*	252
Livestock farming in / close by Natura2000 areas	- Measures to reinforce the ecological value in Natura2000 areas - Specific measures for the livestock sector	-	100
Peat(y) soils	- Increasing water level	1.0	276
Agricultural soils and open soil cultivation	- Pilots, vocational training and information	0.4 – 0.6	28
Trees, forest, and nature	- National Forest Strategy	0.4 – 0.8	51
Horticulture (glass)	- Production and use of renewable energy	1.8 – 2.9	250
Food waste, residual flows, and biomass	- Training and information on circular agriculture - Activities towards preventing food waste	0	13

*of which at least 1 Mton CO_2-eq of methane emission reduction (in line with coalition agreement).

Source: (Ministerie van Economische Zaken en Klimaat, 2019).

Concerning relevant policies, there is a complex subset of negative impacts associated with the current livestock sector that triggers the public debate and drive policy action to improve the sustainability of the agriculture/livestock sector. This includes a range of impacts on soil (land use, soil quality, soil health, use of fertilizers, pesticides), water (eutrophication), air (ammonia/nitrogen emissions), climate (CO_2, CH_4, N_2O emissions), flora (monoculture grasslands) and fauna (soil biodiversity, animal welfare, human health), etc. To govern/regulate all these impacts a comprehensive framework and complex web of generic policies and specific measures apply. Generic policies include the EU's common agricultural policy, the laws on environmental management (Dutch: “Wet milieubeheer”), best available technology guidelines, etc. Specific policies include among others:

- Law on ammonia (NH_3) emissions and animal husbandry (Dutch: “Wet ammoniak en veehouderij”)
- Law on odour nuisance and animal husbandry (Dutch: “Wet geurhinder en veehouderij”)
- Decree low emission animal housing (Dutch: “Besluit emissiearme huisvesting”)
- Production rights pig & poultry (Dutch: “Productierechten varkens / pluimvee”)
- Specific laws on phosphate rights and phosphate production dairy cattle (Dutch: “Fosfaatrechten / fosfaatproductie melkvee”)
- Regulations for manure storage, - transport, and - processing
- Regulations for housing and caretaking of animals, and use of antibiotics
- Regulations on the use of (manure, organic, fossil) fertilizers on soils
- Subsidies and fiscal support schemes e.g. manure processing, low-emission stable systems, biogas production, air filtration systems, etc.

The current governance regime puts most emphasis on regulating and stimulating the sustainability of farm-level activities while the rest of the supply chain such as the agro-food processing industries, and supermarkets face a different governance regime (e.g. EU ETS, Energy Efficiency regulations, and other health, safety and environment (HSE) regulations and support schemes). Specific rules and regulations for consumers/end users tend to focus more on voluntary actions or nudging and less on price regulations. While sugar- and meat taxes are part of the political and public debate, to date they have not been implemented. For consumers, softer measures like promotional campaigns for more sustainable or vegetarian/vegan food dominate.

One of the key political challenges is linked to nitrogen/ammonia emissions. The existing policy regime, the so-called programmatic approach nitrogen (Dutch: “Programmatische Aanpak Stikstof”), that serves as a governance framework and basis for the government for permitting economic activities[10] was declared inadequate by the Dutch Council of State. [11] This ruling has caused the ‘nitrogen crisis’ as it is currently blocking a wide range of economic activities. Agriculture is one of the major contributors to nitrogen (NOx) and ammonia (NH_3) emissions with resp. 16% and 85% of national emissions (livestock is the main source of NH3 emissions in the country at about 87% of total NH3 emissions in agriculture).

Any climate change mitigation/negative emission scenario within this sector will likely face heavy (political and public) scrutiny for its positive or negative impact on mitigating the nitrogen crisis. In

[10] Such as the expansion of livestock stables, building construction activities, and infrastructure works on roads, etc.
[11] **Invalid source specified.** and **Invalid source specified.**

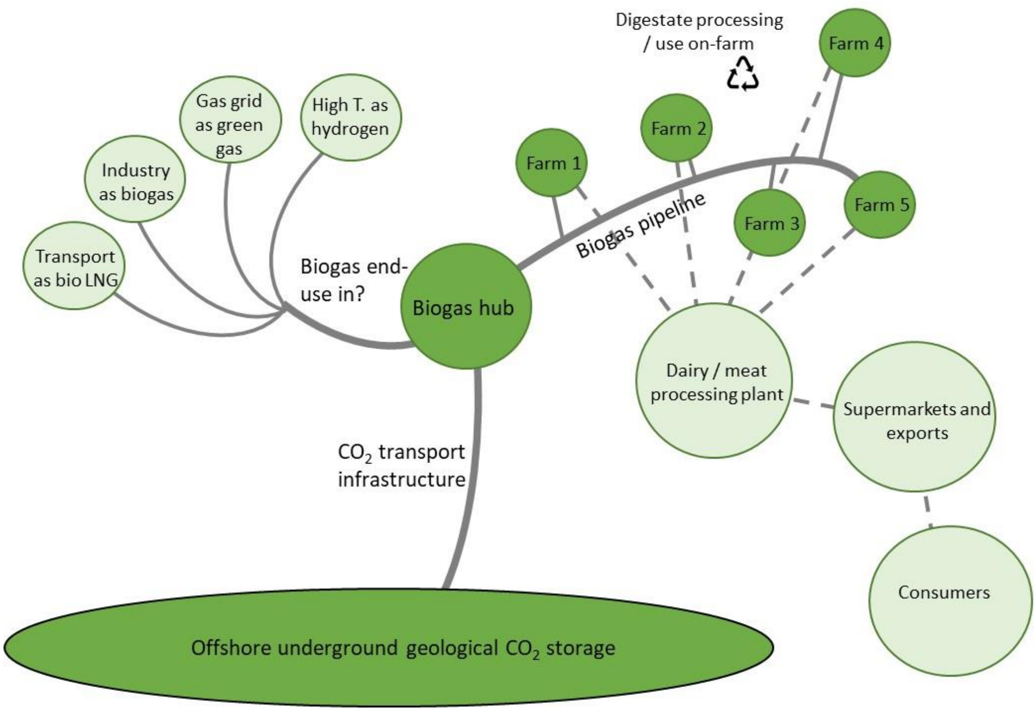
addition to this other sustainable development objectives (e.g., biodiversity impact, land use, animal welfare, etc.) will also be included in such transition pathway evaluations.

The biogas-hub scenario, which includes manure digestion, adjustments of stable (floor) systems, has the potential to significantly contribute to reductions in NH_3 emissions. However, a more in-depth qualitative risk and impact assessment and quantitative assessment are needed to evaluate the real scaling potential of this scenario and the associated co-benefits and trade-offs.

Stakeholders and actors involved

The biogas hub CCS scenario adds a new economic activity to a market system with its structure (see Figure 3-4) and dynamics. Livestock farmers produce dairy and meat as their core activity and supply this to meat/dairy processing factories. The biogas hub and the efforts to enhance soil carbon also make the farmers renewable energy producers, and 'carbon farmers'. The biogas based energy can be supplied via an intermediary (energy trader) or directly to different end-use sectors (transport, industry, heating). CO_2 transport and geological CO_2-storage services will most likely be provided by independent legal entities as well.

Figure 3-4: Simplified market system for a biogas hub BECCS scenario



3.4.3 Current land use and potential land-use competition

Grassland and land use for feed/fodder production comprise about 65% of total land use in agriculture (see Table 13). While domestic agricultural land is mainly used for roughage and fodder for the livestock sector, the sector also has significant indirect land use resulting from the import of animal feed (e.g. soy, mixed feeds, etc.).

Table 3-5: Agricultural land use in the Netherlands in 2010 and 2019 (in 1000 ha)

Land use category	2010	2019
Agricultural area, total	1,872	1,816
Arable land	542	532
Horticulture in the open	87	93
Horticulture under glass	10	10
Grassland and feed crops	1,232	1,182

Source: (Statline, 2020)

Any significant land-use change resulting from the biogas-hub & soil carbon enhancement scenario is not expected as this LMT depends on manure as input. In case the livestock sector would shrink for political reasons or competing land claims from other sectors, this may have consequences for the supply of manure. Competing land claims on land used to feed the livestock sector may arise from the rewetting of peat(y) soils, afforestation, an extension of built areas, and expansion of wind and solar electricity generation on the land. Apart from competing for land use claims outside the livestock sector, some land-use change is expected for additional biogas, gas, and CO_2 pipeline infrastructure, but it is plausible that such infrastructure will largely follow existing infrastructure corridors.

3.4.4 Climate risks & sensitivities

In this section, we focus on climate risks and sensitivities related to the biomass supply which we expect to be more impacted by a higher degree than the technologies for bioenergy generation and CCS. A report by the Dutch Ministry of Agriculture, Nature, and Food Quality addresses climate risks for the agriculture sector (Dutch Ministry of Agriculture, Nature and Food Quality, 2020). Among others, the livestock sector is impacted by more frequent **extreme temperatures** and exposure to UV radiation. This puts additional stress on animal welfare – something that needs to be prevented by farmers e.g., by ventilation and misting in stables and taking precautions when transporting animals.

Droughts can cause lower feed/fodder yields and affect the nutritional value of feed/fodder. Finally, livestock farming can also be confronted with **new animal diseases and zoonoses**, including those transmitted by insects.

3.4.5 Economic implications

A general estimate on BECCS CO2 avoidance costs is provided by (Geden & Schenuit, 2020) which mention a range of 100-200 USD_{2011} / tonne CO2 removed in 2050. However, this is highly dependent on the type of biomass used, transportation distances (e.g., imported biomass) and digester sizes (economics of scale). During our study, we will analyse in more depth the GHG emission mitigation and negative emission potential in the Netherlands.

Manure availability for anaerobic digestion

Detailed figures about the production of the starting product, dairy manure, can be found via the statistics office of the Netherlands (Statline, 2021).

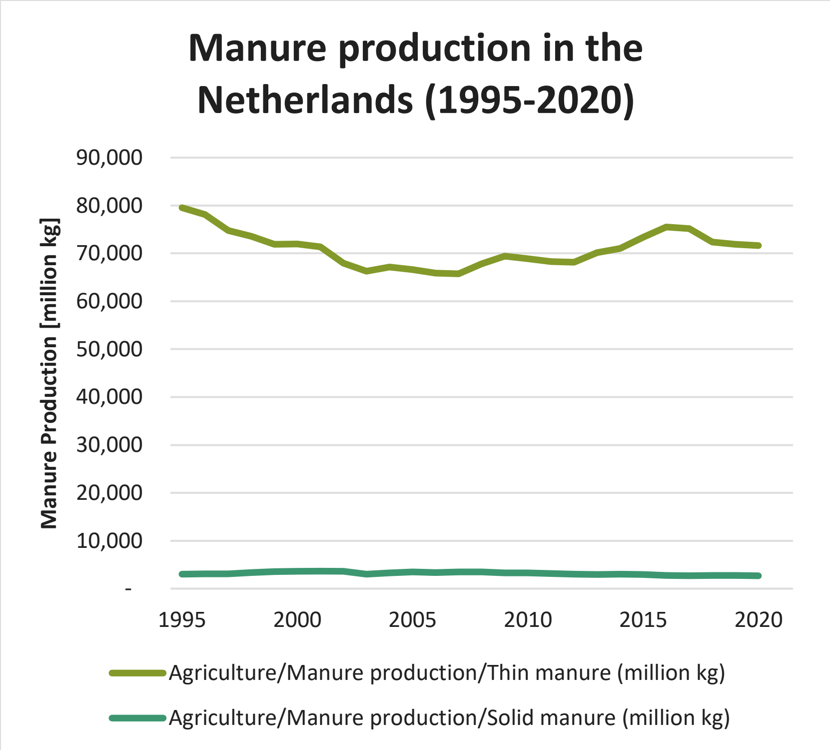


Figure 3-5: Manure production in the Netherlands in the period of 1995-2020

1st scenario: Required integrated manure management to reach national emission reduction target

- Net zero by 2050: "However, even by 2050, greenhouse gas emissions from this sector will be inevitable. This is because greenhouse gases are inherent to natural products, such as methane and nitrous oxide from animal husbandry and fertilisation (even from "green fertilisers"72). At the same time, the sector will increasingly be capturing carbon in soils, forests and materials, produce biomass and generate renewable energy. The sector's aim is to achieve an equilibrium between the unavoidable emissions of greenhouse gases, on the one hand, and the capture of greenhouse gases and production of renewable energy and biomass, on the other hand, by 2050." (Ministerie van Economische Zaken en Klimaat, 2019)
- Link to 1.2 – 2.7 Mt emission reduction target by 2030 of the livestock farming sector, of which at least 1 Mt CO2-eq in methane emission reduction (in accordance with the Coalition Agreement). e.g. by digestate replacing conventional fertilisers,
- *"the Coalition Agreement sets out that "technical measures (e.g. manure processing, mixed feed and energy-producing greenhouses) will* ***take preference over measures aimed at curbing volumes****."" → constant livestock volumes?*

- *“measures for "Manure storage and Fertiliser": changes to livestock facilities, whether or not in conjunction with outdoor storage of methane oxidation, manure mono-fermentation and replacement of part of the grass with clover to reduce the amount of artificial fertiliser used;”*
- *Update own comment: Reduction inevitable due to lifted derogation for Netherlands conventional farmers with largely grassland will be allowed to use around ~30 % (170 compared to 230/250 kg/ha) less manure from next year. That will certainly have an impact on the number of cows. But I also understood that it will not have an impact for everyone. Organic farmers such as Jan already use a maximum of 170 kg/ha, (is that correct?) It will be interesting to see how we will link this development to the scenarios (e.g. 30% fewer cows, excluding organic farmers).*

2nd scenario concerning manure availability: Livestock reduction

- Reduction of livestock in accordance with Greenpeace (Tirado, 2018) suggesting that by 2050 the global production and consumption of meat and dairy should be halved.
- 50% livestock reduction for which farmers are compensated according to the previous subsidy scheme about cessation of dairy farming (Dutch State Secretary for Economic Affairs, 2017)
    - Buy-out price per full grown (dairy) cow: 1,200 EUR
    - Calves (23% of 1200 EUR)
    - Young cattle (53% of 1,200 EUR)

The livestock manure is used to produce biogas and digestate in an anaerobic digestion process, which is described further in the next section.

- Interview summary René Cornelissen:
    - The production of biogas from manure is closely linked to intensive livestock farming. The more livestock is allowed to graze outdoors, the less the ratio of manure that can be retrieved to be used for this purpose, so it could somehow conflict with a future trend in improving animal wellbeing. The ratio of manure that gets to biodigesters from intensive livestock farming is around 90%.

Anaerobic digestion

During the fermentation process of manure, part of the organic matter is converted into methane and carbon dioxide. There are different types of digestors out of which monodigestion (only digestion of one product such as manure) and co-digestion (at least 50% manure and the remainder composing of plant-based biomass) are the most applied in the Netherlands (Netherlands Enterprise Agency, 2021).

“Mono-manure digesters are small digesters in which only manure is processed. These installations are usually located at livestock farms. In a co-digester, manure is fermented in combination with an energy-rich co-substrate such as silage maize. An all-purpose digester is a large-scale digester that can process both mono-substrate (for example WWTP sludge) and co-substrates (different feedstocks). Fermenters do not differ substantially in process technology.”(van der Veen et al., 2020, p. 11)

Manure that is actually available for biogas production = 14%

Tabel 4 - Aandeel vrij beschikbare biomassa voor energietoepassingen en huidige inzet van biomassa, op basis van DNV GL (2017)

		Huidige inzet (alle toepassingen)					
Biomassa-stromen	Huidig aandeel vrij beschikbaar [1]	*Veevoer*	*Bio-brand-stoffen*	*Grond-verbete-raar*	*Elektri-citeit en warmte*	*Biogas en groengas*	*Anders*
VGI	40%						
RWZI-slib	88%						
Natte gewasresten	17%						
Stro	0%						
Mest	14%						
GFT en ONF	61%						
Rest- en afvalhout	53%						
Papierresiduen	93%						
Productiebossen	18%						
Hout van fruit- en boomteelt	29% [2]						
Hout uit landschap	50%						
Natuur- en bermgras	20% [2]						

[1]: 'Vrij beschikbaar' betekent beschikbaar voor energietoepassingen (elektriciteit, warmte, brandstoffen en groengas). De vrij beschikbare biomassa is gelijk aan de technisch beschikbare biomassa min de huidige inzet voor niet-energietoepassingen (DNV GL, 2017). Het percentage in de tabel is ten opzichte van de technisch beschikbare biomassa.

[2]: Hout van fruit- en boomteelt en natuur- en bermgras staan op 0% in DNV GL (2017), terwijl er wel aandelen naar verbranding en vergisting gaan. Daarom zijn hier de door DNV GL gegeven percentages voor 2030 genomen.

(van der Veen et al., 2020, p. 20)

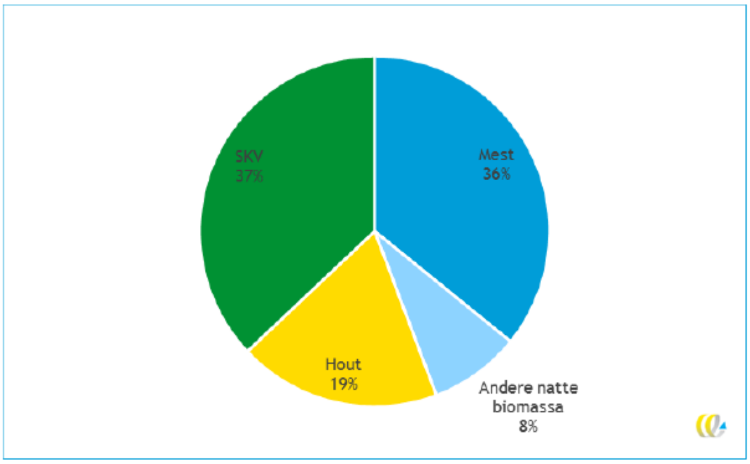
Tabel 6 - Aandelen economisch beschikbare biomassa per stroom en per scenario

Biomassastromen	Aandeel economisch beschikbaar voor groengas in Scenario's A en B	Aandeel economisch beschikbaar voor groengas in Scenario's C en D
VGI	13%	8%
GFT en ONF	34%	21%
Gras uit recreatie	15%	10%
Afvalhout (huishoudens)	40%	25%
RWZI-slib	75%	25%
Slootmaaisel en bermgras	15%	10%
Mest	75%	25%
Akkerbouw: granen	38%	0%
Akkerbouw: groenten en overig	17%	10%
Akkerbouw: gras	15%	10%
Tuinbouw: fruit open grond	22%	14%
Tuinbouw: boomkwekerijen open grond	22%	14%
Overige tuinbouw en glastuinbouw	17%	10%
Bos	13%	8%

*: In Scenario's A en B is er een sterk ondersteunend beleid voor groengas en in Scenario's C en D een matig ondersteunend beleid voor groengas.

(van der Veen et al., 2020, p. 26)

Figuur 6 - Verhouding van de productiecapaciteit van biomassacategorieën en superkritische vergassing in de 'startlijst'



SKV = superkritische vergassing.

(van der Veen et al., 2020, p. 31)

(Ministry of Economic Affairs and Climate Policy, 2022)

"Currently, only a very small part of the manure in the Netherlands is fermented (<5%). Even within a reduction of the livestock, there is therefore still room for manure fermentation."

Existing manure digesters (monomest, co-digestion, ? Mestvergisting (HEW)&(HG):

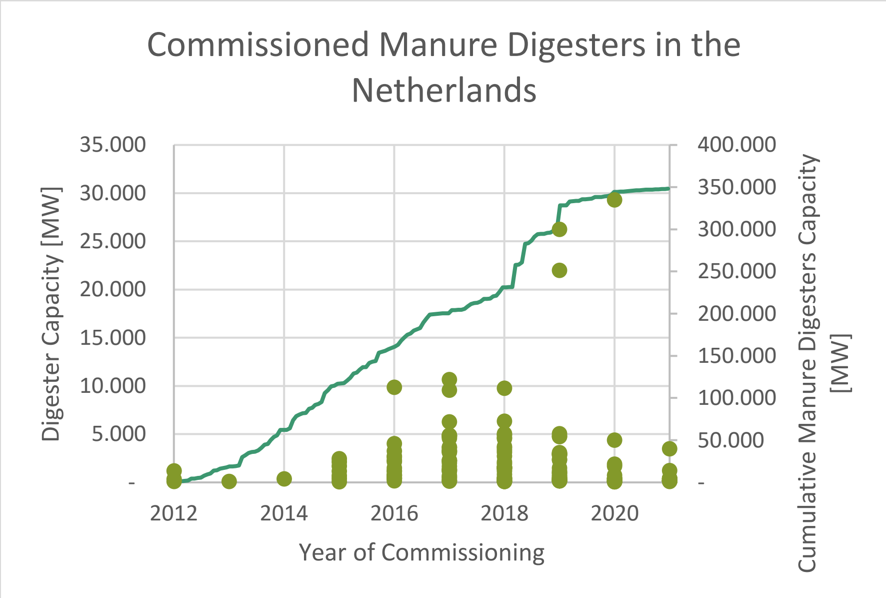


Figure 3-6: Commissioned Manure Digesters in the Netherlands (author's figure based on (RVO, 2022))

Important factor for high biogas production is that the manure is fed into a digester system as soon as possible. A respective study shows that e.g., pig manure stored for one month could already result in a biogas potential decrease about 30 percent from 47.6 m^3/ton manure (three days storage in sewerage) to 33.7 m^3/ton manure (32 days storage in sewerage) (de Buisonjé & Verheijen, 2014).

Focus on monomanure since this is specifically pointed out as a measure in the Dutch climate Agreement (Ministerie van Economische Zaken en Klimaat, 2019, p. 136)

Green gas production from manure can contribute to the reduction of methane and nitrogen emissions. In the CE Delft report, if an emission reduction in the built environment of 2.5 Mton CO2 is achieved, an additional methane emission reduction of 1 Mton CO2-eq. estimated.(Ministry of Economic Affairs and Climate Policy, 2022)

Interview summary René Cornelissen 24 May 2022:

- The most usual configuration for this technique consists in small biodigesters (or co-digesters) that farmers have in their farms (private individual ownership). The biogas produced in these biodigesters is usually sold to large biogas consumers.
- Among the main environmental advantages of this technique, the interviewee cited a strong decrease in methane emissions in these farms that use this technique, and the easy collection of

the CO_2 derived from this process. This is particularly interesting when applied to the small scale, but the economic feasibility of these type of set-ups is at the moment very dependent on external subsidies.

The bottleneck for realizing negative emissions from gasification and anaerobic digestion is in the investment costs of a manure digester and the processing costs of biogas. Generally, if the cost price of bioenergy exceeds fossil energy cost prices, it will be difficult to exploit manure-based anaerobic digestion and gasification at a profitable scale (Strengers, Eerens, Smeets, van den Born, & Ros, 2018). Besides, the export costs of surplus manure at the farm play a role. As these costs increase, farmers get an incentive to look for alternative solutions for surplus manure, for example, as input for digestion. Incentives for manure digesting can be generated by legal obligations.

- *Efficiency*
  - *"Relatively little biogas is produced from this manure. For cattle manure, this is around 25-30 m3 of biogas per tonne of manure in the case of* ***co-fermentation****. For pig manure, this may be slightly higher."*(Netherlands Enterprise Agency, 2021)

Figure 3. Energy Yield Estimation Chart

Material	Biogas Yield per wet tonne of material (m^3/t)	Electrical Yield per wet tonne of material * (kWh/t)	Heat Yield per wet tonne of material * (kWh/t)
Dairy Manure	23	48	62
Corn Silage	180	335	425
Bakery Waste (average)	265	490	630

Source: Böhni Energie & Umwelt, Systemoptimierungen Wirtschaftlichkeitsuntersuchungen Umsetzung

m^3/t = cubic metre per tonne
kWh/t = kilowatt hour per tonne

* Assumes 35 per cent conversion of biogas energy to electricity, 45 per cent conversion of biogas energy to heat. Some of this heat will be required to heat the digester. Electrical efficiency can vary from 25 to 42 per cent.

  - (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021)

Table 7
Renewable energy production from anaerobic digestion of animal manure in 2030*.

	Pig	Cattle
Manure availability in mln. ton (wet basis)	11.65	39.66
Biogas yield per ton of liquid pig manure (in m^3/ton manure)	25	30
Methane content (% CH_4/Nm^3 biogas)	56	56
1 m^3 CH_4 = MJ	35.9	35.9
Energy balance (correction factor for own energy use)	≈ 0.5	≈ 0.6
Total estimated net renewable energy output (in PJ)	2.93	9.57

* Energy yields from manure digestion only attribute to the IMM pathway.

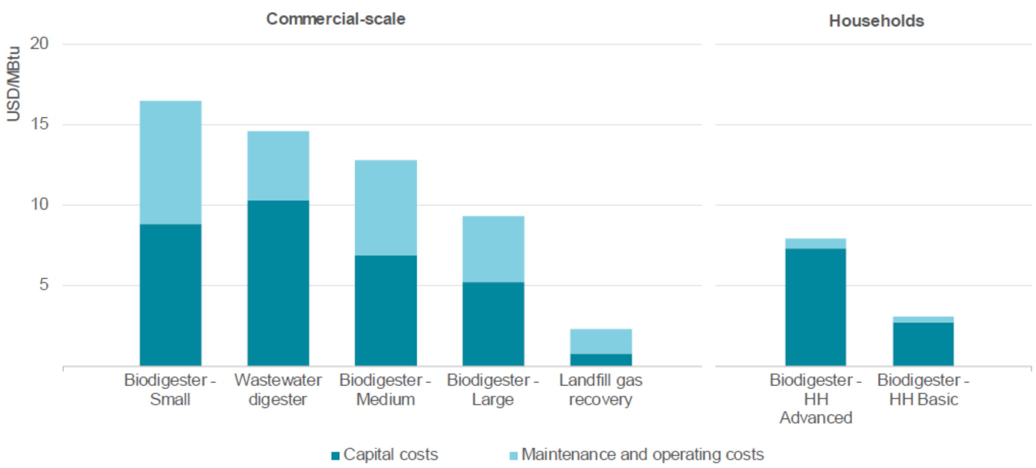
  - (Spijker et al., 2020)

Biogas

- *The methane content of biogas typically ranges from 45% to 75% by volume, with most of the remainder being CO_2. This variation means that the energy content of biogas can vary; the lower heating value (LHV) is between 16 megajoules per cubic metre (MJ/m3) and 28 MJ/m3. Biogas can be used directly to produce electricity and heat or as an energy source for cooking.*(IEA, 2020)

Costs

Average costs of biogas production technologies per unit of energy produced (excluding feedstock), 2018



Notes: HH = household; "HH Basic" includes biodigesters constructed in place using traditional construction materials such as sand, gravel and cement; "HH Advanced" includes pre-manufactured biodigesters made of more expensive composite material. Maintenance and operating costs include ordinary and extraordinary maintenance, labour costs, and energy required to operate the system. Capital costs have been levelised for the production lifetime of each technology: 25 years for landfill gas recovery and advanced household biodigesters; 20 years for centralised biodigesters (small, medium and large) and wastewater digesters; 15 years for basic household biodigesters. 1 MBtu = 0.29 MWh.
Sources: IEA analysis based on different sources (Dennehy et al., 2017; ETSAP, 2013; and others).

(IEA, 2020, p. 28)

- biogas upgrading today is around USD 19/MBtu (IEA, 2020, p. 37)
- Investments required to transform biogas into electricity or heat, and this can be considerable in some cases; for example, adding a co-generation unit and including power grid connection and heat recovery distribution can add an additional 70% to the costs of an integrated project. (IEA, 2020, p. 31)
- Investment and operational costs for monomanure digesters for either green gas production, CHP, or heat generation are available (Lensink & Schoots (red.), 2021)

Tabel 2 - Productiekosten en conversierendement[4]

Categorie	SDE 2018 basisbedrag		SDE 2030 basisbedrag		Conversierendement
	Productie-kosten (€/Nm^3)	Waarvan onrendabele top	Productie-kosten (€/Nm^3)	Waarvan onrendabele top	
Allesvergisting	0,54	0,31	0,49	0,25	60%
Mest/co-vergisting	0,64	0,41	0,59	0,35	60%
Monomest-vergisting	0,76	0,53	0,64	0,40	60%
Vergassing	0,90	0,67	0,59	0,35	70% (reguliere vergassing) 95-99% (in geval van superkritische watervergassing)

De kosten voor productie van groengas kunnen omlaag van de huidige € 0,54-0,90/m^3 naar € 0,25-0,40/m^3 door onder meer ontwikkeling van superkritische watervergassers met hoog omzettingsrendement, en door verwaarding van overige outputstromen zoals hoge druk biogene CO_2 dat kan worden ingezet voor de realisatie van negatieve CO_2-emissies.

(Leguijt et al., 2018, p. 8)

Digestate

Digestate is the biomass that remains in in the digester after the digestion process. In conventional co-digestors, digestate accounts for about 90% of the starting products' mass (Hoeksma, 2013). To be able to use digestate however, additional washing steps could be required to be able to apply it as a fertilizer (spreading over fields), as a substitute for peat, and/ or potting soil.

- *"The N/P ratio in digestate can differ significantly from that in animal manure because co-products often contain much less P than animal manure."* (Hoeksma, 2013) *"The properties of digestate are globally comparable to those of animal manure."*
- *Nutrients:*

Tabel 1: Nutriëntengehalten in rundveedrijfmest en vergiste rundveedrijfmest en in de dikke en dunne fracties na scheiding met een vijzelpers (Verloop et al, 2009)

Mest(fractie)	Stikstofgehalte (N) g/kg	Fosfaatgehalte (P_2O_5) g/kg	Kaligehalte (K_2O) g/kg
A drijfmest	3,4	1,0	5,7
A dikke fractie	4,0	1,9	4,8
A dunne fractie	3,2	0,8	5,6
B vergiste drijfmest	3,5	1,0	6,0
B dikke fractie	4,5	3,6	5,2
B dunne fractie	3,1	0,7	5,6

(Hoeksma, 2013, p. 9)

Tabel 3: Samenstelling (in g/kg) van de fracties uit ***vergiste varkensdrijfmest*** *voor en na scheiding met een centrifuge en een vijzelpers (De Buisonjé en Smolders, 2002)*

	Dr. stof	Org. stof	N-totaal	$N-NH_3$	P_2O_5	K_2O
Centrifuge						
Ingaande vergiste drijfmest	41	23	5,2	3,6	1,5	4,8
Dikke fractie	270	190	9,2	5,1	**17,2**	4,8
Dunne fractie	26	13	4,7	3,5	0,4	4,7
Vijzelpers						
Ingaande vergiste drijfmest	38	23	5,2	3,7	1,3	4,9
Dikke fractie	240	210	7,8	4,1	**4,8**	5,1
Dunne fractie	34	18	5,0	3,7	1,2	4,9

(Hoeksma, 2013, p. 11)

As a by-product of animal manure digestion, digestate can substitute conventional mineral fertilisers. The emission footprint of digestate depends on the total attribution of GHG emissions that are released during the complete life cycle of the anaerobic digestion process. (Timonen, Sinkko, Luostarinen, Tampio, & Joensuu, 2019) conducted a respective LCA considering the life cycle of AD including feedstock procurement, digestion, storage of feedstocks and digestate, energy use (in CHP) and digestate fertiliser use. They conclude that life cycle emissions of the digestate by-product are less compared to the emissions of mineral fertilisers (8.2-10.6 kg CO2 eq/kg N and 11.7 kg CO2 eq/kg N respectively). Costs associated to avoid GHG emissions can be zero if digestate is a by-product and all costs are attributed to the production of biogas. Otherwise, a wholistic analysis of the AD process is required to attribute costs to digestate and biogas, respectively.

- *"The sale of digestate is a significant cost item (up to 40% of the production costs of biogas) which weighs heavily on the economic efficiency of many co-digestion installations."* (Hoeksma, 2013)

Carbon Capture and storage

CCS

Carbon capture and storage (CCS) is a mature technology that can nowadays be applied at an industrial scale. The stored carbon in the biogas stream can be captured at different stages of the value chain, dependent on the final intended use of the produced biogas and technology choice:

1) Pre-combustion capture: To be able to feed biogas in the natural gas grid, it needs to be upgraded to a respective quality. As part of this process, CO2 needs to be removed and can be stored subsequently. It, therefore, qualifies as pre-combustion carbon capture.
2) Post-combustion capture: For power and heat generation in CHPs, it is not mandatory to upgrade biogas to biomethane, but biogas can be combusted directly. After biogas is combusted, the emitted CO2 can be captured from the exhaust gas.

3) Oxy-fuel combustion capture: In this process, biogas is burnt in a nitrogen-free environment using pure oxygen. The CO_2 can be simply captured by separating water from the exhaust gas (CO_2+H_2O) via condensation of water (moisture).

Strengers et al. (2018) mention costs of 70-80 EUR/ tonne CO_2 captured including onshore transport. This is an estimate for large (manure) digesters of more than 1,000 m^3 / h. The same source also states costs for transport and storage at sea with 7.5-13.5 €/ton CO_2.

So far, there are no CCS applications for biogas production. However, there are possibilities to capture CO_2 during the upgrading process of biogas, and to capture CO_2 from flue gases of biogas combustion. The economic feasibility depends on the value of avoided CO_2 emissions, and/ or the value of further CO_2 utilization. For instance, greenhouses are a large consumer of CO_2. Currently, the greenhouse gas operators combust natural gas to generate CO_2 for internal use as a stimulus for plant growth. With increasing gas and CO_2 prices, one may consider compressing CO_2 from biogas/biomethane instead and transporting it in bottles to the greenhouses as an alternative to natural gas.

3.4.6 Co-benefits and trade-offs

Negative impacts

To be profitable, manure digesters on farms should be installed at larger farms with livestock permanently stabled. Larger farms and fewer cattle in meadows harm the landscape (van der Schans, Rougoor, & van der Weijden, 2020).

Some studies suggest that the **emission of nitrogen by digestate is less** compared to untreated manure, so that nearby nature areas suffer less from nitrogen deposition **and biodiversity is increased** (Bertora et al., 2008; van der Schans et al., 2020). On the other hand, Lesschen et al. (2021) find that the risk of N_2O emissions is comparable to slurry. Also, if manure digesters are linked with permanently stabled cows practice less **meadow manure** is produced. This meadow manure acts as a microhabitat for insects that are feed for (meadow) birds(van der Schans et al., 2020).

If the digestate is applied early in the year (February) on the land, nitrogen leaching towards ground and surface water may occur, with deteriorating effects on the water quality (Praktijkonderzoek Plant & Omgeving B.V. - Wageningen Universiteit en Researchcentrum, 2008).

Co-benefits

The application of manure in digesters contributes to solving the longstanding problem of surplus manure in the Netherlands. Also, the digestate by-product can substitute mineral fertilisers which have a higher CO_2 footprint (Timonen, Sinkko, Luostarinen, Tampio, & Joensuu, 2019).

Trade-offs

The main trade-off is related to the solution of the problem of surplus manure and the costs of manure digestion. In the end, large scale manure digesting, linked to regulations on the use of digestate, could prevent a reduction of the livestock population if such a large-scale manure processing could be realized at relatively low costs.

3.4.7 Risks associated with scaling-up

The LMT can easily be applied in the whole country, as farms at which manure digesters can be installed are in all parts of the country. As mentioned previously, the main risk of scaling up CCS based on bioenergy is the supply of large-scale sustainable biomass. For manure based BECCS, policies towards scaling down fattening farms impact the supply of manure for digesters.[12]

3.4.8 Research gaps

Research gaps refer to a lack of knowledge of enabling factors for farmers to apply manure digestion and a lack of insight into the costs of manure digestion.

[12] https://nos.nl/artikel/2372685-einde-lijkt-in-zicht-voor-huidige-kalvermesterij-in-nederland.html

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5. Annex I: Additional information for the national narratives

Table 5-1: Overview of recent agroforestry projects and experiments in the Netherlands

Agroforestry project/ practitioner	Location	Type of agroforestry				Covered area [ha]
		Silvopastoral	Silvoarable	Mix	n.a.	
Farm P. Hermus	North Brabant		X			53
Manders-Selten V.O.F.					X	2.5
Hillekens Hoeve			X			1
Expertisecentrum Agroforestry		X				1
de Kort-van der Hamsvoord V.O.F.				X		2
Janmiekeshoeve				X		35
Lex Verbeek		X				7
De Ruurhoeve				X		2
Bioboerderij het Schop				X		2
Hoeve de Mertel		X				8
Maatschap Keijzers			X			4
Ecologische Tuinderij De Weitens			X			5
BoerInNatuur				X		23
van Haperen C&T			X			2
Gertjan Tijssen		X				2
Sprankenhof			X			3
Hanne Hoeve		X				4
Farmlife[13]				X		31.8
Proeftuin Lettele	Overijssel	X				1
Notengaard Bisschop			X			5.5
Boerendiekhuus		X				1
Weerwoud/Utopia	Flevoland			X		1.4
Pluktuin van Geesje	North-Holland			X		2
De Fruittuin van West	North-Holland			X		4.5
de Dennenhoeve	Drenthe	X				2
Oosterbierum	Friesland		X			3
Total	**27 locations**	**8** *(26 ha)*	**8** *(74.5 ha)*	**9** *(103.7 ha)*	1 *(2.5 ha)*	**208.8**

[13] Based on internal information on the sites in Drimmelen, St Oetenrode and Alphen

In the general context of the historic and projected Dutch greenhouse gas emissions, the agricultural and land-use sectors contribute to the total GHG emissions by about 17% or 31 Mton CO2-eq in 2019 (Hammingh et al., 2020). According to current policies, these emissions are expected to decrease by about 0.8-4.5 Mton CO2-eq in 2030, 0.4-0.6 Mton CO2 reduction per year are attributed to agricultural soils (Lesschen et al., 2021). In comparison, the bear share of the emission reductions yet to come by 2030 is planned in the area of power generation with a reduction of 17-31.2 Mt CO2eq. Projections also show that the self-set goals (-49% in 2030) will not be met (projected -34% in 2030) with the current measures being in place. Efforts will need to be increased in all sectors including the agricultural and land-use sectors.

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ANNEX III

Overview of input tables for simulation modelling per country

This project has received funding from the European Unions' Horizon2020 Grant Agreement No 869367

2. Netherlands

2.1. Qualitative storylines by identifying measures and actions from interviews for each LMT scenario

The Netherlands: Full LMT portfolio including BECCS, rewetting, agroforestry and afforestation

	1. Wishes of the future for the LMT: include timing	2. How to achieve the wishes • Who pays? • Who implements?	3. Target/Actions • Policies, strategies, projects
Scenario 1: " Business as Usual "	• Continuation of existing (intensive) livestock farming practices, with associated land use, economic benefits, and social-environmental costs (0 to -5% decline can be assumed).	• Social-environmental costs are born by society and ecosystems. • Complex system agro-food production (consumers, farmers, supermarkets, agro-food companies, guided by policy frameworks)	• Scenario incompatible with a range of air quality, biodiversity, water, climate policies and strategies
Scenario 2: "Scaling nature based solutions"	• Reduction of cattle (& pig) herd size by 30-50% (range) to reduce environmental impacts and free up land for other uses. To achieve targets, this should already be achieved by 2030 or 2035. • Expansion of rewetting organic / peat(y) soils in Northern and Western (coastal) provinces to keep carbon in soils, limit (damage of)	• Livestock farmers and linked agro-food sector will see significant decline in revenue/profits. Compensation for these losses (or finance for buy-out schemes for farmers) will come from the public budget. • Rewetting can be implemented by farmers / landowners (parcel level), but also at subregional level (for	• 30-50% reduction of livestock sector (question of balance between poultry, pig, cattle) to meet 2030-2035 - NH3 emission reduction target. • Rewetting target = -1 $MtCO_2$-eq. emissions from peat soils by 2030 (current level at 4-7 $MtCO_2$-eq. per year.

	soil subsidence and preserve / improve biodiversity. This could technically be scaled up rather fast by 2030-2035, simply by limiting draining the country via existing water infrastructure. • Expansion of agroforestry and afforestation in Southern and Eastern part of country on sandy/clay soils to increase carbon storage in trees (and materials) while improving biodiversity. Agroforestry may scale up a bit faster as hedgerows and planting of productive trees, fiber crops can be done faster. Full scale implementation by 2050 according to a linear trajectory should be feasible. Afforestation target by 2050 could be achieved, but phase-in will likely start slower as as massive amounts of seedlings need to be planted, land needs to be purchased (legal procedures).	each catchment area 'polder' by regional water boards). This is done by increasing water levels. In case farmers execute this, funding may come from private sector or EU agricultural funds. When done by water boards, extra water management costs may be charged to society (to fund rewetting and/or compensate farmers). This may be funded through avoided future damage costs. • Agroforestry likely implemented by farmers in collaboration with expert third parties. In most cases no land acquisition needed as farmland is already owned. Farmers will need to invest, which can be funded by the market (new other market products or carbon market), or public funds (EU CAP/forestry funds). • Afforestation likely implemented by semi-public nature conservation / forestry agencies. Will entail costs for land acquisition / buy outs. Other costs involve cultivating, buying, and planting seedlings/trees. Land acquisition costs likely to come from public sources (although there are some	• Agroforestry expansion set at range of 7.000-25.000 ha by 2030. *Dutch Forest Strategy, the total climate impact of agroforestry is quantified as part of the sector goal "trees, forest and nature" with 0.4 Mton CO2 and 0.8 Mton CO_2 ('ambitious goal') in 2030. However, it is not clear yet how much of the aimed GHG emissions are assigned to non-agroforestry in this sector such as landscape elements. According to (Lesschen et al., 2021), agroforestry could contribute to 0.1 Mton CO_2, however, assuming a more ambitious target of 25,000 ha in 2030 compared to 7,000 ha mentioned in the Dutch Forest Strategy.* • Forest expansion outside Natura2000 (NNN) zones target for 2030 set at 19.000 ha. *Overall forest sector target includes increase (18,000 ha) to be realized in the so-called Nature Network the Netherlands (NNN), which includes all Dutch Natura 2000 sites, and partly (19,000 ha) outside this network in forests that are private property.*

		private funds also buying land). Funds for planting trees to be funded through a mix of public and private schemes (e.g., CAP/forest funds + carbon market)	
Scenario 3: " Scaling engineered solutions"	• Reduction of cattle (& pig) herd size by 5-29% (range) to reduce environmental impacts and free up land for other uses. To achieve targets, this should already be achieved by 2030 or 2035. • Significant expansion of manure treatment facilities (farm-level and industrial scale plants) for production of biogas (biomethane / bio-LNG, organic fertilizers (RENURE) and captured liquid/compressed CO_2. Could theoretically be deployed to all liquid cattle/pig manure captured in stable systems (54,1 mln ton cattle manure, 8,9 mln ton pig manure (link)). Currently, about 5-10% of all animal manure is undergoing some form of manure treatment. Biogas sector has seen slow down (link) of new production coming online (0,23 BCM in 2022, 4% growth rel. to 2021). Large-scale (pig manure) plants could scale up more rapidly,	• Livestock farmers and linked agro-food sector will see significant decline in revenue/profits. Compensation for these losses (or finance for buy-out schemes for farmers) will come from the public budget. • Farming sector, energy and fertilizer sector will be most involved in implementation. Energy component can be funded through a range of renewable energy subsidy schemes (e.g., feed-in premium, co-firing under EU ETS, renewable transport fuel tradable certificates) for biogas and even a green gas blending target (link) may be implemented. Also, several market-based schemes for using organic fertilizers, carbon market may apply.	• 5-29% reduction of livestock sector (question of balance between poultry, pig, cattle) to meet 2030-2035 - NH3 emission reduction target. • Domestic policy target for biogas/green gas production is 2 BCM by 2030 (link). Also EU has specific strategy to increase production of biomethane (link). • No quantified target for circular agriculture, but nutrient (N, P, K and SOC) recycling can be improved significantly by enabling manure treatment to produce organic fertilizers. However, use of organic fertilizers from animal origin has been capped by EU-law. More recently Dutch farming has lost rights (link) to use 230-250 Kg animal manure N per ha. By 2026 it will limited to 170 Kg N per ha, current derogation will be gradually phased out until2026. This is expected to increase the use of chemical fertilizers to maintain

	relative to development of farm-scale biogas systems or biogas hubs.		productivity. RENURE (link) fertilizers are becoming more important with increasing prices for gas and chemical fertilizers.