MODELLING INDIVIDUAL DECISIONS TO SUPPORT THE EUROPEAN POLICIES RELATED TO AGRICULTURE

Deliverable 3.3: Report on modelling greenhouse gas emission including adoption behaviour of farmers regarding mitigation strategies and interfaces to the MIND STEP model toolbox

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EXECUTIVE SUMMARY

In 2017, the percentage contribution of agriculture to world GHG emissions in CO2eq from all human activities was 20 percent. This included a contribution of 11 percent from crop and livestock activities within the farm gate and an additional 9 percent from related land use (FAO, 2020). Milk production account for about 20 to 25% to this. In the Netherlands the share of milk production in GHG emission from agriculture is quite a bit higher, as agricultural production in the Netherlands is specialized in dairy and milk production. From the other hand average CO2-eq emission intensities (emission of GHG per unit of product) in the Netherlands equals between 1.2 and 1.6 kg CO2-eq/kg FPCM, this is far below word wide average regional emission intensities. Nevertheless, following the Paris climate agreement, CO2-eq emission reduction goals In the Netherlands are 49% in 2030 and even 95% in 2050 relative to 1990. The main objective of this deliverable is to apply the bio-economic farm model FarmDyn to analyse economic impacts and GHG mitigation potentials of GHG mitigation options per average dairy farm group for a large number of dairy farm groups in the Netherlands. Marginal Abatement Costs (MACs) are in average lowest for the group of intensive dairy farms. This is explained by relative low income per cow on intensive dairy farms, due to high feed costs and costs of manure disposal from the farm. Given differences in MACs per farm, it is shown that command and control policies to proportionally reduce GHG emission per farm are less cost effective as compared to market based GHG emission reduction policies. The deliverable also discusses behaviour and preferences of Dutch dairy farmers regarding GHG mitigation options, following principles of behavioral economic theories. Chapter 4 discusses in detail the linkage of the individual farm data with the satellite data to estimate grassland yields. Results are applied to analyse impacts of market based policies on farm management and farm income. The scenarios take into account differences in GHG emission reduction potentials from the MAC analysis (Chapter 2) and farmers' preferences and 'willingness to adopt first' (Chapter 3). Compared to a 2020 reference, a system of subsidies on GHG emission reduction could reduce GHG emission in the Dutch dairy sector between 20% and 26%, depending on the level of the subsidy. Excluding the subsidy, the income decreases between 150 mio Euro and 235 mio Euro. Farm income in the dairy sector in 2020 equals about 881 mio Euro. Different budget schemes could be thought of, including a tax system such that the subsidy is paid by the dairy sector itself.

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1. GENERAL INTRODUCTION

1.1. Background

In 2017, the percentage contribution of agriculture to world CO2eq emissions from all human activities was 20 percent. This included a contribution of 11 percent from crop and livestock activities within the farm gate and an additional 9 percent from related land use (FAO, 2020). In physical terms, world total GHG emissions from all economic sectors totaled 51 billion tons CO2eq (Gt CO2eq yr-1), and as much as 56 Gt CO2eq yr-1 including emissions from land use. Emissions from agriculture were 11.1 Gt CO2eq yr-1, composed of 6.1 Gt CO2eq yr-1 from crop and livestock activities within the farm gate and 5.0 Gt CO2eq yr-1 from agricultural land use, largely due to deforestation and peatland degradation (FAO, 2020). Milk production account for an important part of total emission from crop and livestock activities. Based on Life Cycle analysis using data around 2005, global GHG emissions from milk production was estimated at 2.2 Gt CO2-eq or about 20% of total emissions from agriculture (Opio et al., 2013; FAO, 2020). The largest source of GHG emissions in ruminant production is methane (CH4) from enteric fermentation, which worldwide accounts for about 47 percent of the sector's emissions and more than 90 percent of the total CH4 emissions. Nitrous oxide (N2O) emissions originating mainly from feed production and N deposited during grazing represent 24 percent of the sector's GHG emissions.

There are variations in emission intensities (emission of GHG per unit of product) across and within regions and production systems for meat and milk output (Opio et al., 2013). The differences within the same region under comparable conditions (production systems and climatic zones) points to the existence of a considerable emission intensity gap. Variations in emission intensities are explained by factors such as reproductive efficiency (higher fertility rates, lower age at calving,) animal health (lower mortality rates), management (higher slaughter weights, reduced time to slaughter), and better feed quality in mixed farming systems. All these factors combine to result in higher productivity and lower emission intensity. Regional emission intensity ranges from 1.6 kg CO2-eq/kg to 9.0 kg CO2-eq/kg Fat and Protein Corrected Milk (FPCM). Generally, milk production in low productive systems have higher emission intensities than in high production systems of most affluent counties where better animal feeding and nutrition results in lower enteric and manure emissions and emission intensity at animal level. Improved genetics and animal health care and animal husbandry combine with better feeding to reduce the breeding overhead (i.e. animals kept to maintain the herd) thus further reducing emission intensity at herd level. CO2-eq emission intensities (emission of GHG per unit of product) in the Netherlands equals between 1.2 and 1.6 kg CO2-eq/kg FPCM (Doornewaard et al., 2022). This is far below the world wide average regional emission intensities.

Figure 1 shows that GHG emission in the agricultural sector decreased with about 18% (CBS, https://www.cbs.nl/nl-nl/dossier/dossier-broeikasgassen/welke-sectoren-stoten-broeikasgassen-uit-) between 1990 and 2020. As GHG emission from other sectors decreased more, share of agriculture in GHG emission increased over time. Figure 2 shows the importance of fermentation, mainly from feeding dairy cows, in total GHG emission in agriculture. Over time the importance of fermentation has increased, as emissions from manure and stable/storage has decreased much larger compared to fermentation. This, among others, explains the relative high share of milk production in GHG emission from the agricultural sector.

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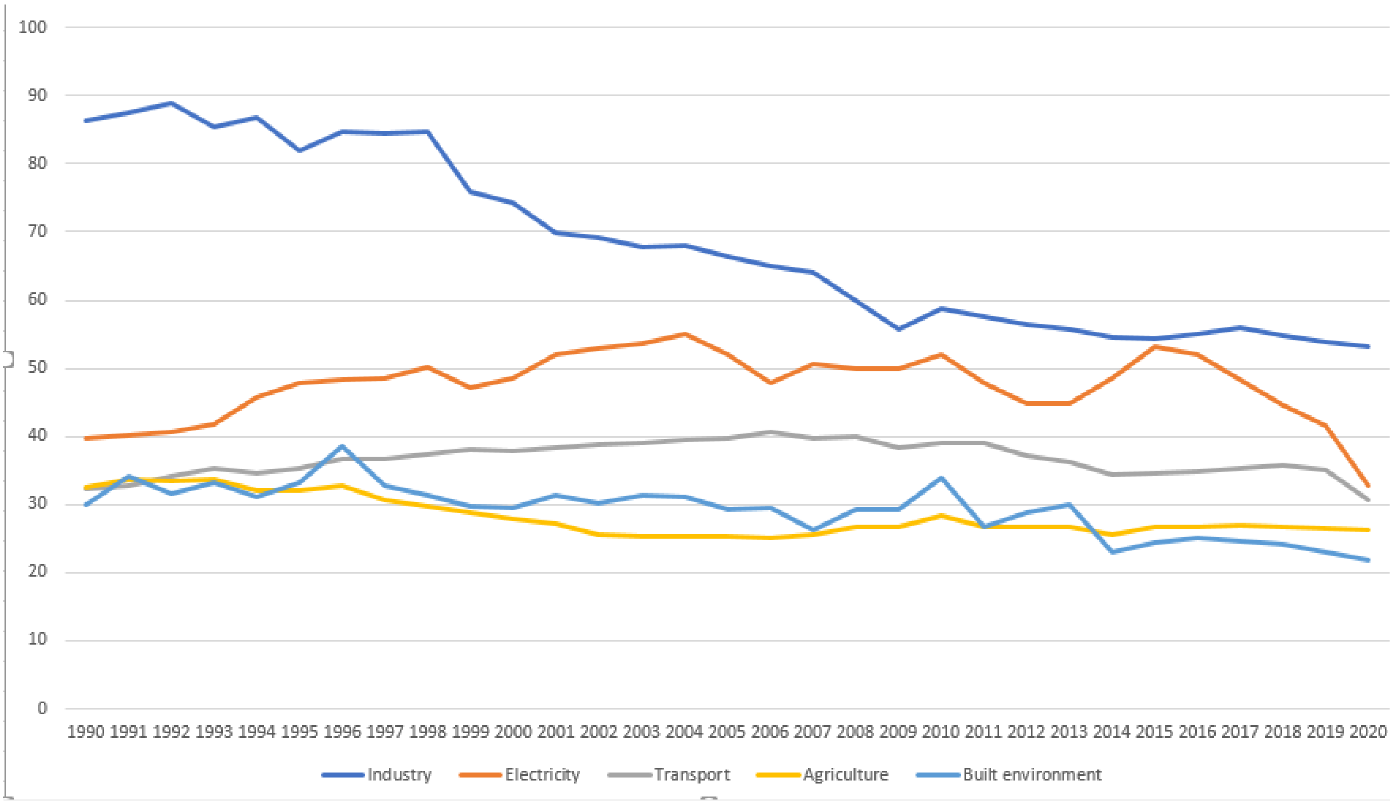

Figure 1 GHG emission per sector in the Netherlands (MT CO-eq)

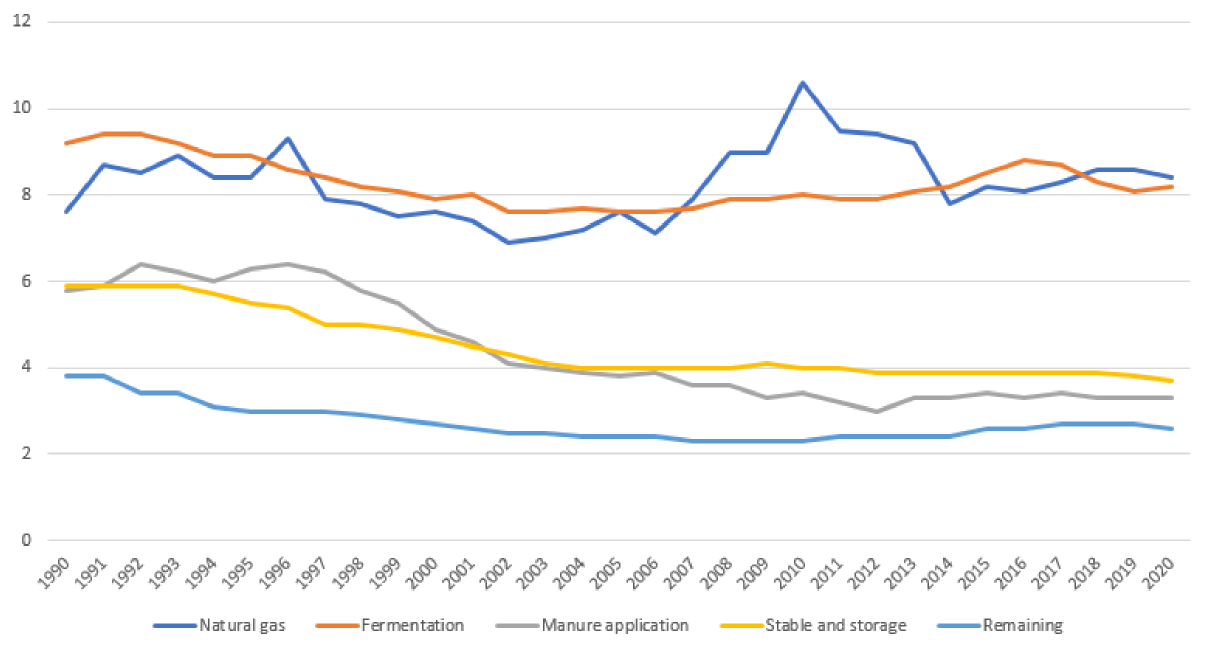

Figure 2 GHG emission in Dutch agriculture by source (megaton CO2-eq)

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1.2. Problem statement

The Paris climate agreement foresees a reduction of GHG emission of minimal 40% in 2030 relative to 1990. Countries that signed the Paris agreement have to make plans how they are going to reach this reduction. In The Netherlands the reduction goals are secured in a climate law in 2018. This law states that the GHG emission reduction must be 49% in 2030 and even 95% in 2050 relative to 1990. GHG emission in the agricultural sector decreased with about 18% between 1990 and 2020. The agricultural sector is also bound by the climate law and further GHG emissions reductions are agreed upon in the a so-called climate agreement for the "Agriculture and Land use" sector in the Netherlands". Reduction goals are set per theme, broken down to mitigation options, see also NN (2019). For the dairy sector separate reduction goals are defined involving GHG emission reductions from "Animals and Feeding", "Manure storage and application", "Soil and crops", "Energy saving", "Production of renewable energy" and reducing the dependency of foreign protein rich concentrates for dairy feed.

An extensive list of literature exists describing technologies that would address GHG emission mitigation options and future agricultural GHG emissions e.g. Eory et al. (2020); Lesschen et al. (2020) (in Dutch with English summary), de Vries et al. (2018, , in Dutch), Pérez et al. (2020) and Lanigan and Donnellan (eds., 2019). The studies give insights into questions as a) which technologies should farmers use and b) which farmers are likely to adopt what technology. In the Netherlands de Vries et al. (2018) gives an extensive overview of GHG mitigation options for the Dutch dairy sector. Lesschen et al. (2020) apply a scenario study to analyse the technical and economic consequences for Dutch livestock sector of, among others, GHG emission reduction targets by 2050. For the dairy sector the main GHG mitigation options considered were stable adjustment, assuming a methane mitigation potential of 75%, breeding assuming a methane mitigation potential of 22% and application of feed additives, assuming a methane mitigation potential of 40%. It is assumed that all farmers in the Netherlands will follow the chosen development direction and apply all associated measures. It is found that the 2050 GHG mitigation target of net-zero GHG emission cannot be reached without further reduction of the number of animals in the livestock sector. Economic impacts in the livestock sector are derived from changes in livestock numbers and production, as the investment costs and costs of changes in farm management are not included.

This deliverable focusses on abatement costs of GHG emissions on different types of dairy farms in the Netherlands, using data from the Dutch Farm Accountancy Network (FADN). In Dutch this is also referred to as Bedrijveninformatienet (BIN). The GHG mitigation options included focus on investments and changes in farm management that can be reached in the medium to short term. This complements existing more technical studies on farm level and long term studies at sector level (Lesschen et al., 2020; de Vries et al., 2018).

1.3. Research objectives and research questions

Insights in farm level abatement costs and heterogeneity between individual farms or groups of farms is important information to understand the acceptance of GHG mitigation options and adoption behaviour of farmrs and to develop more efficient GHG emission reduction policies. To achieve this the main objective of this deliverable is to apply the bio-economic farm model FarmDyn (Britz et al., 2016) to realistically analyse mitigation strategies to climate change for a large number of dairy farms in the Netherlands. FarmDyn will be developed in such a way that it can be linked to the individual farm, financial-economic and technical data from the Dutch Farm Accountancy Data Network (FADN). The FarmDyn data from FADN will be enhanced with biophysical data from different sources. The deliverable will discuss how satellite data can be used to improve grassland yield data in economic

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models. A survey will be conducted to measure farmers' attitude, subjective norm, and perceived behaviour, to more realistically model farmers' behaviour regarding adoption of new technologies.

Research questions addressed in this deliverable are:

- What are the most relevant more short to medium term GHG mitigation options for Dutch dairy farmers?
- What are the abatement costs of the selected GHG mitigation options for different groups of dairy farms in the Netherlands?
- What are farm and farmers' characteristics that can explain adoption of GHG mitigation measures
- What GHG mitigation measures are preferred by farmers
- What are impacts of different GHG mitigation policies on GHG emission and farm income[1] in the Dutch dairy sector.

1.4. FarmDyn: Model description

FarmDyn is a bio-economic, mixed-integer programming model at individual farm level, that simulates farmer's decisions regarding agricultural production and investments in a comparative static or dynamic setting (Britz et al., 2016; http://www.ilr.uni-bonn.de/em/rsrch/FarmDyn/FarmDynDoku/). The model was developed at the University of Bonn and is primarily used for the analysis of farm-level responses to various environmental and policy scenarios, using data on farm structure, machinery, buildings, animal feed rations, etc., available in a German context. FarmDyn is used at Wageningen Economic Research since late 2018 and is adjusted stepwise to Dutch conditions by exploiting information available from data sources like the Dutch farm accountancy data network (FADN) or quantitative information on farming operations (management handbook Quantitative information (KWIN2), such that it becomes applicable to analyse representative or individual arable and dairy farms in the Netherlands, incorporating Dutch legislation on fertilizer applications and N balances.

The Dutch version of the single farm model FarmDyn allows simulating optimal farm management and investment decisions under changes in boundary conditions such as prices, technology or policy instruments for arable and dairy farming systems. It is based on a model template for a fully dynamic or comparative-static bio-economic simulation, building on Mixed-Integer Programming. Farm branches and other elements such as fertilization and animal manure policy restrictions can be added in a modular fashion to the core model. The model is capable to run every individual (dairy and arable) farm in the Dutch FADN, using farm specific financial-economic and technical data (e.g. input and output prices, crop yields and milk production per cow) (Figure 3). Number of operations per crop, field operation per period, labour hours per operation, machinery need for the different operations and prices, life span and maintenance costs of machineries are taken from KWIN.

[1] In this deliverable income is defined as revenue minus paid costs minus depreciation, including extraordinary expenditures and revenues as defined in the Dutch FADN.

[2] Kwantitatieve Informatie Veehouderij (KWIN-Veehouderij)

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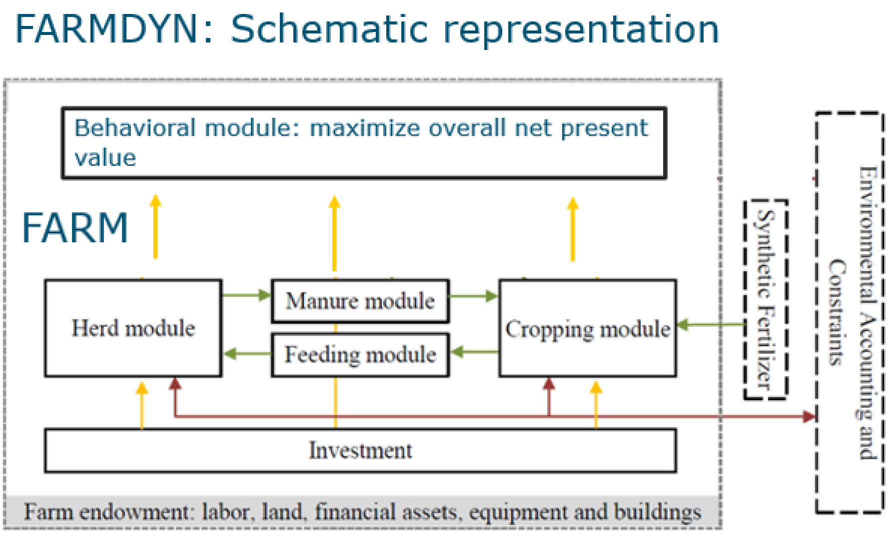

Figure 3 FarmDyn: schematic representation

Source: http://www.ilr.uni-bonn.de/em/rsrch/FarmdynFarmDyn/FarmdynFarmDynDoku/

The farming branches for dairy and cattle farming differentiate raising and fattening processes by month, grazing share and weight gains, and, in case of dairy cows, by month of calving and lactation period. These options interact with multiple, seasonally differentiated grassland management options. Feeding requirements for the dairy herd capture a cost minimal feed mix from own produced fodder and different types of concentrates at given requirements per head and intra-year feeding periods (energy, protein, dry matter) for each cattle herd. The default feed module in FarmDyn is converted to the Dutch feed requirement system using relevant conversion factors and data (CVB, 2016).

Manure excretion of the dairy cows depends on a legally determined combination of Urea number and milk production per cow (Tabel 6 Stikstof en fosfaat per melkkoe (rvo.nl)). A module describes in detail the measures of the Dutch Nitrate and Water Framework directive, that differs per region and for farms with and without derogation from the nitrate directive. FarmDyn allows experiments with different animal manure types and related storage and application chains. Animal manure can be used on the own farm or exported from the farm. Animal manure import is allowed as well. This feature is however not considered in this deliverable.

By default, FarmDyn allows to define up to 10 different types of grassland management options by the following attributes: 1. total dry matter output and nutrient content of grass, 2. Level of effective nitrogen input from animal manure and mineral fertilizer 3. distribution of fresh grass and grass silage over months 4. Number of cuts (only applicable for grass silage). The different types of grassland management each produce three types of fresh or silage grass (early, middle and late). Production of early silage grass requires more cuts per year. Roughage (silage maize and silage grass) can be exported (sales) from the farm or imported (purchase). In this deliverable we allow purchase of silage maize, while purchase and sales of silage grass is not considered. Sales of silage maize is also not considered. The grassland management options and data are adjusted to the Dutch situation, among others using satellite data. This is explained in Chapter 4 of this deliverable.

The cropping module optimises the cropping pattern subject to land availability, reflecting yields, prices, machinery and fertilizing needs and other variable costs for a list of arable crops. The crops can be differentiated by tillage (ploughing, minimal tillage, no tillage) and intensity level (normal and reduced fertilization in 20% steps). As stated above, machinery use is linked to field working-day requirements depicted with a bi-weekly resolution during the relevant months. Operation and machinery data are taken from above mentioned management handbooks. Crop rotational constraints

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are modelled as simple maximal shares. The model can capture plots which are differentiated by soil and land type (arable land and grassland with both mowing and grazing, only mown or with only grazing (pasture)) and size.

Investments into a detailed machinery park, stables and other structures are depicted by integer variables, the same holds for the possibility to work off-farm. The model distinguishes on-farm labour needs for field operations, stable work and management/maintenance. Management and maintenance work as well as differently sized investments in machinery and stables provoke increasing returns-to-scale in branch sizes and depict different labour-capital intensities endogenously.

FarmDyn was stepwise developed based on funds provided by research projects. It is currently maintained by the Economic Modeling of Agricultural Systems research group at Bonn University and used as well as extended by several international partners. It is hosted on a revision control system, its coding follows guidelines and quality management measures include automated testing of the model on a larger set of test cases with reporting of differences in key results against previous revisions. Like other models (e.g. IFM-CAP and CAPRI-FT), it features a graphical user interface (GUI) based on GGIG (Britz, 2014).

1.5. FarmDyn: Applications for dairy and arable farms

For the Netherlands, FarmDyn was first used to analyse impacts of reduction of GHG from peat soils in Dutch agriculture. Here the focus was on dairy farm management impacts of rewetting peat soils, including impacts on emission of NH3 (Poppe et al., 2021; de Koeijer et al., 2020). Daatselaar et al. (2021) used FarmDyn to analyse integrated effects of a switch to more permanent grassland on dairy farms with silage maize. The analysis was based on dairy farms in the Dutch FADN. The amount of GHG emission, including C sequestration, slightly decreases, but ammonia emission increases for the reported four groups of average farms. This is because of higher ammonia emission rates from manure application on grassland. Average abatement costs per average farm group differentiated between 77 and more than 1000 euro per ton CO2-eq.

For the arable sector FarmDyn was used in combination with the tool Nutriëntenbalans Akkerbouw (Nutrient balance Arable farming, NA) (Schröder and Rutgers, 2018) and the model RothC (Coleman et al., 1997; Coleman and Jenkinson, 2014) to analyse impacts of different carbon sequestration scenarios on a representative consumption potato farm on clay soil in the Netherlands (van Dijk et al., 2022). The different measures to increase carbon sequestration are 1) Substituting pig manure partly by green compost, 2) increasing the area of green manure crops, 3) leaving straw on the land, 4) increasing the area of crops with a high C-supply and 5) substituting pig manure by cattle manure. Results are summarised in table 1. The additional CO2 sequestration of the measures on the arable farm ranges from 0.11 to 0.52 ton per ha. Substituting the pig slurry (partly) by green compost or cattle slurry and incorporating the wheat straw gave the highest CO2 sequestration. Substituting sugar beets by winter wheat had a relatively small effect as the difference in C input by crop residues of both crops is small (see Figure 1). This applies to a situation where the straw is removed. Furthermore, it must be emphasized that compared to the reference scenario also the pig slurry C input on the farm was higher. If also a green manure crop is grown on the extra winter wheat area, the additional CO2 sequestration increases from 0.11 to 0.35 ton per ha. The effect of a green manure crop after onions is smaller than when established after winter wheat due to a later sowing time. Except for substituting pig slurry by cattle slurry, the measures decrease the income up to almost 200 € per ha (extra winter wheat plus green manure) . The required CO2 price to compensate for this decrease ranges from 15 to 1605 € per ton CO2. Especially changing the crop rotation is an expensive measure.

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The NA also gives insights into impacts on other environmental emissions. Although for some measures the GHG emissions increase somewhat, this increase is smaller than the additional CO2 sequestration. The N soil surplus increases when the pig slurry is (partly) substituted by green compost or cattle manure and when straw is incorporated in the soil. This also applies for the P2O5 soil surplus except for substituting pig slurry by cattle manure. The NH3 emission increases when sugar beets are substituted by winter wheat and when pig slurry is substituted by cattle slurry. For both measures this is due to a higher NH3-N emission with slurry application.

Table 1 The effect of the measures on income, additional CO2 sequestration, GHG-emissions, N and P2O5 surpluses and NH3-emissions arable farm.

	Income	Additional CO2-sequestration	Required CO2 price	GHG emission	N soil surplus	P2O5 soil surplus	NH3 emission
	€/ha	ton CO2/ha/year	€/ton CO2	ton CO2-eq/ha	kg/ha	kg/ha	kg/ha
REF	3083			3.16	79	-1	24
Compost	3075	0.52	15	3.11	85	5	24
Cattle slurry instead of pig slurry	3156	0.45	-164	3.18	99	-1	29
Catch crop after onion	3048	0.14	240	3.16	76	-1	24
Straw incorporated	3015	0.49	137	3.17	85	1	24
Winter wheat instead of sugar beet	2910	0.11	1605	3.13	79	0	26
Winter wheat instead of sugar beet + extra green manure crop	2881	0.35	578	3.19	77	0	26

Source: own calculations with FarmDyn, NA and RothC (van Dijk et al., 2022)

1.6. Stratification of sample farms in the Netherlands with application to dairy farms

FarmDyn can be executed for individual farms in the Dutch FADN, thus allowing to capture the observed heterogeneity across farms in terms of endowments, available technologies, or preferences. In practice, data on field operations, labour requirements, or nutrient contents of animal feeds are not included in farm-levels statistics and are therefore equal across groups of farms in the model. Because of this it is more practical to identify typical or average farms within the sample, which have the relevant characteristics but avoid the execution of FarmDyn over too many instances, which do not differ in terms of technologies and cost structure. The stratification depends on the research question at hand and should capture as much as heterogeneity between farms as possible. An important criterion for stratification for the Dutch version of FarmDyn are restrictions on the use of fertilizer and manure, which are set based on administrative regions and dominant soil types in The Netherlands. For this reason, a basic grouping of farms based on soil types and regions is used here. Figure 4Figure 4 shows the dominant soil types in the Netherlands and the administrative boundaries of the provinces.

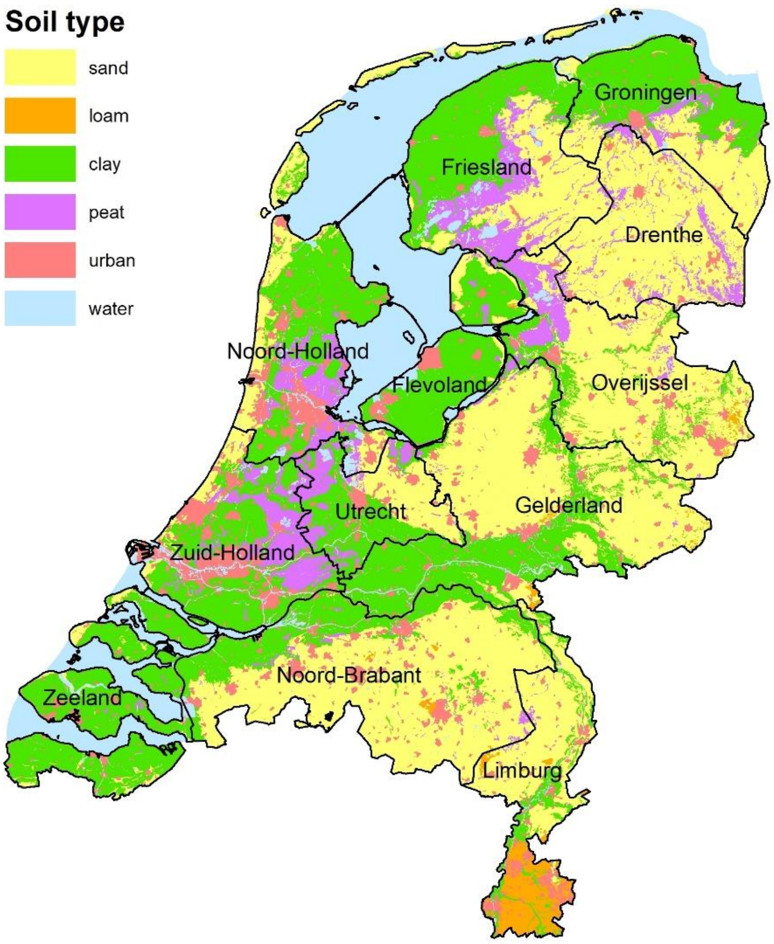

Figure 4 The soil map of the Netherlands overlayed with the provinces

Source: Own compilation.

Due to differing farm characteristics, management practices, water availability, and other criteria, the soil-regions are further split into smaller units (Figure 5 and Table 2). The sandy soils are split in two region, Sand-South (the sandy soils in Brabant Limburg and Zeeland) and Sand-Mid-North (the sandy soils in the rest of the provinces in the Netherlands), where South has more impact from large-scale pig farming. Similarly, the peat soils are split in West and North, where Peat-West has high ground water levels and smaller parcels than Peat-North. Finally, the clay soils are divided in four groups. Clay-North is characterized by large scale intensive dairy farming. Clay-river is more diverse in terms of

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agriculture (also cropland and fruit trees). Clay-polder are the post-war reclaimed polder lands. And Clay-West is characterized by higher ground water levels.

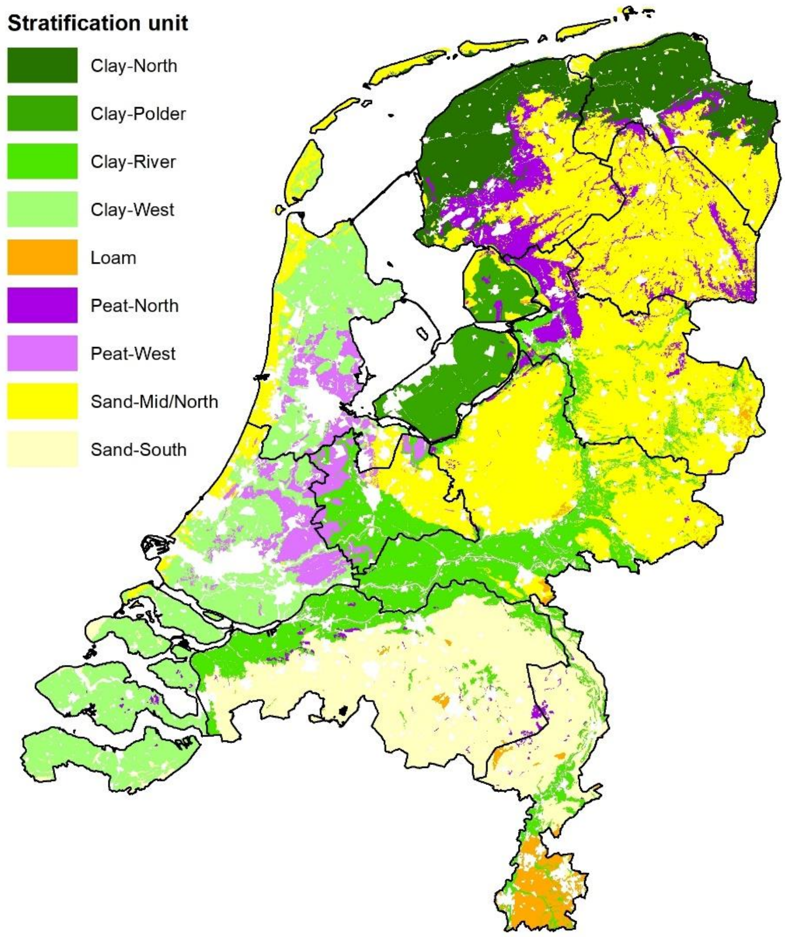

Figure 5: The stratification units in the Netherlands (overlayed with the province boundaries)

Source: Own compilation.

Table 2 Stratification of the grassland areas in the Netherlands

#	Stratification	Soil type	Province
1	Sand-South	Sand	Brabant, Limburg, Zeeland
2	Sand-Mid/North	Sand	Rest of the provinces
3	Peat-West	Peat	Noord-Holland, Zuid-Holland, Utrecht
4	Peat-North	Peat	Rest of the provinces
5	Loam	Leem	All provinces
6	Clay-North	Clay	Friesland, Groningen, Drente
7	Clay-River	Clay	Overijssel, Gelderland, Utrecht, Brabant, Limburg
8	Clay-Polder	Clay	Flevoland
9	Clay-West	Clay	Rest of the provinces

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While the spatial location of farms in the Dutch FADN is not reported in the standard datasets, it is usually possible to identify the administrative region in which the farm is located. In this case, the smallest possible unit are farming areas (landbouwgebieden) determined by the Dutch statistical organization (CBS), which are aligned with the boundaries of the provinces. Using information on dominant soil types and location within these regions, it is possible to stratify the farm statistics according to the considerations above. The following 8 soil-province regions are distinguished:

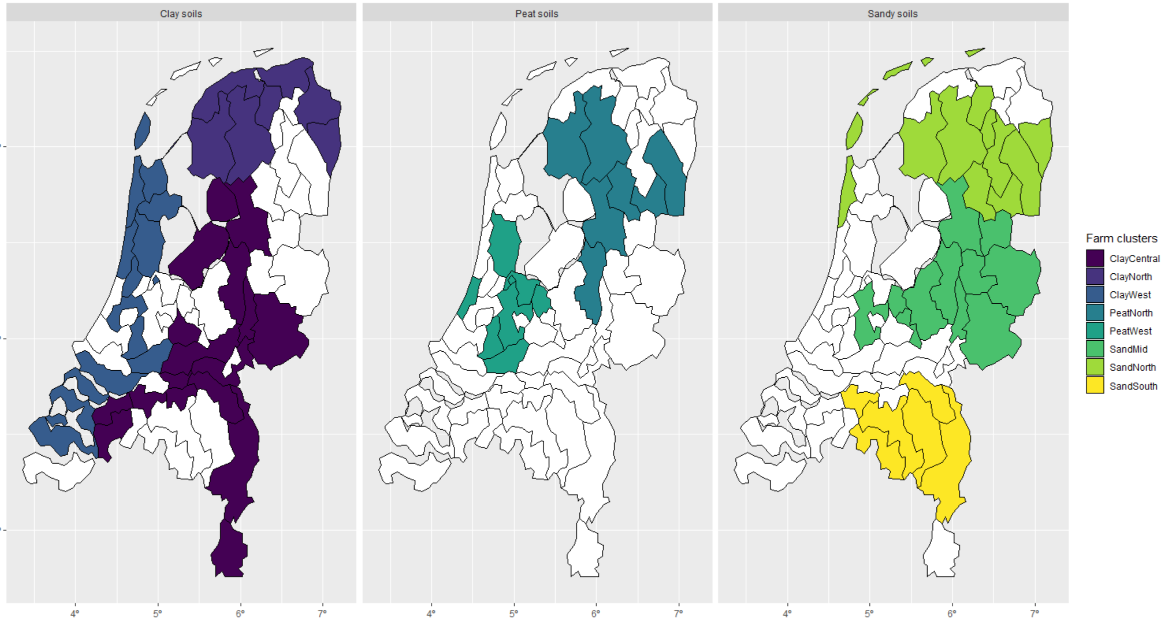

Figure 6: Location of Farm Samples in CBS Landbouwgebieden based on dominant soil types per farm and soil stratification units

Using these soil-regions as a starting point, further distinctions, like livestock density and derogation regulations are be applied. Farms with derogation are allowed to apply more nitrogen from animal manure as compared to the EU nitrate directive (maximum of 170 kg N per ha from animal manure). In regions sand-mid and sand-south the derogation from the EU nitrate directive equals 230 kg N per ha, while in all other regions the derogation equals 250 kg N per ha. Farms that apply for derogation are not allowed to use phosphate from mineral fertilizers. The fertilizer standards of the combined use of N from animal manure and mineral fertilizer on grassland is lowest for farms in the regions sand-south, sand-mid and sand-north, namely 250 kg workable N per ha. In peat regions this standard is 265 kg workable N per ha and in the clay regions this is 345 kg workable N per ha. Differences are based on differences in N leaching per soil type. For arable crops the fertilizer standards of the combined use of N from animal manure and mineral fertilizer is lowest for farms in region sand-south. For silage maize this standard equals 112 kg workable N per ha in region sand-south, 140 kg workable N in regions sand-mid and sand north, 150 kg workable N in the peat region and 185 kg workable N in the clay regions.

Phosphate standards differ per farm depending on the phosphate status of the soil. For reasons of simplicity we assume a legal maximum application of P from animal manure and mineral fertilizer of almost 86 kg P2O5 on grassland and 56 kg P2O5 on arable land, equal for all farms in all regions. In the future we could make this more farm specific.

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Livestock density is defined as farms with more or less than 2.25 livestock units (LSU) per ha: 1 cow is 1 LSU, 1 heifer is 0.8 LSU and 1 calf is 0.4 LSU. The value of 2.25 LSU per ha is chosen to create a reasonable distribution of number of farms per average farm group.

25 average or typical dairy farm groups are distinguished by density and soil type in the optimization in FarmDyn. These farms represent 286 farms in the Dutch FADN and 14004 farms in the Dutch agricultural census. Selected average dairy farm group characteristics are given in Table 3. Average number of cows per farm group equals 107. The average number of cows on the group of intensive dairy farms equals 122, while the average number of cows on the group of extensive dairy farms equals 88. On average number of cows per dairy farm is highest in the clay region, namely 113 cows. Comparing soil types, milk production per cow and number of cows per ha are relatively low in the peat region. On average share of own produced roughage in the total feed ration is relatively high in the peat region, resulting in relative low milk production per cow. Milk production per cow and number of cows per ha are relatively high on sand farms, because of the high share of intensive dairy farms in regions with sandy soils.

GHG emission per kg FPCM is highest on peat farm because of the emission from histosols. Average milk production per farm on intensive farms exceeds the average milk production per farm on extensive farms with about 40%. The same accounts for the GHG emission, meaning that on average the GHG emission per kg FPCM is about equal. However, it can be calculated that GHG emission per ha is relatively low on extensive dairy farms.

Farm income is defined as total revenues minus paid costs and depreciation plus extraordinary revenues/losses. Given the large differences between years, among others determined by differences in weather circumstances, a 2016-2020 five year average is used as a reference base. (Note: compared to the 2016-2020 five year average as can be calculated from Dutch FADN our results are a little bit low, because of the revaluation of the roughage stock in 2020. This is not included in our results.)

Farm income appears relatively high on intensive dairy farms. This is explained by the difference in the number of cows per farm. Average farm income per kg milk and per ton CO2eq is however higher on extensive farms. This is among others explained by higher costs of purchased feeds and costs for manure disposal from the farm on intensive farms.

On regional level average farm income appears highest in the peat region. Because of the GHG emissions from histosols the difference between average farm income per ton CO2-eq in the peat region with average farm income per ton CO2-eq in clay and sand region is more limited. In the sand region average farm income is lowest. Compared with farms on clay soil, average farm income in the sand regions is about 14% lower, while farm income per ton CO2-eq and per ton FPCM is respectively 10 and 8 percent lower compared to dairy farms on clay soils.

Table 3 Representation of number of farms in Dutch FADN and agricultural census, and selected farm characteristics per average farm group in base

	All farms	EXT	INT	Clay	Peat	Sand
represented farms in FADN (number)	286	106	180	94	34	158
represented farms in Agricultural Census (number)	14004	5998	8006	4388	1658	7958
cows per farm (number)	107	88	122	113	101	105
milk production (kg per cow)	8795	8679	8882	8782	8160	8935
grassland (ha per farm)	48	51	46	55	53	43

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maiz silage (ha per farm)	11	10	11	10	10	11
arable crops excl. maiz silage (ha per farm)	2	3	2	3		2
cows per ha (number)	1.8	1.4	2.1	1.7	1.6	1.9
FPCM (ton per farm)	1013	822	1156	1076	880	1007
GHG emission (ton CO2-eq per farm)	1290	1044	1474	1317	1356	1261
GHG emission (kg CO2-eq per kg FPCM)	1.27	1.27	1.27	1.22	1.54	1.25
farm income (euro per farm)	62885	56833	67419	67657	73274	58089
farm income (euro per ton CO2-eq)	49	54	46	51	54	46
farm income (euro per ton FPCM)	62	69	58	63	83	58

Source: own calculations based on Dutch FADN and FarmDyn

1.7. Outline of the deliverable

Chapter 2 describes in detail the GHG emission accounting in FarmDyn and gives a literature review regarding GHG mitigation options for the Dutch dairy sector. Marginal Abatement Costs (MAC) of selected standalone GHG mitigation measures for the Dutch dairy sector as a whole and for selected farm types are discussed in Chapter 2. Chapter 2 also discusses impacts on farm income of command and control scenarios as compared to market based policies, as approximated by the selected GHG mitigation measures and corresponding MAC and GHG mitigation potentials. As a contribution to policy design impacts of a subsidy on GHG emission reduction is discussed, financed by a tax on reference values of GHG emission. Impacts focus on farm income and GHG emission reduction per group of dairy farms.

Chapter 3 discusses behaviour and preferences of Dutch dairy farmers regarding GHG mitigation options. The discussion is based on a survey among a sub-sample of Dutch dairy farms from the national Farm Accountancy Data Network (FADN). Continuing from Chapter 2 different scenarios are defined respecting the differences in MAC (Chapter 2) and adoption behaviour (Chapter 3) between groups of dairy farms.

Chapter 4 discusses in detail the linkage of the individual farm data with the satellite data to estimate grassland yields. Results are applied to analyse impacts of the scenarios defined in Chapter 3 on farm management and farm income.

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2. GREENHOUSE GAS EMISSION ACCOUNTING AND MITIGATION OPTIONS FOR DUTCH DAIRY FARMS IN FARMDYN

2.1. Introduction

Greenhouse Gas (GHG) mitigation options on dairy farms have the purpose of slowing down or reducing their contributions to global warming. In the Paris climate agreement reduction goals were set. The agreement foresees a reduction of GHG emission of minimal 40% in 2030 relative to 1990. Countries that signed the Paris agreement have to make plans how they are going to reach this reduction. For instance, in The Netherlands the reduction goals are secured in a climate law in 2018. This law states that the GHG reduction must be 49% in 2030 and even 95% in 2050 relative to 1990. In the Netherlands a climate agreement between the different stakeholders is in place with GHG emission reduction targets per sector One of these sectors is Agriculture and Land use. Reduction goals are set per theme and the dairy sector will take action on “Animals and Feeding”, “Manure storage and application”, “Soil and crops”, “Energy saving”, “Production of renewable energy” and reducing the dependency of foreign protein rich concentrates for dairy feed. Other countries also have national climate agreements/laws like for instance Sweden, Germany and Belgium.

The objective of this chapter is to analyse economic impacts of different GHG mitigation options on farm level. The analysis focuses on different groups of dairy farms in different regions of the Netherlands, see section 1.6. The economic assessment will be done with the bio-economic farm model FarmDyn, as described in sections 1.4. and 1.5. Greenhouse gas emissions can be modelled in FarmDyn according to IPCC or other, more country-specific standards.

This chapter first focusses on the GHG emission accounting in FarmDyn and base year results regarding GHG emission in the Dutch dairy sector per farm group (section 2.2). Farm level GHG mitigation options play an important role in order to reduce the emission of GHG on the farm. Section 2.3 discusses in detail a large number of farm level GHG mitigation options dairy farmers can implement in order to reduce their GHG emission. These are taken from the literature. Different mitigation options can be modelled endogenously at the same time or simulated as enforced GHG mitigation measures in model experiments (Lengers et al., 2014). This is further explained in section 2.4. Section 2.4 also discusses the selected GHG mitigation measures that are enforced in FarmDyn. Section 2.5 discusses the Marginal Abatement Costs (MAC) of selected stand-alone measures for the Dutch dairy sector as a whole and for selected farm types. The MAC approach is often used to quantify the opportunities for abatement of agricultural GHG and related costs and benefits. Results show that there are large differences in MAC per farm type, meaning that proportional GHG mitigation policies, like command and control policies, will have disproportional impacts on farm income. Market based policies potentially could achieve GHG emission reduction levels at lower economic costs (Bakam et al., 2012). This is demonstrated using the MAC curves and GHG mitigation potentials per farm type (section 2.6). Section 2.7 ends with discussion and conclusion.

2.2. GHG emission accounting in FARMDYN: approach

FarmDyn is able to calculate GHG emissions for individual farms and different farm branches. It has a specific GHG module. The base of this GHG module is the original version developed by the University of Bonn. The principle of the current version of the GHG calculation is based on a product environmental footprinting (PEF), without allocation of GHG emissions from milk and meat production. The GHG emission accounting is updated specifically according to Dutch methodology. It is clear that

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the model can also be updated to specific methodology used in other countries. However FarmDyn generates GHG accounting for different farm branches the current version of the GHG module is mainly tested for dairy farming. The GHG emission accounting in FarmDyn is described below. Further details can be found in the appendix to this chapter.

2.2.1. Accounting for non CO2 emissions

Non CO2 emissions, like methane (CH4) and nitrous oxide (N2O) are modelled in FarmDyn according to the methodology of the Dutch National Emission Model for Agriculture (NEMA) (Zee et al., 2021) and the Annual Nutrient Cycle Assessment model (ANCA) (Van Dijk et al., 2021). The GHG accounting methodology in the ANCA model is specifically for the emissions from dairy farming.

2.2.2. Accounting for CO2 emissions

The GHG accounting in FarmDyn focusses more on the non-CO2 emissions, which are more dependent of farm/animal management, but some CO2 emissions are accounted for. The CO2 emissions can be distinguished in on-farm (e.g. CO2 from diesel use) and off-farm emissions (e.g. CO2 from fertilizer or feed purchases). Not all CO2 emissions that can occur on a farm are covered in the model. Only emissions from on-farm diesel use and the emissions from the purchase of feed and artificial fertilizer are taken into account in the current model version.

2.2.3. Methodology for accounting GHG emissions in FarmDyn

This section describes the methodology of the GHG accounting in FarmDyn per emission source.

2.2.3.1. Enteric fermentation methane emission

The enteric fermentation methane emission for dairy cattle is based on a methane emission factor per feed (Tier 3). These emission factors per feed are available in the Feedprint database (Vellinga et al., 2013, Wageningen UR, Feedprint or van Dijk et al., 2021). For other cattle the emission factor is per animal (Tier 2).

The feed intake is determined endogenously in FarmDyn. The feed requirement for animals is calculated for nutrient and energy need. The intake of feed products is then optimized in the model according to the feed requirements and feed prices.

2.2.3.2. Methane emission from manure management

The methane emission from manure management consists of the emission in animal housing/manure storage and the pasture.

Pasture emission

The emission of methane from pasture manure is based on a Tier 2 approach (Zee et al., 2021). The volume of manure excreted in the pasture is calculated based on grazing days per year and hours per day. The number of grazing days and hours are determined exogenously, based on farm specific or farm average information. The pasture manure volume is then multiplied by the methane emission factor. The methane emission factor is calculated according to Zee et al. (2021).

Housing/storage emission

The emission from methane from animal housing/manure storage is based on a Tier 2 approach (Zee et al., 2021). The volume of manure that is excreted in the barn or is stored the manure storage is calculated by deducting the total volume of manure produced by the herd with the manure excreted in the pasture. The remaining volume is multiplied by the methane emission factor. The methane emission factor is calculated according to Zee et al. (2021).

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2.2.3.3. Nitrous oxide emissions from manure management

The nitrous oxide emission from manure management consists of the emission in animal housing/manure storage, the pasture, animal manure application and artificial fertilizer application.

Pasture emission

The nitrous oxide emission from grazing is calculated according to Zee et al. (2021). The total amount of nitrogen from animal manure deposited by grazing animals is multiplied by the nitrous oxide emission factor. The emission factor is distinguished for organic soils and mineral soils.

Housing/storage emission

The nitrous oxide emission from animal housing/manure storage is calculated according to Zee et al. (2021). The total amount of nitrogen from animal manure produced by the herd, excluding pasture manure, is multiplied by the nitrous oxide emission factor.

Animal manure application emission

The nitrous oxide emission from animal manure application is calculated according to Zee et al. (2021). The total nitrogen application from animal manure is multiplied by the nitrous oxide emission factor. The emission factor is distinguished by mineral and organic soils and also by land use (grassland or arable land).

Artificial fertilizer application emission

The nitrous oxide emission from artificial fertilizer application is calculated according to Zee et al. (2021). The total nitrogen application is multiplied by the nitrous oxide emission factor. The emission factor is distinguished by mineral and organic soils and also by land use (grassland or arable land).

2.2.3.4. Other nitrous oxide emissions

The nitrous oxide emission from other sources consists of the emission of indirect emissions, crop residue, leaching and histosols.

Indirect emission

The indirect emission of nitrous oxide occur after atmospheric deposition of nitrogen compounds that have evaporated in the form of NH3 and NOx from animal housing, manure treatment and manure storage, as well as from inorganic N fertilizer, the application of animal manure, grazing, sewage sludge and compost (Zee et al., 2021). In FarmDyn the indirect emissions from animal housing/manure storage, inorganic N fertilizer, the application of animal manure and grazing are taken into account according to Zee et al. (2021).

The total NH3 and NOx farm emissions are multiplied by the nitrous oxide emission factor.

Crop residue emission

The nitrous oxide emission from crop residues is calculated according to Zee et al. (2021). The crop area per crop is determined endogenously in the model. By multiplying and aggregating the crop area per crop with the nitrogen residue per crop and the nitrous oxide emission factor, the total emission is calculated.

Leaching

De-nitrification in groundwater or surface water creates nitrous oxide emissions. The nitrous oxide emission from leaching is calculated according to Zee et al. (2021). The total nitrogen applied to the soil is multiplied with the fraction of nitrogen that is leaching and running off. This results in the total leached nitrogen, which is multiplied with the nitrous oxide emission factor.

The fraction of nitrogen that is leaching and running off is different in FarmDyn in comparison with Zee et al. (2021). In this publication a country specific value is applied. This country specific value does not take the soil type into account. Soil type has a big influence on the leaching of nitrogen in the Netherland. In order to take also soil type into account the leaching fraction is calculated based on Fraters et al. (2012). This results in different leaching factors for clay, peat, sand and loess soils.

<u>Histosols</u>

The agricultural use of organic soils (peat) lead to nitrous dioxide emissions due to mineralised nitrogen in these organic soils. The nitrous oxide emission from histosols is calculated according to Zee et al. (2021). The area of organic soils is multiplied with the nitrous oxide emission factor.

2.2.3.5. Carbon dioxide emissions

The carbon dioxide emission consists of the emission of on-farm diesel use and off-farm emissions from the purchase of feed and artificial fertilizer.

<u>On-farm emission</u>

FarmDyn endogenously defines the use of machines for the production processes (activities). For each machine, which uses diesel, the diesel use (in liter) per hour is defined and per activity the number of hours are available. The diesel use is than converted into MJ. The diesel carbon dioxide emission factor (CO2-eq/MJ) is obtained via the SimaPro Ecoinvent database.

<u>Off-farm emission</u>

Feed produced outside the farm also cause GHG emissions which in turn will be allocated to the farm. FarmDyn models the feed intake of different feeds endogenously, based on the feeding requirements of the animals. The quantities (in ton product) of purchased feeds are modelled and can be used to calculate the off-farm carbon dioxide emissions. By multiplying with the emission factor per feed, the total carbon dioxide emissions can be calculated. In the current version of FarmDyn the emission factors are only defined for dairy feeds including Land Use and Land Use Change (LULUC).

In the model the use of artificial fertilizer is determined endogenously. The artificial fertilizer input per product is multiplied with the carbon dioxide emission factor per product and then aggregated. The carbon dioxide emission factor per product is obtained via the SimaPro Ecoinvent database.

2.2.4. Base-year GHG emissions in FarmDyn

Table 4 shows the average GHG emission by source in base, aggregated over all farms in the sample, per farm group (extensive and intensive) and per region. Average share of GHG emission from fermentation in total GHG emission per farm equals about 44%. This is about the same for all farm groups distinguished in Table 4 , with the exception of the average farm in the peat region. Including the upstream emission from purchased feeds, the average share in total GHG emission equals about 70%. This is higher on the average intensive farm and on the average farm in the sand region.

Average GHG emission per farm in CO2-eq per kg FPCM is highest in the peat region. This is especially explained by the GHG emission from histosols and from application of mineral fertilizer. The latter is explained by the high share of grassland in cropping plan and because the emission factor for organic soils is higher than for mineral soils (Zee et al., 2021). Average total GHG emission in CO2-eq per kg FPCM per extensive and intensive farm group is about equal. The composition is however quite different. On extensive farms the GHG emission from application and storage of animal manure and GHG emission from purchase and application of mineral fertilizer is relatively high, while on the intensive farms the upstream emission from purchased feeds is relatively high. Share of imported CO2

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emission from purchased feed is also relatively high on the average farm in the sand region. Share of intensive dairy farms in total number of dairy farms in the sand region is relatively high.

Table 4 GHG emission by source in base. Average per farm type and region (kg CO2-eq per kg FPCM)

	Total	EXT	INT	Clay	Peat	Sand
Total CO2-eq[1]	1.27	1.27	1.27	1.22	1.54	1.25
CH4 CO2-eq fermentation	0.56	0.57	0.56	0.56	0.59	0.56
CH4 CO2-eq pasture	0.00	0.00	0.00	0.00	0.00	0.00
CH4 CO2-eq storage	0.15	0.16	0.15	0.15	0.17	0.15
N2O CO2-eq stable/storage	0.01	0.01	0.01	0.01	0.01	0.01
N2O CO2-eq indirect	0.02	0.02	0.01	0.02	0.02	0.01
N2O CO2-eq pasture	0.04	0.04	0.04	0.03	0.08	0.03
N2O CO2-eq application animal manure	0.02	0.03	0.02	0.02	0.05	0.02
N2O CO2-eq application mineral fertilizer	0.05	0.07	0.04	0.05	0.16	0.03
N2O CO2-eq Crop residu	0.00	0.00	0.00	0.00	0.00	0.00
N2O CO2-eq leaching	0.02	0.02	0.01	0.01	0.00	0.02
N2O CO2-eq Histosols	0.02	0.03	0.01	0.00	0.18	0.00
CO2 from artificial fertilizer	0.07	0.09	0.06	0.09	0.07	0.05
CO2 from purchased feed (incl. LULUC)	0.31	0.24	0.35	0.26	0.20	0.36

1.does not exactly add up because of remaing emissions are not included in the table.

Source: Own calculations with FarmDyn

2.3. GHG mitigation options: Literature review

An extensive list of literature exists describing technologies that would address GHG emission mitigation options and future agricultural GHG emissions e.g. Eory et al. (2020), Lesschen et al. (2020, in Dutch with English summary), de Vries et al. (2018, in Dutch), Pérez et al. (2020) and Lanigan and Donnellan (eds., 2019).

Table 5 presents possible dairy farm level mitigation options (de Vries et al., 2018). This table is translated from Dutch into English. De Vries et al., 2018 maps the required effort of the Dutch dairy to reduce GHG emission to climate mitigation and adaption potential of available technical options. The reduction potential of feed additives is estimated to be 32-48 g CO2e/kg milk. This is a significant reduction and therefore additives can play a big role in reducing the methane emissions of dairy farming. In addition, replacing common concentrates with concentrates which reduce the emission of methane from enteric fermentation (EF) can add to more methane emission reduction. An important condition is that the production level does not change. The reduction potential of concentrates with low EF factor is estimated to be about 3 g CO2e/kg milk. Through better animal management it is possible to extend the lifespan of dairy cows which leads to less GHG emissions through less young stock. Extending the lactation of dairy cows can lower the GHG emission with 10-20 g CO2e/kg milk per extra year of life. Regarding upstream emissions from the use of N from mineral fertilizer, the enhancement of the fertilizer efficiency (less N from mineral fertilizer with equal crop yields) gives a possible emission reduction of 31 g CO2e/kg milk. Using less fertilizer ensures less CO2 emission by the production and application. Increased share of permanent grassland can increase carbon

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sequestration with 20-40 g CO_2e/kg milk. Other mitigation options with high reduction potential are digestion (100-130 g CO_2e/ kg milk), higher milk production per cow (40-55 g CO_2e/ kg milk, +1000 kg/cow), nitrification inhibitors (30-60g CO_2e/ kg milk), etc. See de Vries et al. (2018) for more reduction potentials.

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Table 5 Mitigation measures in the dairy sector. According to De Vries et al. (2018)

Measure	Explanation
1. Enhance efficiency	
Cattle:	
- Higher milk production per cow	Through better feed- , animal management or breeding measures the feed efficiency can increase and the milk production rise. Emissions can then be divided over a higher milk production.
- Lifespan extension dairy cow	Through better animal management, like better fertility and heat detection, it is possible to extend the lifespan which leads to less GHG emissions through less young stock
- Enhance animal health	Prevention of illness has a positive effect on the milk production, fertility and lifespan and make sure that less milk will be spilled because of antibiotics use.
Nutrients:	
- Grass clover	The application of grass clover in grassland realizes more nitrogen fixation and the need for less artificial fertilizer. The lower grass yield can lead to additional emissions, because of the need for extra fodder. Because of this, the net emission reduction is dependent of the current fertilizing levels and the measure is most effective on more extensive (kg milk/ha) dairy farms. An optimalization of land use in which grass clover is introduced with crop rotation with silage maize can lower emissions (Vellinga and Van Eekeren, (2017).
- Enhance fertilizing efficiency	Enhancing fertilizing efficiency can lead to less use of artificial fertilizer and therefore less emissions from the production and application of artificial fertilizer.
- Spring fertilizer application	Spring fertilizers contain a higher part of ammonium nitrogen than nitrate nitrogen. Nitrate is more sensitive for leaching than ammonium and can easily denitrificate, which results in more nitrogen gas emission (part N_2O).
- Shorter manure application period	No manure application after the first of August
- Increase roughage production	Increase productivity of grassland and arable land through for instance better manure management, prevention of soil densification, keeping up the acidity levels (grassland) and organic matter (arable land).
- Enhance roughage conservation	Prevention that roughage declines in nutritional value of ends as waste.
Energy:	
- Energy saving (diesel, gas, electricity)	Diesel saving (e.g. fitting machinery/capacity, fuel saving driving, minimal number of operations, reducing transport distance), gas saving (energy efficient boiler, less use of warm water) and electricity saving (milking process (cooling/heat recovery/pre-cooling/frequency converter), illumination (LED, motion detectors) and other thinkable measures.
2. Reduce emissions	
Cattle:	
- Ration adjustments	Ration adjustments which reduces/slows down the methane emission from digestion
* Better protein/energy ratio on rumen level	If protein levels are still too high in the ration, compensate with concentrates with lower protein levels.
* Higher fat content in concentrates	Adding oil and fat to concentrates. This application is limited because of rational demands and hardness of the concentrates. It also may not influence the milk composition. Per per cent fat the methane production can reduce with 4-5%.
* Additives	Adding additives tot the ration can reduce the enteric methane emissions, e.g. nitrate, 3NOP.
- Breeding	Genetic selection on animals with al lower enteric methane emission.
Manure:	

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- Combination of primary manure separation, frequent transport, closed storage and capture of gasses.	Less nitrous oxide and methane emissions in the barn (primary manure separation, frequent transport), manure storage (capture of gasses) and with manure application; better use of nitrogen and savings on nitrogen of artificial fertilizer and artificial fertilizer energy use.
- Cold manure storage	Less methane emission from manure storage due to less bacterial activity.
- Acidification of manure	Less methane emission from manure storage due to lowering pH of manure.
Soil:	
- Nitrification inhibitors	Slowing down the nitrification process in the soil.
- underwater drainage/increasing water level in peat soils	In peat soils the ground level decline by peat breakdown can be halved by the application of underwater drains in combination with a relative high water level in the waterway. The reduced peat breakdown reduces the emission of carbon dioxide and nitrous oxide.
Energy:	
- Solar and wind energy	The production of solar and wind energy can reduce the emission of CO2 from fossil fuels.
3. Carbon sequestration	
Grassland (increase organic matter):	
- preserve permanent grassland from short in between fodder or other crop cultivation	A lot of organic matter is broken down when grassland is turned into crop land. This leads to a high greenhouse gas emissions and a decline of nitrogen-supply capacity of the soil. This will lead to lower crop yields and more nitrogen fertilizer (or more purchasing of fodder). The loss of organic matter will be compensated in the following years (e.g. Hoving en Vellinga, 2010). To reduce the reseeding is good grassland management of high importance (e.g. better mowing and fertilizing practices, avoid soil densification)
- Limit reseeding and stimulate overseeding	If renewing of the grassland is needed to secure the production and/or quality of the gras and roughage, than overseeding is a good alternative instead of reseeding. This leaves the tillage completely behind and without substantial damage to the high level of organic matter of permanent grassland
- Reduce the grass-phase with the grass-maize crop rotation to max 3 years	In order to reduce emissions it is recommended that in grass-maize rotation the grass-phase in the rotation is limited to two or at most three years. A longer period of grass leads to bigger losses of organic nitrogen (nitrate leaching) and with that higher greenhouse gas emissions.
Arable land:	
- no tillage	No tillage can reduce the breakdown of organic matter.
- cropping plan adjustment	The cultivation of crops that produce more stubbles, roots and crop residues, like grains. Variety of crop land and grassland has, if well performed, advantages for organic matter supply on arable land.
- Green manure/catch crops	Green manure/catch crops make sure that still available nitrogen is fixed and organic matter is produced.
- supply organic matter through manure/compost	The supply of organic matter via manure is limited (mostly) due to legislation. Supply of compost on dairy farms is limited.
- Agroforestry	Cultivation of trees in combination with agricultural crops or at parcel borders. This is common in tropical areas. There is little know of effects in moderate climate zones.
4. Capture of gasses (end-of-pipe)	
- Manure digestion	Mono digestion (only manure) and co-digestion (manure together with other organic material) lead to less (mostly) methane emission because manure is removed from the barn directly. Also the CO2 emission is lower because of the conversion to biogas. Co-digestion is only useful if products are unusable as animal feed.
- Methane oxidation	Methane is captured and thermal (flared) or microbially (via (e.g. soil-) bacteria) converted in the less harmful carbon dioxide. Through thermal oxidation is it possible to reduce the

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	emission with 62%. Also under sealed barn floors can gasses be captured. Capture from barn air is possible, but expensive.
5. Structural measures	
- Herd size	Reduction of the herd size in order to reduce the total emission volume
- Transition agricultural area to (wet) nature.	Less fodder production and emissions that accompanies this fodder production, more carbon storage in new shaped nature (biomass, soil). In wet nature it is also possible to prevent peat oxidation.

The GHG mitigation options presented in Table 5 are confirmed by other studies in other countries. For example Lanigan and Donnellan (eds., 2019) mention different mitigation options from farm management like grass clover on grazing land, herd management measures focussing on animal health (replacement rates, fertility rates, milk yield, mortality, etc.), sequestration in agricultural soils like increased share of permanent grassland and energy mitigation like digestion of slurry and grass for the production of gas which is used to power combined heat and power (CHP) plants. Table 6 shows the GHG mitigation options and the targeted emissions included in the EU agricultural sector model CAPRI (Pérez et al., 2020). Increased legume share on temporary grassland reduces the need for N fertilizer application. Also additional carbon sequestration between 300-500 kg C per ha and year is assumed. Grassland yields are assumed constant. Anaerobic digestion (AD) on farm scale will reduce GHG emissions from stored manure and N20 emissions from livestock slurries. In Pérez et al. (2020) it is assumed that due to the economies of scale, only farms with more than 200 livestock units can use AD as an economically viable technological option. Adding linseed to the feed ration will increase the energy content of the diet, decrease the dry matter intake and reduce methane emissions from EF through improved digestion. In Pérez et al. (2020) the feeding of linseed is limited to max 5% of total dry matter intake. Milk production per cow is maintained and for each percent of fat added a 5% reduction of CH_4 emission from enteric fermentation is achieved. Improved cow longevity/increased number of lactations is included without any extra costs (Pérez et al., 2020).

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Table 6 Technological GHG mitigation options included in EcAMPA 3

Mitigation option	Emissions targeted	New compared to EcAMPA 2
Crop sector		
1. Better timing of fertilisation	N_2O; (NH_3; NO_x; NO_3)	
2. Nitrification inhibitors		
3. Precision farming		Updated assumptions; farm size structure dependent cost functions for VRT
4. Variable rate technology		
5. Increasing legume share on temporary grassland	N_2O; CO_2	Inclusion of CO_2 sequestration
6. Rice measures	CH_4	
7. Fallowing histosols (abandoning the use of organic soils)	N_2O; CO_2	Inclusion of CO_2 emissions
8. Winter cover crops	CO_2	New mitigation option
Livestock sector		
9. Anaerobic digestion: farm scale	CH_4; N_2O	
10. Low nitrogen feed	N_2O; CH_4; (NH_3)	Updated assumptions
11. Feed additives: linseed	CH_4	
12. Feed additives: nitrate	CH_4	
13. Genetic improvements: increasing milk yields of dairy cows	CH_4	
14. Genetic improvements: increasing ruminant feed efficiency	CH_4	
15. Vaccination against methanogenic bacteria in the rumen	CH_4	

Note: Emissions in brackets are the emissions also affected in addition to the GHG emissions.

Source: Pérez et al., 2020

Applying a bio-economic, optimization model of a dairy farm, Mosnier et al. (2019) found that by implementing a carbon tax dairy farmers adjusted their farm practice by reducing young stock, using less (artificial) fertilizer, adjust productive grasslands and consumption of concentrates in order to reduce their GHG emissions. Heinrichs et al. (2021) and Gaudino et al. (2018) conclude that reduction of GHG emissions can mainly be achieved by herd reductions. Also a large number of mitigation options in table 2 can be found in ICF (2013). This document is meant to facilitate a better understanding of the financial incentive that would be necessary for agriculture producers to start adopting specific mitigation practices and technologies as part of their normal production and land management operations. Cerri et al. (2010) looked especially to mitigation options for land-use change, livestock and agriculture in Brazil. They find e.g. that avoided deforestation, afforestation/reforestation, rational adjustments (enteric fermentation), no-tillage and covering-crops can be mitigation options to reduce the GHG emissions of Brazilian agriculture. Finally Panchasara et al. (2021) find that smart farming/smart agriculture, the use of best management practices in dietary and nutrition management (enteric methane emission) in general, but also the use of supplements such as oils, fats, probiotics, etc. can help to reduce GHG emissions. The article also mentions the reduction of the number of young stock by extending the lactation of dairy cows, better fertilizer management and nitrification inhibitors.

2.4. GHG Mitigation options in FarmDyn

Bio-economic farm optimization models like FarmDyn can be used to find the economic optimal combination and adoption rates of GHG mitigation options, depending on the policy incentives to reduce GHG emissions. FarmDyn optimizes farm decisions (e.g. feeding, manure management, crop management) which in turn can have an endogenous effect on the farm GHG emissions. Enforced GHG

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mitigation measures can be added and assessed in scenarios or experiments. The endogenous mitigation options in FarmDyn and the selected enforced mitigation options are further explained in this section.

2.4.1. Endogenous mitigation options in FarmDyn

FarmDyn optimizes the feeding ration of dairy cows based on numerous feeds, including different qualities of roughage and compound concentrates. Soybean meal can be included in the feed ration as a single or raw concentrate. The feeds, their quality and the cost of the feeds are added to the model. The model selects the most optimal feeding ration based on the different feed requirements of the animals, the feeding costs and possible incentives from policy measures to adjust the feed ration. The original model contained three types of compound concentrates for dairy cattle, a basic, a protein rich and an extra protein rich variant. These concentrate types were based on the average concentrate purchases of Dutch dairy farmers. The quality of the compound concentrates like Net Energy of Lactation (NEL), protein content, dry matter, methane emission factor, etc. was also based on the average of Dutch concentrate purchases.

To reduce the methane emission of dairy cows an option in FarmDyn is to select feeds which have a low(er) methane emission factor per kg dry matter intake. This is valid for as well roughages as concentrates. Concentrates are often purchased and most of the roughages are produced on the farm, and so dependent on weather circumstances and farm management conditions. In the short term it is easier for farmers to reduce methane emissions from enteric fermentation by adjusting the ingredients in the compound concentrates. In FarmDyn six extra compound concentrates are defined, based on Šebek et al. (2016), with a lower methane emission than the more commonly used concentrates. These six concentrates are divided into three concentrates (basic, protein rich, extra protein rich) with a methane emission reduction of 5% relative to the basic concentrates and three concentrates with a reduction of 10%. The nutritional value has not changed. Prices of the low methane emission concentrates are based on the extra feeding cost (Šebek et al., 2016). Low methane emission concentrates are more expensive than the basic concentrates and the concentrates with 10% reduction are more expensive than the concentrates with 5% reduction.

The implementation of low emission compound concentrates focusses on the enteric fermentation. But this is just a part of the total GHG emission of concentrates. Feed products which are purchased have also caused GHG emissions outside the farm, the so called off-farm or up-stream emissions. Compound concentrates, but also raw ingredients, like soybean meal, emit CO2 before it is bought by the dairy farmers. Soybean meal has for instance a high off-farm emission factor. Replacing this raw concentrate with a lower emission alternative can reduce the emissions of a dairy farm. Reducing or removing soybean meal in the dairy ration because of the high CO2 emission factor can have implication of the ration composition. FarmDyn can model alternative rations based on the reduction of the off-farm CO2 emission.

An endogenous option to reduce GHG emission is related to application of N from mineral fertilizers and animal manure. FarmDyn contains different grassland management options. Corresponding dry matter yield and ingredients (e.g. energy and raw protein content) differ by fertilization level (200, 300 or 400 kg N per ha) and number of cuts (see chapter 4 of this deliverable). Application of N from mineral fertilizers and animal manure on arable crops is included via a stepwise N-response curve, including different yield levels at 80, 60, 40 and 20% of the optimal N fertilization level. In this study the optimal N fertilization level is put equal to the legal maximum N fertilization level.

A final endogenous solution is to reduce the number of dairy cows on the farm. This is possibly an option for intensive dairy farms in the Netherlands that are not producing enough roughage on the farm to feed the dairy herd and that have to pay for the manure disposal from the farm. The income

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per cow is relatively low on these farms. With reducing number of dairy cows, the number of young animals on the farm will reduce as well. This is because, so far, the number of young animals is modelled as a fixed ratio per dairy cow.

2.4.2. Selected enforced mitigation options in FarmDyn

This section describes the selected exogenous or enforced GHG mitigation options in the model to be further analysed as standalone measure in section 2.5. Feed additives affect the methane emission from enteric fermentation. The use of feed additives is controlled exogenously in FarmDyn by setting the use of additives on or off. When the option is on, the model forces the intake of additives in the dairy ration. This will change the composition of the ration, because additives also contain dry matter and/or NEL. In FarmDyn two additives are modelled: adding supplementary fat or Bovaer® to the ration. Adding supplementary fat to the diet of livestock will reduce the amount of carbohydrate consumed. It is known that fats reduce the number of protozoa, while some of the unsaturated fatty acids compete with methanogens for hydrogen (Rasmussen et al., 2011; Toprak, 2015). Addition of fat to the ration of dairy cows is effective to reduce methane emission. Bovaer® is a feed additive for cows (and other ruminants, such as sheep, goats, and deer) researched and developed over 10 years by DSM (DSM, 2022). Bovaer® suppresses the enzyme that triggers methane production in a cow's rumen and consistently reduces enteric methane emission by approximately 30% for dairy cows and even higher percentages (up to 90%) for beef cows.

Per additive the minimal and/or maximum ration share is set and if applicable feeding quality like dry matter and NEL. The emission reduction and purchase prices per additive are also defined. For feeding fat the product quality and price are gathered by consulting commercial distributors. For Bovaer®, because it is not yet commercially available, the information about the product price was obtained by confidential information of the manufacturer (DSM, 2022). The possible methane reduction from enteric fermentation under Dutch conditions is based on Gastelen et al. (2022) and is set to 30%.

Extending the lactation of dairy cows can lower the GHG emission, because less young stock is needed for replacement. It has a high reduction potential but is not easy to implement. So is there a high heterogeneity between farmers. Some farmers have already increased the dairy cow's life span, others have high potential to increase the life span. This is also a mid- or long-term option because it may include breeding goals and cow breed selection. Changing the life extension of dairy cows is a plain model setting. The model user sets the average lactation period of the dairy cows, and the model will use this setting to model the farm herd size. In this chapter it is assumed that the life time of the cows increases with 1.5 years per cow on all farms. The extra costs are assumed equal to 40 euro per cow.

De Vries et al. (2018) state that the application of grass clover in grassland realizes more nitrogen fixation and reduction of the use of N from mineral fertilizer. The lower grass yield can lead to additional emissions, because of the need for extra purchased fodder. Because of this, the net emission reduction depends on the current fertilizing levels and the measure is probably most effective on more extensive (kg milk/ha) dairy farms. An optimalization of land use in which grass clover is introduced with crop rotation with silage maize can lower emissions. This option depends on various assumptions, such as the grass yield and application of mineral fertilizers. On farm level, in the Netherlands, a farm is prohibited to use more nitrogen and phosphate from animal manure and mineral fertilizers than a certain quantity. This maximum is based on the cropping plan and the crop area of the farm. If a farm takes grass clover into the cropping plan with lower need of nitrogen, it is allowed to use the saved nitrogen on other crops. In balance the total farm nitrogen use does not change. For this reason this mitigation option is not included as an enforced GHG mitigation option.

Increased acreage of grassland can increase carbon sequestration. In this chapter it is assumed that 25% of the arable crop, including silage maize on the farm is replaced by grassland. The supply of effective organic matter (EOM) per ha grassland is about twice as high as the supply of effective

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organic matter of silage maize including the cover crop after silage maize (assumed on all dairy farms in the Netherlands). Finally, a reduction of milk production per cow is assessed as an enforced mitigation option. Milk production per cow is also discussed by Lengers et al. (2014). Dairy cows with lower milk yield require less own produced and purchased feeds and produce less manure. The justification for this measure is again especially relevant for farms that have to purchase part of the required roughage to feed the animal herd and have to purchase manure disposal room to dispose the surplus manure from the farm.

GHG mitigation measures that focus on N from mineral fertilizer and amount of N in feed are not considered as enforced standalone measure in section 2.6. This is because the stand alone measures are enforced without any link to carbon prices, GHG emission capping or GHG emission cap and trading systems. Without GHG emission reduction targets or economic incentives, the stand-alone measures that focus on N from feed or mineral fertilizers might as well increase GHG emissions as e.g. lower grassland yields are replaced by increased use of purchased concentrates or feed rations might change in such a way that GHG emissions, including upstream emissions from purchased feeds increase. Of course these measures can come into play in case of GHG emission taxes or GHG emission reduction targets are in place as well.

2.5. Marginal Abatement Cost (MAC) following a standalone measures approach

2.5.1. Marginal Abatement Cost: concept

This section discusses the Marginal Abatement Costs (MAC) of selected standalone measures as discussed in section 2.4. The MAC approach is often used to quantify the opportunities for abatement of agricultural GHG and related monetary costs and benefits. The MAC curve shows the abatement potential of GHG mitigation technologies, and the related relative monetary costs/ income foregone ranked from low to high (Lanigan and Donnellan, eds., 2019). Possible win-win situations, decreasing GHG emission and decreasing costs or increasing revenues are depictured as negative costs, see Figure 7. The width of the bar represents the mitigation potential (MT CO2eq) and the height of the bar represents unit costs of one ton CO2eq mitigated (EUR/t CO2eq mitigated). In Figure 7 measures are ranked according to costs. Ranking technological mitigation options in this way is appealing as it immediately shows the options that offer the greatest mitigation potential and cost effectiveness per unit GHG mitigated.

In Figure 7 each bar in the MACC represents a different technological mitigation option as a standalone measure. This means that each technological mitigation option is implemented in isolation, without considering interactions with other measures (Pérez et al., 2020). Implemented in this way, it is assumed that the enforced GHG mitigation measure is adopted and implemented by all average farm groups in our sample, independent of the cost of the GHG mitigation measure. The total GHG emission reduction and costs can be summed to show total GHG emission reduction and costs per farm type and sector.

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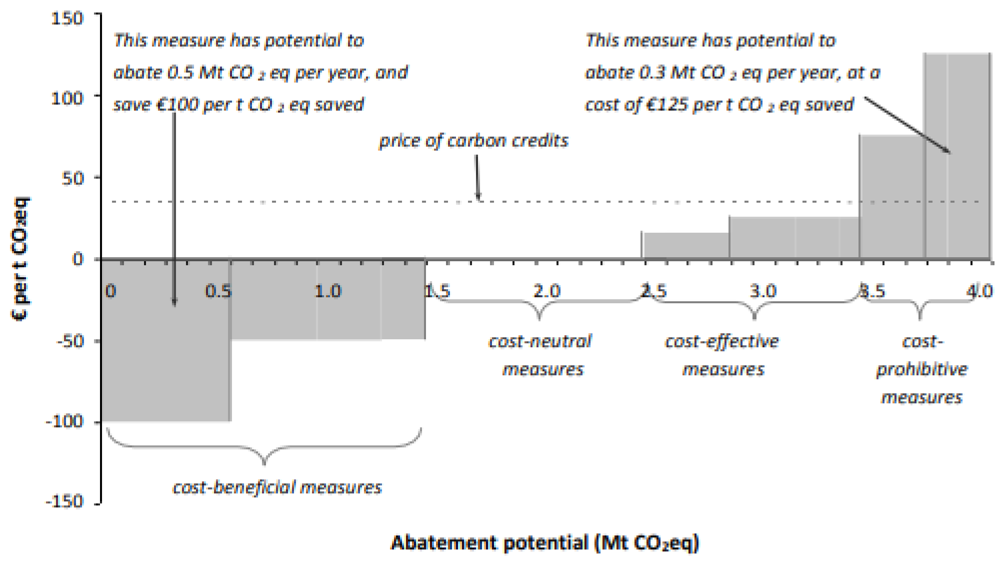

Figure 7: Hypothetical example of Marginal Abatement Cost Curve

Source: Lanigan and Donnellan (eds., 2019)

It should be noted that the possibility to draw conclusions on the total mitigation potential and costs of a set of ranked stand-alone mitigation options is generally limited. This is because it is assumed that the mitigation options are applied to their assumed maximal implementation without consideration of economic feasibility and adoption rates and interaction between mitigation options. Notwithstanding the above shortcomings, resulting differences in marginal abatement costs per mitigation option per farm type are useful to characterise the average farm groups with high and low marginal abatement costs per mitigation option. It will be shown how the results can be used to approximate possible impacts of more cost-effective market based policies, allowing farmers to adopt GHG mitigation measures that are in their own interest (Bakam et al., 2012).

Chapter 4 will present results following a combined GHG mitigation measures approach, overcoming the problem with the stand alone measures as explained in Chapter 2 of this deliverable. This is done via carbon prices with all endogenous mitigation technologies available and the selected enforced GHG mitigation options per farm group. The carbon prices and the selected enforced GHG mitigation options are among others based on the results of the standalone approach as presented in this chapter. In this way the stand alone approach is seen as complementary to the combined measures approach.

Different from Lanigan and Donnellan (eds., 2019) we do not consider win-win situations, as the optimization farm model FarmDyn assumes that win-win situations either assume technologies that are not ready available on the farm or not main stream yet or already incorporated in the base situation. Technical-economic farm level data as available in the Dutch FADN, shows large differences in environmental emissions between farms. For example, based on the Data Envelope Analysis (DEA) approach, Lamkowsky et al. (2021) show large differences in N surplus per farm. Large reductions in emission can be reached if farms with high emissions adjust their farm management to their peers. Reasons to explain these differences are differences in knowledge and access to information (Lamkowsky et al., 2021).

Also important to note is that we assume fixed input and output prices. Possible changes in input and output prices due to changes in production and farm management resulting from the GHG mitigation measures are potentially important drivers of MAC (Lengers et al., 2014). Equilibrium models that

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include price feed-back therefore tend to find higher MACs compared to farm level models because of the induced input and output price changes.

2.5.2. Marginal abatement cost curves of Dutch dairy farms following a standalone measures approach: results

Table 7 gives the short names of the different standalone GHG mitigation measures and descriptions. Table 8 shows that the GHG mitigation measure with the lowest marginal abatement costs, averaged over all farms, are the enforced changes in the feeding ration (EF low concentrates and less soybean meal in the feed ration). The abatement cost of the use of concentrates with low EF factors is comparable to the abatement cost mentioned in de Vries et al. (2018). The contribution of these two measures to total GHG mitigation is however very limited.

Table 7 Short name and description of standalone measures. Everything else equal as compared to the base

Short name	Description
EF low Concentrates	Standard concentrates with relative high EF factor not allowed in feed ration. Use of soybean meal put equal to amount in the base.
Soybeanmeal	Purchase of soybean meal maximum 50% of amount of soybean meal in the base scenario
Permanent grassland	25% of the base arable crop, including silage maize on the farm is replaced by grassland.
Lower milkyield	10% decrease of milk yield per cow as compared to the base.
Number of cows	10% decrease in number of dairy cows as compared to the base
Use of Feed additive	30% methane reduction from enteric fermentation per lactating dairy cow. Costs are around 50 to 70 euro per cow, depending on the dry matter intake.
Extended lactation	Life time of the cows assumed to increase with 1.5 years per cow as compared to the base. Costs are assumed equal to 40 euro per cow.

Average marginal abatement costs of use of feed additives (Bovaer®) and extended lactation are also quite comparable between different groups of dairy farms. The decrease in GHG emission in the extended lactations scenario is especially achieved via less young stock on the farm. It should be noted that marginal costs data of increasing the lactation period is very uncertain and might differ a lot per farm among other depending on farm characteristics (e.g. stable capacity) and management quality. Average marginal abatement costs of increasing the share of permanent grassland and decreasing the number of dairy cows over all dairy farms in the Netherlands are also quite comparable. Note however that the contribution of decreasing the number of dairy cows to total GHG mitigation is much larger. Finally, decreasing the milk yield of the dairy cows with 10% on all dairy farms appears to be the least cost effective, resulting in an average abatement costs of almost 130 euro per ton CO2-eq. This measure however contributes highest to the aggregated GHG mitigation of 7.3 MT CO2-eq. The

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decrease in GHG emission from lower milk yield is especially achieved via less use of purchased concentrates and corresponding decrease of upstream emissions.

The aggregated GHG mitigation equals more than 40% of the GHG emission in the base. This is for a little more than 50% explained by the enforced 10% decrease in milk yield per cow and number of dairy cows. Total costs of the standalone measures equal about 600 mio. Euro. This for almost 65% explained by the assumed decrease in milk yield per cow and number of dairy cows.

Table 8 Total and average GHG emission, GHG mitigation, change in income and marginal abatement costs per measure and aggregated over all measures

Total	GHG emission (MT CO2-eq)	GHG mitigation (MT CO2-eq)	Change income (mln euro)	marginal abatement costs (euro per ton CO2-eq)
Base	18.1	0.0	0.0	0.0
EF low Concentrates	18.0	-0.1	-1.6	26.3
Soybeanmeal	17.5	-0.6	-20.2	33.3
Permanent grassland	17.4	-0.6	-53.4	82.7
Lower milkyield	16.2	-1.9	-241.7	129.3
Number of cows	16.2	-1.8	-162.1	88.0
Use of Feed additive	16.5	-1.6	-97.6	61.3
Extended lactation	17.4	-0.7	-45.8	69.1
All measures		-7.3	-622.4	85.5
Lower milk yield plus lower number of cows		-3.7 (51%)	-403.7 (65%)	108.8
Remaining measures		-3.6 (49%)	-218.6 (35%)	61.3
Sum of CO2-eq emission decrease (% of total in base)		-40.3		
farm income in base (mln euro)			881	
Sum of decrease farm income (% of total farm income in base)			-70.7	

Altogether farm income (five year average 2016-2020) decreases with almost 71%. It should be noted that this decrease is probably overestimated as e.g. depreciation and paid labour is kept constant.

Table 9 shows results for average extensive and intensive farm group. MAC of use of feed additives and concentrates with lower EF factors are quite comparable between the two farm types.

More detailed inspection of the results show that reducing purchase of soybean meal is especially cost effective on intensive dairy farms with relative high share of soybean meal in the feed ration. The high marginal abatement costs on extensive farms is especially explained by the fact that impact on GHG emissions is very limited (or GHG might even increase), while compared to this the impact on farm income can be large.

Increasing share of permanent grassland to reduce net GHG emission is especially costly on extensive farms. On the one hand because acreage of grassland and amount of fresh and silage grass in the feeding ration of the cows is already less a problem on these farms. On the hand share of high margin arable crops like potatoes in cropping plan is relatively high on extensive dairy farms.

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Extended lactation of the dairy cows and resulting decrease in number of young animals on the farm, is especially cost effective on intensive dairy farms because of the savings in purchased feed and manure disposal costs of the farms. For the same reasoning the relative low income per dairy cow on intensive dairy farms results in relative low MAC of reduction of number of dairy cows and milk yield on intensive dairy farms as compared to extensive dairy farms.

The aggregated GHG mitigation equals about 33% on average extensive farm and about 44% on the average intensive farm. At the same time farm income on average extensive dairy farm decreases with almost 79% while farm income on the average intensive dairy farm decreases with almost 66%. This difference is explained by the limited cost effectiveness, as indicated by the MAC of the assessed GHG mitigation measures, on extensive dairy farms, especially the enforced reduction of number of dairy cows on the farm and the reduction of the milk yield per cow.

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Table 9 Total and average GHG emission, GHG mitigation, change in income and marginal abatement costs per measure and aggregated over all measures average per extensive (EXT) and intensive (INT) farm type

Total	GHG emission (MT CO2-eq)		GHG mitigation (MT CO2-eq)		Change income (mln euro)		marginal abatement costs (euro per ton CO2-eq)	
	EXT	INT	EXT	INT	EXT	INT	EXT	INT
Base	6.3	11.8	0.0	0.0	0.0	0.0	0.0	0.0
EF low Concentrates	6.2	11.8	0.0	0.0	-0.6	-1.0	26.4	26.3
Soybeanmeal	6.3	11.2	0.0	-0.6	-2.8	-17.4	201.9	29.0
Permanent grassland	6.1	11.3	-0.1	-0.5	-29.6	-23.7	233.3	48.9
lower milkyield	5.7	10.5	-0.5	-1.3	-91.2	-150.5	169.2	113.1
number of cows	5.7	10.5	-0.6	-1.3	-80.0	-82.1	141.3	64.3
Use of Feed additive	5.7	10.8	-0.6	-1.0	-34.3	-63.3	61.0	61.4
Extended lactation	6.0	11.4	-0.3	-0.4	-30.4	-15.5	121.3	37.5
All measures			-2.1	-5.2	-268.9	-353.4	129.1	68.4
Lower milk yield plus lower number of cows			-1.1 (53%)	-2.6 (50%)	-171.2 (64%)	-232.6 (66%)	154.9	89.2
Remaining measures			-1.0 (47%)	-2.6 (50%)	-97.8 (36%)	-120.9 (34%)	100.0	47.1
Sum of CO2-eq emission decrease (% of total in base)			-33.3	-43.8				
farm income in base (mln euro)					340.9	539.8		
Sum of decrease farm income (% of total farm income in base)					-78.9	-65.5		

Table 10 shows results for average dairy farm in the clay, peat and sand region. Results are mainly explained by shares of intensive and extensive dairy farms in the region. Especially in the sand region, the share of intensive farms in total number of farms is relatively high. Another important difference between the sand farms and the farms in the clay and peat region is the average lower grassland yield, see chapter 4. This among others explains the relative low MAC of lower milk yield at the average farm in the sand region, compared to the average dairy farm in the other two regions and the average extensive and intensive dairy farm.

Table 10 Total and average GHG emission, GHG mitigation, change in income and marginal abatement costs per measure and aggregated over all measures, average per region

Total	GHG emission (MT CO2-eq)			GHG mitigation (MT CO2-eq)			Change income (mln euro)			marginal abatement costs (euro per ton CO2-eq)		
	Clay	Peat	Sand	Clay	Peat	Sand	Clay	Peat	Sand	Clay	Peat	Sand
Base	5.8	2.2	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EF low Concentrates	5.8	2.2	10.0	0.0	0.0	0.0	-0.6	-0.2	-0.8	26.2	26.2	26.4
Soybeanmeal	5.7	2.3	9.5	-0.1	0.0	-0.5	-3.4	-0.7	-16.1	54.6	Na	29.4
Permanent grassland	5.7	2.2	9.5	-0.1	0.0	-0.5	-10.1	-5.7	-37.6	98.9	161.5	74.0
lower milkyield	5.3	2.1	8.8	-0.5	-0.1	-1.2	-84.9	-28.2	-128.5	163.1	224.8	105.1
number of cows	5.2	2.1	8.9	-0.5	-0.2	-1.1	-64.4	-21.8	-75.9	120.8	119.8	67.3
Use of Feed additive	5.2	2.1	9.1	-0.5	-0.2	-0.9	-32.5	-10.4	-54.7	61.3	60.8	61.4

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Extended lactation	5.6	2.2	9.7	-0.2	-0.1	-0.4	-21.4	-8.6	-15.8	100.8	97.8	43.6
All measures				-2.0	-0.6	-4.7	-217.4	-75.6	-329.3	109.6	124.9	70.2
Lower milk yield plus lower number of cows				-1.1	-0.3	-2.4	-149.3	-50.0	-204.4	141.7	162.7	86.9
Remaining measures				-0.9	-0.3	-2.3	-68.1	-25.6	-125.0	73.2	85.8	53.4
Sum of CO2-eq emission decrease (% of total in base)				-34.3	-27.0	-46.7						
farm income in base (mln euro)							296.9	121.5	462.3			
Sum of decrease farm income (% of total farm income in base)							-73.2	-62.3	-71.2			

Impact on farm income is relatively low on the average farm in the peat region. This is especially explained by the relative high income per average dairy farm in the peat region in the reference situation.

The standalone measures show large differences in MAC per intensive and extensive dairy farm type and per average farm per region. This shows that proportional GHG mitigation targets e.g. command and control policies, will have disproportional income effects for the different farm types, especially at high GHG emission reduction levels.

2.6. Market based policies and combined enforced measures

Below we focus on impacts of a combined tax and subsidy scenario to contribute to improved policy design. This scenario combines enforced measures. As mentioned before the results of the standalone scenario are not very useful to give insights into the impacts of such market scenario as the full endogeneity of the model is not used. Moreover, interaction between enforced measures affects the overall MAC and the resulting GHG emission reduction. This will be further investigated in chapter 4. It is assumed that this interaction especially takes place between the measures lower milk yield, extended lactation and number of dairy cows e.g. the MAC of reduction in cow numbers increases with extended lactation possibly also decreasing milk yield.

The left panel of Table 11 shows the impacts of a combined tax and subsidy scenario on the average intensive and extensive dairy farm as approximated by the MAC and the mitigation potential of selected standalone measures (see Table 9). The market policy consists of a tax on GHG emission and a subsidy on mitigated GHG emission, equal for all farms. GHG mitigation measures lower milk yield and number of dairy cows are excluded from this static analysis.

The subsidy is assumed equal to the average MAC of the GHG mitigation measure ‘feed additive’ on the group of intensive dairy farms. This is the highest MAC within the group ‘remaining measures’ on the group of intensive dairy farms, see Table 9. It is assumed that the subsidy provokes a decrease of GHG emission on intensive dairy farms, equal to the sum of the GHG emission reduction of the group of remaining measures. At the same time the subsidy only covers the average MAC of “EF low concentrates and “Use of feed additive” on the group of extensive dairy farms, see Table 9. The tax on total GHG emission in the initial situation is determined in such a way that the “known” (approximated by the MAC and GHG mitigation potential of the selected standalone measures in Table 9) subsidy costs on GHG mitigation is covered. The farm level GHG emission abatement costs on intensive dairy farms is equal to 120.9 mio. Euro, as the sum of the abatement costs of the group remaining measures mentioned in Table 9. The farm level GHG emission abatement costs on extensive farms is equal to the sum of the measures “EF low concentrates and “Use of feed additive”. The average MAC on the group of extensive dairy farms of all other measures is above the assumed subsidy of about 61.4 euro per ton CO2-eq emission.

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The market based tax and subsidy policy in Table 11 results into a total GHG emission reduction of about 17%, while total farm income on sector level decreases with about 18%. The subsidy and tax system results into an income transfer from extensive farms to intensive farms. Farm income on extensive dairy farms decrease with about 19% while farm income on intensive dairy farms decrease with about 17%.

Table 11 Impacts of a cap and trade scenario and proportional GHG mitigation scenario on GHG mitigation and farm income per farm type and total

	Tax and subsidy scenario			Proportional GHG mitigation scenario		
	EXT	INT	Total	EXT	INT	Total
GHG emission base (MT CO2-eq) (A)	6.3	11.8	18.1	6.3	11.8	18.1
tax (Euro/ton CO2-eq) (B)	10.7	10.7				
Tax income (mio Euro) (C=A*B)	67.1	126.4	-193.5			
Subsidy (Euro/ton CO2-eq mitigated) (D)	61.4	61.4				
Mitigated GHG emission (MT CO2-eq) (E)	-0.6	-2.6	-3.1	-1.1	-2.1	-3.1
Subsidy costs (mio Euro) (F=D*E)	-36.0	-157.5	-193.5			
Changes in farm income, excl tax and subsidy (mio Euro) (G)	-35.0	-120.9	-155.8			
Farm income base (mio Euro) (H)	340.9	539.8	880.6	340.9	539.8	880.6
Change in farm income, incl tax and subsidy (mio Euro) (I=-C-F+G)	-66.0	-89.8	-155.8	-114.0	-88.8	-202.8
Updated farm income (J=H+I)	274.9	450.0	724.8	226.9	450.9	677.8
Updated GHG emission (K=A+E)	5.7	9.2	14.9	5.2	9.7	14.9
Mitigated GHG emission (%) (L)	-9.4	-21.7	-17.4	-17.4	-17.4	-17.4
Decrease farm income (%) (M)	-19.4	-16.6	-17.7	-33.4	-16.5	-23.0

Source: own calculations based on FarmDyn results from selected standalone GHG mitigation measures

As a comparison, the right panel of Table 11 shows that a proportional GHG emission reduction e.g. via a command and control system, of 17.4% on both extensive and intensive dairy farms would provoke a reduction in average farm income of about 33% and 17% respectively. These income effects are far below the income effects reported in table 9. Mitigation measures with highest MAC (especially reduction of milk yield and number of cows) are not implemented. The impact of the command and control scenario on farm income on intensive dairy farms is about equal to the tax and subsidy scenario. The advantage of the tax and subsidy scenario is more clear for the extensive dairy farms as more expensive GHG mitigation options are circumvented.

Results in Table 11 only give directions of possible scenario impacts as real impacts can only be analysed within an equilibrium framework with all possible GHG mitigation measures included simultaneously (Bakam et al., 2012; Lengers et al., 2014)

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2.7. Conclusions

The detailed bio-economic farm level model Farmdyn was used to assess impacts of different GHG mitigation options and policies on farm income and GHG emission on Dutch dairy farms. Regarding the GHG accounting in FarmDyn the most recent methodology for estimating GHG emissions from agriculture in the Netherlands is used. The methodology is as detailed as possible, based mostly on country specific information (Tier 2 and 3). The LMM GHG emission model uses farm specific data from the Dutch FADN and therefore greenhouse gas sources can be calculated with more precision than FarmDyn could do. For instance the use of different energy carriers like diesel, different gasses, electricity etc., but also the purchase of specific inputs like seeds and contract work. The main difference is that the FADN is a monitoring system and FarmDyn an optimalisation model. In FarmDyn the different greenhouse gas emissions are a result of model calculations and not from empiric results. It is however concluded that with respect to greenhouse gas methodology between LMM and FarmDyn the differences are minimal. The GHG emission accounting was used to assess the MAC of a selected number of standalone GHG mitigation options on groups of dairy farms in the Netherlands. The selected GHG mitigation options are based on literature and assumed feasible in the short to medium term. Costs of management practices to extent the number of lactations and increase lifetime of the cows are difficult to obtain from literature. So far a constant cost component per cow is included while revenue is coming from savings of feed costs and manure disposal costs from the farm. Under these settings, the measure appears especially relevant for intensive dairy farms in the Netherlands. An important finding is that overall the MAC of the selected GHG emission reduction options on extensive dairy farms exceeds the MAC on intensive dairy farms by far. Including more GHG mitigation options could change this picture, but overall it is concluded that market based policies are more efficient than command and control policies, with emission reduction targets the same for all farms. This further elaborated in Chapter 3 and 4.

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3. ADOPTION OF GHG MITIGATION MEASURES ON DUTCH DAIRY FARMS

3.1. Introduction

The reduction of GHG emissions from the agricultural sector depends on the available mitigation options and farmers' willingness to include those measures in their farm plan. Empirical evidence points to the complexity of farmers adoption behaviour regarding environmentally friendly farming practices like e.g. farmers' willingness to adopt GHG emission mitigation measures. Farmers' production choices and management decisions are not always exclusively based on economic incentives. For instance, even a profitable and climate-friendly innovation may not be adopted by farmers. Some European member state experts explain that in practice, changes in behaviour can be limited by the role of habits and/or traditions, especially when farmers have lower education (European Commission, 2018). What's more, many other factors influence adoption behaviour in various contexts, like perceived risks, perceived control, perceived costs and benefits, knowledge, as well as social factors (need for social approval, status, social comparison and etc.) and less-salient dispositional factors (resistance to change, personality, risk tolerance, moral and environmental concerns and etc.) (Dessart et al., 2019).

A survey among a sub-sample of Dutch dairy farms from the Dutch FADN was conducted to investigate farmers' willingness in adopting GHG reducing measures. The survey was designed based on the theory of the self-regulated stage model of behavioural change (SSBC) (Bamberg et al., 2011). The action of adopting GHG measures is reflected by four qualitatively different stages in the SSBC model (pre-decisional, pre-actional, actional, and post-actional) which are each influenced by constructs taken from the norm activation model and the theory of planned behaviour (Keller et al., 2019). In the actional stage, farmers are likely implementing mitigation measures. In the pre-actional stage, farmers are more prone to select which mitigation measures to adopt. Farmers that are in pre-decisional stage are most likely late adopters. Farmers that are in post-actional stage have already adopted GHG mitigation measures and are likely not going to adopt more GHG measures. We estimated what types of farms are in which stages based on the stage model.

The objective of this chapter is to present and discuss the survey and the survey results. Next, translation/application to all dairy farms in the Dutch FADN is discussed. Finally, it is discussed how the survey can be used in bio-economic farm models to define more realistic scenarios per group of dairy farms and the milk production sector as a whole.

Section 3.2 discusses the farm survey and results of the stage model, including a list of most preferred mitigation measures by survey respondents. Under certain assumptions related to the distribution of cognitive and behavioural factors and distribution of the four stages over all dairy farms in the Dutch FADN, the estimated stage model permits the calculation of the likelihood by which a certain dairy farm in the Dutch FADN is in one of the four stages. This will be explained in section 3.3. Section 3.4 discusses how the results of the survey could be used to define more realistic scenarios per group of dairy farms using the bio-economic FarmDyn model.

3.2. Farm Survey and Stage Model

A survey among a sub-sample of Dutch dairy farms from the national FADN was conducted to generate insights in farmers' willingness to participate in GHG reducing measures. A list of mitigation options that farmers could choose from was part of the survey. The list was based on Zijlstra et al. (2019), who

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prepared the mitigation measures based on experts' estimates on their suitability for Dutch dairy context and their impact on mitigating GHG emissions and farm profitability. The survey was designed based on the theory of the self-regulated stage model of behavioural change (SSBC) (Bamberg, 2013), which consists of a rich set of socio-psychological and socio-demographical factors in explaining a farmer's readiness for the adoption of mitigation options in general (Figure 8). The SSBC provides indications for what farmers are more likely to adopt GHG mitigation measure first, independent of exact GHG mitigation measure.

Based on the current adoption of GHG mitigation measures of 100 complete records (which is a sub-sample of Dutch FADN dairy farms), 7% participating farmers assign themselves to pre-decisional stage, 35% of surveyed farmers are in pre-actional stage, 8% of them are in actional stage and 50% of them are in post-actional stage (Wang, et al., 2022). An ordered probit model was used to evaluate the association of a rich set of socio-psychological and socio-demographical factors with farmers' stage in taking up climate mitigation measures (current adoption). Results are presented in Table 12. The dependent variable is the stage membership (based on current adoption of GHG mitigation measures) as indicated by the respondents in the survey, the independent variables are those in the 1st column. From the set of cognitive factors, only negative emotion was significantly and positively associated with stage membership (beta = 0.423, $p < 0.05$). For every unit increase in farmers negative emotion, the odds of being in a later SSBC stage increase with 52.7%, *ceteris paribus*. From the set of behavioural factors, action planning on 'how to' implement the mitigation measures has a statistically significant positive association with stage membership (beta = 0.387, $p < 0.05$).

For the socio-demographical factors, age has a significant inverted U-shaped relation with farmer adoption behaviour of climate mitigation measures (at the critical 5% level). The optimal age is 50 years for Dutch dairy farmers to participate in climate mitigation measures. Farmer whose age is further away from 50 has less tendency in adopting GHG mitigation measures than those that are close to 50 years. Regarding education level, farmers with basic agricultural education are more likely to be in the later stages of the behavioural change process (beta = 0.379, $p < 0.01$) compared to farmers with only practical farming experience. However, farmers with full agricultural education are even less likely to be in the later stages (beta = −0.183, $p < 0.01$) than farmers with only practical farming experience. Moreover, livestock density was significantly and positively associated with SSBC stage (beta = 0.337, $p < 0.1$), while yearly farm income was not.

Another crucial outcome of the survey was a ranking of GHG emission mitigation options farmers would prefer to implement in the near future (Table 13). Farmers could only choose one measure from the list. It should be clear that the preferred option can be different from the GHG mitigation measures already applied at the farm (current adoption). Among the higher-ranking options were the inclusion of leguminous plants in the grassland management options and thus in the animal feed ration, production of renewable energy on farms, increase in feed efficiency and decrease artificial N-fertilizer. Preferred options appeared differently depending on farm structure (e.g., number of livestock units per ha) and farmers' characteristics (e.g., age and education level).

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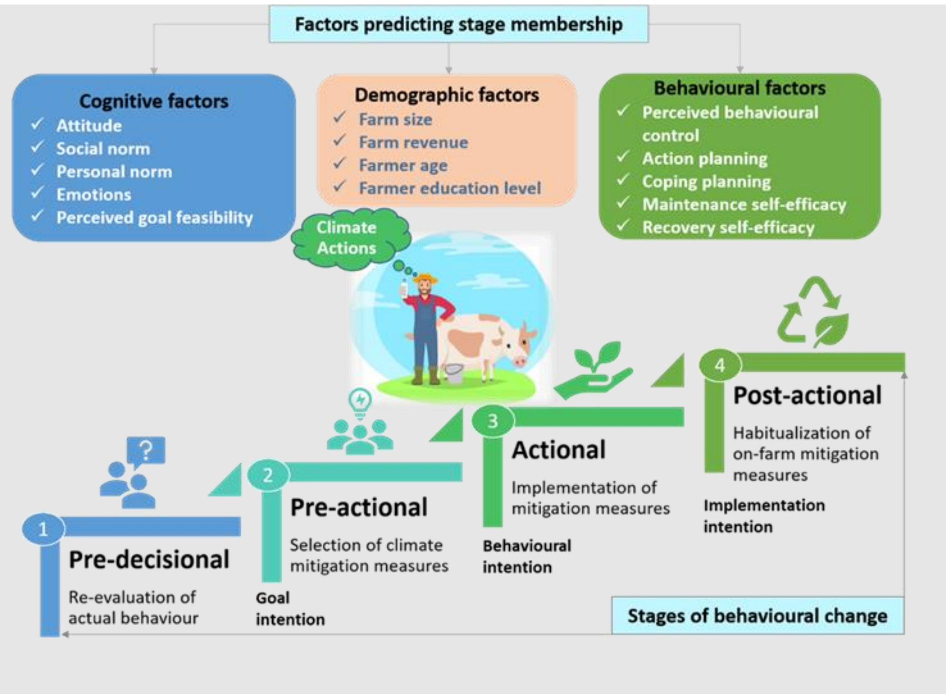

Figure 8 Self-regulated model of behavioural change (adapted from Bamberg, 2013) (Wang, et al., 2022)

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Table 12 Ordered probit model results for adopting climate mitigation measures (Wang, et al., 2022)

	Dependent variable: Stage membership			
	Coefficients (SE)	P-value	95% CIs	Odds ratio
Cognitive factors				
Positive emotion	-0.186 (0.186)	0.318	-0.550, 0.179	0.831
Negative emotion	0.423** (0.178)	0.017	0.075, 0.772	1.527**
Perceived social norm	0.110 (0.208)	0.597	-0.297, 0.517	1.116
Personal norm	0.185 (0.215)	0.389	-0.236, 0.606	1.203
Perceived goal feasibility	0.288 (0.177)	0.105	-0.060, 0.636	1.334
Attitude	-0.283 (0.226)	0.210	-0.725, 0.160	0.754
Behavioural factors				
Perceived behavioural control	0.163 (0.214)	0.446	-0.257, 0.583	1.177
Action planning	0.387** (0.169)	0.022	0.055, 0.718	1.472**
Coping planning	0.362* (0.218)	0.097	-0.065, 0.789	1.436*
Maintenance self-efficacy	-0.144 (0.191)	0.450	-0.518, 0.230	0.866
Recovery self-efficacy	-0.283 (0.196)	0.150	-0.668, 0.102	0.754
Socio-demographical factors				
Age	0.107** (0.041)	0.010	0.025, 0.188	1.113**
Age squared	-0.001** (0.0005)	0.019	-0.002, -0.000	0.999**
Basic agricultural education	0.379*** (0.025)	0.000	0.331, 0.428	1.461***
Full agricultural education	-0.183*** (0.051)	0.000	-0.283, -0.082	0.833***
Yearly family farm income	-0.004 (0.013)	0.722	-0.029, 0.020	0.996
Livestock density	0.337* (0.175)	0.054	-0.005, 0.680	1.401*
Intercepts				
1|2	4.088***(0.024)	0.000		
2|3	5.697***(0.236)	0.000		
3|4	5.945***(0.237)	0.000		
Observations			100	
Note:			$^{*}p<0.1$ $^{**}p<0.05$ $^{***}p<0.01$	

Pseudo-R2 (McFadden): 0.153;
Residual Deviance: 186.666; AIC: 226.666

Table 13 List of most preferred mitigation measure by survey respondents

Below is the list of climate mitigation measures presented to farmers; Survey respondents were asked to tick the measure that he/she prefered the most to achieve their future emission reduction target on the farm.	Total count	Frequency
Combine more leguminous plants (e.g. clover) with grass in the ration	19	17.12%
Production of renewable energy (solar energy, biogas, wind energy)	18	16.22%
Increase in feed efficiency (less losses, more frequent feeding)	16	14.41%
Decrease artificial N-fertilizer	13	11.71%
Decrease concentration share in ration	9	8.11%
Measures other than those mentioned above	8	7.21%
Energy-saving technologies	7	6.31%
Higher milk production per cow	4	3.60%
Increase in share of maize in ration	4	3.60%
Emission-reducing floor	3	2.70%
Reduce renewal rate of grassland	3	2.70%
no meaures	3	2.70%
Use of renewable energy	2	1.80%
less young stock	2	1.80%
Sum	111	100%

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3.2.1. Application to individual dairy farms in the Dutch FADN

The cognitive and behavioural factors tested are not recorded in the Dutch FADN. While it is possible to apply GHG mitigation scenarios to the farms in the survey only, extending the analysis to a larger number of farms as available from the Dutch FADN would account for the heterogeneity in a larger sample of farms. Therefore, we have investigated the associations of the socio-demographical factors with each mitigation measures asked in the survey using a multinomial logistic regression model. The results are shown in Table 14.

To allocate individual dairy farms in the Dutch FADN to a certain stage it is assumed that a) cognitive and behavioural factors are identically and independently distributed and stage membership is completely determined by socio-demographical factors and b) the share of farms' membership in BIN is equal to the survey. To explain this further, farmers in actional and post actional stages tend to be around age of 50, have at least a basic formal agricultural education level and a high livestock density. These factors are captured by the socio-demographic coefficients shown in Table 12, which permit calculating a combined indicator. The socio-demographic factors available in the Dutch FADN (or BIN) are multiplied with the respective coefficients in Table 14 to calculate a combined indicator for the farm membership per stage. When determining a threshold for the stage membership, it is assumed here that the distribution of stage memberships in BIN is similar to the distribution in the sample, i.e. that 50% of the farms are post-actional and further 8% are actional (Figure 9).

Table 14 Multinomial logistic regression model results

	Dependent variable:												
	Decrease artificial N fertilizer	Decrease concentration share in ration	Emission reducing floor	Energy saving technologies	Higher milk production per cow	Increase feed efficiency	increase share of maize in ration	less young stock	more leguminous plants	other measures	Production of renewable energy	Reduce renewal rate of grassland	Use of renewable energy
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Family_farm_income	-0.033	-0.171*	0.059	-0.299**	-0.288**	-0.062	-0.160	-0.088	-0.052	-0.051	-0.053	0.017	-0.070
	(0.068)	(0.092)	(0.064)	(0.138)	(0.146)	(0.070)	(0.118)	(0.140)	(0.064)	(0.075)	(0.068)	(0.064)	(0.114)
Age	-2.196***	-2.041***	-1.556***	-0.550***	2.581***	-2.292***	1.933***	1.390***	-0.650***	-2.124***	-1.931***	1.841***	1.442***
	(0.132)	(0.136)	(0.197)	(0.149)	(0.222)	(0.134)	(0.188)	(0.237)	(0.139)	(0.138)	(0.130)	(0.215)	(0.227)
I(Age2)	0.017***	0.015***	0.013***	0.005**	-0.030***	0.017***	-0.017***	-0.015***	0.004*	0.017***	0.015***	-0.019***	-0.012***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.004)	(0.002)	(0.003)	(0.004)	(0.002)	(0.002)	(0.002)	(0.004)	(0.004)
Livestock_density	-0.780**	-1.536***	-1.240***	-0.594**	1.225***	-0.871**	-1.343***	-0.163***	-1.235***	-2.548***	-0.228	-1.360***	-2.354***
	(0.386)	(0.114)	(0.046)	(0.267)	(0.064)	(0.420)	(0.025)	(0.032)	(0.442)	(0.129)	(0.295)	(0.034)	(0.017)
Education_level_s_l2	-24.930***	-1.469***	57.085***	-4.467***	-16.633***	16.399***	-4.898***	-22.504***	16.652***	56.953***	-23.881***	-5.760***	-3.651***
	(0.000)	(0.000)	(0.009)	(0.000)	(0.000)	(0.022)	(0.000)	(0.000)	(0.029)	(0.023)	(0.000)	(0.000)	(0.000)
Education_level_s_l3	1.319***	47.601***	42.425***	30.519***	-2.108***	1.577***	5.619***	-1.418***	2.101***	41.749***	1.594***	4.033***	3.538***
	(0.041)	(0.005)	(0.011)	(0.004)	(0.013)	(0.011)	(0.006)	(0.017)	(0.022)	(0.022)	(0.031)	(0.008)	(0.008)
Constant	72.192***	24.590***	4.498***	-11.404***	-50.136***	77.079***	-54.709***	-29.235***	28.636***	32.324***	63.949***	-43.718***	-40.511***
	(0.004)	(0.005)	(0.006)	(0.004)	(0.009)	(0.006)	(0.006)	(0.008)	(0.004)	(0.005)	(0.004)	(0.008)	(0.007)
Note:	*p**p***p<0.01												

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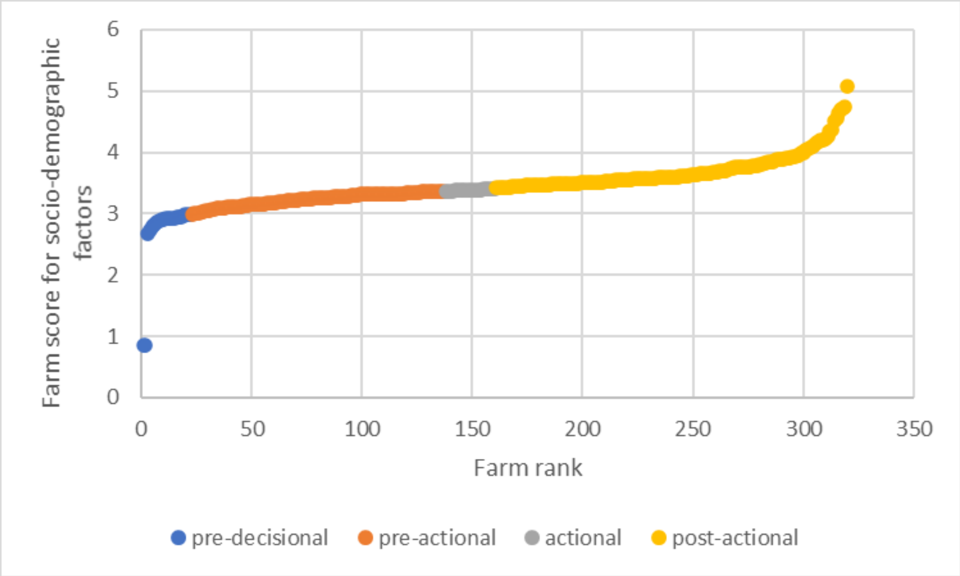

Figure 9 Farm specific score for socio-demographic factors

A similar approach is chosen when ranking the preferred GHG mitigation measures in the survey. Figure 10 below shows that this approach delivers a reasonable comparable distribution with the results based on the sub-sample of farms in the survey.

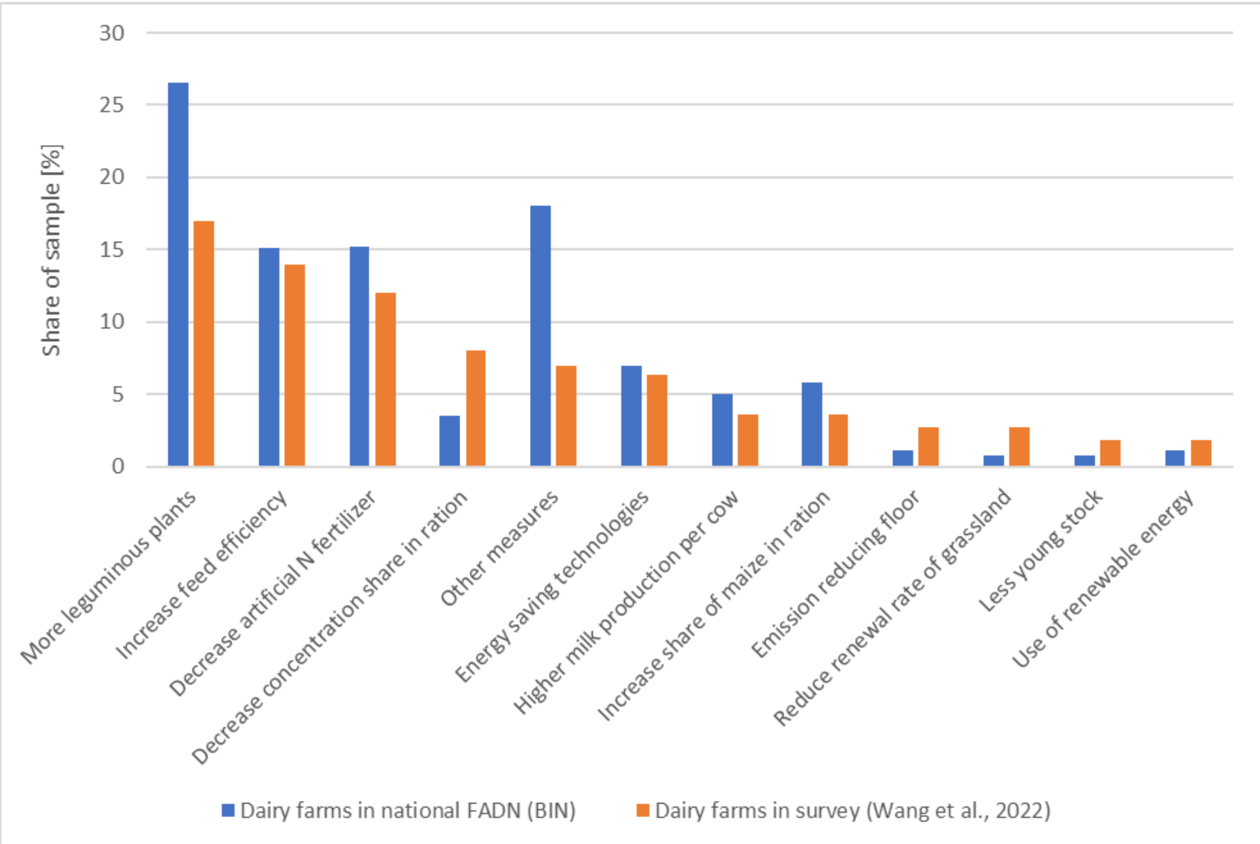

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Figure 10 Preferred mitigation measures by all dairy farms in the survey and calculated scores based on Dutch FADN (BIN)

3.3. Scenario definition

3.3.1. Implementation of survey results

While the cognitive and behavioural factors tested in Table 12 are not recorded in the Dutch FADN, it appeared possible to estimate stage membership of all dairy farms in the Dutch FADN, using the socio-demographic factors. The livestock density appeared to be the most relevant factor to explain current stage membership and the willingness to adopt first. This points at the relevance to distinguish groups of dairy farms by intensity. At the same time this result is consistent with the MAC analysis in chapter 2. The average MAC of the analysed GHG mitigation options on the group of intensive farms appear far below the average MAC of the group of extensive farms. This can be implemented in the sample construction of FarmDyn, distinguishing between intensive and extensive dairy farms. Scenarios can be developed that include enforced mitigation measures for the group of intensive dairy farms, while these measures are not assumed on the group of extensive dairy farms. Preferred GHG mitigation options as decreased use of N from mineral fertilizer and decrease concentration share in ration are endogenous options in FarmDyn. Selected enforced mitigation measures are discussed in chapter 2 and can be found in the ranking of GHG mitigation measures in Table 13.

3.3.2. Scenario definition

Chapter 4 will present scenario results following a combined GHG mitigation measures approach. This is done via carbon prices with all endogenous mitigation technologies available and the selected enforced GHG mitigation options per farm group. Combining results of chapter 2 and chapter 3 the following scenarios are defined:

Scenario 1 (CO2 sub 65 E/t): Implementation of a CO2-eq emission subsidy on all farm groups in the sample:

- Tax equal to 65 euro per ton CO2-eq
- No enforced mitigation measures included

Scenario 2 (CO2 sub 130 E/t): Implementation of the CO2-eq emission subsidy on all farm groups in the sample:

- Tax equal to 130 euro per ton CO2-eq
- No enforced mitigation measures included

Scenario 3 (CO2 sub 65 E/t + MIT): Implementation of the CO2-eq emission subsidy scenario on all farm groups in the sample:

- Subsidy equal to 65 euro per ton CO2-eq
- Bovaer, extended lactation and permanent grassland as GHG mitigation options enforced on all intensive dairy farms in the sample
- Bovaer as GHG mitigation option enforced on all extensive dairy farms in the sample

Scenario 4 (CO2 sub 130 E/t + MIT): Implementation of the CO2-eq emission subsidy scenario on all farm groups in the sample:

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- Subsidy equal to 130 euro per ton CO2eq
- Everything else equal to scenario 3

Sensitivity analysis/Scenario 5 (CO2 sub 130 E/t + MIT + LMY)): Implementation of the CO2-eq emission subsidy scenario on all farm groups in the sample:

- lower milk yield enforced on all farms in the group of intensive dairy farms
- everything else equal to scenario 4

The stand-alone assessment of GHG mitigation measures in Chapter 2 indicates that under a CO2-eq emission subsidy of 130 euro per ton CO2eq, the extended lactation GHG mitigation measure could also be interesting for extensive dairy farms. This measure is however only included for intensive farms as it is expected that prices of young female calves will decline (Pérez et al., 2020). This increases the MAC of the extended lactation measure and lower prices of young female calves would quickly make the measure less interesting for extensive dairy farms. The sensitivity analysis regarding milk production per cow is included to show the tradeoff between decreased number of dairy cows and decreasing milk yield. Different preferred GHG mitigation options mentioned in this chapter could also lead to lower milk yield especially less use of concentrates, less youngstock, more clover in grassland and reduction of renewal rate of grassland.

3.4. Discussion and conclusions

This survey study explored the adoption behaviour of Dutch dairy farmers for climate change mitigation measures using a self-regulated stage model of behavioural change (Wang, et al., 2022). The empirical analysis assessed the statistical associations of a rich set of socio-psychological and socio-demographical factors with Dutch dairy farmers' adoption of climate change mitigation measures. Approx. 50% of the farmers in our sample assigned themselves to the post-actional stage, while 35% claimed to be in the pre-actional stage. Another 8% of them were in the actional stage and 7% were in the pre-decisional stage. Our regression results show that negative emotion related to taking no climate mitigation measures, as well as action planning and coping planning are significantly and positively associated with the likelihood that farmers being in later stages, in which they have already adopted climate mitigation measures (Wang, et al., 2022). Furthermore, farmers below and up to 50 years old with basic agricultural education and farms with high livestock density are found to be significantly and positively associated with later stages in the SSBC model (Wang, et al., 2022).

This survey study suggests the effectiveness of 'soft' behavioural policy interventions targeting farmers' adoption of climate mitigation measures. An important precondition for our policy recommendations relates to the fact that the GHG emission mitigation measures in our survey are cost-effective for Dutch dairy farmers (Zijlstra et al., 2019). Communication campaigns should highlight farmers' negative emotions associated with not taking climate mitigation measures. For example, confronting farmers with the negative consequences on climate from their farming practices could evoke negative moral emotions such as guilt or shame (Rees et al., 2015). Smart framing plays an important role in this light, considering Dutch farmers long for a more positive framing in the media (Gomes & Reidsma, 2021). Additionally, policy makers should facilitate action planning and coping planning for reducing farming related GHGs emissions. This can be achieved through farm extension services in supporting farmers with planning on 'how to' implement selected mitigation measures and plans to cope with potential obstacles during the implementation stage. Finally, it may be useful to target farmers younger than 50 years old, with full agricultural education level and farms with low livestock density.

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The self-regulated stage model of behavioural change provides a rich theoretical framework to investigate the role of socio-psychological and socio-demographical factors in predicting farmers' stages in taking up climate mitigation measures. Significant predicting factors are suggested to be pointers of intervention for future studies. In order to further estimate all Dutch FADN dairy farmers' stage membership in taking up climate mitigation measures, we used only the socio-demographical factors as they are registered in the FADN database. In addition, we were able to estimate preferred climate mitigation measures for all FADN dairy farmers based on the results of the survey farmers' preferences.

4. FARM-LEVEL ASSESSMENT OF GHG TAXATION AND MITIGATION OPTIONS

4.1. Introduction

Grassland plays an important role in the Dutch livestock sector, namely in the North-Western regions, where fresh grass and gras silage accounts for more than 50% of the dry matter composition of the animal rations (CBS 2021). From a climate perspective, the optimization of the grass-based animal rations have a potential to reduce methane emissions from enteric fermentation, while the grassland itself serves as a sink for carbon. Depending on the management practices, methane emissions can be reduced by timely harvests (de Vries et al., 2018), carbon storage can be improved, for instance by controlling groundwater levels, and the introduction of clover can increase the nitrogen content of the grassland outputs, thus reducing the share of protein-rich concentrates and the associated up-stream GHG emissions in the places where the concentrates are produced. Due to the importance of grassland in Dutch livestock production and the potential to contribute to climate change mitigation measures, grassland management options receive a lot of attention in Dutch climate change mitigation scenarios (de Vries, 2018, Leschen at al., 2020).

Model-based analyses of the proposed grassland management options to identify environmentally and economically viable combinations of measures requires detailed information about a range of decision variables at farm level, for both, existing and potential practices. The nitrogen content of the harvested grass depends, among other, on the amount of nitrogen from chemical fertilizer and animal manure applied to the fields, the season, the number of mowing events in the case of silage, and time between the mowing events. Despite the importance of grassland management options, this information is usually not obtainable from farm level statistics. Sources like the "Landelijk Meetnet effecten Mestbeleid" (LMM), which is based on the Dutch Farm Accountancy Data Network (FADN) provide indirect information on average grassland yields and fertilizer applications at farm level, but does not allow identifying a detailed range of possible management practices that were applied at the sampled farms. To identify the range of management practices, researchers often have to rely on agronomic information from handbook data on good practices, which permit the specification of average grassland management options across all farmers in a region or country.

Grassland-related policy assessments using simulation models can therefore benefit greatly from more refined specifications of grassland management options. The solution proposed here is based on the combined use of farm-level statistics, agronomic information from handbook and satellite images. The Dutch AgroDataCube project (Janssen et al., 2018) comprises a wide range of spatial datasets, including satellite images that permit an assessment of the number of cuts and cumulative yields at plot level. The satellite-based information at plot level is combined with farm level statistics on average grass yields and total nitrogen from chemical fertilizer and animal manure from LMM. By using a cross-entropy method, it is possible to ensure compliance of the final results with both databases as well as agronomic data about e.g. plausible ranges of fertilizer application rates per dry-

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matter yield. Based on this, farm and region-specific response curves of grassland yields are derived, which depend on fertilization level and the number of mowing events. Nutrient contents of the dry matter are taken from Dutch feed standards (Voedernormen) and depend on time between cuts indicated by the satellite images. The created database is used as an input for the bio-economic farm optimization model FarmDyn (Britz et al., 2016), and permits the modelled farms to choose an optimal combination of grassland management options with regard to fertilization levels and number of cuts, while meeting the nutrient requirements of their animal herds. Several policy options are tested, which aim at the reduction of nutrient losses and GHG emissions from agriculture.

The main objectives of this chapter is to provide information on the data required to enrich the representation of grassland in the model. We will apply FarmDyn to run scenarios in the GHG mitigation reduction in line with findings of chapter 2 and chapter 3. Results will especially focus on the potential reduction of up-stream emissions from purchased feed and to which extent the purchased feed can be replaced by grass-based feeds of similar qualities. Required information are the nutrient contents of the harvested grass in different management systems, the nitrogen fertilizer requirements, the cost associated with the higher number of cuts, and the circumstances under which farmers could be willing to switch from prevalent management systems to more intensive ones. Section 4.2 provides an overview of what is needed in Farmdyn to parameterize the new grassland management options and the methods and data used. Section 4.3 presents scenario results. Section 4.4 elaborates on policy design, discussing the impact of market based policies including a system of subsidies on GHG emission reduction and taxes on reference GHG emission levels. Section 4.5 finalises with discussion and conclusion.

4.2. Methods and Data

4.2.1. Grassland Data in the FarmDyn Model

Grassland management in FarmDyn is represented by two parameters. The first includes total dry-matter yield of each management system and the distribution of the grassland outputs over types of outputs and the months.

	DM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
yield	8.50												
earlyGraz				10.00	15.00								
middleGraz						20.00	20.00						
lateGraz								15.00	10.00	10.00			
earlyGrasSil													
middleGrasSil													
lateGrasSil													
hay													

Source: FarmDyn grassland options table, screenshot from FarmDyn GUI

The second parameter includes information on the nutrient contents of the different grassland outputs. By default, FarmDyn distinguishes three silage options and three grazing options, depending on the stage of the grazed or harvested grass in the growth cycle. For instance, "early" means that the

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grass is in an early stage of the growth cycle, with a possibly higher content of raw protein than later harvested grass.

	DM"Dry Matter"	XF"Crude Fibre"	aNDF"Structured Fibre"	XP"Crude Protein"	nXP"Usable raw protein"	RNB"N-Ratio in Rumen"	NEL"Net energy lactation"	ME"Metaolisable energy"
earlyGraz	150.00	170.00	380.00	215.00	152.00	10.00	7.06	11.
middleGraz	180.00	240.00	490.00	172.00	137.00	6.00	6.02	11.
lateGraz	200.00	275.00	550.00	150.00	130.00	3.00	5.78	9.
earlyGrasSil	350.00	192.00	410.00	190.00	149.00	7.00	6.65	10.
middleGrasSil	350.00	190.00	410.00	188.00	141.00	7.00	6.20	10.
lateGrasSil	350.00	258.00	510.00	160.00	129.00	5.00	5.66	9.
hay	860.00	315.00	606.00	98.00	118.00	-3.00	5.27	9.

Source: FarmDyn grassland nutrient content table, screenshot from FarmDyn GUI

Including a wider range of grassland management strategies requires data for these two tables discussed in this section. The major sources for information are the Dutch FADN and handbooks on good feeding practices, as explained in the following sections

4.2.2. Farm-level statistics (BIN and LMM)

The Farm Accountancy Data Network (FADN) contains data on the economic results of farmers from a sample covering all member states of the European Union (EU). This data is used by the EU to monitor the current state of affairs, to evaluate existing policy measures and to evaluate new policies. FADN is the only source of microeconomic data based on harmonised bookkeeping principles. It is based on national surveys and only covers EU agricultural holdings which, due to their size, can be considered commercial. Data for the Netherlands is collected using the "Bedrijveninformatienet" (BIN), a network consisting of around 1500 agricultural and horticultural enterprises.

The dataset "Landelijk Meetnet effecten Mestbeleid" (LMM) consists of a sample of 450 farms within the BIN. It's main purpose is to describe and explain groundwater quality in relation to environmental pressure and policy measures and to permit exploratory research regarding changes in agricultural practices and their consequences for groundwater quality.

LMM provides, among others, information on average grassland yields, fertilizer applications, and dominant soil types at farm level. Average grassland yields from 2006 to 2019 for the four typical soil types are shown in Figure 11. Grassland yields range between 8 and 12 t/ha, and while there is no obvious difference in yields across the soil types, it has to be noted that 2018 was a very poor year due to the extensive summer draught, and 2019 and 2017 tend also to be low compared to previous years.

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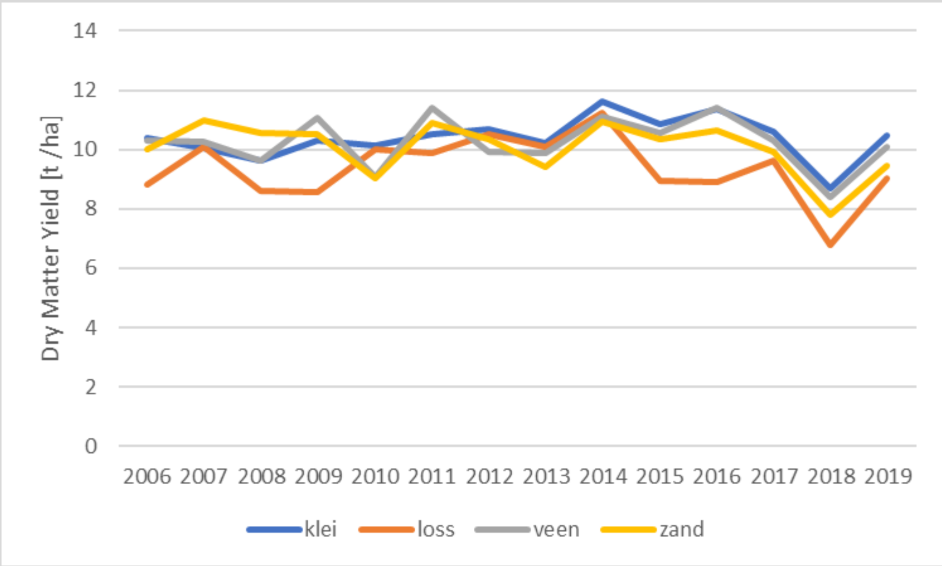

Figure 11 Dry matter yield of grassland by dominant soil type

The LMM data provides important information to parameterize observed grassland management options in FarmDyn, but does not allow identifying details about alternative grassland management practices at the sampled farms.

4.2.3. Process data (Handboek Melkveehouderij, voederwaarden)

Management handbook related to dairy farming among others include data describing number of growing days needed to produce a certain quantity of grass (kg dry matter (dm) per ha) as a function of effective nitrogen input, number of cuts and total number of growing days per year. These data are used to determine grassland yield (kg dry matter (dm)) and ingredients per kg of dm for grassland management strategies that are differentiated by fertilization level and number of cuts. The grassland yield is harvested different times per year, depending on the number of cuts, see first screenshot in section 4.2.1.

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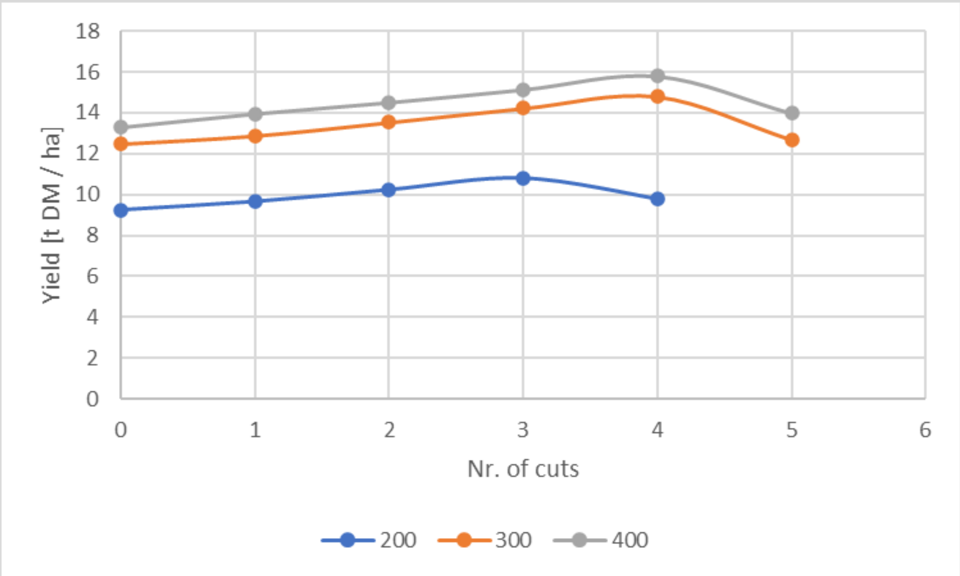

Figure 12 Dry matter yield of grass silage by number of cuts and fertilization level (in kg N / ha)

Source: Remmelink et al. (2020)

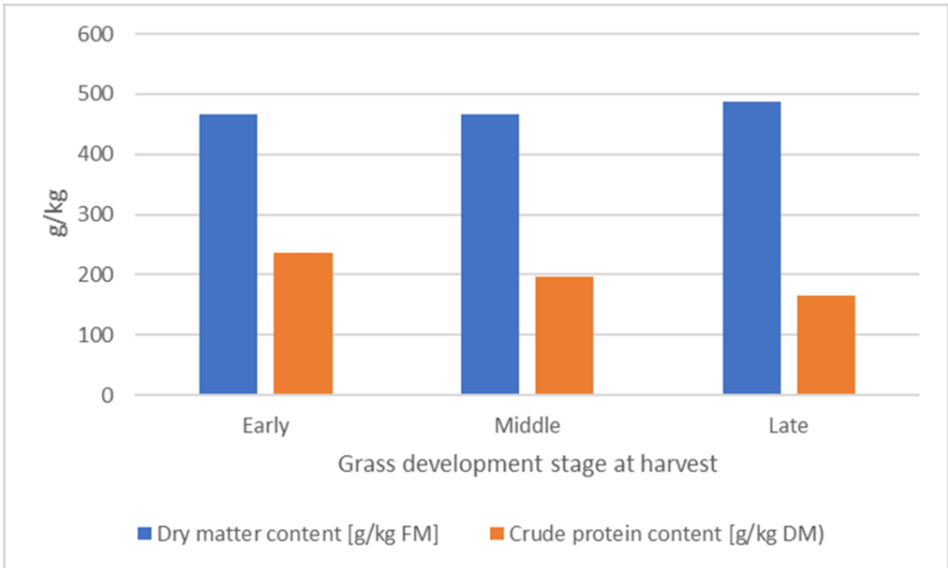

Figure 13 Dry matter and protein content of grass silage harvested at different stages

Source: Duinkerke et al (2016)

4.2.4. Satellite data

Green Monitor

The Green Monitor data platform (www.groenmonitor.nl) started in 2012 to map the Netherlands with high resolution satellite imagery. The Netherlands Space Office (NSO) in collaboration with the Ministry of Economic Affairs started the Netherlands Satellite Data Portal initiative to encourage Dutch companies and research institutions and other public institutions to get ready for the operational phase of the Sentinel-2 missions by investing money to make similar satellite data as the Sentinels

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already available for the Dutch public. This in order to encourage the collaboration between industries, research institutes and end users to speed up operational applications. The Green Monitor is developed as an easy-to-use webtool for visualization and interpretation of time series of NDVI satellite images covering the Netherlands.

The Green Monitor offers two major advantages over standard time series of Sentinel-2 images:

Highly accurate cloud and shadow detection masking by using AI techniques (for pattern recognition) and an additional manual check for hazy cloud patterns. High quality errorfree time series of satellite data are crucial when abrupt changes (like grass mowing) are the subject of research, as cloud contamination causes similar abrupt changes in the signal.

Additional Landsat images are merged in the time series of NDVI images to increase the temporal resolution. The NDVI images are calibrated against the Sentinel-2 images.

The average spectral and VI values per parcel are stored in the AgroDataCube, together with other open data, like weather data, soil data and DEM data.

Figure 14: Screenshot of the green Monitor, where the graph highlights 5 mowing cuts as sharp dips in the NDVI curve of the selected grassland parcel

Source: screenshot www.groenmonitor.nl

AgroDataCube

Many valuable open data sources are available for the Netherlands that can improve data science and decision making in agriculture and food. However, these data sources are still scattered and are published using a range of different, standardized, and non-standardized formats and protocols. This means that substantial efforts are required to find, collect, and combine such data repeatedly, to feed the many applications that use such data. The AgroDataCube functions as a hub that brings together these heterogeneous data streams, enriches them, adding in-house analytics, and publishes the result as harmonized, up-to-date, standardized datasets accessible through an open REST API (agrodatacube.wur.nl).

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In 2018, version 2 of the AgroDataCube has been developed. Through integration with Green Monitor, the AgroDataCube now also provides a remote sensing-based vegetation index (NDVI) at sub-parcel resolution. Such vegetation indices are used for research, e.g., crop modelling and yield forecasting, by farmers to monitor the development of their crops, or to monitor agricultural practice, e.g., complying with CAP regulations.

The approach: Merge, harmonize and publish

Many distributed data services relevant for the agri-food domain already feed into the AgroDataCube. These sources are heterogeneous about different aspects. While for instance remote sensing data or weather data are voluminous, available daily and are processed near-real time, soil data and parcel data are smaller and relatively static. The AgroDataCube automatically structures and harmonizes the incoming data streams and links their spatial and temporal dimensions. This means that for example time-series of weather data or NDVI (Normalized Difference Vegetation Index) data can be retrieved on the level of agricultural parcels. Data is delivered in a standardized format and therefore easily reusable, for instance in data analytics tools and decision support systems.

AgroDataCube currently provide data services that publish spatially and temporally explicit data from the following resources:

- Agricultural parcels and parcel attributes (parcel geometries and crop information from BRP, AAN)
- Soil data (Soil map 1:50.000, BOFEK)
- Weather data (observations from KNMI stations)
- Elevation (AHN)
- Administrative regions (NUTS and postal codes)
- Green Monitor satellite data
- NDVI, WDVI vegetation indices (mean and standard deviation)
- Grassland markers: mowing dates, ploughing date, management intensity
- Arable land markers: ploughing date, sowing date, emergence, harvest, catch crop
- Radar coherence (Sentinel-1)

The ADC is filled near real-time with current data (weather data, green monitor satellite data), so that the current situation in the field is always available and there is a perspective for action.

The AgroDataCube is an innovation in big open data. It is one of the first real results of combining data from different batches and make them unequivocally available to the user. It is based on open data principles and is open documented.

The AgroDataCube:

- makes an innovative contribution to the aspect of interoperability of data in the agri-food domain
- is of great importance for different interest groups
- makes new research and new business and consumer-oriented solutions

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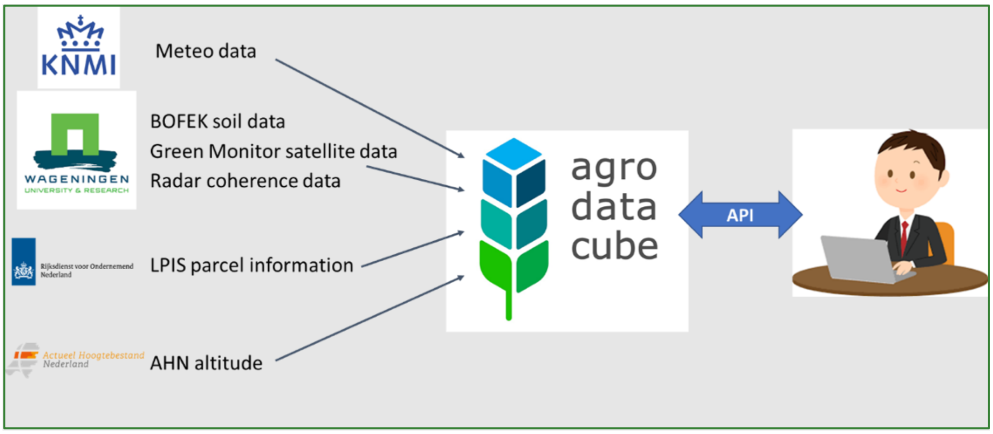

Figure 15: Schematic representation of the AgroDataCube

Source: Own compilation.

							Mowing cut (day of year)						Quality (period of days)											
Crop_type	Farm_ID	Field_ID	Area (m2)	no_sat_img	no_25m_pix	no_mowing_cut	1	2	3	4	5	6	1	2	3	4	5	6	cum_NDVI	avg_NDVI	max_NDVI	min_NDVI	cum_height	NDVI_winter
Permanent grassland	205177477	8630084	24310	25	4	3	155	208	251	0	0	0	22	29	13	0	0	0	1.35	0.76	0.94	0.47	43.22	0.88
Permanent grassland	205177477	8630382	25065	25	10	2	133	211	0	0	0	0	19	13	0	0	0	0	1.26	0.82	0.91	0.59	40.46	0.90
Permanent grassland	205177477	8630385	16219	27	9	2	198	251	0	0	0	0	19	13	0	0	0	0	1.04	0.81	0.91	0.65	31.75	0.83
Permanent grassland	205177477	8630837	46476	27	40	3	183	211	243	0	0	0	28	13	7	0	0	0	1.62	0.82	0.92	0.47	57.38	0.87
Permanent grassland	205177477	8725958	4697	24	1	2	211	238	0	0	0	0	13	2	0	0	0	0	1.40	0.59	0.88	0.32	32.16	0.44
Permanent grassland	205177477	8726238	68824	29	54	2	155	179	0	0	0	0	22	18	0	0	0	0	1.03	0.72	0.93	0.50	27.30	0.90
Permanent grassland	205177477	8726702	23604	25	12	1	211	0	0	0	0	0	13	0	0	0	0	0	0.97	0.75	0.88	0.49	20.23	0.84
Permanent grassland	205177477	8726704	28162	25	11	1	208	0	0	0	0	0	47	0	0	0	0	0	0.85	0.78	0.94	0.58	14.30	0.86
Permanent grassland	205177477	8726705	27777	26	12	2	155	208	0	0	0	0	24	29	0	0	0	0	1.05	0.79	0.94	0.59	39.21	0.85
Permanent grassland	205177477	8726706	30749	24	11	1	208	0	0	0	0	0	47	0	0	0	0	0	0.89	0.79	0.92	0.46	13.54	0.85
Permanent grassland	205177477	8726708	116003	30	133	1	179	0	0	0	0	0	11	0	0	0	0	0	1.02	0.71	0.94	0.41	22.43	0.89
Permanent grassland	205177477	8820256	12183	25	3	2	211	243	0	0	0	0	13	7	0	0	0	0	1.19	0.78	0.89	0.54	33.99	0.82
Permanent grassland	205177477	8820260	38889	27	12	1	179	0	0	0	0	0	24	0	0	0	0	0	1.23	0.73	0.93	0.44	31.91	0.85
Permanent grassland	205177477	8821004	10466	24	1	2	211	253	0	0	0	0	13	15	0	0	0	0	1.18	0.80	0.91	0.60	35.64	0.82
Permanent grassland	205177477	8821479	25053	26	6	1	226	0	0	0	0	0	18	0	0	0	0	0	1.01	0.81	0.92	0.64	24.33	0.88
Permanent grassland	205177477	8821480	5765	25	1	4	133	161	211	238	0	0	22	6	13	4	0	0	1.55	0.67	0.82	0.48	37.89	0.80
Permanent grassland	205177477	8821751	86335	27	76	2	211	243	0	0	0	0	13	7	0	0	0	0	1.02	0.80	0.93	0.63	22.71	0.87
Permanent grassland	205177477	8915499	23457	26	14	2	198	243	0	0	0	0	19	7	0	0	0	0	1.10	0.79	0.94	0.59	32.24	0.88
Permanent grassland	205177477	8915487	52320	29	31	3	161	183	211	0	0	0	28	15	13	0	0	0	1.33	0.78	0.92	0.52	37.68	0.88
Permanent grassland	205177477	8915928	17634	25	11	1	198	0	0	0	0	0	37	0	0	0	0	0	0.80	0.75	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	8916651	6398	24	1	2	211	251	0	0	0	0	50	13	0	0	0	0	1.27	0.74	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	8916652	75668	30	53	3	151	186	226	0	0	0	18	18	18	0	0	0	1.30	0.75	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	8916653	29484	25	24	1	211	0	0	0	0	0	13	0	0	0	0	0	0.77	0.74	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9009756	58032	25	40	2	211	253	0	0	0	0	13	15	0	0	0	0	1.10	0.79	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9010019	23967	25	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.72	0.82	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9010020	31316	28	11	2	183	253	0	0	0	0	15	15	0	0	0	0	1.05	0.83	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9010762	33176	25	7	2	198	253	0	0	0	0	37	15	0	0	0	0	1.07	0.81	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9105664	24363	25	9	1	211	0	0	0	0	0	13	0	0	0	0	0	0.92	0.81	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9105907	21694	28	14	2	151	251	0	0	0	0	37	13	0	0	0	0	1.07	0.82	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9106352	45574	29	28	2	151	179	0	0	0	0	18	18	0	0	0	0	1.24	0.70	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9200258	34313	25	23	2	211	243	0	0	0	0	13	7	0	0	0	0	1.06	0.77	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9201255	22308	28	13	1	251	0	0	0	0	0	13	0	0	0	0	0	0.89	0.83	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9294785	36039	25	27	1	211	0	0	0	0	0	13	0	0	0	0	0	0.99	0.79	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9294786	23099	26	5	3	155	198	243	0	0	0	22	19	7	0	0	0	1.23	0.73	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9295068	35894	28	17	1	179	0	0	0	0	0	18	0	0	0	0	0	0.80	0.69	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9295070	29715	24	1	2	198	211	0	0	0	0	43	3	0	0	0	0	1.00	0.73	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9295546	19962	28	13	3	108	151	243	0	0	0	2	37	7	0	0	0	1.43	0.69	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9295548	23820	26	6	2	161	211	0	0	0	0	28	13	0	0	0	0	1.09	0.81	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9295549	18336	27	9	2	208	243	0	0	0	0	25	7	0	0	0	0	1.17	0.79	[illegible]	[illegible]	[illegible]	[illegible]
Permanent grassland	205177477	9295809	89163	29	95	2	179	226	0	0	0	0	18	18	0	0	0	0	1.22	0.74	0.92	0.40	21.40	0.92
Permanent grassland	205177477	9296279	26389	24	11	2	155	243	0	0	0	0	22	7	0	0	0	0	0.94	0.77	0.94	0.44	23.78	0.87

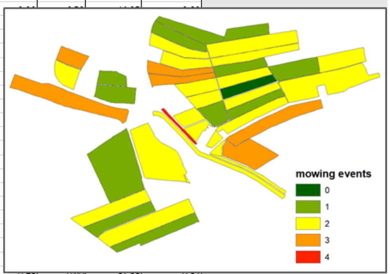

Figure 16: Structure of parcel data

Grassland markers

For each grassland parcel the number of mowing events can be detected as abrupt decreases in the NDVI time series. The number of mowing events can also be an indicator on how intensive or extensive the grassland is used. Also the related mowing dates of the mowing cuts are recorded, which gives also information the intensive/extensive management of the grassland. Finally, the annual cumulative NDVI sum is recorded, where the cumulation continues after each mowing event and is converted into cumulative grass length.

- The ADC the following relevant satellite data at grassland parcel level:
- NDVI time series
- Annual cumulative NDVI and cumulative grass length
- Number of grass mowing cuts
- Mowing dates

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

All data stored in the ADC is anonymized. However, using the parcel level data as input for the FarmDyn model requires associating the IDs of the parcels with the corresponding farm ID, if possible, or at least with another meaningful classification (e.g. agro-ecological zones), to which the farm-level data can also be linked. For this case study we used a sample of farms across the Netherlands. The extraction of the relevant parcel data from the ADC was done manually with the following processing steps:

- Provision of the officially registered farm ID's to Wageningen Environmental Research
- Request for authorized use of the personalized LPIS parcels information (BRP crop parcel dataset with username and farm ID) to the Dutch authorities (RVO)
- Selection of the relevant field ID's with corresponding farm ID's in the personalized LPIS parcels information system. In total 10000 field ID's were queried.
- Extraction of the relevant ADC data (see above) for the selected 10000 field ID's
- Creation of one dataset with Farm ID, Field ID and ADC data

For the GIS coupling of the datasets in this case the ArcGis software was used. Once established as a practical workflow, the process can be fully automated in the future, provided that the request for authorized use of the personalized LPIS parcels information is granted by either the authorities or on an individual basis by the involved farmers. The information available from ADC is summarized in Table 15. The most important variables are those related to the number of mowing cuts (no_mowing_cuts), the range of days during which the mowing took place (m1-m6, q1-q6), and the total cumulative height (cum_height) as indicator for total dry-matter yield. This permits an immediate linkage to the FarmDyn tables shown in section 4.2.1.

Table 15 AgroDataCube: Grassland markers

ADC Data	Data type / unit	Description
Crop_type	Factor	
Farm_ID	ID	
Area_m2	m2	Plot area
Field_ID	ID	
Extraction	date	Date of the satellite image
no_sat_img	n	Number of NVDI satellite observations per year
no_25m_pix	n	Number of 25 m resolution pixels that encompass the field
no_mowing_cuts	n	Total number of mowing cuts
cum_NDVI	index	cumulative NDVI
avg_NDVI	index	average NDVI
max_NDVI	index	max. NDVI
min_NDVI	index	min NDVI
cum_height	cm	Cumulative height of the grass
m1..6	day_of_year	Day of the year .. mowing cut
q1..6	days_since_last_ob	Number of days between the image where ploughing occurred and the previous image

Source: ADC, own summary compilation.

To get more insight on the grassland growth and production the statistics of the grassland markers per stratification unit are generated (Table 16). These statistics are produced for parcels which are big enough to encompass at least a single 25 m resolution pixel, in order to avoid parcels with only mixed pixels and consequently unsecure figures. The statistics of three grassland markers are also visualised in Figure 17.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Table 16 Grassland markers statistics of 2020 for each stratification unit

Stratification unit	Parcels	Obser-vation	Mowing cuts	Date first mowing cut	ΣNDVI	NDVI end of winter
Clay-North	43133	35.9	2.01	167.8	1.3405	0.80
Clay-Polder	1852	43.5	2.41	161.1	1.3358	0.74
Clay-River	62793	43.5	2.07	157.4	1.3133	0.81
Clay-West	28775	30.4	1.58	166.9	1.1109	0.79
Loam	7113	41.4	1.74	157.8	1.1598	0.82
Peat-North	36537	38.9	2.02	166.0	1.3249	0.80
Peat-West	21208	37.1	1.49	163.7	1.0670	0.80
Sand-Mid/North	138390	39.1	2.06	157.6	1.3013	0.82
Sand-South	38210	43.9	1.90	154.7	1.1869	0.79

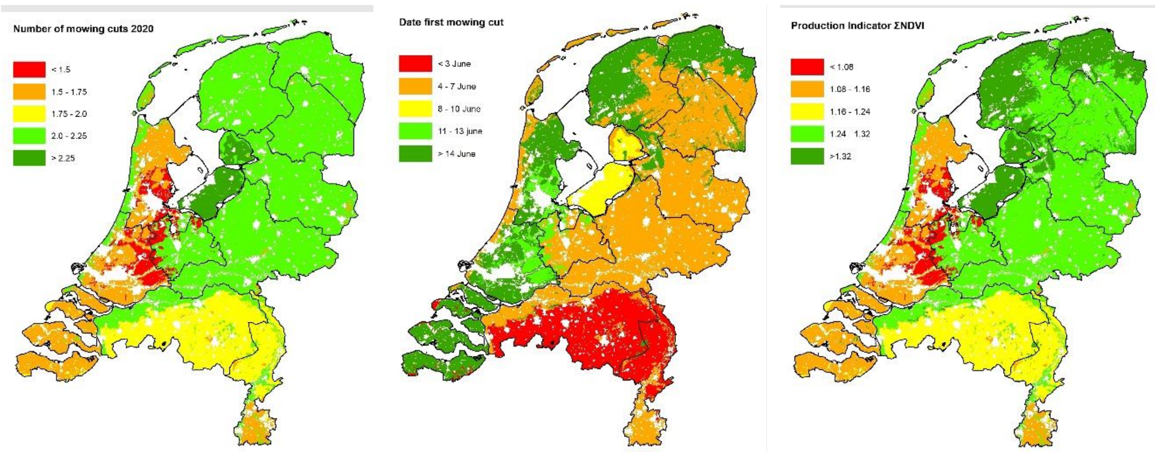

Figure 17: Maps of the grassland markers 2020 for each stratification unit. Left: the average number of mowing cuts. Middle: the average date of the first mowing cut. Right: the cumulative NDVI

Source: Own compilation.

The statistics show that the clay-polder unit has the highest number of mowing cuts (2.41 on average) and peat-West has the lowest (1.49 mowing cuts on average). The recently reclaimed lands in Flevoland proof to be very productive, followed by the other Northern regions on clay, sand and peat. The Western regions on clay and peat are the least productive; also in terms of the cumulative NDVI (ΣNDVI). The cumulative NDVI is the NDVI value where the NDVI decrease as a consequence of mowing cuts are neglected. So the cumulative NDVI continues to increase after each mowing cut.

A clear trend from South-East to North-West can be seen regarding the date of the first mowing cut. Due to the relative warmer weather the first mowing cut in the South-East corner is earlier than in the North-Western regions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

4.2.5. Combining data sources

Farm-level statistic for average grassland yields, handbook data for typical yields by the number of cuts and fertilization levels, and spatial information on yield levels by number of cuts permit the construction of yield-response curves for grassland. A first step in the combination of satellite data with the farm-level statistics was a comparison of the grassland areas indicated by both sources, to ensure that the datasets are aligned. Figure 18 plots the areas obtained from satellite images (x-axis) against the areas from BIN/LMM. As can be seen, the farm-level measurements are located on or scattered around the black diagonal line in Figure 18. A Loess filter (blue line) applied to the sampled data points is also very close to the diagonal with a rather narrow confidence interval (grey area). Despite the fact that satellite and statistical data are not perfect matches, they appear to be sufficiently close to conclude that both datasets are comparable.

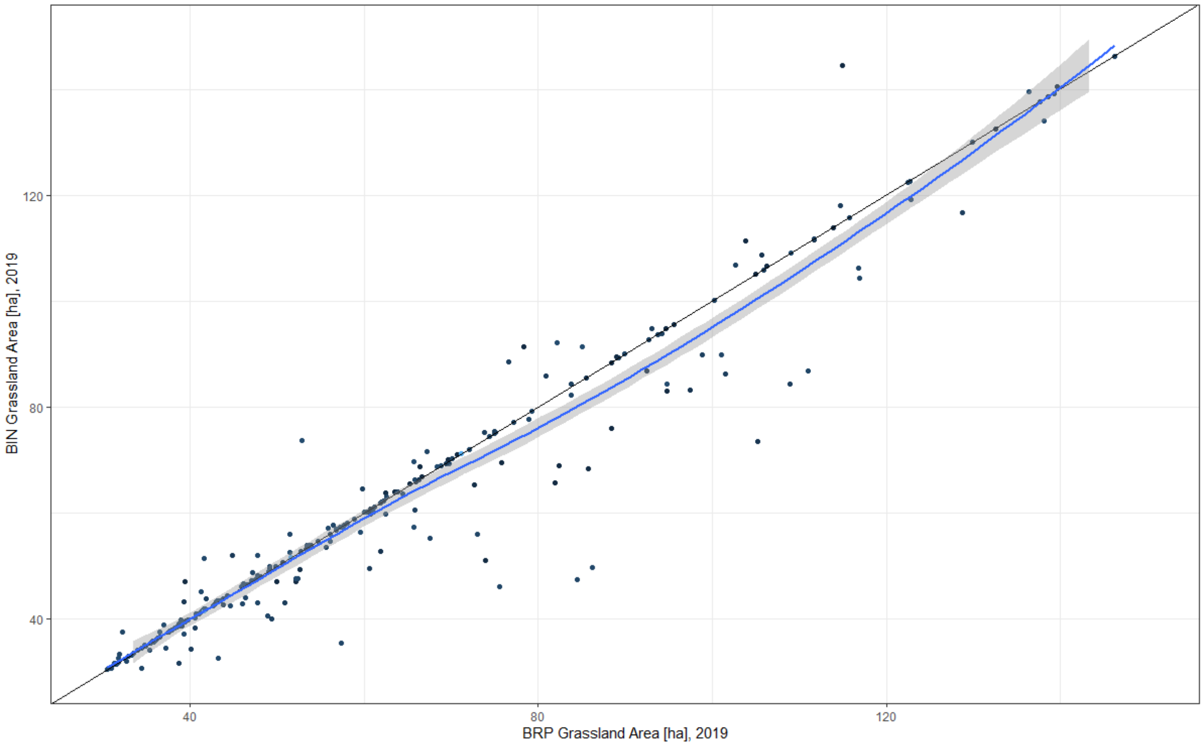

Figure 18: Grassland areas from satellite data (x-axis) and farm level statistics (BIN/LMM) (y-axis)

Using a numerical fitting procedure, yields per cut from the satellite images were combined with the farm-level statistics, such that the resulting yield response curves are sufficiently close to the response curves from the handbook data but account for region-specific variation. An example for a resulting response curve is shown in Figure 19 for clay soils in the central regions of the Netherlands. The three curves represent the different fertilization levels (on average 200, 300, and 400 kg/ha) and each curve shows the grassland yield response to the number of cuts. It can be seen that the marginal effect of additional nitrogen fertilizer is large when moving from a lower to a medium level, while the yield increase is smaller for the next step. The impact of increasing number of cuts on dry-matter yields is small in comparison, but it has to be taken into account that the protein content of the grass increases with the number of cuts (Figure 13).

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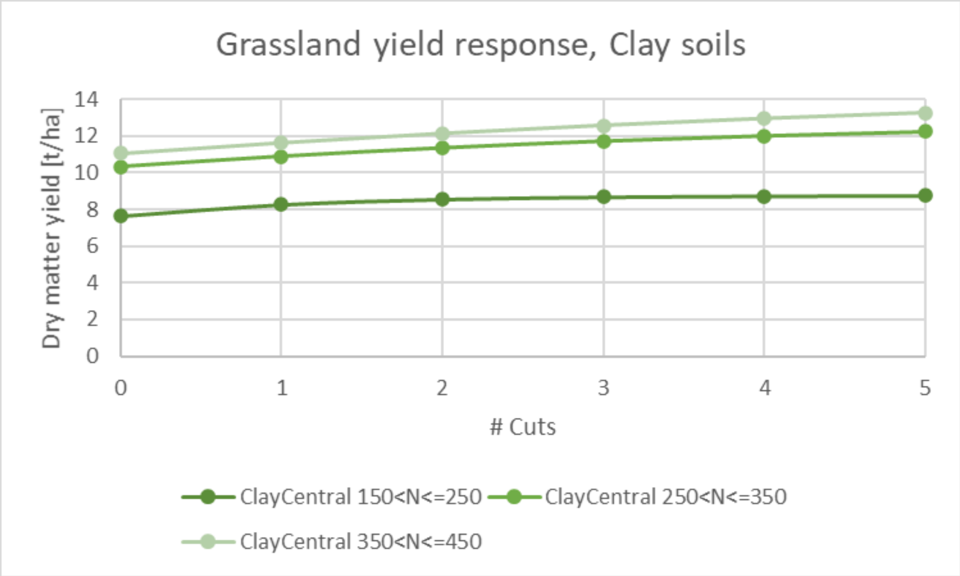

Figure 19: Derived grassland yield responses, e.g. for clay soils

The resulting yield response curves are then used, together with handbook data on nutrient contents, to parameterize the grassland-related part of FarmDyn as discussed in the beginning of this chapter.

4.3. Scenario Results

The more detailed representation of grassland management options in FarmDyn permits a comprehensive representation of the adjustments at farm level taking place in response to new policies or technology options. With the focus on the reduction on GHG emissions, the scenarios proposed in chapter 3.4 are implemented to see how a subsidy of GHG emission reduction would affect farming outcomes. The first two scenarios are implemented as a pure subsidy at 65 and 130 Euro/t CO2 equivalent for deviations from the reference level. In this case, emission reduction can be achieved only by current management options. Further scenarios demonstrate the impacts of additional mitigation options. As a contribution to a market policy design on GHG mitigation chapter 4.4 discusses the finance of the subsidy in line with discussions in chapter 2.6.

The impact of the two levels of subsidy rates without additional mitigation measures on farm management decisions is shown in the first two columns of Table 17, while the GHG emissions are shown in Table 18. A subsidization of GHG reduction of 65 Euro/t of CO2 equivalent result in an almost 10% reduction of total emissions across all farm types, while a tax rate of 130 Euro/t causes an almost 20% reduction. This reduction is mainly due to the decrease of herd sizes, which go in total down by 4% and 12%, respectively, and the adjustment of the animal rations, which contain less purchased feeds like soybean meal and maize silage. The adjustment of herd sizes is more pronounced in the case of intensive farms (Figure 20). This is mainly due to the fact that income per cow tend to be lower at intensive farms due to the higher share of purchased feed cost and the cost of manure export as it cannot be brought out on own fields. This has two effects: First, receiving the subsidy is more attractive than keeping the herd size at their original levels and second, the reduction of up-stream emissions from purchased feeds is more noticeable than in the case of more grass-based extensive farms.

In addition to the subsidization of emission reductions, scenarios 3 and 4 (third and fourth columns in Table 17 and Table 18) include mitigation options that cannot be selected endogenously by the model

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but have to be set as constraints or by changing the respective model parameters. These additional or enforced mitigation options include the use of the feed additive Bovaer®, which is implemented on all farms, while the extension of lactation periods and higher shares of permanent grassland are included only for the intensive dairy farms in the sample. The inclusion of such measures causes a further decrease of GHG emissions, for instance by more than 25% in the case of a 130 Euro subsidization level, while reducing the cow herd by less than 9%.

In scenario 5 (fifth column in Table 17 and Table 18), a reduction of the average milk-yield per cow in intensive farms is added to the mitigation options in the previous scenarios. Such lower milk-yields imply a reduction of the animal feeding, such that GHG emissions are reduced in total by almost 30%, while the herd size declines by less than 7%. Figure 20 shows that the changes in herd sizes is largely driven by adjustments on intensive farms, for which more extra mitigation options are included in the scenarios, based on MAC per farm group in Chapter 2 and considerations in Chapter 3 on the impact of livestock density on the likelihood that a farmer would adopt a certain measure.

Table 17 Management results by scenarios

		CO2 Sub 65E/t	CO2 Sub 130E/t	CO2 Sub 65E/t + MIT	CO2 Sub 130E/t + MIT	CO2 Sub 130E/t + MIT + LMY
Number of cows	Base=100	96.05	87.56	97.24	91.64	93.54
Fresh grass	Base=100	96.89	86.70	95.35	87.59	88.50
Grass silage	Base=100	100.62	101.14	106.98	107.51	107.19
Maize silage	Base=100	83.53	61.53	66.27	52.03	57.22
Standard concentrate	t dm/farm/year	141	0	0	0	0
Concentrate, EF CH4 low	t dm/farm/year	167	163	172	173	152
Soybean Meal	Base=100	45.21	27.37	45.15	28.25	15.37
FeedAdd Bovaer	kg dm/farm/year			395	365	359
Mineral Fertilizer N	Base=100	95.06	85.90	98.65	90.37	90.36
Total Feed	Base=100	98.48	99.14	101.14	101.05	98.92

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Table 18 GHG results by scenarios [index, base=100]

	CO2 Sub 65E/t	CO2 Sub 130E/t	CO2 Sub 65E/t + MIT	CO2 Sub 130E/t + MIT	CO2 Sub 130E/t + MIT + LMY
Total CO2-eq	90.58	80.80	80.21	74.25	70.67
CH4 CO2-eq fermentation	94.69	86.29	74.21	70.00	69.07
CH4 CO2-eq pasture	90.42	71.82	86.49	73.60	74.53
CH4 CO2-eq storage	97.14	90.62	94.33	90.66	92.59
N2O CO2-eq stable/storage	98.79	94.67	95.49	93.61	92.72
N2O CO2-eq indirect	100.34	98.88	100.63	99.42	98.75
N2O CO2-eq pasture	90.52	73.68	85.94	74.36	73.09
N2O CO2-eq application animal manure	97.40	96.70	93.96	92.12	91.10
N2O CO2-eq application artificial fertilizer	94.81	87.23	96.97	90.12	90.10
N2O CO2-eq Crop residu	102.33	104.62	106.36	108.35	107.02
N2O CO2-eq leaching	99.02	96.31	99.74	97.08	96.74
N2O CO2-eq Histosols	100.00	100.00	98.16	98.16	98.16
CO2 from artificial fertilizer	95.04	85.95	97.06	88.63	88.62
CO2 from purchased feed (incl. LULUC)	78.38	65.51	76.93	69.02	56.94

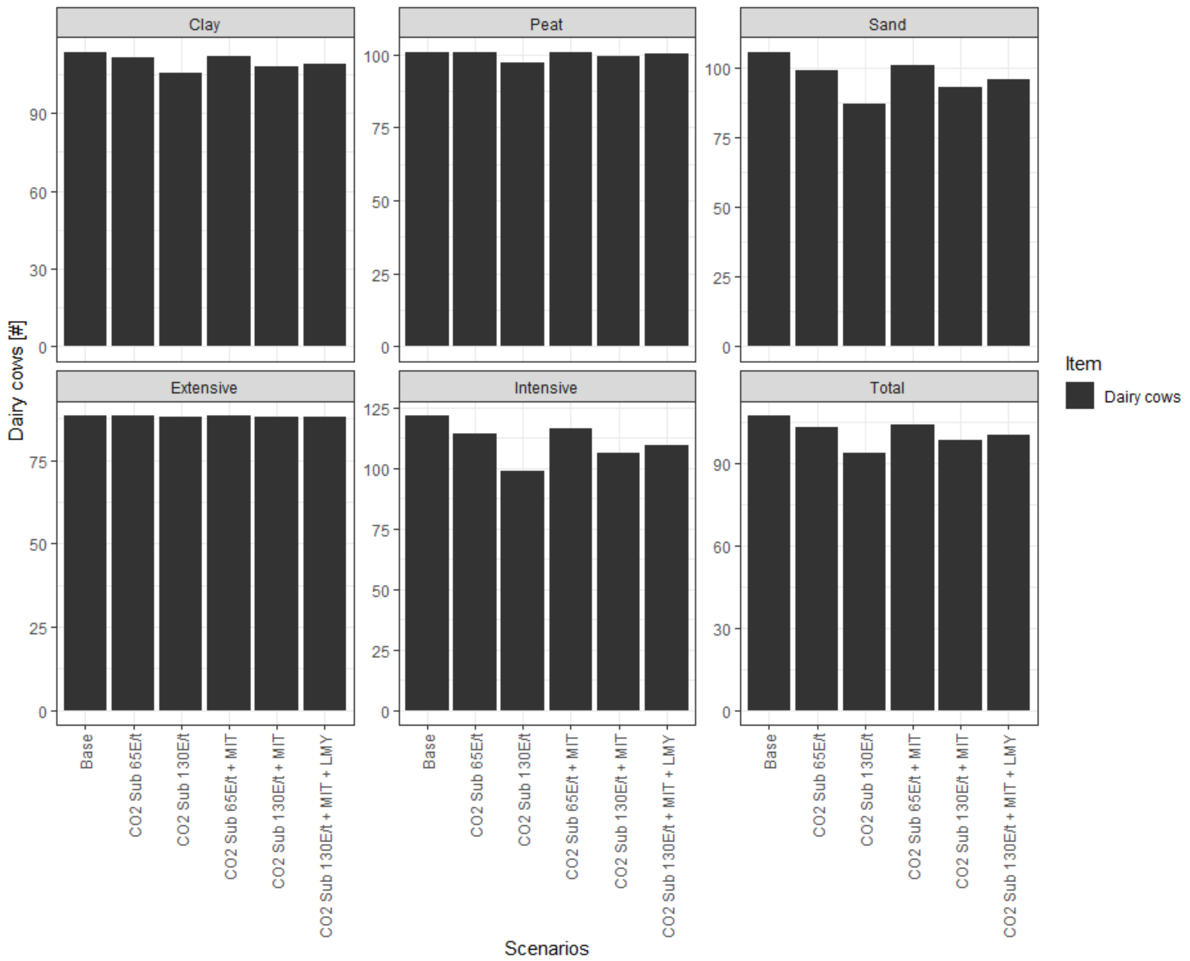

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Figure 20: Number of dairy cows by farm group across scenarios

At farm level, the total farm income increases when including the subsidies for GHG emission reduction (first row in Table 19); without, they would decline (first row in Table 19) by more than 8% for the average farm, amounting to 170 million Euro at sector level in the case of a subsidization level of 130 Euro, including mitigation options. Reasons are reduced revenues as consequence of the smaller herd sizes and the higher expenditures for purchased concentrates, feed additives, and veterinary costs in the case of the extension of the number of lactation period per cow. Still, total variable costs tend to decline, largely driven by the reduction of purchased roughages (i.e. silage maize) and lower cost for manure exports due to the smaller herds.

Table 19 Economic results by scenarios, difference to base [million Euro]

	CO2 Sub 65E/t	CO2 Sub 130E/t	CO2 Sub 65E/t + MIT	CO2 Sub 130E/t + MIT	CO2 Sub 130E/t + MIT + LMY
Farm income, incl subsidy	69.93	280.13	82.03	368.99	333.28
Revenue	-225.77	-694.64	-290.03	-593.99	-779.66
Total variable costs	-185.08	-524.08	-139.76	-358.39	-424.39
Costs of purchased roughage	-145.91	-339.84	-215.60	-338.74	-295.44
Costs of purchased concentrates	7.34	-36.60	115.58	93.10	-12.30
Costs of feedadd Bovaer	0.00	0.00	94.90	90	88
Costs of manure application	4.57	9.73	5.20	9.12	11.93
Cost of manure export	-18.48	-48.25	-29.98	-47.59	-47.87
Cost of fertilizer	-6.32	-16.80	-3.81	-13.49	-13.48
Farm income, excl subsidy	-40.69	-170.56	-150.27	-235.60	-355.28

The total adjustment of the animal rations, as reflected in the changing cost for purchased roughages and concentrates in Table 19, is driven by changes of animal ration composition on intensive farms. As shown in Figure 21, in scenarios 1 and 2, where no additional mitigation measures are considered, the total dry-matter (DM) requirement per dairy cow remains at the level of the base scenario, but the composition changes. The share of maize silage, which is frequently purchased on intensive farms with limited area, declines and is replaced by higher shares of grass silage and concentrates on intensive farms. Only minimal adjustments take place on extensive farms as they operate already with a high share of grass in the ration. In scenarios 3 and 4, the use of feed additives is included as mitigation measure on extensive and intensive farms. In the case of intensive farms, further included mitigation measures are the extension of lactation periods and the mandatory extension of grassland. The reduction of total DM per cow and year in scenarios 3 and 4 (CO2 Sub + MIT) is caused by the smaller replacement herd in response to the increased number of lactation periods per cow. In scenario 5, where also reduced milk-yields per cow are considered, the total dry-matter requirements per dairy cow declines further due to lower feed requirements by the cows.

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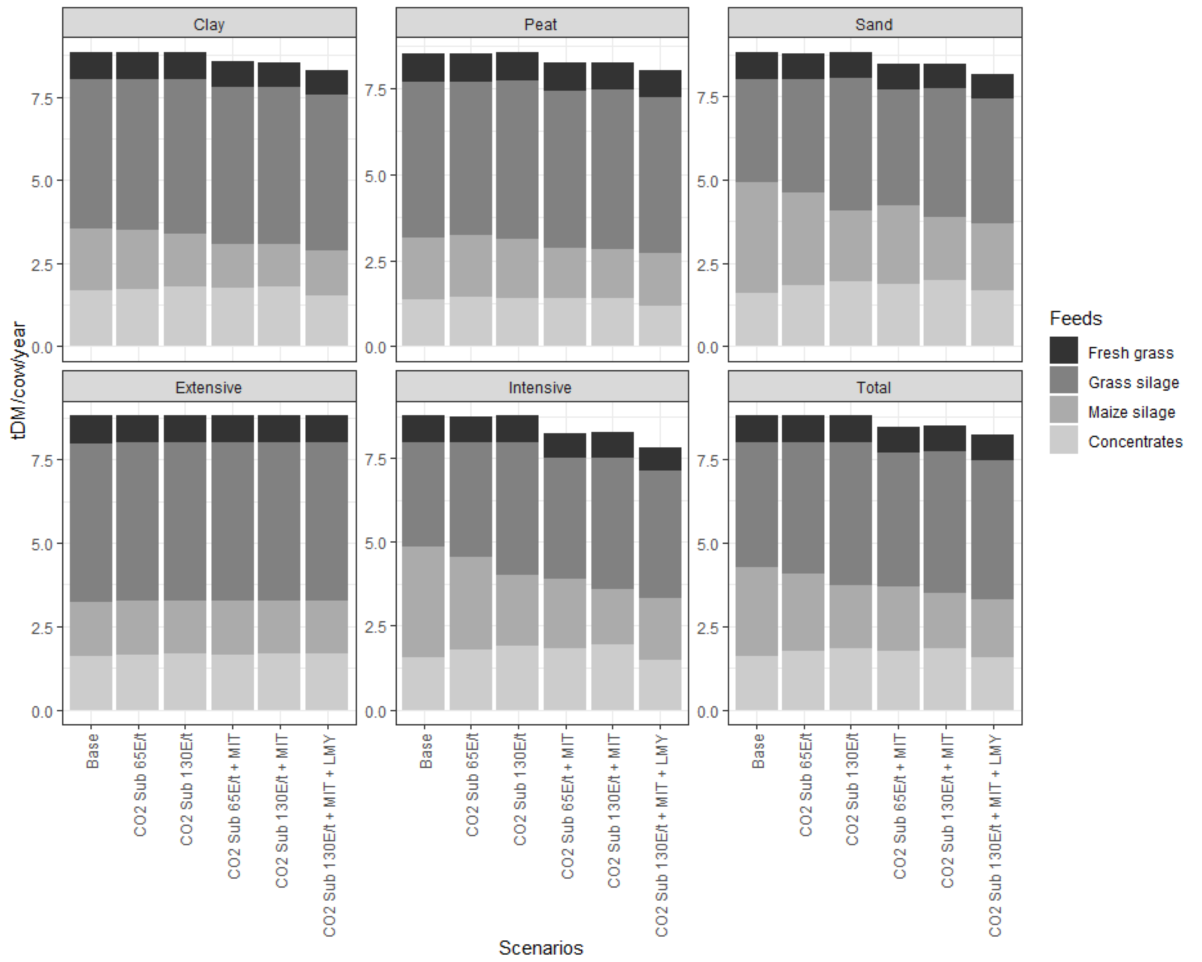

Figure 21: Composition of animal rations per cow across scenarios

Note: The reduction of total DM per cow and year in scenarios 3 and 4 (CO2 tax + MIT) is because of the reduction of the required replacement herd in response to the increased number of lactation periods per cow.

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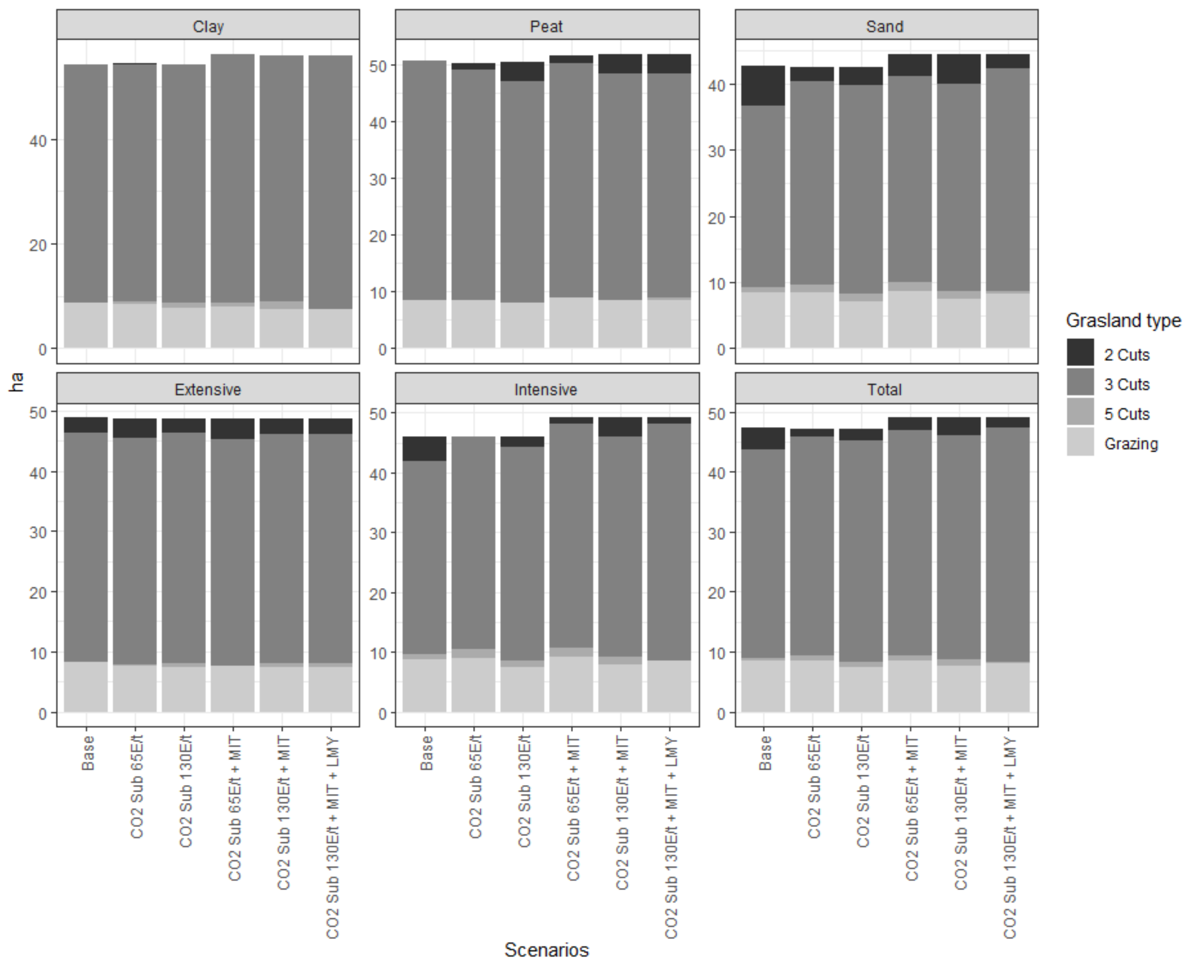

Figure 22: Adjustment of grassland management systems across scenarios

In the case of grassland management, the dominant intensity level in the base scenario is gras silage production with 3 cuts. No substantial changes take place in scenarios 1 to 5 take place, but there is a small tendency to reduce he share of grassland with 2 cuts and a slight increase of 5-cuts systems (Figure 22).

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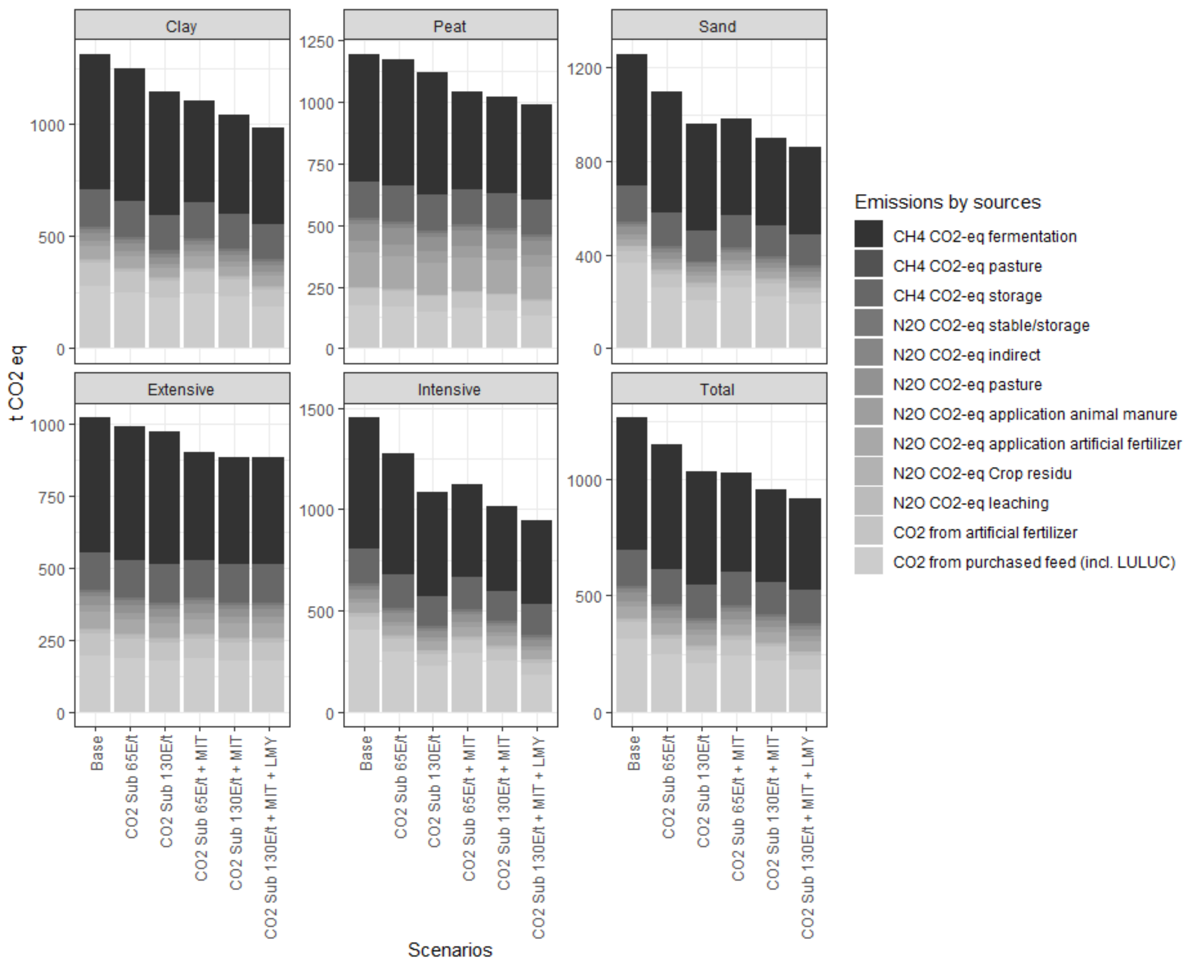

Figure 23: Changes of GHG emissions across scenarios [in tons per farm]

At intensive dairy farms, endogenous reductions in GHG emissions are especially achieved via changes in composition of the feed ration per cow and decrease in number of cows per farm (Figure 23) . The share of purchased feeds with high upstream emissions and high enteric fermentation factors in the total feed ration decreases. The enforced measures contribute via less young animals, less emissions via the use of feed additives and increased carbon sequestration via increased share of grassland in the crop rotation. At extensive dairy farms, room for manoeuvre is much less, see also chapter 2. Endogenous reductions are especially achieved via decrease in use of N from mineral fertilizers. This also decreases the upstream emission from mineral fertilizers. Additionally it is assumed that feed additives are adopted at extensive dairy farms as well.

4.4. Policy design: impacts of a combined subsidy and tax scenario

Market-based GHG mitigation policies allow farmers to adopt GHG mitigation measures that are in their own interest, given the policy restrictions (Bakam et al., 2012). In section 2.6 we looked at impacts of a combined tax and subsidy scenario on extensive and intensive dairy farms, using the MAC and GHG mitigation potentials of a selected number of standalone GHG mitigation measures. In this section this is repeated for scenarios 3 and 4, but with endogenous and enforced GHG mitigation measures included simultaneously. As explained above we assume different enforced GHG mitigation

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measures for extensive and intensive dairy farms. Table 20 and Table 21 show the results on farm income and GHG mitigation per scenario 3 and 4 with a) an uniform taxation rate for the reference period emission for all farms and b) a differentiated taxation rate, based on the realised GHG mitigation and required subsidy per intensive and extensive dairy farm group. The tax rate is calculated ex-post and based on the GHG emission in the base or reference period and on the required subsidy (GHG mitigated amount multiplied with subsidy rate). The equal tax rate can be motivated because the group of intensive farms contribute a lot more to the GHG mitigation reduction, as extra GHG mitigation measures are enforced. The targeted tax rate can be motivated by the relatively low GHG emission per ha on extensive dairy farms and the wish of the Dutch government to steer the dairy sector into pathways of extensification. Table 20 and Table 21 show that total GHG mitigation in the milk production sector is about 20% and 26% in scenario 3 and 4, respectively. Total farm income decreases with 17% and almost 27%, respectively. GHG mitigation per farm group is quite different per scenario. Because of the relatively low income per cow and relatively low MAC of adjustments in feed rations and number of dairy cows and strengthened by the enforced GHG mitigation measures, the decrease in GHG emission on intensive dairy farms equals about 24% and 32% in scenario 3 and 4, respectively. The decrease in GHG emission equals 12.5% and 14.6% on extensive dairy farms in scenario 3 and 4, respectively. Change in farm income is especially large on extensive dairy farms in case of equal tax rate over all farm groups. This is completely different in the case of targeted tax rates per farm group. In the latter case, change in farm income in scenario 2 equals about - 14% and -35% on extensive dairy farms and intensive dairy farms respectively.

Table 20 Subsidization rate and Impact on farm income and GHG emission of scenario 3

	Equal subsidy rate			Targeted subsidy rate		
	EXT	INT	Total	EXT	INT	total
GHG emission base (MT CO2-eq)	6.30	11.80	18.10	6.30	11.80	18.10
Tax (Euro/ton CO2-eq)	12.90	12.90		8.10	15.40	12.90
Tax income (mio Euro)	80.50	151.80	-232.30	50.70	181.60	232.30
Subsidy (Euro/ton CO2-eq mitigated)	65.00	65.00		65.00	65.00	
Mitigated GHG emission (MT CO2-eq)	-1	-3	-4	-1	-3	-4
Subsidy costs (mio Euro)	-51	-182	-232	-51	-182	-232
Farm income loss, excl GHG emission tax (mio euro)	-38.20	-112.00	-150.30	-38.20	-112.00	-150.30
Farm income base (mio Euro)	340.90	540	881	341	539.80	880.60
Change in farm income (mio Euro)	-68.10	-82.20	-150.30	-38.20	-112.00	-150.30
Updated farm income (mio Euro)	272.80	457.60	730.40	302.70	427.70	730.40
Updated GHG emission (MT CO2-eq)	5.50	9.00	14.50	5.50	9.00	14.50
Mitigated GHG emission (%)	-12.50	-23.70	-19.80	-12.50	-23.70	-19.80
Change farm income (%)	-20.00	-15.20	-17.10	-11.20	-20.80	-17.10

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Table 21 Subsidization rate and Impact on farm income and GHG emission of scenario 4

	Equal subsidy rate			Targeted subsidy rate		
	EXT	INT	Total	EXT	INT	total
GHG emission base (MT CO2-eq)	6.30	11.80	18.10	6.30	11.80	18.10
Tax (Euro/ton CO2-eq)	33.50	33.50		19.00	41.20	33.50
Tax income (mio Euro)	209.60	395.00	-604.60	118.90	485.70	604.60
Subsidy (Euro/ton CO2-eq mitigated)	130.00	130.00		130.00	130.00	
Mitigated GHG emission (MT CO2-eq)	-1	-4	-5	-1	-4	-5
Subsidy costs (mio Euro)	-119	-486	-605	-119	-486	-605
Farm income loss, excl GHG emission tax (mio euro)	-46.90	-188.70	-235.60	-46.90	-188.70	-235.60
Farm income base (mio Euro)	340.90	540	881	341	539.80	880.60
Change in farm income (mio Euro)	-137.70	-97.90	-235.60	-46.90	-188.70	-235.60
Updated farm income (mio Euro)	203.20	441.80	645.00	294.00	351.10	645.00
Updated GHG emission (MT CO2-eq)	5.30	8.10	13.40	5.30	8.10	13.40
Mitigated GHG emission (%)	-14.60	-31.70	-25.80	-14.60	-31.70	-25.80
Change farm income (%)	-40.40	-18.10	-26.80	-13.80	-35.00	-26.80

4.5. Conclusions

In this chapter we explained the further refinement of the grassland module for FarmDyn combining farm-level statistics, handbook data, and satellite data. A general challenge was that neither satellite images nor farm-level statistics provide information on fertilization levels per plot, so it is not clear if the recorded yield variations originate from different fertilizer applications or from the number of cuts. Still, the relative yield deviations by number of cuts provided an indication of plausible ranges for the marginal effects of the cuts. A future solution for this problem would be to align not only farm-average yields but also average fertilizer application levels from statistics with the satellite images, but that requires further information on ranges of plausible fertilization levels per yield level and number of cuts beyond the available handbook data.

Based on the combined data, management systems were developed for regions and dominant soil types rather than at farm level. This was deemed more adequate as a farm-specific representation of management systems would restrict model simulations to the observed rather than the potential systems a farm could switch to, given its location in a certain agro-ecological zone and its dominant soil type. The aggregation to region/soil type combinations also improves the re-usability of the methods in other EU countries because the linkage of satellite images of plots to the corresponding farm statistics is usually restricted by privacy regulations.

Further identified data gaps were the nutrient contents of the harvested grass in the different management options. This information is important for the integration in FarmDyn as it determines the range by which grassland can substitute imported feeds, namely protein-rich concentrates. The needed data was obtained from handbooks and literature on feed values.

The Dutch version of the FarmDyn model with an enriched representation of grassland management options was applied to a sample of dairy farms, grouped by regions, dominant soil type, and livestock density. Five scenarios were tested: the first two involved a subsidization of GHG emission reduction compared to a reference level determined by the base scenario. The subsidization levels were 65 and 130 Euro per ton of CO2-equivalent, respectively. Scenarios 3 and 4 also assumed these subsidization level, but further mitigation options were included. The usage of feed additives, higher number of

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lactation periods per cow, mandatory conversion of arable land into grassland were included for intensive farms, while extensive farms were assumed to rely only on feed additives for this purpose. The reason for this distinction between intensive and extensive farms with regard to their technology options takes into account findings by Wang et al. (2022) (also discussed in Chapter 3.2 of this report). Empirical results from a survey of Dutch dairy farmers indicate high livestock density as a contributing factor for the likelihood of a farm to adopt mitigation measures. This empirical finding supports also the FarmDyn results from scenarios 1 and 2, where the overall reduction of GHG emissions is driven by intensive farms. Even without additional mitigation technologies, emissions across all sample farms can be reduced by almost 20% in the case of the high subsidization rate of 130 Euro/t CO2 equivalent in scenario 2. The responsiveness of intensive farms to the subsidy is mainly due to the fact that income per cow tend to be lower at intensive farms because of higher share of purchased feed cost and the cost of manure export as it cannot be brought out on own fields. When the monetary incentive for the reduction of emissions is combined with other mitigation measures on intensive farms, an overall reduction of 25% appears to be possible. The three considered measures are a rather limited sample form a much wider range of potential management and technology options as for instance shown in Table 5 and Table 6. The introduction of clover-rich grassland or further increases of fertilizer efficiency may allow for further decreases of emissions. Data about the GHG reduction and the cost at farm level for the implementation of such measures are a critical factor for an appropriate assessment of available technology options with a simulation tool like FarmDyn.

The main incentive for farmers to reduce emissions in the presented scenarios were subsidies on the negative deviations from a reference level. The question arises, how these subsidies should be financed. Options to use funds within the CAP or from national budgets would have to be explored. Another alternative is a market-based policy scenario, assuming re-financing of GHG mitigation subsidies by sectoral and targeted budget-neutral taxes on GHG emission in a reference period. This is explored in the last section of this chapter. It was found that under scenario 3 and 4, a targeted tax rate was favourable for extensive farms, while a uniform tax rate was favourable for intensive farms. Subsidization of GHG emission reduction and the discussed option to re-finance them by taxation within the sector are based on the levels of GHG emissions in a reference period. Decreasing the reference emission levels over time would result in an eventual phasing-out of the policy once the reduction potential has been reached. The timing of such a phasing-out would have to take into account the availability of new management or technology options like e.g. the progress in animal breeding. Difficulties with market-based emission policies are mentioned by Bakam et al. (2012) and Lengers and Britz (2012). Among others, the measurement of emissions from a given area with reasonable accuracy at reasonable costs is difficult. Uncertainties common in agricultural activities, including lack of understanding of biophysical processes, linking inputs to outputs, poor validation of results and weather-induced variability contribute to high measurement costs. Lengers et al. (2014) develop a meta-model of the MAC curve using results of a large number of scenarios/experiments with a bio-economic dairy farm model. The experiments combine enforced mitigation options and endogenous farm management adjustments. Such meta-models could be used to determine MAC for farms which are the basis for GHG emission trading in models able to simulate markets such as agent-based models or partial equilibrium models.

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5. LITERATURE

Bakam, Innocent, Bedru Babulo Balana, Robin Mathews (2012). Cost-effectiveness analysis of policy instruments for greenhouse gas emission mitigation in the agricultural sector. Journal of Environmental Management 112(2012) 33-44/

Bamberg, S. (2013). Changing environmentally harmful behaviors: A stage model of self-regulated behavioral change. Journal of Environmental Psychology, 34, 151-159. doi:10.1016/j.jenvp.2013.01.002

Bamberg, S., Fujii, S., Friman, M., & Gärling, T. (2011). Behaviour theory and soft transport policy measures. Transport policy, 18(1), 228-235.

Britz, W., 2014. A New Graphical User Interface Generator for Economic Models and Its Comparison to Existing Approaches. German Journal of Agricultural Economics 63 (670-2016–46010): 271–85.

Britz W., Lengers, B,. Kuhn, T. and D. Schäfer, 2016. A highly detailed template model for dynamic optimization of farms - FarmDyn, University of Bonn, Institute for Food and Resource Economics, http://www.ilr.uni-bonn.de/em/rsrch/FarmDyn/FarmDyn_docu.pdf.

Britz, W., P. Ciaian, A. Gocht, A. Kanellopoulos, D. Kremmydas, M. Müller, A. Petsakos & P. Reidsma, 2021. A design for a generic and modular bio-economic farm model. Agricultural Systems 191, 103133

Cerri, Carlos Clemente, Martial Bernoux, Stoecio Malta Ferreira Maia, Carlos Eduardo Pellegrino Cerri, Ciniro Costa Junior, Brigitte Josefine Feigl, Leidivan Almeida Frazão, Francisco Fujita de Castro Mello, Marcelo Valadares Galdos, Cindy Silva Moreira, João Luis Nunes Carvalho (2010). Greenhouse gas mitigation options in Brazil for land-use change, livestock and agriculture. Sci. Agric. (Piraciacaba, Braz.), v 67, n.1, p. 102-116. January/February 2010.

Coleman, K., Jenkinson, D.S., Crocker, G.J., Grace, P.R., Klir, J., Korschens, M., Poulton, P.R., Richter, D.D., 1997. Simulating trends in soil organic carbon in long-term experiments using RothC-26.3. Geoderma 81, 29-44.

Coleman, K. and D.S. Jenkinson, 2014. RothC - A model for the turnover of carbon in soil - Model description and users guide (Windows version) (Updated June 2014). Rothamsted Research, Harpenden, UK.

CVB Table Booklet Feeding of Ruminants 2016. CVB series no 52, November 2016.

Daatselaar, C.; Helming J.F.M.; Michels R.; Reinhard S.; Berkhout P., 2021. Integrale effecten klimaatmaatregelen. Available online: https://edepot.wur.nl/555268 (accessed on 25.11.2022).

de Koeijer, T.; Helming, J.; Greijdanus, A.; Müller, M.; Blokland, P.W (2020). Modelinstrumentarium voor groene cirkels: Demonstratiemodel voor verkenning trade-offs duurzaamheidsindicatoren in melkveehouderij en akkerbouw; Wageningen Economic Research. Available at: https://edepot.wur.nl/530490: 2020.

Dessart, F. J., Barreiro-Hurlé, J., & Van Bavel, R. (2019). Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. European Review of Agricultural Economics.

de Vries, M., I.E. Hoving, J.C. van Middelkoop, J. ten Napel, R.Y. van der Weide, J. Verhagen, T.V. Vellinga, 2018. Klimaatslimme melkveehouderij. Een routekaart voor implementatie van mitigatie- en adaptatiemaatregelen. Wageningen Livestock Research rapport 1131.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Doornewaard G.J., M.W. Hoogeveen, J.H. Jager, J.W. Reijs en A.C.G. Beldman, 2022. Sectorrapportage Duurzame Zuivelketen; Prestaties 2020 in perspectief. Wageningen, Wageningen Economic Research, Rapport 2022-002. 174 blz.; 19 fig.; 18 tab.; 65 ref.

DSM (2022). https://www.dsm.com/corporate/sustainability/our-purpose/minimizing-methane-from-cattle.html

Eory, Vera, Kairsty Topp, Bob Rees, Illka Leinonen, Juliette Maire, Michael MacLeod, Alasdair Sykes, Eileen, 2020. Marginal abatement cost curve for Scottish agriculture. Wall Scotland's Rural College August 2020 DOI: http://dx.doi.org/10.7488/era/755 1

European Commission. 2018. "Proposal for a Regulation of the European Parliament and of the Council for 'CAP Post 2020'." *COM(2018) 392 Final*. https://eur-lex.europa.eu/resource.html?uri=cellar:aa85fa9a-65a0-11e8-ab9c-01aa75ed71a1.0003.02/DOC_1&format=PDF.

FAO, 2020. The share of agriculture in total greenhouse gas emission. Global, regional and country trends 1990–2017. FAOSTAT Analytical Brief Series No. 1. Rome.

Fraters, B., T.C. van Leeuwen, A. Hooijboer, M.W. van Hoogeveen, L.J.M. Bouwmans, J.W. Reijs, 2012. De uitspoeling van het stikstofoverschot naar grond- en oppervlaktewater op landbouwbedrijven. Herberekening van uitspoelfracties. RIVM, Rapport 680716006/2012.

Gastelen, Sanne, Jan Dijkstra, Jeroen M. L. Heck, Maik Kindermann, Arie Klop, Rudi de Mol, Dennis Rijnders, Nicola Walker and Andre Bannink (2022). Methane mitigation potential of 3-nitrooxypropanol in lactating cows is influenced by basal diet composition. Journal of Dairy Science Vol. 105 No. 5, 2022.

Gaudino, S., P. Reidsma, A. Kanellopoulos, D. Sacco, M.K. van Ittersum (2018). Integrated assessment of the EU's greening reform and feed self-sufficiency scenarios on dairy farms in Piemonte, Italy. Agriculture 2018, 8, 137, doi:10.3390/agriculture8090137.

Gomes, A., & Reidsma, P. (2021). Time to Transition: Barriers and Opportunities to Farmer Adoption of Soil GHG Mitigation Practices in Dutch Agriculture. Frontiers in Sustainable Food Systems, 5. doi:10.3389/fsufs.2021.706113

Heinrichs, J., J. Jouan, C. Pahmeyer, W. Britz (2021). Integrated assessment of legume production challenged by European policy interaction: a case-study approach from French and German dairy farms. Q Open, 2021,1,1-19, doi: 10.1093/qopen/qoaa011. 15 February 2021.

Hoving, I. E., & Vellinga, T. V. (2010). Broeikasgas door maïs op gescheurd grasland. V-focus, 7(1), 28-29.

ICF (2013). Greenhouse gas mitigation options and costs for agricultural land and animal production within the United States. Washington, ICF International. February 2013.

Janssen, H., Janssen, S. J. C., Knapen, M. J. R., Meijninger, W. M. L., & Roerink, G. J. (2018). AgroDataCube: a big open data collection for agri-food applications.

Keller, A., Eisen, C., & Hanss, D. (2019). Lessons Learned From Applications of the Stage Model of Self-Regulated Behavioral Change: A Review. Frontiers in Psychology, 10, 1091. doi:10.3389/fpsyg.2019.01091

Lanigan, G.J., T. Donnellan (eds.) (2019). An analysis of abatement potential of greenhouse gas emissions in Irish Agriculture 2021-2030. Teagasc, Oak Park, Carlow

Lamkowsky, M., O. Oenema, M.P.M. Meuwissen en F. Ang, (2021). Closing productivity gaps among Dutch dairy farms can boost profit and reduce nitrogen pollution. Environmental Research Letters, 16(12), [124003].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

Lengers, B. and Britz, W., 2012. The choice of emission indicators in environmental policy design: an analysis of GHG abatement in different dairy farms based on a bio-economic model approach, Review of Agricultural and Environmental Studies, Vol. 93, (2012) pp. 117–144.

Lengers B., W. Britz, & K. Holm-Müller, 2014. What drives marginal abatement costs of greenhouse gases on dairy farms? A meta-modelling approach, Journal of Agricultural Economics 65(3): 579–599.

Lesschen, J.P., Reijs, J., Vellinga, T., Verhagen, J., Kros, H., de Vries, M., Jongeneel, R., Slier, T., Gonzalez Martinez, A., Vermeij, I. and Daatselaar, C. (2020). Scenariostudie perspectief voor ontwikkelrichtingen Nederlandse landbouw in 2050 (Wageningen: Wageningen Environmental Research) Available online at: https://edepot.wur.nl/512111.

Mosnier C, Britz W, Julliere T, De Cara Sté, Jayet P-A, Havlik P, Frank S, Mosnier A, (2019). Greenhouse gas abatement strategies and costs in French dairy production. Journal of Cleaner Production, doi: https://doi.org/10.1016/j.jclepro.2019.07.064.

NN (2019). Klimaatakkoord, 28 June 2019 Den Haag. Available online at: https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/klimaatakkoord

Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B. & Steinfeld, H. 2013. Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome.

Panchasara, H.; Samrat, N.H.; Islam, N. 2021. Greenhouse Gas Emissions Trends and Mitigation Measures in Australian Agriculture Sector—A Review. Agriculture 2021, 11, 85. https://doi.org/10.3390/agriculture11020085

Pérez Domínguez I., Fellman T., Witzke P., Weiss F., Hristov J., Himics M., Barreiro-Hurle J., Gómez Barbero M., Leip A., Economic assessment of GHG mitigation policy options for EU agriculture: A closter look at mitigation options and regional mitigation costs (EcAMPA 3), EUR 30164 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17854-5, doi: 10.2760/4668, JRC120355

Poppe, K.; van Duinen, L.; de Koeijer, T. Reduction of Greenhouse gases from peat soils in Dutch agriculture. EuroChoices 2021, 20, 38-45, doi:https://doi.org/10.1111/1746-692X.12326.

Rees, J. H., Klug, S., & Bamberg, S. (2015). Guilty conscience: motivating pro-environmental behavior by inducing negative moral emotions. Climatic Change, 130(3), 439-452. doi:10.1007/s10584-014-1278-xRemmelink, G., van Middelkoop, J., Ouweltjes, W., & Wemmenhove, H. (2020). Handboek melkveehouderij 2020/21 (No. 44). Wageningen Livestock Research.

Schröder, J.J.; Rutgers, B. 2018. Kringloopwijzer Akkerbouw: rekenmodel versie ‘april 2018’; Stichting Wageningen Research, Wageningen Plant Research, Business unit ...: 2018.

Šebek, L.B., Mosquera, J., Bannink, A. 2016. Rekenregels voor de enterische methaanemissie op het melkveebedrijf en reductie van de methaanemissie via mest-handling; het handelingsperspectief van het voerspoor inzichtelijk maken met de Kringloopwijzer. Lelystad, Wageningen UR (University & Research centre) Livestock Research, Livestock Research Rapport 976.

Toprak, N.N. (2015). Do fats reduce methane emission by ruminants? - a review. Animal Science Papers and Reports vol. 33 (2015) no. 4, 305-321. Institute of Genetics and Animal Breeding, Jastrzębiec, Poland.

van Dijk, Wim, Sjaak Conijn, Jan Peter Lesschen, Erwin Mollenhorst, Hassan Pishgar Komleh, Co Daatselaar & John Helming (2022) Combined use of farm and soil carbon models to study measures for carbon sequestration on dairy and arable farms and their effects on economy and environment. Unpublished factsheet. Available upon request.

van Dijk, W., J.A. de Boer, M.H.A. de Haan, P. Mostert, J. Oenema & J. Verloop, 2021. Rekenregels van de KringloopWijzer 2021; Achtergronden van BEX, BEA, BEN, BEP en BEC: actualisatie van de 2020-versie. Wageningen Research, Rapport WPR-1119. 159 blz.; 7 fig.; 53 tab.; 86 ref.

Vellinga, T. V., Blonk, H., Marinussen, M., van Zeist, W. J., & Starmans, D. A. J. (2013). Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization (No. 674). Wageningen UR Livestock Research.

Vellinga, T., & van Eekeren, N. (2017). Effect verandering landgebruik op emissies broeikasgassen. V-focus, 14(2), 38-39.

Wang, S., Höhler, J., Ang, F., & Oude Lansink, A. G. J. M. (2022, April 4-6). Dutch dairy farmers' adoption of climate mitigation measures – the role of socio-psychological and socio-demographical factors [Paper presentation]. The Agricultural Economics Society, Leuven, Belgium.

Zee, van der T., A. Bannink, C. van Bruggen, K. Groenestein, J. Huijsmans, J. van der Kolk, L. Lagerwerf, H. Luesink, G. Velthof & J. Vonk, 2021. Methodology for estimating emissions from agricultrue in the Netherlands. Calculations for CH4, NH3, N2O, NOx, NMVOC, PM10, PM2.5 and CO2 using the National Emission Model for Agriculture (NEMA) – Update 2021. RIVM, Rapport 2021-0008.

Zijlstra, J., Timmerman, M., Reijs, J., Plomp, M., Haan, M. d., Šebek, L., . . . Eekeren, N. v. (2019). Doelwaarden op bedrijfsniveau voor de KPI's binnen de Biodiversiteitsmonitor Melkveehouderij [1 online resource (PDF, 101 pages) : illustrations]. Retrieved from https://doi.org/10.18174/471202

Weblinks:

http://www.fao.org/ag/againfo/livestock-benchmarking/en/

http://www.ilr.uni-bonn.de/em/rsrch/FarmDyn/FarmDynDoku/

https://www.rvo.nl/sites/default/files/2019/01/Tabel-6-Stikstof-en-fosfaatproductiegetallen-per-melkkoe.pdf

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6. ANNEX 1: ONLINE QUESTIONNAIRE SURVEY 2021

Online Questionnaire Survey 2021

Introductions:

Dear participants,

As you may already know, farming in the Netherlands as well as Europe has undergone several reforms. In the upcoming Common Agriculture Policy, there is an increased link to act on climate change, and deliver environmental as well as ecosystem services among other pillars. 40% of the total CAP budget is expected to be spent on climate change in the period of 2023-2027.

The survey is part of the ongoing EU horizon 2020 Project MINDSTEP (https://mind-step.eu/). MINDSTEP aims to **support** public decision making in agricultural, rural, environmental and climate policies by taking into account behaviours of individual farmers. In this survey, we are particularly interested in your views on measures to reduce on-farm greenhouse gases (GHGs) mitigation measures. **On-farm GHGs mitigation measures** in this survey refer to measures and practices that aim primarily to reduce GHGs emissions from agricultural practices into the atmosphere.

Instructions:

Please read each question carefully and answer it to the best of your ability. There are no correct or incorrect responses; we are merely interested in your personal opinions. The survey will take about 10-15 minutes.

Feedbacks:

All answers to this survey are kept completely confidential. We will analyse the answers on an aggregated level. If you are interested in the survey results (e.g. your colleagues' attitudes towards climate mitigation measures, general preference for (non-) financial incentives, etc.), please leave your email address at the end of the survey. We will then send you the aggregated results of this survey.

Contact persons:

In case you have any further questions, you are always welcome to contact us.

Scarlett Wang: Onderzoeker scarlett.wang@wur.nl

Julia Hoehler: Universitair Docent julia.hoehler@wur.nlï¿½

Thank you in advance for your cooperation!

Yours sincerely,

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Scarlett Wang

Business Economics Group | Wageningen University and Research

Q1: Could you select one of the following statements which **best describes your current adoption level** of on-farm GHGs mitigation measures?

Focus	**Measurement level, type and survey questions**
Dependent variable	

Phase Model	**Ordered ï¿½ 4 Phases (participants choose the statement fits his/her goal the most)**
Pre-decisional	*a-I am not planning to take any on-farm GHGs emissions mitigation measure and also see no reason why I should do it.*
	b- I am not planning to take any on-farm GHGs emissions mitigation measure because it *would be impossible for me to do so currently.*
Pre-actional	*c- I would like to reduce my on-farm GHGs emissions, but now I am not sure about how I can reduce it, or when I should do so.*
Actional	*d- I already know which mitigation measures I want to use for my farm, but, I have not put this into practice yet.*
Post-actional	*e- I have already taken measures to reduce GHGs emissions on my farm via mitigation measures. I shall maintain or further reduce my already low level of on-farm GHGs emissions for the coming 3 years.*

Q2. Could you indicate which on-farm GHGs measures you have adopted in the past three years up to now? *You can tick more than one option.*

Mitigation option	Tick here ⇦🕘🕖
Less young stock	
Higher milk production per cow	
Increase feed efficiency (less losses, more frequent feeding)	
Decrease artificial N-fertilizer	
Increase legumes in grass	

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Renewable energy production (solar, biogas, wind)	
Increase maize share in ration	
Decrease concentration share in ration	
Use of renewable energy	
Reduce renewal rate of grassland	
Energy saving technologies	
Emission-reducing floor	
Any other measures than the ones mentioned above	
No measures	

Now we want to know how you feel and think about reducing on-farm GHGs emissions. Could you indicate to what extent do you agree or disagree with the following statements?

Socio-psychological variables (Independent Variables)	
Emotions associated with consequences	Q3: I feel bad if I take no measures to reduce my farming related GHGs emissions.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
	Q4: I feel happy if I succeed in reducing my on-farm GHGs emissions.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Social norm	Q5: People I am dealing with (e.g. fellow farmers and business partners) expect me to reduce my on-fam GHGs emissions.ï¿½
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
	Q6: People who are important to me (e.g. family/friends), think that I should take measures to reduce my on-farm GHGs emissions.ï¿½
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Personal norm	Q7: Regardless of what other people do, my values and principles oblige me to reduce farming related GHGs emissions.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
	Q8: I think that reducing GHG emissions is the right thing to do for me.

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	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)

How strong is your **future goal** in reducing on-farm GHGs emissions **within the coming 3 years**?

Goal intention	Q9: My goal to reduce on-farm GHGs emissions within the coming 3 years is…
	(-2 very weak, -1 weak, 0 neutral, 1 strong, 2 very strong)

ï¿½

Perceived goal feasibility	Q10: How feasible is it for you to reach your future goal in reducing on-farm GHGs emissions within the coming 3 years?
	(-2 very difficult, -1 difficult, 0 neutral, 1 easy, 2 very easy)

Q11: Now we present you a list of on-farm GHGs mitigation options. We would like you to **tick the option you prefer the most** for reaching your **future** on-farm emission reduction goal. *You can tick one option.*

Mitigation option	Tick here ⇦🕘🕖
Less young stock	
Higher milk production per cow	
Increase feed efficiency (less losses, more frequent feeding)	
Decrease artificial N-fertilizer	
Increase legumes in grass	
Renewable energy production (solar, biogas, wind)	
Increase maize share in ration	
Decrease concentration share in ration	
Use of renewable energy	
Reduce renewal rate of grassland	
Energy saving technologies	
Emission-reducing floor	
Any other measures than the ones mentioned above	
No measures	

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Q12: Could you indicate to what extent do you agree or disagree with the following statements for not implementing any GHG mitigation measures? (Note: Q12 is dependent on Q11, only if ï¿½**No measuresï¿½** is chosen, then farmers will see and answer Q12. After Q12, farmers will be directed to the last question Q24.)

I am not interested in implementing any GHG mitigation measures, because...

a.... they are too costly.	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
b.... there are too limited practical advice and support.	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
c.... they conflict with my investments in reducing other emissions (e.g. nitrogen, ammonia).	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
d.... of another reason, namely:	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)

Keep the on-farm GHGs mitigation option you have selected in mind, we would like to know to what extent do you agree or disagree with the following three statements.

Behavioural intention	Q13: I plan to adopt my chosen GHGs mitigation option within the coming 3 years
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Implementation Intention	Q14: I have already informed myself about the necessary details to get started on my chosen GHGs mitigation option.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
New behaviour	Q15: I have already made commitments to implement my chosen GHGs mitigation option, e.g., ask for a permit, new farm management plan, new production plan, investment and etc.ï¿½
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)

Attitude	Q16: Adopting my chosen GHGs mitigation option on my farm is advantageous for me.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)

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	Q17: It is important to me that the measure I have chosen to reduce greenhouse gas emissions is applied to my company.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Perceived behaviour control	Q18: Adopting my chosen GHGs mitigation option would be **…** for me.
	(-2 very difficult, -1 difficult, 0 neutral, 1 easy, 2 very easy)
	Q19: I do not depend on anyone to implement the measure I have chosen to reduce greenhouse gas emissions.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Action planning	Q20: I have already run through my head on how to best carry out my plan of implementing my chosen GHGs mitigation option. (-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Coping planning	Q21: I have already figured out how I will solve potential problems and obstacles during the implementation of my chosen measure to reduce greenhouse gas emissions. (-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Maintenance self-efficacy	Q22: I am capable of maintaining implementation of my chosen GHGs mitigation option despite potential barriers.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)
Recovery self-efficacy	Q23: I rely on my ability to successfully implement measures to reduce greenhouse gas emissions in the event of setbacks.
	(-2 strongly disagree, -1 disagree, 0 neutral, 1 agree, 2 strongly agree)

Q24: Regarding your **preferred incentives for mitigating on-farm GHGs in general,** Could you indicate whether you agree or disagree with the following statements?ï¿½ You are asked to give your options on all the listed incentives *and if you think we missed your preferred incentive, please suggest it in 1st cell of the last row.*

I would implement (additional) GHGs mitigation measures on my farm if....	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
...I get paid extra to compensate my efforts in reducing GHGs emissions					
...this is what society desiresï¿½					

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...I get free practical advice on how to do so					
...I can monitor my on-farm GHGs emissions via a smart app on my phone or PC					
... I can get a price premium if I meet the lower carbon footprint of my product ï¿½					
...that is required by law					
....there is emission trading system for the agriculture sector					
... others, namely..					

Closure

You have come to the end of the survey. Thank you very much for your time and effort to participate in this survey. If you would like to receive the summary of the results of this survey, please include your email address below.

Email address:

If you have any questions or remarks, you are welcomed to indicate them here.

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