Report WP 3.3. “Socio-economic and trade off aspects of mitigation practices and techniques” [1]

Assessing the impact of different greenhouse gas mitigation scenarios on the environmental and economic aspects of dairy farming systems: comparison of different production systems

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Wageningen livestock research

April 2023

[1] *This study was supported by ERA-GAS/ERA-NET Susan/ICT-AGRI, project “Climate Care Cattle farming systems” (ID: 3274), National Funding Center Netherlands: NWO (ENW file number: 39274) and Topsector Agri&Food: TKI (EU-20011)*

Contents

Abstract

Tackling climate change and other environmental concerns is a global challenge. Given the high contribution of livestock sector on the greenhouse gas (GHG) emissions, this industry has come into focus. Efforts have been initiated by introducing many mitigation strategies. However, still there are debates about effectiveness of them. Given the complexity of dairy system, quantifying the impacts is a challenge. In this study some of the available mitigation strategies have been models using a farm model (DairyWise). The assessment had two parts: 1) combination of a set of mitigation strategies as different production systems, 2) individual assessment of mitigation strategies. For individual assessments, five mitigation strategies including increasing milk production level (6,000, 8,500, and 10,000 kg milk/cow), increasing longevity by changing the youngstock ratio (5, 6.7, and 8 youngstock per 10dairy cow), increasing area of long-term grasslands (20:20, 33:6, 39:0 grass area:maize silage area), sowing clover on grasslands, and increasing grazing intensity (900, 1,600, and 3,600 hours/year) were selected and evaluated at three levels. To have a better overview, three production systems including extensive-regular (ER), extensive-organic (EO), and high-tech (HT) dairy systems were compared with the baseline system (BS) to show the technical, environmental, and economic differences. The production systems differed from the point of view of the stocking rate, milk production level, grazing intensity, cultivation of clover, available land area, and type of stall. For comparisons, environmental (GHG and ammonia emissions), technical (nutrient balance), and economic aspects were considered. Obtained results showed that EO and HT scenarios were the most attractive ones for farmers due to the high turnover. However, regarding GHG emissions, EO and ER were in a better position. Regarding the ammonia emissions, HT and EO were in similar situation compared to BS while ER system led to higher NH3 emissions in both sources of emissions (ammonia from land and stable and manure storage). Results of individual assessments showed that keeping milk production at 8,500 kg milk/cow, reducing the youngstock ratio to 5 youngstock per 10 dairy cows, keeping the share of grass-maize ratio 50:50, and sowing clover and keeping the grazing intensity as 1,600 hours/year results in better turnover and lower GHG and NH3 emissions.

Keywords: mitigation strategies, DairyWise, extensive-regular, extensive-organic, high-tech, dairy production.

1 Introduction

Tackling climate change and other environmental problems is a worldwide challenge nowadays. Based on the Intergovernmental Panel on Climate Change (IPCC) report, agriculture is responsible for 24% of total anthropogenic greenhouse gas (GHG) emissions (Edenhofer et al., 2014). The livestock sector contributes to around 14.5% of total GHG emissions. Among the different livestock, dairy is responsible for around 23% of the sector emissions (Gerber et al., 2013). Given the high contribution of livestock sector on the GHG emissions, this industry has come into focus. In addition to GHGs, there is a high pressure on the livestock sector to reduce other environmental impacts such as nitrogen (N) losses to air and groundwater. Given the low N-use efficiency, livestock sector is vulnerable to N loss (Burchill et al., 2016). The main sources of N losses in dairy farm are application of organic and mineral fertilizers and deposition of slurry in barns and grasslands. Denitrification converts much of N to dinitrogen (N_2) but also results in production of nitrous oxide (N_2O) and nitric oxide (NO). Compared to N_2, the proportion of N_2O and Nitric oxide (NO) is considerably lower. Ammonia (NH3) is another source of N losses which has negative impact on environment through eutrophication and acidification. Moreover, ammonia volatilisation contributes to indirect N2O emissions.

The GHG emissions from dairy farms are affected by many factors such as the breed, farm management, environment, diet, physiological stage, etc. One of the concerns in livestock production in Europe is about intensive production systems where insufficient land makes the recycling of wastes from livestock difficult, leading to nutrients overloads and environmental issues. An increase in food production results in increase in the GHG and N related emissions. It also leads to negative impacts on other environmental issues. In this situation keeping more attention on sustainable intensification is crucial. The concept of sustainable intensification refers to a rise in the overall food produced from the current agricultural land available worldwide. This helps avoiding the heightened competition for land with ecological habitats while also reducing or dissociating the linked environmental effects (Schulte et al., 2014). In other words, sustainable intensification means increasing the production without negative impact on environment (including resources). To achieve the sustainable intensification goal, several environmental policies have been set and the future growth in production must be aligned with these policies. Examples of policies aiming to reduce the impacts on the environment are the European Union Nitrates Directive (EU, 1991) for nitrates, the European Union Climate and Energy Package for 2020 (EU, 2009) and the European Union Climate and Energy Framework for 2030 (European Council, 2014) for N2O, and the National Emission Ceilings (NEC) Directive for ammonia (EU, 2016).

Reducing the environmental impacts of livestock sector can be achieved by lowering the production or reducing the emissions intensity or by combination of the two. To mitigate the environmental issues in dairy farms, many options are available which can be classified as i) feed related options (e.g. feed or feeding management, application of supplements, etc.), ii) manure management related options (e.g. manure storage, treatment and application), iii) animal related options (e.g. genetic improvements, animal health strategies, etc.), iv) farm related options (e.g. crop rotation, grassland management, grazing intensity, etc.). In the literature a large number of technical and management-based solutions to reduce N2O, methane (CH4), and carbon dioxide (CO2) emissions from agricultural systems have been proposed (Beldman et al., 2021a; Beldman et al., 2021b; Hristov et al., 2013a; Hristov et al., 2013b; Jarvis and Ledgard, 2002; Montes et al., 2013; Smith et al., 1997). At the farm level, organic farming has been considered as a possible strategy for reducing GHG emissions (Dalgaard et al., 2001; Flessa et al., 2002).

In order to have a more comprehensive overview, it is essential to assess not only the environmental consequences but also technical and economic aspects of mitigation strategies in a dairy farm. The extent to which livestock farms can move towards reducing emissions, highly depends on many parameters such as costs, knowledge requirements, accessibility, and ease of use. Among the mentioned parameters, economic aspect is an important one. Assessing the environmental and economic impacts of mitigation strategies was the subject of many studies (Mosnier et al., 2019; Vermont and De Cara, 2010). De Cara and Jayet (2011) conducted simulations showing that a 10% reduction of GHG emissions in European Union (EU) agriculture, costs around 35 €/t CO_2eq. In a study carried out by Pellerin et al. (2017) an abatement of at least 10% for the French agriculture is costing less than 25 €/t CO_2eq. For dairy in France, a 5% reduction of the carbon footprint of one kg milk costs around 40 €/t CO_2eq. Lengers et al. (2014) ran simulations showing that a 10% reduction of GHG emissions in a typical German dairy farm would require a carbon price of over 100 €/t CO_2eq.

Most of the previous studies focused on an individual mitigation strategy. However, in a case a set of mitigation strategies are applied in a farm, the assessment requires more deep evaluations. For example, in a pasture-based farming system where land is being used to produce the home-grown roughages, several production parameters play a role. In a dairy production system, the production parameters are connected to each other, and it is difficult to separate the impact of an individual mitigation strategy among a set of strategies. Therefore, in this situation the whole farm must be addressed. To have a better insight about the mitigation strategies, we aimed to assessing both individual and combination of mitigation strategies. For individual assessment five mitigation strategies namely change in the level of milk production, youngstock ratio, grazing intensity, grass-maize share, and planting clover were assessed. For the combined mitigation strategies, three scenarios (from now on we call them production systems) including extensive-regular system (ER), extensive-organic system (EO), and high-tech system (HT) were compared with the baseline system (BS) to show the environmental and economic impacts of a transition from the BS to various dairy production systems. To assess the impacts not only on GHG emissions, but also on NH3, economic and technical aspect, a farm model was applied for the related assessments.

2 Material and methods

2.1 Model description

DairyWise (Schils et al., 2007) is a whole-farm dairy model which simulates technical, environmental (including GHG emissions, energy and nutrient balance), and financial processes. DairyWise is a tool that can be used for integrated scenario development and evaluation. It calculates technical and economic indicators based on a combination of farm-specific and normative input values. Using the technical and economic indicators, strengths and weaknesses of a farm can be detected and consequences of changes can be assessed. The structure of DairyWise is shown in Figure 1. This model integrates all the main subsystems of a dairy farm into a farm model. The model input consists of user-defined traits that describe a dairy farm. The central component is the FeedSupply model that balances the herd requirements, as generated by the DairyHerd model, and the supply of homegrown feeds, as generated by the crop models for grassland and maize silage. The FeedSupply model's outputs are being used as input for several technical, environmental, and economic sub-models. The sub-models simulate a range of farm aspects such as N, phosphorus (P) and potassium (k) cycling, nitrate (NO_3^-) leaching, NH_3 emissions, GHG emissions, energy use, and a financial farm budget. The final output is a farm plan describing all material and nutrient flows and the consequences for the environment and economy.

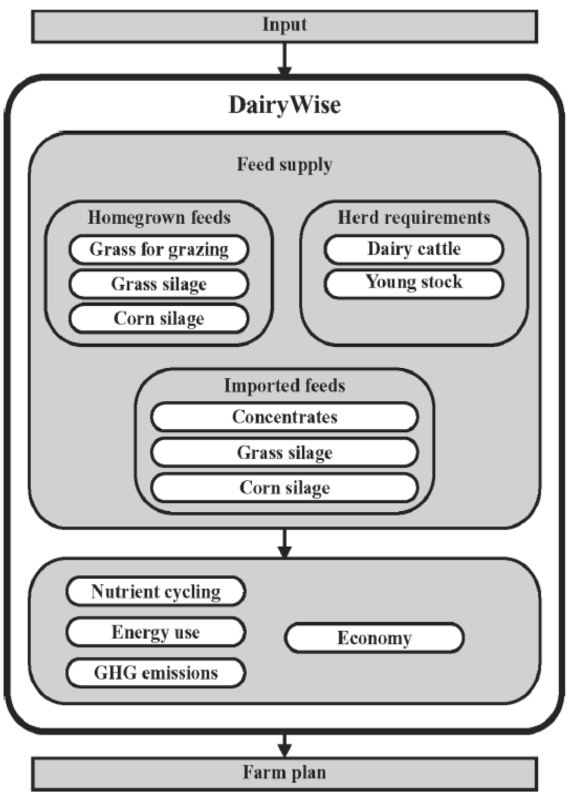

Figure 1. The structure of DairyWise model. Source: Schils et al. (2007)

DairyWise aimed at modelling at farm level and includes dairy farming, including its youngstock and home-grown grass, maize as silage or corncob mix, triticale, lucerne and fodder beets. Feed and mineral fertilizer can be imported, and milk, meat (live animals) and manure can be exported from the modelled farm. Animal feed requirements and production as well as animal manure production and its utilisation in roughage growth are modelled.

DairyWise is a flexible model which can be run with different levels of inputs. It provides different input options depending on the data availability. At the minimal level, data of livestock and feed management, land and crop management and some other variables should be provided. Livestock and feed management categories consists of data related to the number of dairy cows, the grazing system and feeding strategy. Land and crop/roughage management category includes the soil types, the land area (grass, maize silage, and other forage crops), and the fertilizer application rates. In each step it is possible to extend the list of inputs to change the default values.

As it is seen in Figure 1 and discussed previously, DairyWise applies various models. For crop models DairyWise applies GrassGrowth and maize models. Three models are used in DairyWise as animal models: for dairy cows (DairyCow model), for youngstock (YoungStock model) and for herd characteristics (DairyHerd model). Also, for feed, the FeedSupply model is applied to balance the herd energy and protein requirements with the supply from the homegrown feeds and imported ones.

Besides the applied models, a wide range of calculations are carried out by DairyWise, including the nutrient cycling, feed supply details, energy assessment, GHG emission calculations, labour demand, and economic evaluations. All the detailed information about the applied methods can be found in Schils et al. (2007). DairyWise provides a long list of outputs as mentioned some of them above, and also consequences of animal manure policies on a dairy farm. Some of the generated outputs are based on the "Annual Nutrient Cycle Assessment" (in Dutch: "KringLoopWijzer Melkveehouderij" (KLW)) calculations (De Vries et al., 2020).

DairyWise has been applied in many studies to assess different aspects of circular agriculture. Vellinga and Hoving (2011) used DairyWise in combination with the Introductory Carbon Balance Model (ICBM) to show that mitigation of methane emissions by increasing the amount of maize silage in the ration can be offset by land use change. It is also used to study cost effectiveness of GHG (Vellinga et al., 2011) or NH_3 (Evers et al., 2015) emission mitigation options at farm level or to assess the environmental (GHG and NH_3) and economic effects of mono-digestion of manure on dairy farms (Evers et al., 2019). Furthermore, Hutchings et al. (2018) compared DairyWise with three other farm-scale models on their ability to estimate GHG emissions. More recently, Reijs et al. (2021) have used DairyWise to calculate the economic impact of NH_3 emission reducing measures in the context of the Dutch N policy.

In this study DairyWise applied to evaluate the impacts of different strategies on a dairy farm.

2.2 Scenario analysis

The scenario analysis consists of two parts; the first part of assessment consists of simulating a set of GHG mitigation strategies as different production systems and comparing them with the baseline. In addition to baseline scenario (BS), three scenarios were defined as extensive-regular (ER), extensive-organic (EO) and high-tech (HT). In the following sections, the details of each production systems are presented.

The second part of the scenario analysis include simulating different GHG mitigation strategies as individual scenarios at different levels. The selection of possible mitigation strategies was based on the technical feasibility for implementation in whole Europe, cost-effectiveness and national policy-related issues.

2.2.1 Baseline scenario

Generally, dairy farming in Europe can be classified as three main production systems namely pasture-based, mixed, and industrial systems (Gerssen-Gondelach et al., 2017; Herrero et al., 2013; Robinson et al., 2011). The three production systems are defined as following:

1) Pasture-based system: a production system in which dairy cows are grazing during the warm seasons for a period of time. For the rest of the year, they kept in barns. The diet includes pasture forage (may also include clover and legumes), grass silage, maize silage, hay and concentrates as well. Depending on the farm management, the grazing intensity and the share of maize silage land in total available area might be different from farm to farm. Moreover, depending on whether the production system is an extensive or intensive, the milk production level and stocking rate might vary (Gerssen-Gondelach et al., 2017).

2) Mixed system: a production system in which involves both growing crops and breeding livestock. In this system grazing is still important, however, the share of concentrate in the diet is higher than pasture-based system. Generally, in the mixed system the stocking rate and milk production level is higher than pasture-based, however, there might be many exceptions.

3) Industrial system: a production system in which dairy cows are confined whole year. Animals are fed a mix diet including silage (grass and maize), hay, concentrates and combination of feed supplements (Gerber et al., 2013). Grazing is not important in this system and entirely excluded. The stocking rate and milk production level is the highest among the other systems.

In this study the baseline scenario (BS) was defined as a typical pasture-based dairy farm in Europe. Given the high variation in dairy farming systems in whole Europe, it was difficult to identify a typical dairy farm which is representative for the whole Europe. Based on studies carried out by Hoekstra et al. (2020) and Reijs et al. (2021) and after discussion with dairy experts, the baseline was defined. The details of baseline and the other three scenarios (ER, EO and HT) are presented in

Table 1. The baseline was defined as a dairy farm with 60 dairy cows on available land area of 39 ha, resulting in a stocking rate of 1.54 dairy cows/ha. Milk yield at BS was defined as 8,500 kg/cow where fat and protein content of milk was 4.3%, 3.5%, respectively. The average reseeding rate of the grassland area was set as 10% per year. Out of total available area of 39 ha around 33 ha was grassland, and 6 ha was used for cultivation maize silage. The grazing intensity was 1,260 h/year (180 days per year and 7 hours grazing time per day). The typical dairy barn which considered for simulation was a barn with slatted floor with a convex rubber top layer, with manure scraper. For economic analysis, the Dutch market was simulated and applied in the calculation where milk price is 0.38 €/kg milk.

Table 1 Overview of baseline (BS), extensive-regular (ER), extensive-organic (EO) and high-tech (HT) dairy farms as different common production systems in Europe.

Items	Unit	Baseline (BS)	Extensive-Regular (ER)	Extensive-Organic (EO)	High-tech (HT)
Number of dairy cows	(number)	60	60	60	85
Number of heifers	(number)	21	21	21	29
Number of calves	(number)	20	20	20	28
Youngstock intensity	(Youngstock/10 cow)	6.70	6.70	6.70	6.70
Stocking rate	(cow/ha)	1.54	1.28	1.28	2.18
Milk production	(kg/cow)	8,500	7,000	7,000	11,000
Milk production	(kg/ha)	13,077	8,974	8,974	23,974
Milk production	(kg/farm)	510,000	420,000	420,000	935,000
Cultivation area	(ha)	39	47	47	39
grassland area	(ha)	33	40	40	33
maize land area	(ha)	6	7	7	6
Grazing intensity	(days/year)	180	179	179	0
Grazing intensity	(hours/day)	7	10	10	0
Milk price	(€/kg)	0.38	0.38	0.50	0.37
Cultivation of clover	(-)	no	yes	yes	no
Type of stall	(-)	barn with slatted floor	barn with slatted floor	barn with slatted floor	Low emission floor

2.2.2 Extensive-Regular scenario

In the extensive-regular (ER) scenario, we simulated the impact of reduced stocking rate (by increasing the available area), cultivation of clover on grassland, reduced milk production per cow, increased grazing intensity, and reduced mineral fertilizer application rate on the environmental, economic and nutrient balance of a representative dairy farm. The stocking rate, milk production, and grazing intensity for ER scenario were 1.28 dairy cow/ha, 7,000 kg/dairy cow, 1,790 h/year, respectively (

Table 1). The net yield of maize silage was assumed to be same as BS (12,563 kg dry matter/ha). The rest of parameters such as manure application, grass yield, feed intake, concentrate use, etc. were optimized by the model.

2.2.3 Extensive-Organic scenario

For the extensive-organic (EO) scenario, it was assumed that stocking rate, cultivation of clover on grassland, grazing intensity and milk production per cow were same as ER scenario while no mineral fertilizers were applied in lands compared to ER scenario. It was also assumed that the produced organic milk is sold with a higher price (30% higher price) (

Table 1). The net yield of maize silage was assumed to be same as BS and ER (12,563 kg DM/ha). The rest of parameters such as grass yield, manure application, feed intake, concentrate use, etc. were optimized by the model.

2.2.4 High-Tech scenario

Compared to BS, the stocking rate and milk production per cow were increased in the high-tech (HT) scenario, however, no clover was cultivated on grassland, and no animal was grazed. A barn with low emission floors was included in HT scenario (

Table 1). The net yield of maize silage was assumed to be same as BS (12,563 kg DM/ha) while the grass yield was optimized by model. For the rest of items, such as manure application, feed intake, concentrate use, etc. the model optimized the parameters.

2.2.5 Individual scenarios

Although a quite number of GHG mitigation strategies are being discussed in literature, only a limited number of them were considered suitable to be assessed in this study. Depending on how common the mitigation strategy is in EU, its GHG mitigation efficiency, data availability, technical feasibility, and possibility of being modelled by our available model (DairyWise), the following five measures were selected:

Increasing milk production level (kg milk per dairy cow): there are several approaches to increase dairy cow productivity (milk production per cow) such as genetics improvements, animal health improvements, and diet optimization. The genetic improvement (artificial insemination) has significantly increased milk production of dairy cows over the last years. The dairy industry has also improved veterinary medicine. Moreover, lots of efforts have been made to shift the health programs from treating sick animals to preventing dairy cows to become sick. Providing a nutritious diet is crucial for increasing milk production. The nutritious diet consists of high-quality forage, concentrates and supplements. A tailored made diet to meet the needs of the dairy cows is essential to increase the milk production level. In addition to the items mentioned, proper herd management such as providing comfortable housing, and maintaining good hygiene in the barn can also be important to increase milk production. Among the items mentioned, we focused on the diet adjustment to achieve the set goals for the milk production levels. However, we noticed that to achieve the targeted milk production in addition to diet optimization further adjustments in the feed intake capacity of available dairy cows are essential. Therefore, for all the scenarios where milk production was increased, feed intake capacity was increased as well. Three milk production levels including 6000, 8500 and 10000, were studied for the individual scenario analysis (Table 2).

Increasing longevity by changing the youngstock ratio: keeping dairy cows in a herd for a longer period reduces the total GHG emissions of herd. All emissions associated with growing calves are allocated to produced milk. Therefore, keeping a diary cow in a herd for a longer period and reducing the number of young stocks added to herd yearly, can reduce the total GHG emissions of dairy farm. Therefore, the emissions per kg of produced milk can be reduced. Three levels were defined for youngstock ratio including 5, 6.7 and 10 youngstock per 10 dairy cows (Table 2).

Expansion of long-term grasslands: increasing the share of permanent grassland has both negative and positive impacts on environmental and economic aspects of a dairy farm. Permanent grasslands help to improve the soil quality by increasing the soil organic matter, reducing erosion, and improving soil structure. Moreover, grasslands capture and store nitrogen in the soil. This occurs through the process of nitrogen fixation where atmospheric nitrogen is stored into a form that can be taken up by plants. By this process, grasslands can reduce the need for synthetic nitrogen fertilizers, which can have negative environmental impacts. Expanding the grasslands might have negative impact because of lower yields compared to other roughages. The expansion of long-term grasslands was studies at three levels (as described in Table 2).

Sowing clover on grasslands: sowing clover on grasslands is a common practice used to improve the grassland soil fertility and productivity. Clover is a legume plant with the ability to fix nitrogen form the atmosphere. Fixing nitrogen reduces the need for mineral N fertilizers. The impact of sowing clover on grasslands was tested as one of the scenarios.

Increasing the grazing intensity: grazing intensity defines as the number of hours animals spent on grasslands. By grazing, a more diverse range of plants is consumed by animals, which can improve their nutritional intake and result in higher milk production. Grazing reduces the costs of purchasing forage consumed by livestock.

Grazing can also reduce the amount of energy needed for feed production, and reduce GHG emissions from manure, however, by increasing the share of grass in diet, enteric fermentation increases. Three different levels of grazing intensity defined and assessed as 900, 1620, and 3600 h/year. The last level was considered as the scenario in which animals have unlimited access to grassland.

The mentioned mitigation strategies were modelled in DairyWise, and their potential to reduce GHG emissions at farm level was assessed. To have a more comprehensive overview, in addition to GHG emissions, the impacts on NH3, technical aspect, economic aspects, etc. were also assessed. It should be mentioned that carbon sequestration is not incorporated in DairyWise, thus the impact of increasing grazing intensity on the amount of soil organic matter and carbon sequestration was out of the scope of this study.

Table 2 Characteristics of individual scenarios.

Mitigation strategy (individual scenarios)	Unit	Low level	Medium level	High level
Increasing milk production level	kg milk per dairy cow	6,000	8,500	10,000
Increasing longevity by changing the youngstock ratio	youngstock per 10 cows	5.0	6.7	10.0
Expansion of long-term grasslands	grassland area (ha): maize land area (ha)	20:20	33:6	39:0
Sowing clover on grasslands	(-)	no	yes	
Increasing grazing intensity	hours per year	900	1,620	3,600

All the individual scenarios were modelled at different levels (as describe in Table 2) using DairyWise tool and the results of technical, environmental and economic modelling are presented in the next section.

3 Results and discussion

In this section the obtained results are presented. The results are presented in two main parts. First, the results of assessing four different production systems (BS, ER, EO, HT) are presented and then the results of individual analysis are shown and discussed.

3.1 Comparison of production systems (analysis a set of scenarios)

Figure 2 shows the comparison of different scenarios in terms of environmental and economic aspects. To make the comparison easier, all the three production systems were compared with the BS and the differences are presented in percentage. More details of results for each scenario can be found in the Appendix (Figure A1).

As it is shown, all the scenarios had a better economic output (turnover) compared to BS. The highest positive turnover was seen for EO (+72%) and followed by HT (+32%) and ER (+1%). The highest price of organic milk and meat resulted in the higher income for EO and made this scenario very attractive for dairy farms among the studied scenarios. In HT, the productivity is high and resulted in a high turnover for this scenario. As it has been mentioned before, to achieve the high milk production, DairyWise adjusted the feed to find the optimum situation. After the first run it was revealed that the animal feed intake adjustment is required to achieve the desirable milk production. Therefore, to achieve the highest milk production level (11,500 kg milk per cow), the animal feed intake capacity was increased which means new breeds with a higher feed intake was used in the herd. With a higher efficiency in HT, the higher turnover was seen compared to BS.

To have a more in deep evaluation, the total GHG emissions were divided to on-farm and off-farm emissions. The on-farm emissions include all emissions occurs in a dairy farm including emissions due to enteric fermentation, manure storage, and feed production on farm while off-farm emissions refer to emissions associated with the production of inputs applied in a dairy farm such as emissions due to energy sources, supply of on farm inputs (feed and fertilizers). The results showed an increase in off-farm GHG emissions in HT scenario (+10%) compared to BS, while for the ER and EO, GHG emissions were declined by 36% and 40%, respectively. In ER and EO scenarios, because of higher cultivation area, the homegrown feeds covered a high portion of the feed requirements of animals, therefore a small share of required feed was supplied from outside farm. The HT scenario was highly depending on the imported feeds; therefore, the off-farm emissions were higher than the BS. On the contrary, for the on-farm GHG emissions, a reduction in GHG emissions was seen for HT (-6%) while an increase in GHG emissions was illustrated in the ER (+12%) and EO (+11%) systems. A higher share of consumed feeds in EO and ER systems was supplied by own farm which resulted in higher GHG emissions in these systems compared to BS. However, in HT system the contribution of on-farm feeds was less than BS and resulted in reduction in the on-farm emissions compared to BS. Moreover, because of higher efficiency of HT compared to BS, lower on-farm emissions per kg fat protein corrected milk (FPCM) was reported. Due to high milk production level in HT, the share of concentrates in the diet was higher than the other production systems.

Similar to GHG emissions, the ammonia emissions were split into a) emissions from land, and b) emissions from stable or manure storage. Different units namely kg NH_3/ha and kg NH_3/LU were applied for emissions from land and emissions from stable or manure storage, respectively). One dairy cow, heifer and calf were assumed to be equal to 1, 0.53 and 0.23 livestock unit (LU). Obtained results showed that NH_3 emissions from land was higher in both HT (+26%) and ER (+23%) compared to BS. However, lower NH_3 emissions from land were seen for EO (-15%) compared to BS. In HT scenario, high manure and mineral fertilizers were applied to supply the high demand of feeds. Therefore, high level of NH_3 emissions were seen from land in this system. In ER, the higher NH_3 emissions from land can be explained by the higher N content of manure, where with the same application rate of manure (compared to BS) higher amount of NH_3 was per ha was seen. The lower

NH3 emissions from land for EO compared to the BS can be explained by no application of mineral fertilizers on this system. Higher grazing also reduces the NH3 emissions from land. Regarding NH3 from stable and manure storage, higher emissions were reported for both ER (36%) and EO (7%) compared to BS, while lower emissions was seen for HT (-25%). In both ER and EO systems the diet is more dependent on the roughages and the N content of diet was higher, this means the higher N content of manure which resulted in higher NH3 emissions from stable and manure storage. For the HT scenario the lower NH3 from stable and manure storage can be explained by application of low emissions floors in this scenario which resulted in 25% reduction of NH3.

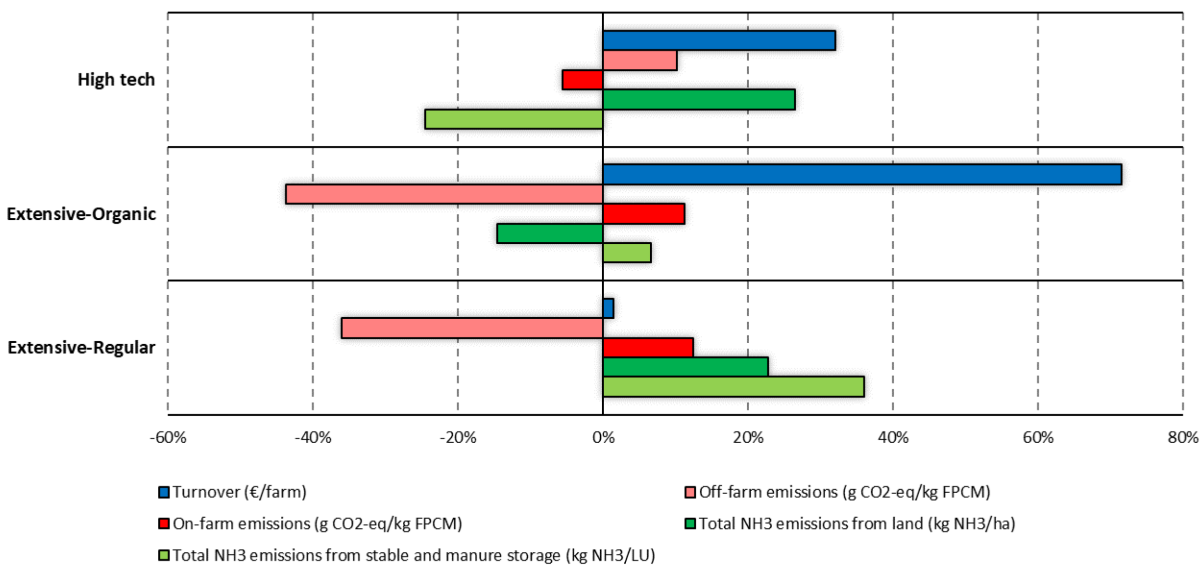

Figure 2. Comparison of extensive-regular (ER), extensive-organic (EO), and high-tech (HT) production systems with the baseline scenario (BS).

Based on the obtained results, it was revealed that EO and HT scenarios were the most attractive ones for farmers due to the high positive economic impacts. However, regarding GHG emissions, EO and ER were in a better position where the sum of on-farm and off-farm GHG emissions of these two systems were lower than BS. Regarding the total NH3 emissions, HT had a better situation for emissions from stable however regarding the NH3 emissions from land, EO had the best place. Based on the obtained results it was revealed that because of the interaction between the mitigation strategies it is essential to assess the impacts of each individual scenario. In the following section the results of individual scenarios are presented. Comparison of the individual assessment and different production systems helps to have a better insight about the effectiveness of mitigation scenarios.

3.2 Individual scenario analysis

For the individual scenario analysis, five scenarios including increasing milk production level, increasing longevity by changing the youngstock ratio, expansion of long-term grasslands, sowing clover on grasslands, and increasing the grazing intensity were tested at different levels and the environmental and economic impacts were assessed. For comparison, in scenarios with three level of assessments, the middle level was used for comparison. The results of individual scenario assessments are presented in Figure 3 to Figure 7.

As it is mentioned before, three annual milk production levels (6,000, 8,500, and 10,000 kg/cow) were assessed and compared. As it is shown in Figure 3, increasing the milk production resulted in increase of farm income and turnover. The farm's turnover for low milk production level was 37% lower than medium milk production level. For high milk production level, turnover was 12% higher than the medium milk production level. The feed intake capacity of dairy cows was higher at higher milk production level which means higher efficiency at this level.

The results of GHG emissions showed that by increasing the milk production level, off-farm GHG emissions increased. At low milk production level, the GHG emissions per kg FPCM was 40% lower than BS while at high milk production level it was 14% higher off-farm GHG emissions was reported. By increasing the milk production level, the demand for importing feeds from outside of farm increased and subsequently the off-farm GHG emissions increased per kg FPCM. By reducing the dependency of farm on imported feed, the on-farm GHG emissions increased. The on-farm GHG emissions for the scenario with low milk production level was 15% higher than the medium milk production level while for the high milk production level, the on-farm GHG emissions was 15% lower than the medium milk production level (Figure 3). The total GHG emissions (sum of on-farm and off-farm GHG emissions) was increased by increasing the milk production. Although the efficiency is increasing by increasing the milk production, the impact of higher GHG emissions of purchased feed was greater and resulted in higher GHG emissions per FPCM for high milk production scenario.

The NH3 emissions from land reduced by increasing the milk production level. However, reverse trend was seen for NH3 emissions per LU from stable and manure storage. It was seen that by increasing the milk production, the N content of diet and subsequently the N content of manure increased. It resulted in higher levels of NH3 emissions from stable and manure storage in the high milk production level.

Based on the obtained results it was revealed that increasing milk production per dairy cow was very attractive for the farmers in terms of financial consequences however, it was seen that it had negative impact on the total GHG emissions (sum of on-farm and off-farm emissions). Increasing milk production level increased the NH3 emissions from stable and manure storage but led to lower level of NH3 emissions from land in high milk production level.

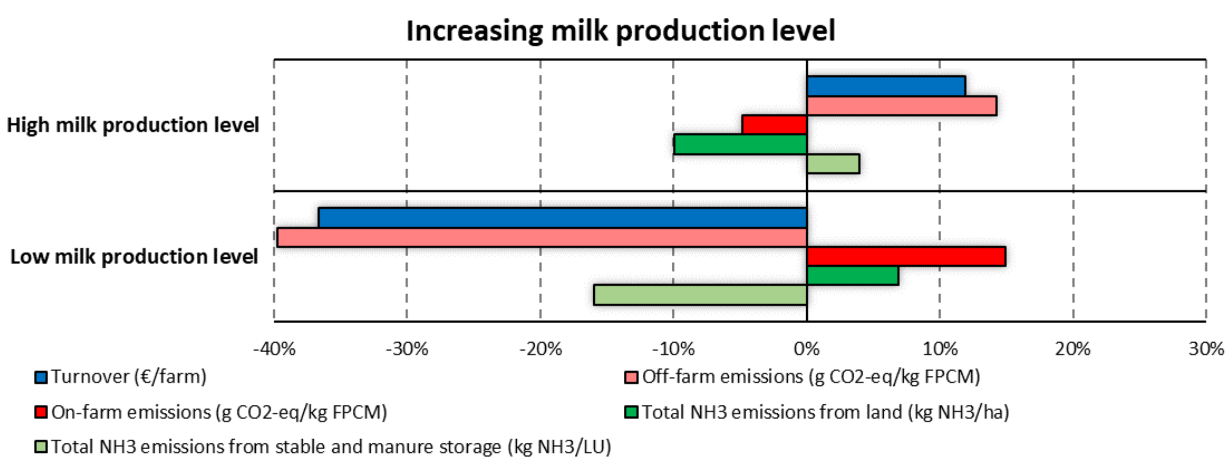

Figure 3. The impact of milk production level on the environmental and economic aspects of a dairy farm. Comparison with the farm with medium milk production level.

The results of environmental and economic impacts of changing the youngstock ratio in a dairy farming system are shown in Figure 4. As it is shown, by increasing the young stock ratio from low ratio (5 youngstock per 10 cows) to high ratio (10 youngstock per 10 cows), the turnover reduced. Dairy farm with low youngstock ratio had 7% higher turnover compared to the medium level of youngstock ratio (6.7 youngstock per 10 cows) while in a dairy farm with high youngstock ratio, the turnover was 12% lower than the farm with a medium youngstock ratio. Replacing the dairy cows with the young animals more often, increased the costs of milk production. Older dairy cows have the higher milk production levels. Moreover, keeping dairy cows for a longer period in the herd results in distributing the cost of growing young animals over more lactation years which means lower annual costs.

The results of on-farm and off-farm GHG emissions showed that increasing the youngstock ratio increased the both on-farm and off-farm emissions per kg of produced milk. However, the level of changes in GHG emissions was less than 2%.

Ammonia emissions from land and stable and manure storage for low youngstock ratio was higher than the medium level while for the high youngstock ratio it was calculated less than the medium level. As it is shown the impact of youngstock ratio on the NH3 was not substantial. Based on the obtained results, lowering the young stock ratio does not have substantial impacts on environment however it has positive impact on the economic aspects of a dairy farm. Therefore, it is an attractive strategy for dairy farmers.

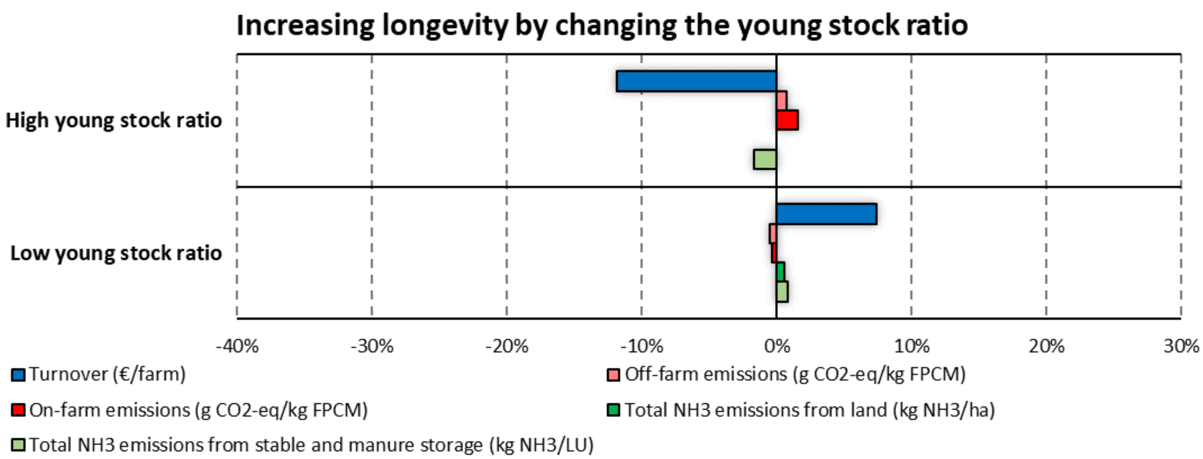

Figure 4. The impact of youngstock ratio on the environmental and economic aspects of a dairy farm. Comparison with the farm with medium youngstock ratio.

The impact of expansion of long-term grasslands on the environmental impacts of a dairy farm was studied. Results showed that increasing the share of grasslands reduced the turnover of a dairy farm. In the studied farm where the share of maize and grass is same, a 13% higher turnover was seen compared to the situation where 85% of total area was under the grass production. The main conclusion is that because of higher economic value of maize, cultivation of maize is more efficient for the dairy farms compared to the scenario with high grassland land area where maize is imported from outside the farm.

By increasing the share of grassland area, it was seen that the off-farm GHG emissions increased from -3% to 3% for low and high grassland area. Maize silage is an important ingredient in a ration. In a scenario in which zero area is under maize cultivation, the required maize silage should be imported from outside the farm. The GHG emissions associated with the production and transport of maize silage increased the GHG emissions of produced milk. Although increasing the share of grassland increased the off-farm emissions, it led to lower on-farm GHG emissions. The grasslands N requirements is lower than maize silage lands which means less manure and mineral fertilizer were applied in the farm. Therefore, the on-farm GHG emissions of the studied dairy farm reduced by increasing the grasslands area.

The NH3 emissions from land ranged around 50%. The NH3 emissions from land was 16% higher for high grassland area and 33% lower for low grassland area compared to the medium grassland land level (Figure 5). Based on the obtained results it can be concluded that expanding the grassland area increased the NH3 emissions from land.

The results for NH3 emissions from stable and manure storage showed that by increasing the share of grassland area, the amount of NH3 from stable and manure storage increased substantially. In a case the share of grassland in the total area was around 50%, the NH3 from stable and manure storage was 33% lower than the situation where the share of grassland area increased to 85%. By increasing the grassland area, the available grass increased which resulted in higher contribution of grass in the animal diet. This means higher protein content of diet and increase in the N content of manure. At the end, all these consequences led to higher NH3 emissions in stable and manure storage.

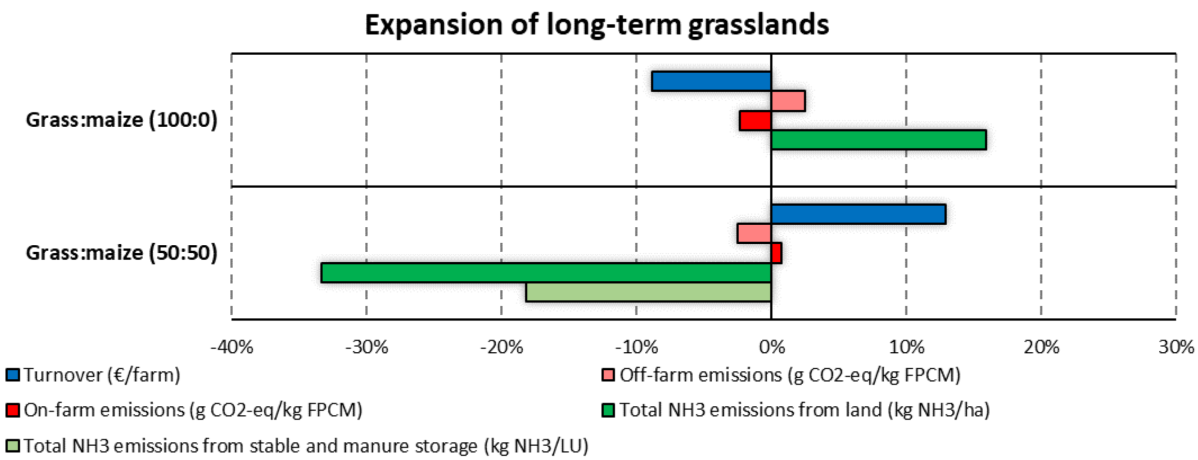

Figure 5. The impact of expansion of long-term grasslands on the environmental and economic aspects of a dairy farm. Comparison with the farm with grass-maize ratio of 85:15.

Figure 6 shows the impact of sowing clover on turnover, NH3 emissions and GHG emissions of the studied farm compared to the situation where no clover was cultivated in grasslands. Sowing clover reduced the cost of buying mineral fertilizers however, increased the cost of cultivation related operations. In total, sowing clover on grasslands resulted in higher turnover of 3% compared to a farm without clover. The obtained results showed that sowing clover could slightly reduce the off-farm emissions (-5%) while resulted in higher on-farm emissions (+2%) compared to the scenario where no clover is sown on grasslands. By sowing clover, less mineral fertilizer is consumed which leads to less off-farm emissions. Sowing clover increased the nitrogen content of produced grass and increased the N content of the diet. This means higher N2O emissions from manure which is one the most important GHG gasses. The higher N content of manure resulted in 17% increase in the NH3 emissions from stable and manure storage. Higher N content of ration results in higher N excreted which resulted in higher NH3 emissions from stable and manure storage.

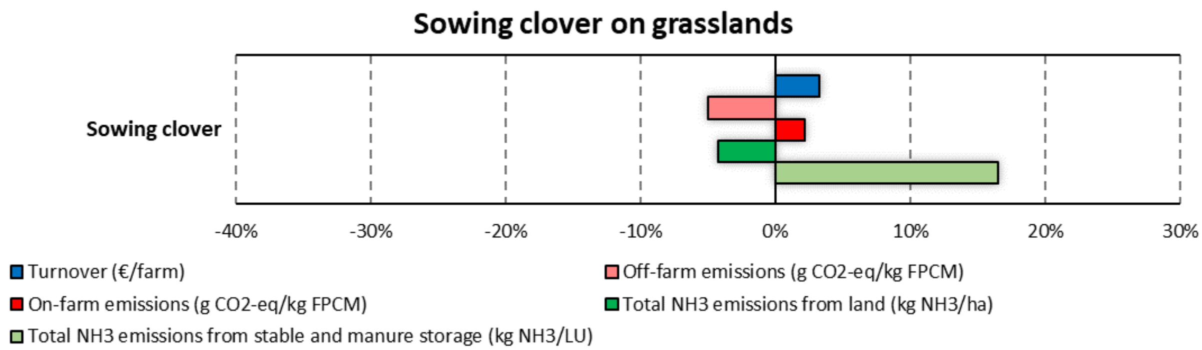

Figure 6. The impact of sowing clover on grassland on the environmental and economic aspects of a dairy farm. Comparison with the farm without clover.

To show the impact of grazing intensity on the environmental and economic aspects, two scenarios (low and high grazing intensity) were compared to the scenario with a medium grazing intensity. Results showed that both low and high grazing intensity scenarios had lower turnover compared to the scenario with medium grazing intensity. Low grazing intensity had around 10% lower turnover compared to the scenario with medium intensity while the turnover of the scenario with high grazing intensity was 2% lower than the medium scenario (Figure 7). In a scenario with low grazing intensity, more costs occurred because of more mowing operation. Moreover, application of stored manure in barn costed a lot compared to the scenario with medium or high grazing intensity. Surplus stored manure which should be sold means additional costs for farm. DairyWise a cost for exporting manure. Although high grazing intensity had a higher turnover compared to the scenario with low grazing intensity, it still had a lower turnover compared to the baseline scenario (a scenario with medium grazing intensity). By increasing the grazing intensity, the loss of yield due to grazing increased compared to situation more area is mowing. Obtained results showed that the off-farm emissions in a scenario with low grazing intensity is higher than the scenarios with medium and high grazing intensity. Low grazing means higher emissions due to mowing the grass and stored manure in barns. High grazing intensity scenario had the lower off-farm GHG emissions but still higher than medium scenario. The total NH3 emissions from land reduced by increasing the grazing intensity. Due to natural separation of the liquid and solid parts during grazing, the NH3 emissions reduced in a scenario with high grazing. By increasing grazing intensity, the amount of manure stored in the barn reduced which means lower NH3 emissions from barn.

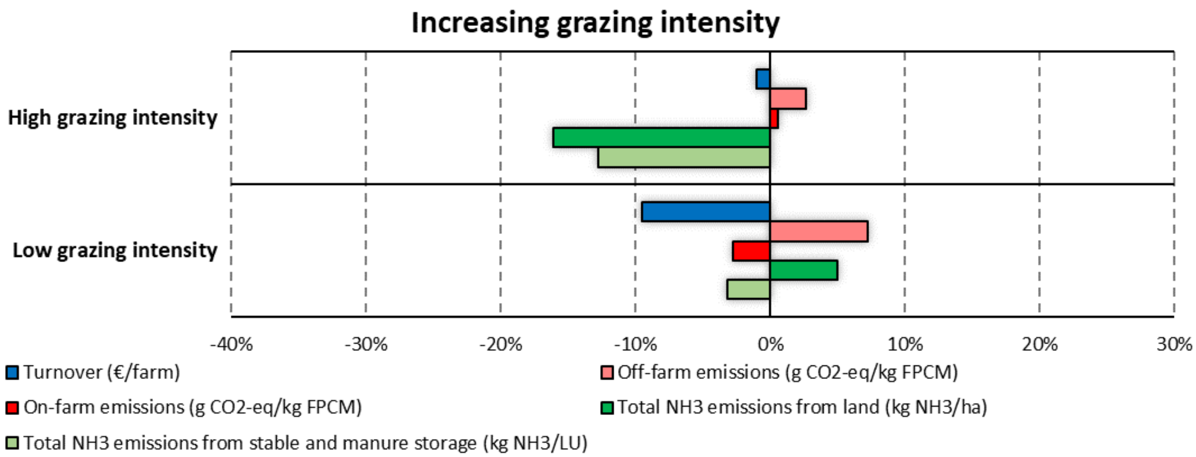

Figure 7. The impact of increasing the grazing intensity on the environmental and economic aspects of a dairy farm. Comparison with the farm with medium grazing intensity.

4 Conclusion

The impact of various GHG mitigation strategies on the environmental and economic aspects of a dairy farm was studied using a farm model (DairyWise). To have a deeper analysis, a set of strategies were assessed individually and in combination with each other. For individual assessments, five mitigation strategies including increasing milk production level, increasing longevity by changing the youngstock ratio, increasing area of long-term grasslands, sowing clover on grasslands, and increasing grazing intensity were selected and evaluated at different levels. The combined strategies were named as three production systems, extensive-regular (ER), extensive-organic (EO), and high-tech (HT) dairy systems and were compared with the baseline scenario (BS). The production systems differed from the point of view of the stocking rate, milk production level, grazing intensity, cultivation of clover, available land area, and type of stall. Based on the carried-out analysis, the following results were obtained:

Comparison of production systems showed that EO and HT were the most attractive scenarios for farmers because of their high positive economic impacts. All the studied scenarios had a higher turnover compared to BS. Regarding GHG emissions, EO and ER were in a better position where the total GHG emissions was lower than BS. However, HT scenario resulted in higher GHG emissions than BS. Regarding the NH3 emissions, the worst scenario was ER scenario in which the higher NH3 emissions was seen compared to BS due to high protein in the diet and therefore also in the manure. Based on the obtained results, shifting production system from EO to HT resulted in lower NH3 emissions from stable and manure storage per LU due to low emission floor while the GHG emissions per ha from land increased due to more import of feed.

Assessment of individual scenarios showed that increasing milk production per dairy cow was very attractive for the farmers in terms of financial consequences however, it was seen that it had negative impact on the GHG emissions (sum of on-farm and off-farm emissions), because more feed is needed. Increasing milk production level increased the NH3 emissions from stable and manure storage but led to lower level of NH3 emissions from land in high milk production level.

It was found that lowering the young stock ratio has positive impact on the economic aspects of a dairy farm, but it does not have substantial impacts on environment. Therefore, it is an attractive strategy for dairy farmers.

The results of increasing the share of grassland showed that the most effective scenario would be equal share of grass and maize land area where the highest turnover can be achieved and the NH3 emissions would be lower than the other two scenarios. Moreover, in a scenario with equal share of grass and maize land, lowest total GHG emissions was calculated.

Assessing the environmental and economic aspects of sowing clover showed the positive impacts of clover on turnover, GHG emissions and NH3 emissions from land compared to the scenario in which clover is not cultivated. However, higher NH3 emissions from stable and manure storage was seen because of higher N content of diet and excreted manure.

The results of assessing the impacts of increasing grazing intensity revealed that both low and high grazing intensity had a lower turnover compared to medium grazing intensity. However, the farm with higher grazing intensity had lower NH3 emissions. The total GHG emissions of the farm with high grazing intensity was slightly higher than the farm with medium grazing intensity.

The results of this study provided a broad overview to the researchers, farmers, and policy make about the technical, economic and environmental consequences of different GHG mitigation strategies.

5 Acknowledgement

This study was supported by ERA-GAS/ERA-NET Susan/ICT-AGRI, project "Climate Care Cattle Farming Systems", ID: 3274. National Funding Center Netherlands: NOW (ENW file number: 39274) and TKI (Topsector Agri&Food, EU-20011).

We would also like to acknowledge our colleagues "Aart Evers" and "Johan de Boer" for their cooperation, advice, and support which greatly improved the quality of this research.

Appendix

The appendix contains supplementary information that supports and/or expands upon the main text of the document. The details of comparison of four different production systems are presented in Figure A1. Technical aspects consist of grassland and maize silage yield, feed intake, purchased feeds, sold feeds, manure production and application. Ammonia emissions including NH3 from land (kg NH3/ha) and storage (kg NH3/LU). GHG emissions were divided to on-farm (enteric fermentation, manure storage, and feed production on farm) and off-farm emissions (energy sources, supply of on farm inputs such as feed and fertilizers). For the economic overview we considered milk yields, turnover and growth, pasture money, sold fodder, income from cattle farming, and other incomes as the farm income. Contract work, lease price land, manure export, low emissions floor (additional cost compared to the typical floors), animal feed, energy, plant protection products, fertilizers n, P2O5, K2O, organic fertilizers, other fertilizer costs, seed, plant and propagating material, other raw and auxiliary materials, and other product-related costs were considered to calculate the total cost of a dairy farm.

Figure A1 Comparison of production system in term of environmental impacts, economic and technical aspects.

Items	unit	Baseline (BS)	Extensive-Regular (ER)	Extensive-Organic (EO)	High tech (HT)
Technical aspects					
Grassland yield	(kg dm/ha)	6,885	5,569	4,194	12,329
Maize silage yield	(kg dm/ha)	12,563	12,563	9,799	12,563
Feed intake - dairy cows					
Fresh grass	(kg dm/year/cow)	1,223	2,159	2,125	0
Roughage	(kg dm/year/cow)	3,398	3,252	3,333	5,332
By product	(kg dm/year/cow)	0	0	0	0
Concentrate	(kg/year/cow)	2,862	757	809	3,900
Feed intake - dairy cows					
Fresh grass	(kg dm/day/cow)	3.4	5.9	5.8	0.0
Roughage	(kg dm/ day/cow)	9.3	8.9	9.1	14.6
By product	(kg dm/ day/cow)	0.0	0.0	0.0	0.0
Concentrate	(kg dm/ day/cow)	7.8	2.1	2.2	10.7
Purchased feeds					
Forage	(kg dm)	8,244	8,285	16,548	107,038
By product	(kg dm)	0	0	0	0
Concentrate	(kg)	180,930	52,954	54,928	345,548
Milk powder	(kg dm)	882	882	0	1,250
Sold feeds					
Forage	(kg dm)	50,601	69,090	0	0
By product	(kg dm)	0	0	0	0
Manure production	(ton)	1,763	1,621	1,570	3,569
Manure application	(ton)	1,162	1,360	1,411	1,695
Manure sold	(ton)	601	261	159	1,875
Manure application					

Items	unit	Baseline (BS)	Extensive-Regular (ER)	Extensive-Organic (EO)	High tech (HT)
Grassland	(ton/ha)	28	27	26	45
Maize land	(ton/ha)	40	40	54	35
Ammonia emissions					
NH3 emissions-stable and manure storage	(kg NH3/LU)	12.2	16.6	13.0	9.2
NH3 emissions-fertilization and harvest	(kg NH3/ha)	18.5	22.7	15.8	23.4
Total NH3 emissions	(kg/farm)	1,641	2,314	1,720	1,895
GHG emissions					
Total emissions	(g CO2-eq/kg FPCM)	1,207	1,175	1,137	1,199
On-farm emissions					
Enteric fermentation	(g CO2-eq/kg FPCM)	559	601	597	523
Manure storage	(g CO2-eq/kg FPCM)	175	188	191	211
Feed production on farm	(g CO2-eq/kg FPCM)	98	146	138	52
Off-farm emissions					
Energy sources	(g CO2-eq/kg FPCM)	66	80	84	61
Supply of on farm inputs (feed and fertilizers)	(g CO2-eq/kg FPCM)	309	160	127	352
Economic overview					
Total income	(eur)	225,949	195,862	236,716	377,726
Milk yields	(eur)	195,433	160,818	206,544	345,587
Turnover and growth	(eur)	14,922	14,922	16,976	21,137
Pasture money	(eur)	0	0	0	0
Sold fodder	(eur)	4,592	6,926	0	0
Income from cattle farming	(eur)	0	0	0	0
Other income	(eur)	11,002	13,196	13,196	11,002
Total cost	(eur)	181,298	150,572	160,130	318,784
Contract work	(eur)	17,831	18,533	19,421	30,771
Lease price land	(eur)	39,000	46,800	46,800	39,000
Manure export	(eur)	6,608	2,866	1,744	20,620
Low emissions floor (additional cost compared to the typical floors)	(eur)	0	0	0	20,832
Animal feed	(eur)	52,481	19,269	35,191	115,215
Energy	(eur)	21,308	20,609	20,569	32,250
Plant protection products	(eur)	1,109	1,348	0	1,116
Fertilizers N, P2O5, K2O	(eur)	10,684	8,086	5,389	13,724
Organic fertilizers	(eur)	0	0	0	0
Other fertilizer costs	(eur)	3,717	4,460	4,460	3,717
Seed, plant and propagating material	(eur)	1,926	2,517	3,263	1,970
Other raw and auxiliary materials	(eur)	10,139	10,570	11,136	13,885
Other product-related costs	(eur)	16,495	15,514	12,157	25,684
Turnover	(eur)	44,651	45,290	76,586	58,942

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