Evaluating Carbon and Nitrogen Footprints of Intensive and Extensive Dairy Systems from Land Use and Production Perspectives

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DEDICATION

To my beloved parents

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LIST OF ABBREVIATIONS AND ACRONYMS

ARC	Agricultural Research Council
ANCA	Annual Nutrient Cycling Assessment
Av.	Average
ATD	Atmospheric deposition
BNF	Biological nitrogen fixation
Bo	Manure maximum CH_4 producing capacity
BW	Body weight
C-BNF	Cultivation-induced biological nitrogen fixation
CBS	Centraal Bureau voor de Statistiek (Dutch Central Bureau of Statistics)
CF	Carbon footprint
CH_4	Methane
CSDEK	Climate-smart and inclusive dairy business models in Kenya and Ethiopia
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CP	Crude protein
DM	Dry matter
ECM	Energy corrected milk
E	Extensive
Eq.	Equation
FAO	Food and agriculture organisation
FPCM	Fat and protein corrected milk
FU	Functional unit
GDFCS	Githunguri Dairy Farmers Cooperative Society
GE	Gross energy
GHG	Greenhouse gas
GWP	Global warming potential
I	intensive
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
K	Kenya
kg CO_2-eq	Kilograms of carbon dioxide equivalent
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
MCF	Methane Conversion Factors
ME	Marine eutrophication

MEP	Marine eutrophication potential
MFA	Material flow analysis
N	Nitrogen
N_2	Nitrogen gas
N_2O	Nitrous oxide
NB	Nutrient balance
N-eq	Nitrogen equivalent
NH_3	Ammonia
NH_4 +	Ammonium
NL	The Netherlands
NO	Nitrogen monoxide
NO_3^-	Nitrate
NO_x	Nitrogen oxides
Nr	Reactive nitrogen
NUE	Nutrient use efficiency
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
TIAPD	Tegemeo Institute of Agricultural Policy and Development
VHL	Van Hall Larenstein
VI	Very intensive
VS	Volatile substance

UNITS

d	Day
g	Gram
ha	Hectare
ha^{-1}	Per hectare
kg	Kilogram
kg $FPCM^{-1}$	Per kilogram fat and protein corrected milk
L	Litre
LU	Livestock units
MJ	Megajoule
Mtonne	Million tonnes
t	Tonne
yr	Year
yr^{-1}	Per year

ABSTRACT

The present work aims at providing broader insight into the environmental impact of milk production by comparing greenhouse gas (GHG) and nitrogen (N) emissions of milk production among the intensive and extensive dairy farming systems from production and land-use perspectives. Three dairy farms in the Netherlands and four dairy farms in Kenya were purposively selected as study cases to illustrate the impact of milk production on dairy developed regions and dairy-developing regions, respectively. The selection of these farms was based on the accessibility of the data of the farms.

A large set of environmental indicators were derived from life cycle assessment (LCA), nitrogen balance (NB), and nitrogen use efficiency (NUE) approaches, which focussed on GHG and nitrogen flows. A comparison of the two systems was made while considering the geographical context of the farms.

The results indicated that almost all environmental performance indicators differed between the intensive and extensive systems. Intensive farms in the Netherlands showed better performance in 4 out of the 5 used product-based indicators (GHG, whole-farm NB, corrected NB, and chain-level NB) per kilogram of fat-and-protein-corrected milk (kg FPCM) and the dimensionless NUE. Marine eutrophication potential (MEP) per kg FPCM of was the only indicator that has shown similar values for the intensive Dutch and the extensive farms. The extensive farms showed better performance in all area-based indicators (GHG, MEP, whole-farm NB, corrected NB, and chain-level NB per hectare (ha) of farmland (on-farm) and per ha of the total land, including the land used to cultivate external feed (on+off farm).

GHG emissions of the three Dutch farms were 1.16, 1.23, and 1.45 kg of carbon dioxide equivalent (CO_2-eq) per kg FPCM, counting from the most intensive to the least intensive farm, respectively. These farms also had GHG emissions of 26710, 20722, and 8770 kg CO2-eq when expressed per ha farmland, indicating that GHG per ha-on-farm increase with low GHG per kg FPCM for the studied farms. The GHG emissions of the Kenyan farms were 1.5, 3.5, 2.2, and 2.2 kg CO_2-eq per kg FPCM while they had 255136, 50883, 49626 and 18868 kg CO_2-eq when expressed per ha farmland, counting from the most intensive to the least intensive farm, respectively. When off-farm land hectares were accounted for, the emissions dropped for all the studied farms but maintained a similar pattern to that of per ha farmland.

The results also showed that intensive farms in the Netherlands had both higher N surplus per ha and nitrogen use efficiencies at the farm level. This means a farm with a greater nitrogen use efficiency can nevertheless pollute the environment locally due to the high N surplus per ha. Kenyan farms also showed higher N surplus per ha for intensive farms but did not maintain a clear pattern for the NUEs.

A more representative and detailed assessment considering both GHG and nitrogen-related impacts from different perspectives are necessary to understand the extent of environmental pressure for the different dairy production systems. In addition, more comparative research on environmental impacts of milk production in Kenya, other than GHG such as N balances, acidification, and eutrophication potentials, are needed to establish a baseline for the different production systems. The dataset used here was limited but gave a clear indication of the environmental performances of the studied farms.

Keywords: Greenhouse gas, nitrogen, environmental indicators, intensive, extensive, Kenya, the Netherlands

1. INTRODUCTION

1.1. Background

The need for producing more food while minimizing the accompanying environmental burdens is putting agriculture in a dilemma. There is an evident public concern on the relationship between agriculture and environmental threats such as climate change, loss of biodiversity and degradation of land and freshwater. Within agriculture, livestock have received extra attention because of their significant role in GHG emissions along with other environmental impacts (Steinfeld et al., 2006). Globally, livestock are estimated to release 7.1 gigatons CO_2 -eq per year, representing 14.5% of human-induced GHG emissions. Primarily, these emissions are attributed to beef and cattle milk production accounting for 40% and 20% of the sectors' emissions, respectively (FAO, 2013). The main direct emissions from dairy farms are methane (CH_4) and nitrous oxide (N_2O) from enteric fermentation, manure, and soil sources, as well as carbon dioxide (CO_2) from fossil fuel combustion and decomposition of crop residues on field, applied lime and urea. Indirect emissions include ammonia and nitrate losses that potentially transform to N_2O beyond the farm boundaries (Rotz, 2018).

Additionally, livestock production systems are a major source of human-caused global Nitrogen (N) and phosphorus (P) cycle disruption (Bouwman et al., 2011). Excessive fertilizer use combined with poor nutrient use efficiency by crops and animals result in substantial losses of reactive N (all nitrogen forms except N_2) and P. Farm animals absorb only 15-40% of the N and P ingested in their feed, and subsequently, most of these nutrients in their diet end up in the manure (Cederberg et al., 2012).

On a whole farm and system level, commonly 15 to 55% of the total N input to the farm (including fixed and deposited N) and 56 to 74% of the total P input to the farm is transformed into edible and inedible farm products (Gerber et al., 2014; Powell et al., 2017). Most of the remaining nutrients are lost to the environment. Once lost to the environment, the nitrogen moves through the Earth's atmosphere, forests, grasslands, and waters, causing a cascade of environmental changes that negatively impact both people's health and the ecosystem (Leach et al., 2012). This includes pollution of local air quality due to emission of ammonia (NH_3), and nitrogen oxides (NO_x), contamination of local water by nitrate (NO_3^-) and ammonium (NH_4^+) and contributing to the greenhouse gas effect through Nitrous oxide (N_2O) (Galloway et al. 2003).

Improving the environmental sustainability of agricultural production systems requires the ability to track and measure the fates of nutrients as they cycle throughout the ecosystem. Various environmental performance frameworks and methods have been established, including LCA, nutrient budgets, nutrient use efficiencies and material flow analysis (Gerber et al., 2014).

Life cycle assessment (LCA) has been widely used to measure GHG emissions and other environmental impacts associated with agricultural production. In an LCA approach, the environmental performance indicator is defined via the selection of functional unit (FU) according to the function of the investigated agricultural system. Three main groups of FUs can be recognized: product-based, area-based, and financial FUs. The product-based FUs correspond to the productive function of agriculture (the production of food, feed, and biomass), the area-based FUs refer to the land-use function of agriculture, while the financial

FUs relate to the function of farm income/profit generation (Repar et al., 2016). Most of the available LCA-based studies have focused on the GHG emissions and highlighted the low GHG emission intensities in developed countries with a range of 1.3 to 1.4 kg CO_2 e /kg FPCM and higher GHG emissions in developing countries with a range of 4.1 to 6.7 kg CO_2 e/kg FPCM (FAO, 2019). In LCA, it's also possible to estimate nutrient losses using indicators such as acidification and eutrophication. However, they are laborious to conduct and not easy to understand for farmers and mainstream policy makers. In that case, other indicators are used, such as whole-farm N balances, soil N surplus, chain level N balances expressed per ha or per kg FPCM. Different types of NUEs can also indicate the N losses (Mu, 2017; Thomassen et al., 2008).

Recently, there is a growing emphasis on distinguishing environmental performances of agricultural systems into local (farm-level) and global (on-and-off-farm) environmental performances. Local environmental performance is assessed by the on-farm environmental impact created per unit agricultural area of the farm (Repar et al., 2017) while the global environmental impact is assessed as (i.e., on- and off-farm) environmental impact generated per unit of biophysical product. Repar et al. (2016) indicate that only focusing on a product or output-based indicators related to global environmental issues may undermine local environmental issues.

1.2. Problem statement

Intensification of milk production is often seen as an opportunity to reduce GHG emissions per kg FPCM, implying minimal environmental impact for high yielding dairy farms. However, this can only be true when product-based environmental indicators. Usually, intensification of milk production is achieved through the importation of nutrients (mainly nitrogen) in fertilizers and concentrates to the farm, which in turn disrupts the N cycle at local/farm levels. Generally, 15 to 55% of the total N input to the farm (including N fixation and N deposition) is converted into products where the rest is lost to the environment (Gerber et al., 2014). Many researchers have investigated a wide range of environmental impacts associated with milk production, including N related impacts. Their studies are helpful in informing dairy value chain stakeholders; however, they have often looked at GHG or nitrogen emissions in isolation and mostly based their assessments on one functional unit (either per unit milk or per ha land). The rare studies that have investigated nitrogen emissions using the two functional units, such as that of Mu et al., 2016 have not considered the off-farm land used to cultivate the imported feed. In addition, their study was based only on farm cases from Western Europe. Therefore, the Professorship Climate-Smart Dairy Value Chains of the VHL University suggests that there is a need to investigate further the environmental impact of dairy-based systems using an approach that includes nitrogen and GHG emissions and expressing these in different units with a focus on land-use and production-based indicators while using farm cases from different contrasting dairy regions: in this case being the Netherlands (a country with a well-developed dairy sector) and Kenya (a country with developing dairy sector). This will support more informed discussion on the environmental issues related to dairy farming.

1.3. Objective

To give a broader insight into the environmental impact of milk production by using multiple indicators to compare GHG and nitrogen emissions among contrasting dairy farming systems in the Netherlands and Kenya from production and land-use perspectives.

1.4. Main research question

What are the GHG and nitrogen emission intensities of intensive and extensive dairy farming systems from a land-use perspective (ha) and a production perspective (kg FPCM) in the Netherlands and Kenya? And how do they compare?

1.4.1. Research sub-questions

1. What are the GHG emission intensities of intensive and extensive dairy production systems per ha of land and per kg FPCM in the Netherlands and Kenya?
2. What are the nitrogen emission intensities of intensive and extensive dairy production systems per ha of land and per kg FPCM in the Netherlands and Kenya?
3. How do these farming systems compare for the GHG and N emissions within the boundaries of land use perspective and production perspective?

2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1. Environmental impact of livestock production

Global livestock production is anticipated to double by 2050, outpacing all other agricultural sectors. This is driven by the demand for animal products which increases with the fast-growing population, increased income, and changing lifestyle and diet preferences. Around 1.3 billion people rely on the sector for a living, and it accounts for about 40% of worldwide agricultural output. However, such rapid growth comes at a high cost to the environment (Steinfeld et al., 2006). The livestock sector is responsible for about 14.5% of total anthropogenic greenhouse gas emissions (FAO, 2013). Other than GHG emissions, environmental impacts such as land degradation and water pollution also arise from animal production activities.

2.1.1. Greenhouse gas (GHG) emissions

Major GHGs produced in animal agriculture are methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) (Steinfeld et al., 2006). Methane is a gas that is primarily produced through enteric fermentation and manure storage. Nitrous oxide is a gas that is produced through manure storage and the application of organic and inorganic fertilizers. The global warming potential of these gases are calculated using carbon dioxide equivalent as the standard measurement (IPCC, 2013). The IPCC third assessment report (2007) estimated the global warming potential for methane at 25 (25 times more than that of CO_2) for a period of 100 years. Later, it was estimated at 34 in the fifth assessment report of IPCC (2013). These impact factors help in the interpretation of LCA studies by translating emissions into a limited number of environmental impact scores (Hauschild and Huijbregts, 2015). However, different factors have been used by researchers, which resulted in wide variation in the impact assessments. Goedkoop et al. (2009) developed a life cycle impact assessment method called ReCiPe2008, which was later updated by Huibregts et al., 2016 to ReCiPe2016. The method provides harmonized characterization factors at midpoint and endpoint levels. The Hierarchist (100 years) midpoint characterization factors for climate change are widely used for calculating Global Warming Potential (GWP). These are 1, 34, 298 for CO_2, CH_4 and N_2O, respectively (Huibregts et al., 2016).

Recently, there has been remarkable attention on greenhouse gases emitted from dairy production. A summary of the latest main studies conducted on carbon footprint associated with raw milk production can be found in the work of Laca et al. (2020), which covers the period from 2009 to 2019. The study indicates that there is a general consensus among reviewed studies that the main contributors to milk CF are, namely production of feed and enteric emissions.

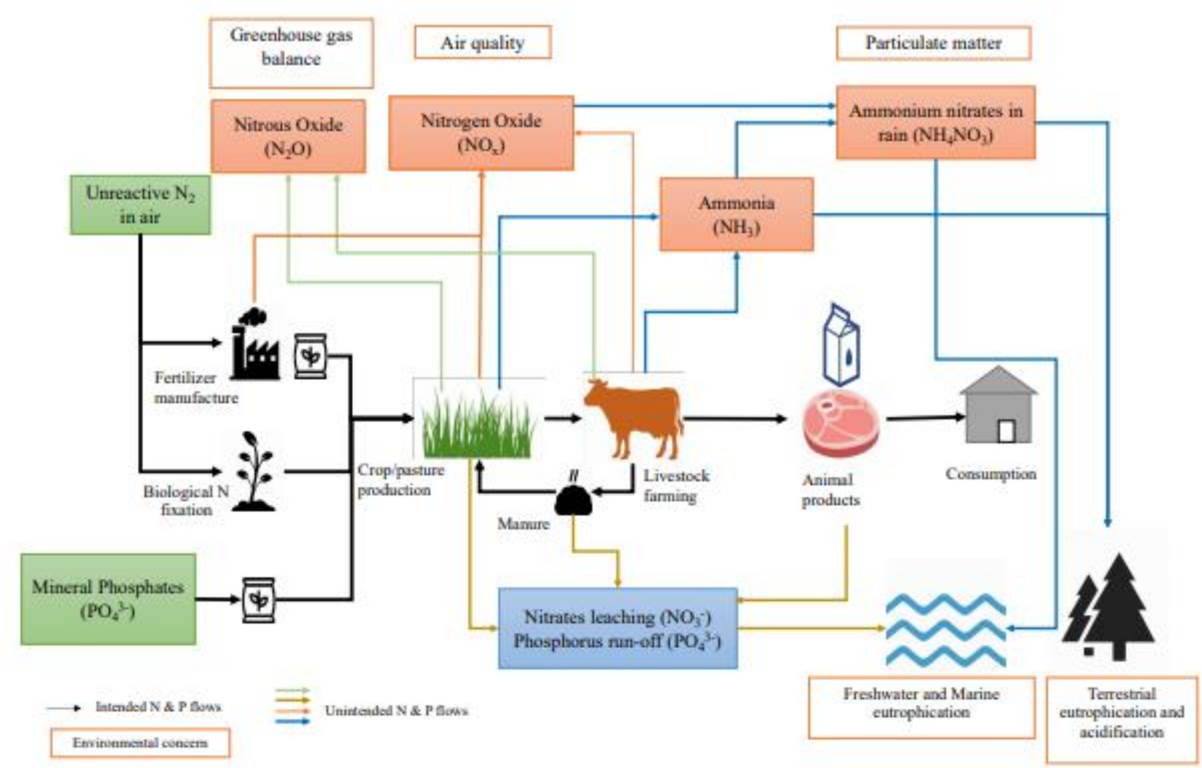
2.1.2. Nutrient-related impacts of livestock production

The livestock sector occupies around 30% of the ice-free terrestrial area of the planet through grazing and through feed/crop production. In many cases, livestock are a primary source of nutrient mismanagement and land-based pollution (Steinfeld et al., 2006). Reactive nitrogen (Nr) emissions from the animal production chain contribute significantly to eutrophication, acidification, and climate change (Figure 1). Phosphorus (P) emissions further increase eutrophication. Its widespread usage in agriculture has also resulted in the rapid depletion of a valuable non-renewable resource, phosphate rock (Cederberg et al., 2012). These effects are more local than global. Regional effects have little effect on other areas unless the pollution is carried by wind or water elsewhere (Herringshaw, 2010).

2.1.2.1. Nitrogen

Nitrogen (N) is required for life and is an important component of food production. Together with water, it is the most critical crop yield-limiting factor on the planet (Sinclair and Rufty, 2012). The development and adoption of Haber–Bosch process in the late 19th century enabled extensive manufacturing and usage of synthetic N-fertilizers to meet the dietary needs of the growing human population (Erisman et al., 2018). Cultivation-induced biological nitrogen fixation (C-BNF) has also increased Nitrogen availability in a variety of agricultural systems, the most important of which being crops, pastures, and fodder legumes. In 2005, more than 100 million tonnes (Mton) of Nitrogen were applied in synthetic fertilizer and leguminous plants, but only 17 Mtonne of N was consumed by humans in the form of crops, dairy and meat products. This emphasizes modern agriculture's extremely poor nitrogen-use efficiency, which has deteriorated in recent decades (Cederberg et al., 2012).

Livestock, which is the fastest-growing sector in agriculture, contributes significantly to the low efficiency of nitrogen use in the food system due to the poor manure management, specialization, and intensification of its production systems (Oenema, 2006). Beusen et al. (2008) estimated the nitrogen excreted in livestock manure worldwide at 112 Mtonne per year, which is equivalent to new reactive nitrogen entering agriculture. Approximately two-thirds of the nitrogen in manure is distributed in mixed and landless systems, 20% is distributed in pastoral systems and about 15% is ultimately distributed outside agricultural systems (for example, manure used as fuel).

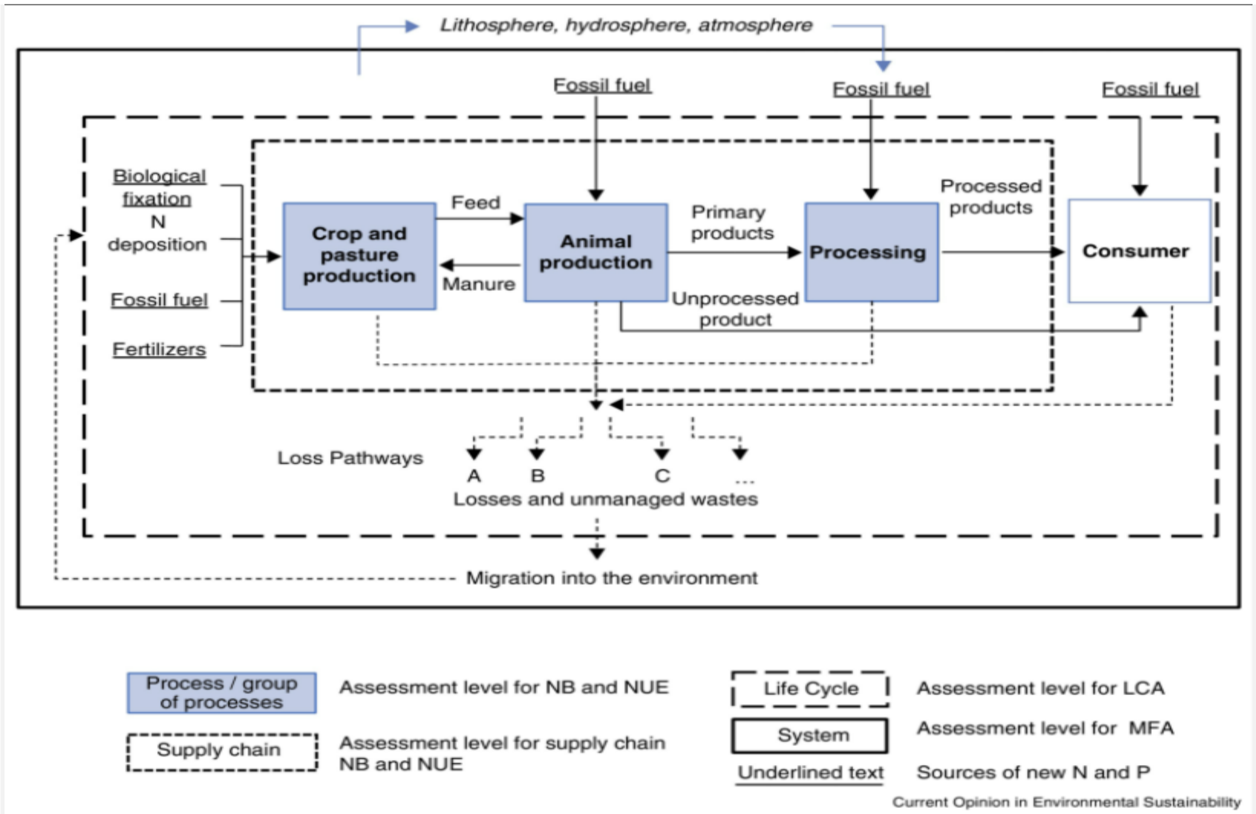


Source: Uwizeye (2019)

Figure 1. A simplified overview of nitrogen (N) and phosphorus (P) fluxes in the livestock supply chain, emphasizing anthropogenic sources, the cascade of reactive forms of nitrogen, and related environmental impacts.

2.2. Assessment of environmental performance

The first stage when evaluating the environmental sustainability of a production system is to assess its environmental impact. Selection of a "set of relevant, measurable, valid, timely and understandable indicators" is required for the assessment of the environmental performance of an agricultural system (Mu, 2017). Gras (1989) defined an indicator as "a variable which supplies information on other variables which are difficult to access and can be used as a benchmark to make a decision" (cited in Lebacq et al., 2013). They can be used alone, as part of a set, or added to a set of indicators to increase the end user's understanding (Van Passel et al., 2007). For livestock-based systems, environmental indicators can be derived from a variety of approaches, including a nutrient balance (NB) approach, material flow analysis, and a life cycle assessment (LCA) (Figure 2).



NB: nutrient balance, NUE: nutrient use efficiency, LCA: life cycle assessment, MFA: material flow analysis, N: nitrogen, P: phosphorus

Source: Gerber et al. (2014)

Figure 2. Main flows of nutrients and assessment levels for the analysis of nutrient use in livestock systems

2.2.1. Nutrient balance (Nutrient budget)

Nutrient balance, also known as nutrient budget, is calculated as the difference between combined inputs and outputs of a production process, usually expressed in kg nutrients (Nut)/ha/year. This straightforward method is extensively used as a tool to increase awareness and advice to farmers and policymakers on issues such as fertilizer use, manure management, and water quality preservation (Gerber et al., 2014). A nutrient deficit (negative value) indicates declining soil fertility. A nutrient surplus (positive data) indicates a risk of polluting soil, water and air (OECD, 2013). This tool is one of the most covered subjects in green accounts or input-output accounting systems (IOA) used in countries with intensive agricultural production (Halberg et al., 2005). Almost 91% of surveyed 55 European IOAs, included nutrient budgets (Goodlass et al., 2003). An NB approach can be applied at different levels in the food chain (Figure 2). It is usually applied at the farm level, focusing on the nutrient elements nitrogen (N) and phosphorus (P), because they are the main nutrient elements that restrict crop growth, and their loss can lead to environmental problems such as eutrophication (Gourley et al., 2012).

2.2.2. Nutrient use efficiency (NUE)

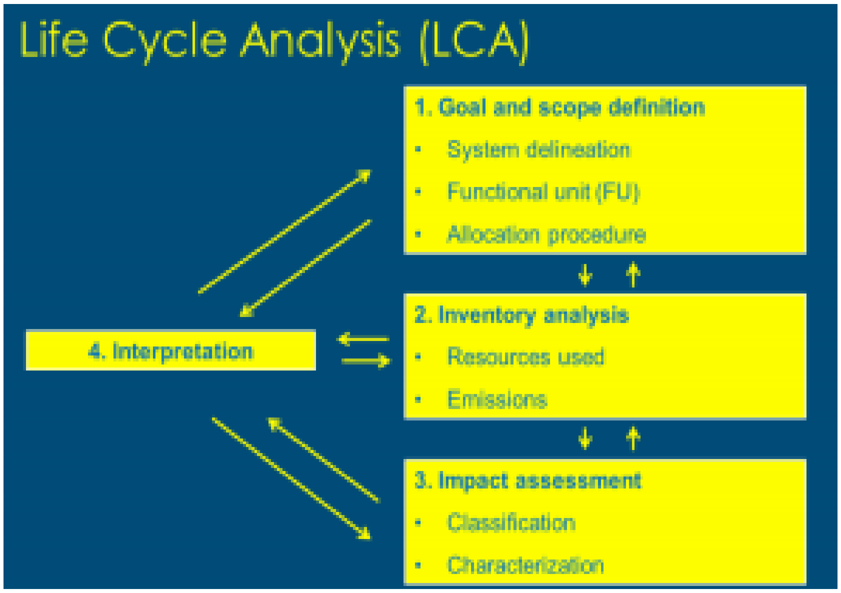
NUE is a dimensionless indicator computed as the ratio between the aggregated amount of nutrients in the outputs and in the inputs. Nutrient Use efficiency such as nitrogen can be calculated at three levels according to Powell et al. (2010); (a) feed conversion (feed-NUE), (b) conversion of manure and fertilizer in crops and pastures (NUE field), and (c) NUE Farm, defined as the ratio of N exports (milk sold, crops, animals, losses) leaving the farm) to N imports (feed, fertilizer, atmospheric deposition (ATD), biological fixation (BNF)). Gerber et al. (2014) suggest that it can be applied to a full chain, assisting decision-making at multiple levels (Figure 2).

2.2.3. Material flow analysis (MFA)

MFA, or substance flow analysis, is based on input and output models, applied to each unit process in the entire supply chain and connected to each other (Cooper and Carliell-Marquet, 2013). It is used to map and quantify the flow of selected items through the production system. Starting from an input or chemical element in the input, such as the reactive nitrogen (Nr) from biological nitrogen fixation, MFA maps and quantifies the flux of this element throughout the system or through defined subsystems. MFA reports the form of loss (pressure) but does not report its impact on the environment. For example, it reports the migration of Nr to surface waters (eutrophication) but does not report the possible impact on biodiversity (Gerber et al., 2014).

2.2.4. Life cycle assessment (LCA)

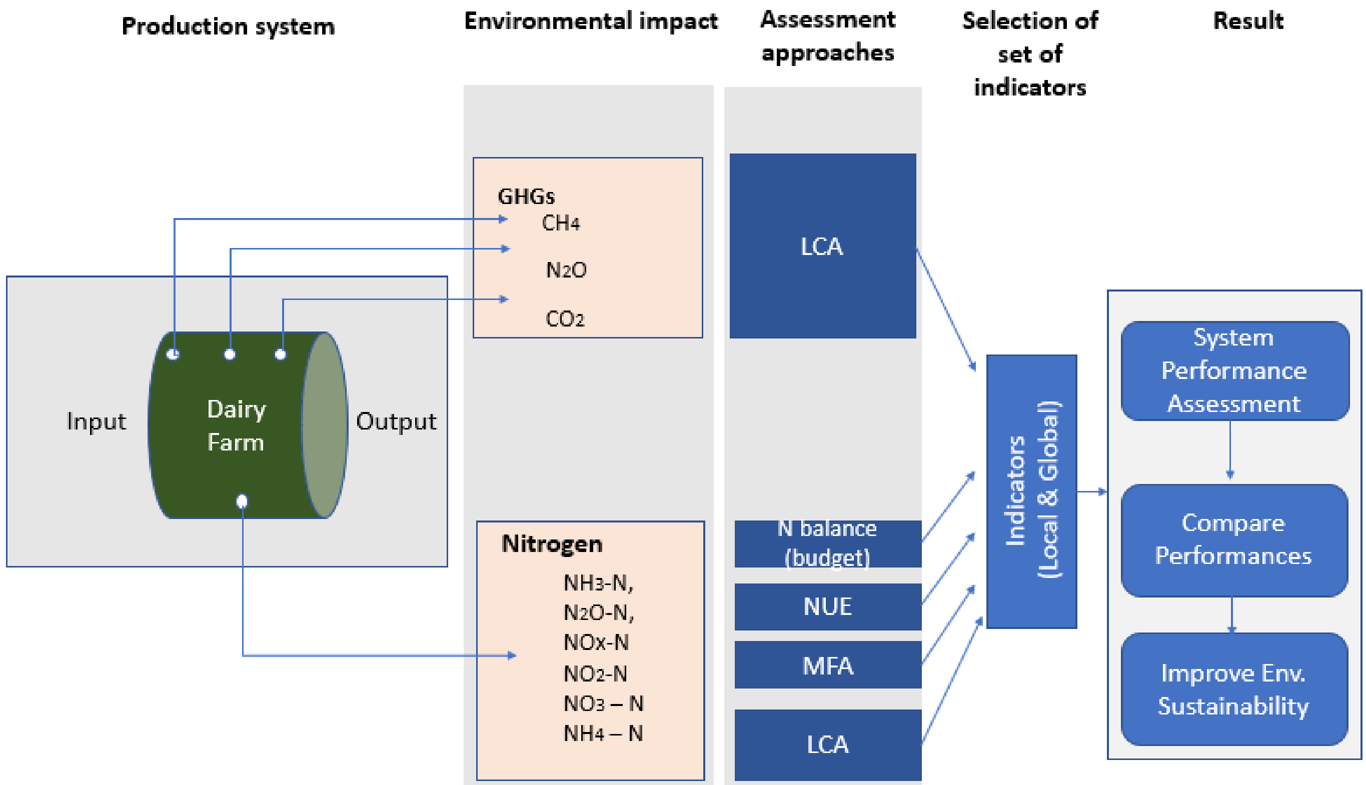
LCA is a holistic accounting approach that captures environmental pressure related to the production, usage and disposal (life cycle) of a product or a service (Guinée et al., 2002). Unlike the MFA, it takes a reverse perspective, taking a unit of product as a reference and looking at all upstream (and downstream) activities and related environmental impacts. Characterization factors are used to estimate the related environmental impacts, reported to a unit of product (impact/ kg product) or unit of land (impact/ha). The most researched impact categories are climate change, land use, energy use, acidification, eutrophication, and the system boundary is usually defined from the cradle to the farm gate (farm processes, such as manure management, milk and food production, and-agricultural processes, such as fertilizer and feed production) (Mu, 2017). Life cycle analysis has 4 main steps: Goal and scope definition, inventory analysis, impact assessment, and interpretation (Figure 3).



Source: Weiler (2013)

Figure 3. The four steps of LCA

2.3. Conceptual framework



Source: Author

Figure 4. Conceptual Framework

3. METHODOLOGY

3.1. Study area

The study used farm cases of two countries: the Netherlands (a country with a well-developed dairy sector) and Kenya (a country with less developed dairy sector). Geographically, the Netherlands is located in Western Europe and has a population of 17.3 million people (CBS, 2019), living within a total area of about 41,800 km^2. The country is well known for being the second exporter of agricultural products worldwide. The dairy industry is very important in Dutch agriculture; dairy farms accounted for over 31% of all farms in the Netherlands in 2016. (CBS, 2017, cited in: Groeneveld, 2018). In the same year, over 17,000 farms were accounted for, which collectively housed 1.8 million cows and produced over 14 billion kg of milk. Over time, the number of dairy farms has decreased, while the average number of cows per farm has increased (LEI Wageningen UR, 2016, cited in: Groeneveld, 2018). Although a wide range of dairy systems are practised in the Netherlands, two systems are easily recognizable: an intensive conventional system and a less intensive organic dairy system (Table 1).

Table 1. Characteristics of typical conventional and organic dairy farms in the Netherlands

		Typical conventional	Typical organic
Grassland	ha	29.9	36.1
Arable land	ha	8.6	10.8
Milking cows	n	63	56
Annual milk production	kg /cow	7630	6390
Density	LU/ha	2.31	1.76

Source: cited in Thomassen et al. (2008)

Kenya is a country in Eastern Africa with a land area of 580,367 square kilometres, and a population of 47.6 million people in the 2019 census (Kenya National Bureau of Statistics, 2019). The dairy industry in the country is growing, and it is considered to be the second largest contributor to livestock value added. In 2014, the industry produced about 4.48 billion litres of milk. Dairy cows provided 76 percent of total milk production, with camels and goats contributing the rest (FAO, 2018). Three systems are recognizable for Kenya's dairy farming, intensive (zero-grazing), semi-intensive (semi-grazing) and extensive (controlled and uncontrolled) (

Table 2).

Table 2. Dairy systems in Kenya

Dairy system	Description
Intensive (zero grazing)	Farmers keep exotic cattle, fed in stalls, and sell most of the milk they produce to the market. Most farmers keep a small number of dairy animals and a small amount of land, allowing for livestock-crop (mostly maize) integration. Intensive dairy farms are found in the agro-ecological zones of mid- and high altitude (especially in Mount Kenya and the middle Rift Valley) where cereal and cash crops are produced.
Semi-intensive (semi-grazing)	This is the most common dairy system. Farmers let the animals to graze during the day and feed them at night, including providing supplements during milking. Dairy animals (cross-bred) are part of a broader herd that includes chickens, sheep, goats, donkeys, and, on rare occasions, pigs. The system is well known in Mount Kenya, Rift Valley, and all areas where crop farming is practiced.
Extensive (controlled and uncontrolled)	This is a pasture-based farming strategy used on large farms (managed grazing with large herds) as well as in marginal and communal grazing grounds (uncontrolled grazing smaller herds). Animals are of exotic and improved breed. They are placed on natural and improved pastures utilizing paddocks or strip grazing and supplied with high quality feed, mineral licks, and concentrates. Uncontrolled grazing system is featured with the natural pastures and is well known in North and South Rift Valley, Coastal and Eastern regions.

Source: FAO (2018)

Selection of the two countries were made purposively to reflect the different production systems in dairy developed regions and dairy developing regions. Selection of individual farms was also purposive based on the accessibility of the researcher to the data of these dairy farms.

3.2. Strategies, methods, and tools

The research comprised a desk study and a case study (Figure 7). Desk study was carried out to obtain literature and secondary data on the environmental impact indicators of livestock-based production systems. This information was obtained from online peer-reviewed scientific journals, reports and books. The focus was on GHG and Nitrogen indicators. Keywords such as "dairy farms", "environmental impacts", "indicator", "local", "global", "GHG", "Nitrogen", "N balance", "NUE", "Eutrophication" and "N surplus", “N budget” were used.

The case study included farm visits, interviews, and retrieval of previous research data of the climate-smart and inclusive dairy business models in Kenya and Ethiopia (CSDEK) project (Baars and Verschuur, 2020). A total of 7 farms of two different systems (extensive and intensive) were included in this study (Table 3). Selecting farms of different intensities is based on the assumption of the researcher that the difference in inputs and management of the two systems will reflect for the selected environmental impact indicators.

The data from dairy farms in Kenya were made available through the CSDEK project while the data from the farms in the Netherlands were collected by the researcher through farm visits and semi-structured interviews with farmers. Two intensive farms and one extensive farm in the Netherlands who permitted to participate in this study were included.

Table 3. Farms included in this study.

	Intensive system	*Extensive System*	*Total*
The Netherlands	2	1	3
Kenya	3	1	4
Total	5	2	7

Extensive farms in this study are referred to farms with livestock density of ≤ 1.76 LU/ha, while intensive farm is referred to farms with livestock density of ≥ 2.3 LU/ha for the Netherlands. This is based on the average density of typical Dutch intensive conventional and less intensive organic farms (Table 2). A distinction based on livestock units/ha of land could not be obtained for the dairy farms in Kenya, intensive farms tend to have zero or very confined grazing land while the extensive dairy farms have a relatively large grazing land. For the purpose of this study, the cases of Kenyan farms are defined as very intensive farm (> 10 LU/ha), intensive (>3 and < 10 LU/ha) and extensive (< 3 LU/ha). Calculations of livestock units were based on the livestock unit co-efficient of 1, 0.7 and 0.3 for milking cows, heifers, and calves, respectively (Nix, 2003; Eurostat, 2021).

Tools that were used included Life Cycle Assessment (LCA), nitrogen balances (NB), and nitrogen use efficiency (NUE).

3.2.1. LCA

3.2.1.1. Lifecycle assessment (LCA) goal and scope

The goal of this study was to examine the environmental impacts of milk production from 7 farms using two different production systems: extensive and intensive dairy farming. Environmental impact categories that were studied include global warming potential and marine eutrophication potential**.**

System boundary: cradle-to-farm gate system boundary were covered Figure 5. All inputs were traced back to production and raw material extraction, and all major GHG emissions (CH_4, N_2O and CO_2) associated with inputs or outputs were accounted for.

Functional units: two functional units were employed to calculate the GHG emissions and marine eutrophication for the different farms:

(1) Kilogram of fat- and protein-corrected milk (kg FPCM) to quantify emissions per unit of production. kg FPCM was calculated as [0.337 + 0.116 × milk fat (%) + 0.06 × milk protein (%)] × milk yield(CVB, 2018). The milk protein and fat percentages in the records of the farmer were used. For the Kenyan farms, this was not possible, therefore fixed values of 3% and 4% obtained from the Githunguri Dairy Farmers Cooperative Society (GDFCS) were used for the protein and fat, respectively (Anastasia, 2019).

(2) Hectare of land to quantify emissions on an area basis (ha). When calculating the GHG emissions per hectare of land, the following two methods were employed to show the differences of the farming systems from the perspective of land use: (1) considering both the farmland and the land used to cultivate the imported feed (off-farm land), (2) considering only the farmland (on-farm land). The off-farm land area was estimated based on the assumptions in Table 4. Yield levels B and C were selected for the Kenyan and Dutch cases, respectively.

Table 4. Assumed plant yields for further calculations (kg dry matter per ha and year)

Yield level	Grassland or perennial crops (roughage)	Arable land or cultivated crops (concentrate)
A (low)	5000	2000
B (medium)	10000	5000
C (high)	20000	10000

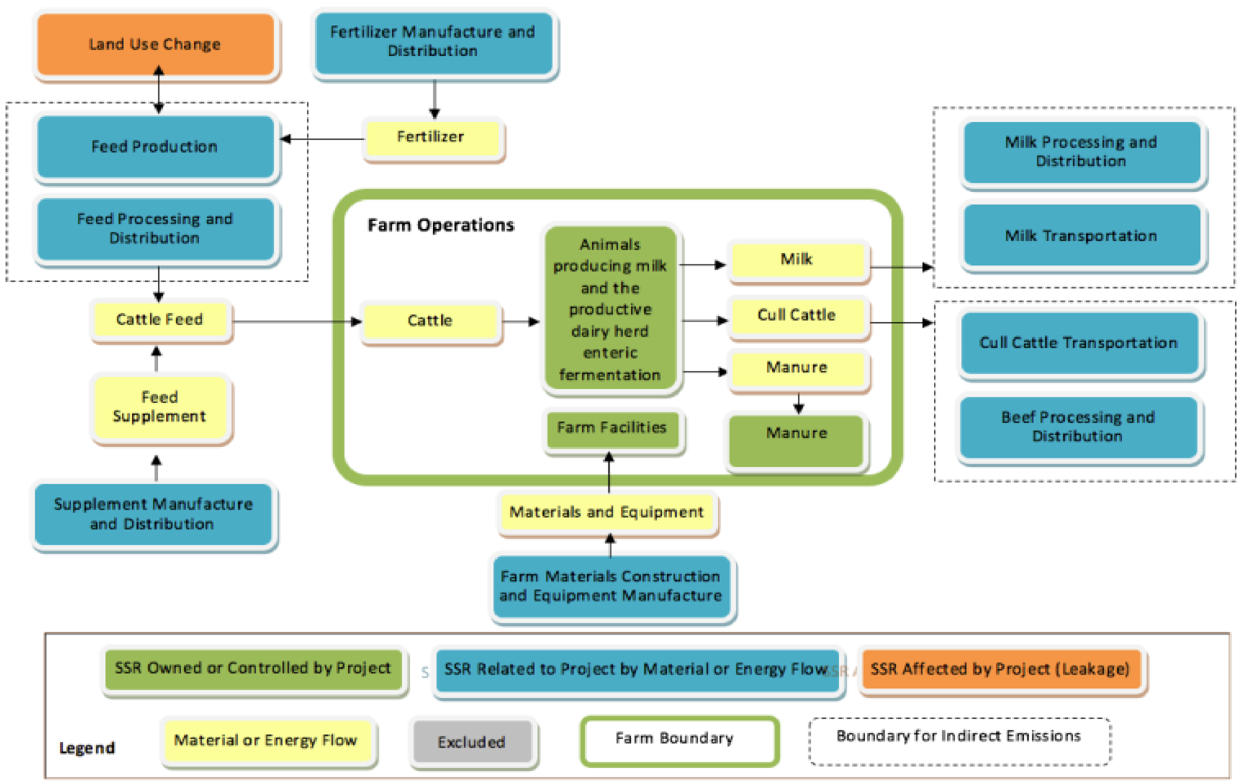
Source: Flachowsky et al., 2017

Allocation: In this study, the economic allocation has been chosen when using product-based functional units (kg FPCM). This approach necessitates the use of economic values for livestock functions. For the Dutch dairy farms, the values of milk and meat have been considered to allocate the impacts. However, livestock manure has an economic value for the Kenyan farms included in this study, thus some of the emissions were allocated for it besides the milk and meat. No allocation was done when calculating impacts per ha.

3.2.1.2. Lifecycle inventory analysis (LCIA)

Inventory analysis includes collecting data on resource use, energy consumption, emissions, and products produced by each activity in the production system. At this stage, each process is analysed in-depth and the factors to be included are defined.

LCA tool to compute the GHG footprint of smallholder milk production (Jerke de Vries et al, 2020) is used to calculate GHGs of the dairy farms in Kenya. This Excel tool supports the computation of the carbon footprint or greenhouse gas emissions (GHGs) for milk production by smallholders. The tool is based on a prior study done at VHL University of Applied Sciences (Tezera, 2018) and works according to the Gold Standard of the FAO. The gold standard follows the main system as provided in Figure 5. For each step in this chain, a corresponding tab is used to collect the data; the so-called life cycle inventory or LCI. For the farms in the Netherlands, an adjusted version of the LCA tool of Jerke de Vries et al. (2020) is used based on the country or region-specific factors. In Table 5, a description of the modified version is provided.



Source: FAO and ILRI, (2016)

Figure 5. Identification of system boundaries and the sources sinks and reservoirs (SSRs) for emissions from typical smallholder dairy.

Table 5. Modifications on the Jerke de Vries et al, 2020 LCA tool

Substance	Description of the methodology used for GHG calculations of the Dutch farms
CH_4 Enteric	This was based on equation 10.21 of IPCC (2006a). The data about gross energy (GE) were obtained from Feedipedia.org (2021) and Kool et el., (2012).
CH_4 Storage	CH_4 emission calculations were according to the IPCC Tier 2 method using 1% and 2% methane conversion factors (MCF) for pit and solid storages respectively, and maximal methane generating capacity (B_0) of 0.24 m^3 CH_4 per kilogram VS excreted.
N_2O direct – manure storage	This was based on Equation 10.25 of IPCC (2006a). Calculation of Nex (Nitrogen excretion per animal) was done by dividing the total N manure obtained from the farm records by the total number of animals). Emission factor (EF) of 0.005 was used for solid storage and 0.002 for pit storage.
N_2O indirect – manure storage	Based on equations 10.26 and 10.28 of the IPCC (2006a) to assess N due to volatilization and leaching, respectively.
N_2O direct – Field	Based on tier 2 methodology of IPCC (2006b) except for the average GASF (fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x) & GASM (volatilization from all organic N fertilizers applied, and dung and urine deposited by grazing animals). A factor of 4% given by van Bruggen et al., 2020 was used instead of the IPCC 10% GASF. For the GASM, 14% (van Bruggen et al., 2020) was used instead of the 20% of IPCC GASM.
N_2O indirect - Field	Similar to N_2O indirect – manure storage
CO_2 external feed	Carbon footprints used were 0.0515, 0.0921, 0.49, 0.4, 1.388, 6.639 kg CO_2-eq/kg DM for maize silage, grass silage, hay, other roughages, concentrates and milk replacers, respectively (FeedPrint, 2020).
CO_2 fertiliser production	Emissions of CO_2 during production of synthetic fertilizers were calculated using emission factors of 3.099, 3.625, 1.332 kg CO_2-eq/kg pure N excluding transportation emissions to the farm for ammonium, nitrate, and urea, respectively (Agri-footprint, 2018).
CO_2 transport	CO_2 from the transport of feed from the producer to the farm is already included in the production of external feed (the emission factor used for external feed accounts for transportation). CO_2 emissions from transportation of other materials such as diesel and fertilizers to the farm were calculated similar to the Annual Nutrient Cycling Assessment (ANCA) tool. In brief, standard distances from regional delivery points were used; 300, 100 and 100 Km for diesel, gas, and synthetic fertilizers,

	respectively. The CO_2 emissions of this mode of transportation were estimated at 0.101 kg CO_2 per tonne per Km (Marion de Vries et al., 2020).
CO_2 energy use (combustion and production)	The use of diesel in kilograms is converted to MJ's per kg (43.2 MJ / kg), and electricity in kWh is converted to MJ's per kWh (3,6 MJ / kWh). Then, these were multiplied by EF values of 0.0725, 0.0566 kg CO_2 -eq per MJ for diesel and natural gas combustion, respectively. To calculate the production footprint, EF values of 0.0123, 0.0199 and 0.2004 kg CO_2-eq were used for diesel, natural gas and electricity, excluding transportation (Marion de Vries et al., 2020).

The computation of the main substances contributing to on-farm marine eutrophication potential (NH_3, NO_3^-, and NO_x and NO_3^-) were calculated using the methods described in the below table.

Table 6. Methodology for calculating marine eutrophication contributing substances

Substance	Methodology for calculating ME contributing substances
NH_3-N storage	A factor of 10% of the excreted nitrogen was used for both pit and solid storages of the Dutch farms (Oenema and Tamminga, 2005). EF used for the Kenyan farms were 5%, 35%, and 15% for anaerobic digestors, composting and solid storage manure management types, respectively (Oenema and Tamminga, 2005).
NH_3-N field	Described in Table 5 under the subheading (N_2O direct – Field)
NO_x-N storage	$N_2O \times 0.1$ (Hamelin et al., 2011) (1)
NO_x-N field	0.55% of applied N (Akiyama et al., 2004)
NO_3^--N field	30% of applied N (IPCC, 2006a)
Off-farm marine eutrophication potential – (imported feed and fertilizer	MEP factors of 1447, 6936, 1447, 4591 and 34198 mg N-eq /kg for maize silage, grassland products, other roughages, concentrates and milk products, respectively (FeedPrint, 2020). An average MEP factor of 0.032 g N-eq/kg pure nitrogen derived from Hasler, et al. 2015 was used to calculate the MEP of fertilizer production for Dutch farms. The data for off-farm feed and fertilizer MEP of the Kenyan farms could not be accessed; thus, off-farm MEP was not calculated for these farms.

(1) Emissions of N_2O-N from different sources have been calculated using the original and adjusted versions of Jerke de Vries et al. (2020) LCA tool for Kenya and the Netherlands, respectively.

3.2.1.3. Lifecycle impact assessment (LCIA)

In this stage, data collected during the inventory, analysis are processed, and environmental impacts are assessed using the impact factors shown below.

Table 7. Studied impact categories, contributing elements and applied characterization factors

Impact category	Unit	Contributing elements	Impact factor	Method and reference
Climate change	kg CO_2-eq	CO_2	1	ReCiPe (Huibregts et al., 2016)
		CH_4	34	ReCiPe (Huibregts et al., 2016)
		N_2O	298	ReCiPe (Huibregts et al., 2016)
Marine eutrophication	kg N-eq	NH_3	0.24	ReCiPe (Huibregts et al., 2016)
		NO_x	0.09	ReCiPe (Huibregts et al., 2016)
		NO_3^-	0.07	ReCiPe (Huibregts et al., 2016)

3.2.1.4. Interpretation

The results of the LCIA were analysed and evaluated, and research conclusions and recommendations are formulated. The contribution of different elements to the different impact categories were identified.

3.2.2. Nitrogen balance and NUE

To investigate the differences on N surplus and NUE among the different farming systems, a model that accounts for N inputs and N outputs of each system was followed (Figure 6). Three types of N surpluses namely, whole farm N surplus, corrected whole farm N surplus and chain level N surplus were calculated for the studied farms. For the NUE, whole farm NUE and chain level NUE were calculated.

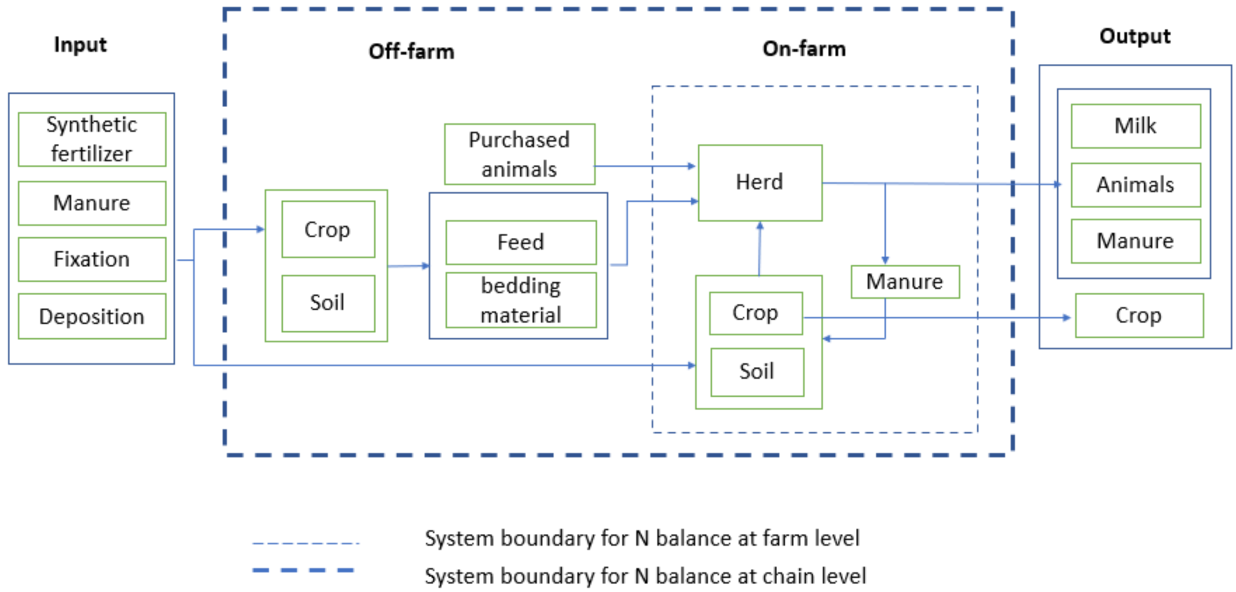


Figure 6. System boundaries for N whole farm and chain-level N balances

Source: Adopted from Mu (2017)

Whole-farm N balance

For the whole-farm N balance and NUE, nitrogen input into the farm system includes synthetic fertilizers, feed, livestock (in the form of replacement or purchase of animals), manure, biological N fixation and deposition. The nitrogen output of the system includes the nitrogen content of the milk, exported calves and cows, exported feed and manure (Table 8). The whole farm N surplus of the system is calculated as follows:

N surplus whole-farm level = N input – N output Eq. 1

N input = N imported fertilizer + N imported feed + N imported animal + N imported bedding +N deposition + N fixation Eq. 2

N output = N exported animals + N exported milk + N exported manure Eq. 3

Corrected whole-farm N balance:

To specify the whole farm nitrogen balance further, correction for the different gaseous N losses (NH_3-N, N_2O-N, NO_x-N, and N_2) has been made. The final N-surplus, therefore, include NO_3^--N and the amount of

N that could not be accounted for the mentioned losses. The corrected whole farm N surplus of the system is calculated as follows:

Corrected N surplus = N input – N output corrected Eq. 4

N input = N imported fertilizer + N imported feed + N imported animal + N imported bedding + N deposition + N fixation Eq. 5

N output corrected = N exported animals + N exported milk + N exported manure + N gaseous emissions on the farm (NH_3-N + N_2O-N + NO_x + N_2-N) Eq. 6

Chain-level N balance

N surplus chain level = N input chain – N output Eq. 7

N input chain = N input on-farm (N imported fertilizer + N imported feed + N imported animal + N imported bedding + N deposition + N fixation) + off-farm N losses to produce external feed and fertilizer

Eq. 8

N output = same as the whole farm N balance Eq. 3

Whole-farm NUE

Whole farm NUE = N outputs ÷ N inputs Eq. 9

N outputs: same as the whole farm N balance Eq. 3

N inputs: same as the whole farm N balance Eq. 2

Chain-level NUE

Chain level NUE = N outputs chain ÷ N inputs Eq. 10

N outputs: same as the whole farm N balance Eq. 3

N inputs: same as the chain-level N balance Eq. 7

Table 8. Calculation of Nitrogen input and output

	N source	Calculation	Reference
Input	Synthetic fertilizer	Quantity × N % of the fertilizer	
	Feed	CP content of the feed [(1)]/6.25	McDonald, 2002
	Purchased animals	BW × N content of the animal (0.024 kg of N/kg of BW for mature cows and 0.029 for calves)	ARC, 1994
	Manure	Quantity × N content manure [(2)]	
	Bedding material	Quantity × N content of bedding material	
	Biological fixation	Ha grassland with clover × clover % × fixation rate [(1)]	
	Deposition	Ha farmland × region-specific deposition rate [(3)]	
Output	Milk	(protein % ÷ 6.38) × milk yield	ARC, 1994
	Sold calves	BW × N content of the animal (0.029 kg of N/kg of BW	ARC, 1994
	Sold cows	BW × N content of the animal (0.024 kg of N/kg of BW)	ARC, 1994
	Manure	Quantity × N content manure	
Gaseous losses [(4)] (for N balance correction)	NH_3-N	Described in Table 6	
	N_2O-N	Described in Table 6	
	NO_x-N	Described in Table 6	
	N_2-N	N_2O-N × 3	Hamelin et al 2011

(1) CP% from the feed analysis reports for the farms were used as much as possible; when not available, the average CP% of feed from Feedipedia.org (2021) has been used.

(2) Manure N percentages provided by the farmer were used; when not available, standard 0.014 was assumed.

(3) An average figure of 30 kg N per ha was assumed for the Netherlands based on the range (29–55) given by Oenema et al., 2015. For farms in Kenya, 11.5 kg per ha was assumed based on the review of Masso et al. 2017.

(4) These four gases were also accounted for in the soil surplus (whole farm nutrient flows including internal nutrient flows) of the ANCA (the Kringloopwijzer) for the studied intensive Dutch farms.

Functional units

Two functional units were employed to calculate the N surplus for the different farms; (1) kg FPCM to quantify N surplus per unit of production, (2) ha of land to quantify emissions on an area basis. When calculating for the N surplus per hectare of land, the farmland (on-farm ha) and total land (on+off-farm ha) were considered as described earlier.

Allocation

Economic allocation has been chosen when using product-based functional units (kg FPCM) as described earlier, while no allocation has been done for the N balances for the area-based functional units.

3.3. Data analysis

Collected data from the 7 case studies were entered into Excel spreadsheets. This was followed by cross-checking with the average typical data of the corresponding system and farm location from the literature to avoid an extremely outlying figure. The data were analysed quantitatively for measuring GHG, and marine eutrophication potential using the excel tool of Jerke de Vries et al. (2020), as well as N balances and NUEs on Excel sheet using the aforementioned equations. Since the number of farms included in this study is small, statistical tests were less meaningful to show how the different systems compare for the results of different indicators. However, the observations and trends were shown qualitatively. For the data obtained through desk studies, analysis was made in a form of summaries. Tables and bar charts were used to present the results (Table 9).

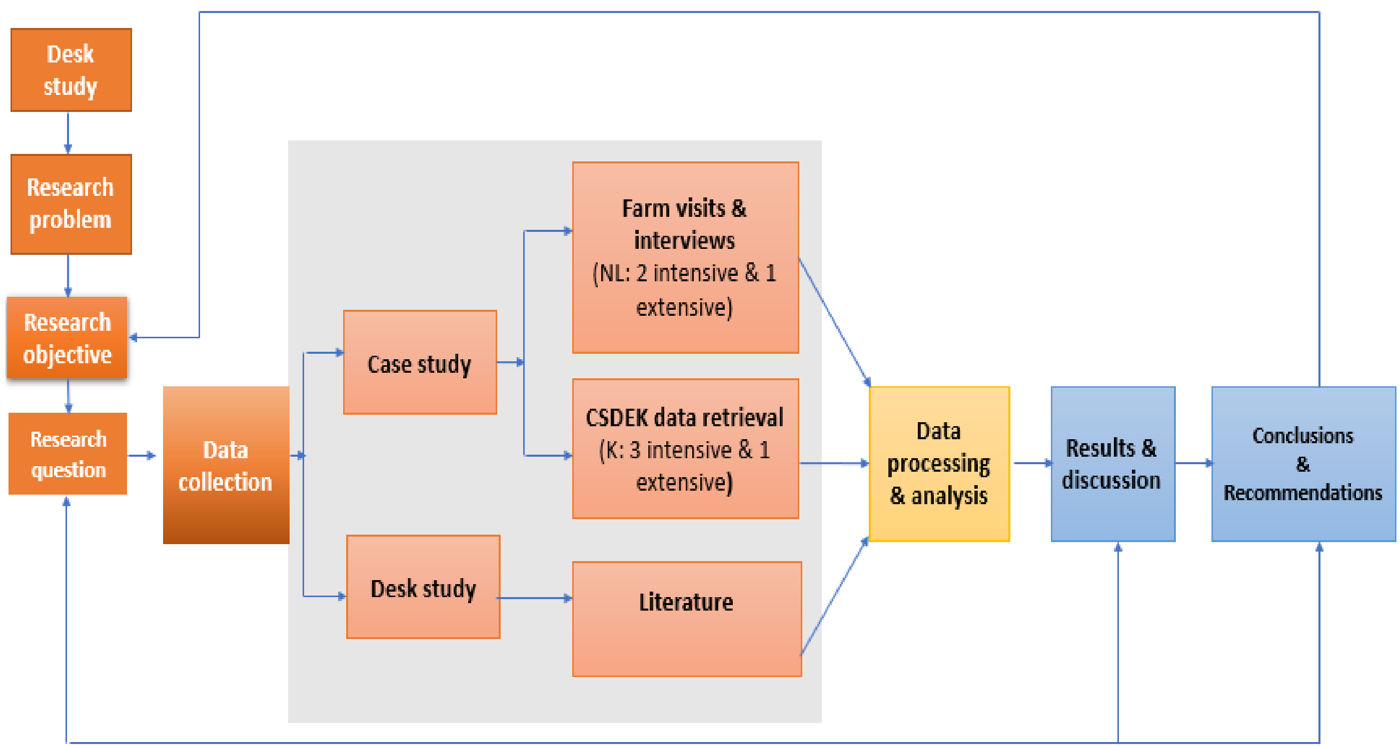
Table 9. Summary of data collection method, analysis, and expected results per each sub-question

Sub question	Source of Data	Method/analysis	Expected results
1. What are the GHG emission intensities of intensive and extensive dairy systems per ha of land and per kg FPCM in the Netherlands and Kenya?	Farm visits (questionnaire) Data from CSDEK project	LCA (LCA tool of Jerke de Vries et al., 2020)	**GHG emissions** • kg CO_2-eq/ kg FPCM • kg CO_2-eq/ ha on-farm • kg CO_2-eq/ ha on+off-farm
2. What are the Nitrogen emission intensities of intensive and extensive dairy systems per ha of land and per kg FPCM in the Netherlands and Kenya?	Farm visits (questionnaire) Data from CSDEK project	Eutrophication (LCA tool of Jerke de Vries et al., 2020)	**Marine eutrophication potential** • (g N / kg FPCM) • (kg N-eq/ha on-farm) • (kg N-eq/ha on+off-farm)
		N Balance (Excel tool)	**Whole farm N surplus** • (kg N/ tonne FPCM) • (kg N/ha on-farm) • (kg N/ha on+off-farm) **Corrected whole-farm N surplus** • (kg N/ tonne FPCM) • (kg N/ha on-farm) • (kg N/ha on+off-farm) **Chain-level N surplus** • (kg N/ tonne FPCM) • (kg N/ha on-farm) • (kg N/ha on+off-farm)
		N Use Efficiency (Excel tool)	**NUEs** • Whole farm NUE (%) • Chain level NUE (%)

3. How do these farming systems compare for the GHG and N emissions within the boundaries of land use perspective and production perspective?	Results of Q1 and Q2.	Qualitative (summary)	Summaries and figures

3.4. Research framework

The research framework in Figure 7, illustrates the overall structure of the research plan and the flow of the steps to be taken from developing the research problem and objectives to conclusions and recommendations. It also depicts how the different steps are related to each other.



Source: author

Figure 7. Research Framework

4. RESULTS

4.1. Main characteristics of the studied cases

The current study included three dairy farms in the Netherlands and four dairy farms in Kenya with different characteristics. Table 10 below shows how the studied Dutch farms compare with the typical Dutch farms based on the Wageningen Economic Research (2021) study conducted over 2017-2019, which covers almost 90% of farms with dairy cows and 94% of the number of dairy cows in the Netherlands. The Wageningen Economic Research (2021) survey divided the farms into organic and conventional farms, subdivided into larger and smaller farms based on total milk production using the median per distinguished group as a limit. However, farms in the current study were divided into intensive and extensive based on the stocking density, which is still comparable to conventional and organic farms of the Wageningen Economic Research (2021), respectively. Although the intensive farms in this study had a higher milk production intensity (18,789 and 14,436 kg per ha per year) than their counterpart typical farms (18,259 and 13,526 kg per ha per year, respectively), the difference in milk production per cow was small (~ 10% for both intensive farms). The Dutch extensive/organic farm had lower total milk production, milking cows, and obviously, lower (~ 33%) milk production per cow than its counterpart typical organic farm (5500 vs 7,122 kg per cow per year). This farm (as the case is with other organic farms) does not use chemical pesticides and fertilizers, which distinguishes them from conventional/intensive farms. Table 10 also shows how the studied Kenyan farms compare with the typical Kenyan farms based on the study of Tegemeo Institute of Agricultural Policy and Development (TIAPD) (2021). The TIAPD study categorized Kenyan dairy farms into zero-grazing, semi-grazing and open-grazing farms. The current study, however, divided the participating Kenyan farms into very intensive, intensive and extensive, which also relates well with classification of TIAPD, (2021). Although the studied Kenyan farms share some degree of similarities with their counterpart typical farms, they produce higher milk production per cow (5,678 vs 3,641 kg per cow per year for very intensive and typical zero-grazing farm) and are larger in the number of milking cows, as shown in Table 10. However, one intensive farm produced significantly lower than its counterpart semi-grazing farm (1,825 vs 2,447 kg per cow per year). It is also worth mentioning that the Kenyan extensive farm did not practice organic farming, unlike the Dutch extensive farm.

Table 10. Main characteristics of the studied cases

	Farm/cases	Total farmland (ha)	Stocking density (LU/ ha)	Production intensity (kg milk per ha/yr)	Milk production per cow (kg /yr)	Milking cows (n)	Total milk production (kg /farm/yr)
The Netherlands (NL)	I 1	105	2.7	18,789	8,883	223	1,976,394
	Typical large intensive (*)	75	-	18,259	9,256	143	1,326,375
	I 2	55	2	14,436	9,132	85	776,220
	Typical small intensive (*)	35	-	13,526	8,205	60	493,032
	E	102	1.4	8,250	5,500	91.5	503,250
	Typical large extensive (*)	108	-	7,924	7,122	119	848,928
Kenya (K)	VI	1.6	35	159,688	5,678	45	250,646
	Typical intensive (Zero-grazing) (**)	-	-	-	3,641	2	7,436
	I 1	0.4	8.3	13,688	1,825	3	5,371
	I 2	0.6	8.3	21,000	3,150	4	12,361
	Typical intensive (semi-grazing) (**)	-	-	-	2,447	2	6,098
	E	24	2.8	7817	4,264	44	184,045
	Typical extensive (open grazing) (**)	-	-	-	2,325	4	7,920

I: intensive, E: extensive, VI: very intensive, LU: livestock units, ha: hectare, n: number

(*) Classification according to Wageningen Economic Research (2021)

(**) Classification according to Tegemeo Institute of Agricultural Policy and Development (2021)

4.2. Overall comparison between the extensive and intensive dairy systems

Table 11 presents the overall results of 17 environmental performance indicators derived from lifecycle assessment, nitrogen balance and NUE approaches. The intensive farms in the Netherlands have shown better environmental performance for 4 out of 5 product-based indicators and for both whole farm and chain level NUE. In comparison, the results of the extensive Dutch farm indicated better performance for all the 10 area-based indicators. A similar pattern to some extent is recorded for the Kenyan farms. The very-intensive farm has shown the best performance in all the product-based indicators except for the MEP; however, the extensive farm has not shown the opposite, unlike the extensive Dutch farm. One of the intensive farms tends to show the worst performance in 4 out of 5 product-based indicators. Regarding area-based indicators for the Kenyan farms, the extensive farm had the best performance when counted the on-farm land but not when the total land, which included off-farm land, was considered.

Table 11. Overall results of the LCA, NB, and NUE-based indicators per unit of milk, per ha farmland and per ha on-farm and of-farm land.

			Per kg FPCM					Per ha (method 1 = on-farm ha)					Per ha (method 2 = on-farm + off-farm ha)						
Country	farming system	Livestock density LU/ha	GHG (kg CO_2-eq)	MEP (g N-eq)	Whole farm NB (kg N tonne $FPCM^{-1}$)	Corrected whole-farm NB (kg N tonne $FPCM^{-1}$)	Chain level NB (kg N tonne $FPCM^{-1}$)	GHG (kg CO_2-eq)	MEP (kg N-eq)	Whole farm NB (kg N)	Corrected whole-farm NB (kg N)	Chain level NB (kg N)	GHG (kg CO_2-eq)	MEP (kg N-eq)	Whole farm NB (kg N)	Corrected whole-farm NB (kg N)	Chain level NB (Kg N)	Whole farm NUE	Chain level NUE
NL	I 1	2.7	1.16	2.5	11.2	6.2	12.53	26,710	57	257	144	289	16,185	35	156	87	175	46%	44%
	I 2	2.0	1.23	2.3	10.9	5.6	12.09	20,722	40	186	96	206	14,724	28	132	68	147	31%	29%
	E	1.4	1.45	2.5	12.3	7.3	13.42	8,770	21	75	44	81	7,518	13	64	38	70	25%	23%
	Av.		1.3	2.4	11.5	6.4	12.7	18,734	39	173	95	192	12,809	25	117	64	130	34%	32%
	SD		0.15	0.10	0.76	0.83	0.67	9134	18	92	50	104	4640	11	48	25	54	0.11	0.10
K	VI	35	1.5	0.2	2.8	1.2	10.2	255,136	28	512	294	1,860	9,635	1.4	19	-27	70	72%	42%
	I 1	8.3	3.5	0.1	30.7	29.8	56.5	50,883	2	489	475	882	9,066	0.4	106	104	191	19%	11%
	I 2	8.3	2.2	0.8	20.6	16.6	37.8	49,626	16	502	408	906	8,562	3.4	105	88	189	20%	12%
	E	2.8	2.2	0.4	16.0	13.2	34.7	18,868	4	146	121	310	4,997	1.0	54	47	115	40%	24%
	Av.		2.3	0.4	17.5	15.2	34.8	93,628	13	412	325	989	8,065	2	71	53	141	38%	22%
	SD		0.82	0.30	11.60	11.78	19.00	108,685	12	178	155	642	2,092	1	42	58	59	0.25	0.14

Av.: average

Best performance within each country farm cases — Worst performance — Averages & Standard deviations

4.3. GHG emission intensity

Figure 8 presents the GHG emission intensities of the studied cases expressed in kg FPCM, per ha on-farmland and per ha of total land used, including the land to cultivate imported feed (on+off farmland).

4.3.1. GHG emission intensity per kg FPCM

There are considerable differences in the level of GHG emission among the studied extensive and intensive farms. When expressed per kg FPCM, a lower impact has been recorded for the intensive farms in the Netherlands (1.16 and 1.23 kg CO_2-eq) compared to the corresponding extensive farm (1.45 kg CO_2-eq). Emissions from enteric fermentation represented half of the total emissions for intensive farms and 62% for the extensive Dutch farm. A different pattern can be observed for the farms in Kenya. Only the very-intensive farm showed lower impact per kg FPCM (1.50 kg CO_2-eq) than the corresponding extensive farm (2.2 kg CO_2-eq); one intensive farm had comparable GHG per kg FPCM to the extensive farm where the other intensive farm demonstrated extremely higher GHG emissions (3.5 kg CO_2-eq). Enteric fermentation was the major portion of these farms' emissions (60% - 68%).

4.3.2. GHG emission intensity per ha on-farm

When expressing the GHG emission intensity per ha of farmland, all studied intensive farms in both countries have shown higher GHG intensities than their counterpart extensive farms. Figure 8 shows that intensive farms in the Netherlands had 26,710 kg and 20,722 kg CO_2-eq ha^{-1} on-farm (three times and two times higher than the extensive farm, respectively), while the very-intensive farm in Kenya had 255,136 kg CO_2-eq ha^{-1} (13.7 times higher GHG emissions of the respective extensive farm).

4.3.3. GHG emission intensity per ha on+off-farm

When expressed per ha of the total land used, the difference in GHG emission intensity falls dramatically than when expressed per ha on-farm; nevertheless, the intensive farms of both countries still show higher GHG emissions.

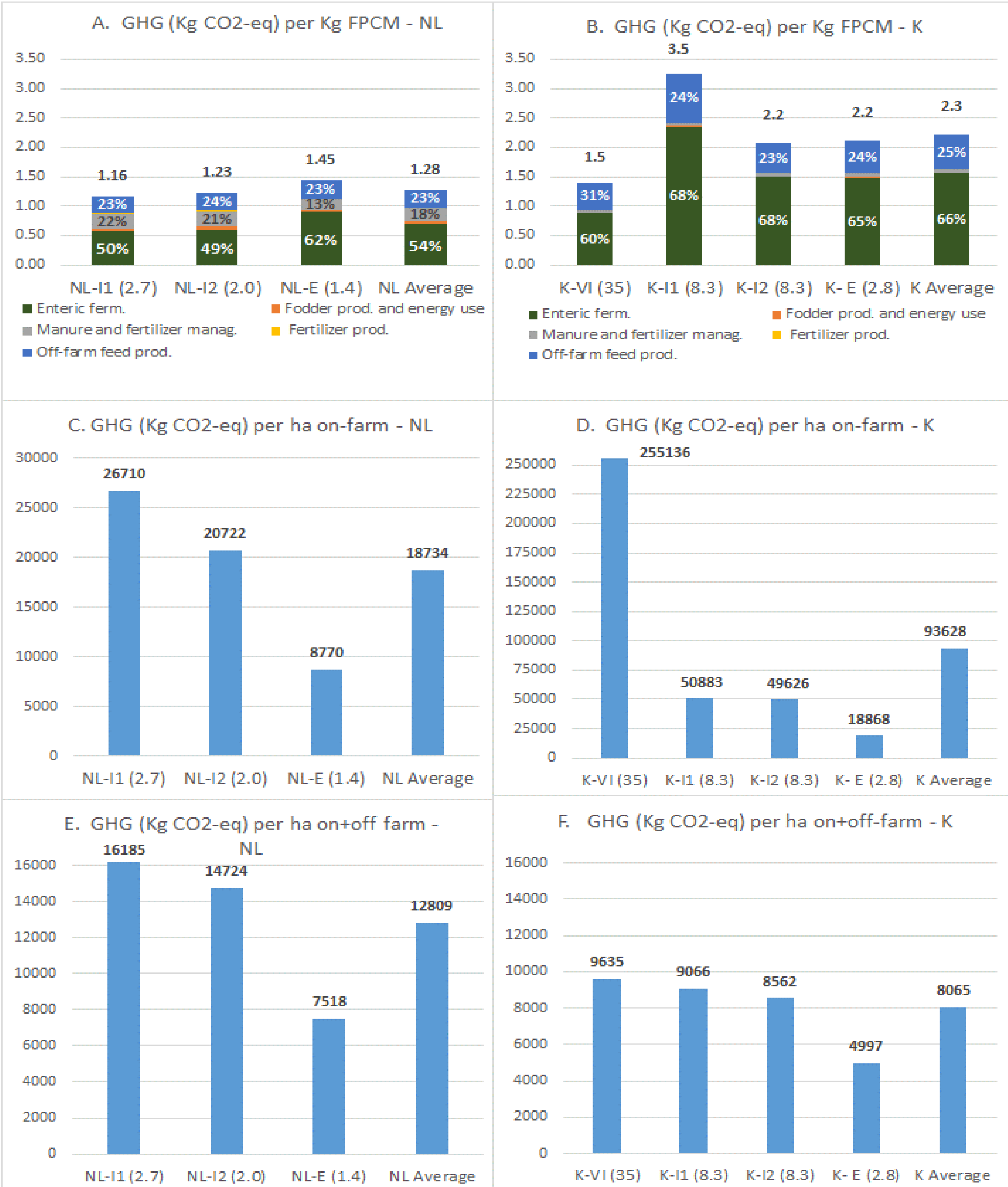


Figure 8. GHG emissions of dairy farms per kg FPCM, per ha on-farm, and per ha on+off-farmland

4.4. Nitrogen emission intensity

This part of the results presents the marine eutrophication potential of the studied systems, whole-farm N balances, corrected whole-farm N balances and chain level N balances expressed in kg FPCM, per ha on-farm and per ha on+off-farmland used. It also illustrates the dimensionless whole-farm NUEs and chain level NUEs of the farms.

4.4.1. Marine Eutrophication Potential

4.4.1.1. Marine eutrophication potential per kg FPCM,

Figure 9 shows an almost comparable marine eutrophication potential per kg FPCM for intensive farms in the Netherlands (2.5 and 2.32 g N-eq) compared to the extensive farm (2.5 g N-eq.). MEP, due to off-farm feed and fertilizer production, was the major contributor for the intensive Dutch farms, unlike the extensive farm. The pattern is not clear-cut for the farms in Kenya. The very intensive farm and one of the two intensive farms showed less on-farm MEP (0.2 and 0.1 g N-eq), while the other intensive farm showed a higher on-farm MEP (0.8 g N-eq) than the extensive farm (0.4 g N-eq). MEP due to production of external feed and fertilizer was not calculated for the Kenyan farms.

4.4.1.2. Marine eutrophication potential per ha on-farm

When expressed per ha farmland, studied Dutch intensive farms have shown values ranging from 40 – 57 kg N-eq per ha on-farm. This is at least double the MEP of their corresponding extensive farm. The very-intensive farm has shown a similar pattern but with a major difference (7 times) higher than the extensive farm. One intensive farm, however, had higher MEP per ha on-farm than the extensive farm (this farm had also higher MEP per kg FPCM).

4.4.1.3. Marine eutrophication potential per ha on+off-farm

A similar pattern to that of MEP per ha on-farm can be observed with a slight reduction when expressed per ha total land used.

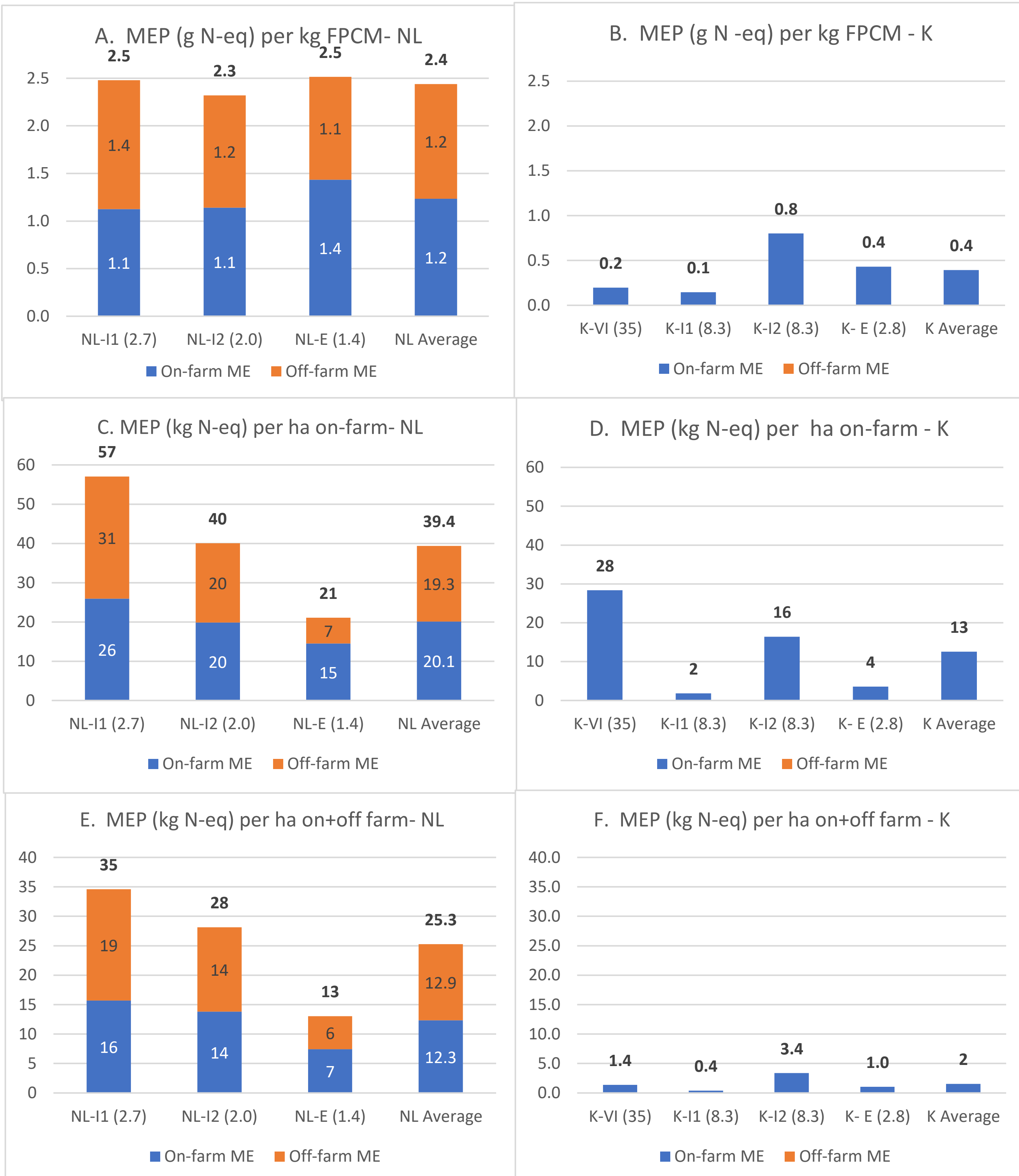


Figure 9. Marine eutrophication potential per kg FPCM, per ha on-farm and on+off-farm land

4.4.2. Whole-farm N balance

4.4.2.1. Whole farm N balance per kg FPCM

Results of the whole farm N balances are shown in Figure 10. N surpluses per tonne FPCM were lower in intensive Dutch farms (11.2 and 10.9 kg N tonne $FPCM^{-1}$ yr^{-1}) when compared with the extensive farm (12.3 kg N tonne $FPCM^{-1}$ yr^{-1}). On the other hand, the Kenyan whole-farm N balance results have not shown the same pattern except one out of the three intensive farms studied in Kenya that had a lower N surplus per this FU.

4.4.2.2. Whole farm N balance per ha on-farm

The N surplus per ha farmland calculated shows that intensive farms had a high N surplus for all studied farms. The Dutch farms had a whole-farm N surplus of 257, 186 and 75 kg N ha^{-1} yr^{-1} counting from the most intensive to the least intensive farm. On the other hand, the whole farm N surplus of the Kenyan farms ranged from 146 to 512 kg N ha^{-1} yr^{-1}.

4.4.2.3. Whole farm N balance per ha on+off-farm

Similar results have been recorded for the farms in the Netherlands when the whole farm N surplus expressed per ha total land, unlike the Kenyan farms where the very-intensive farm has shown extremely lower N surplus per total ha (19 kg N ha^{-1} yr^{-1}) than the corresponding extensive farm (54 kg N ha^{-1} yr^{-1}).

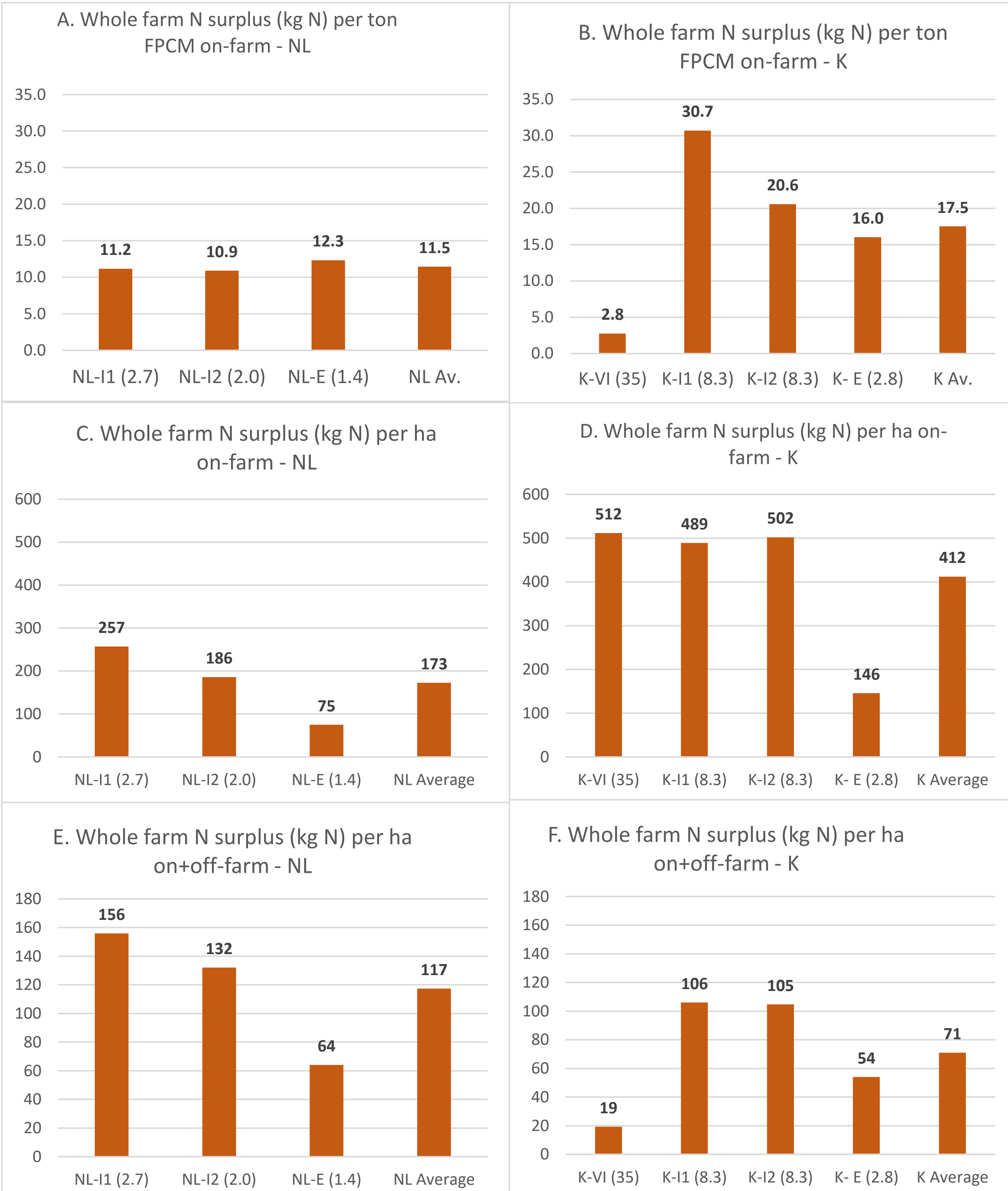


Figure 10. Whole farm N balance and NUE

- E & F, means the N surplus at the farm divided by the total land used

4.4.3. Corrected whole-farm N balance

4.4.3.1. Corrected whole-farm N balance per tonne FPCM

Table 12 illustrates the corrected-N-surpluses of the different farms and the amount of gaseous nitrogen losses accounted for in the calculation of the corrections. The extensive Dutch farm had the highest corrected-whole-farm-N-surplus (6.4 kg N ha^{-1} tonne $FPCM^{-1}$) compared to its two counterpart intensive farms who had 5.1 and 5.6 kg N ha^{-1} tonne $FPCM^{-1}$. The extensive Kenyan farm also had higher corrected-whole-farm-N-surplus (11.8 kg N ha^{-1} tonne $FPCM^{-1}$) than the very-intensive farm (1.2 kg N ha^{-1} tonne $FPCM^{-1}$) but lower than the other two intensive farms.

Looking into the gaseous N losses per tonne FPCM, the table shows that NH_3-N was the biggest loss for all the studied farms (at least more than half of the total gaseous N losses). It can be observed that the NH_3 losses per tonne FPCM of the Dutch farms decrease with increasing intensity (5.1, 3.5, and 5.1 kg N ha^{-1} tonne $FPCM^{-1}$ from the least intensive to the most intensive farm). Although there is no clear-cut pattern for the Kenyan farms, the extensive farm shows higher NH_3 losses (1.94 kg N ha^{-1} tonne $FPCM^{-1}$) than the very intensive farm which had 0.75 kg N ha^{-1} tonne $FPCM^{-1}$.

Table 12. Corrected whole-farm N surplus per tonne FPCM

	kg N tonne $FPCM^{-1}$								
	Total N input	Total N output	Gaseous N Losses					N Output + Gaseous N Losses	Corrected N surplus
			NH_3-N	N_2O-N	NO_x-N	N_2-N	Total G Losses		
NL-I1 (2.7)	20.9	9.7	3.3	0.6	0.1	1.6	5.6	15.3	**5.6**
NL-I2 (2.0)	15.9	5.0	3.5	0.6	0.1	1.6	5.8	10.8	**5.1**
NL-E (1.4)	16.4	4.1	5.1	0.2	0.0	0.5	6.0	10.1	**6.4**
NL Average	17.7	6.3	4.0	0.5	0.1	1.2	5.8	12.0	**5.7**
K-VI (35)	9.4	6.8	0.75	0.07	0.05	0.50	1.39	8.1	**1.2**
K-I1 (8.3)	35.6	6.7	0.57	0.05	0.04	0.36	1.02	7.7	**27.9**
K-I2 (8.3)	24.4	5.0	3.32	0.17	0.11	0.97	4.57	9.6	**14.8**
K- E (2.8)	25.1	10.0	1.94	0.13	0.11	1.08	3.26	13.3	**11.8**
K Average	23.6	7.1	1.6	0.1	0.1	0.7	2.6	9.7	**13.9**

4.4.3.2. *Corrected whole-farm N balance per ha on-farm*

Table 13 shows the corrected whole-farm N balances expressed per ha on-farm. A smaller N surplus per ha farmland (44 kg N) is recorded for the extensive farm in the Netherlands when compared to its corresponding intensive farms who also had major difference among them (96 and 144 kg N ha^{-1}), the number seems to increase with the intensity of the farm. On the other hand, a relatively large corrected-N-surplus is demonstrated for the farms in Kenya, ranging from 121 to 475 kg N ha^{-1}. Intensive farms had clearly higher corrected-N-surplus.

Looking into the gaseous N losses, ammonia N (NH_3-N) was the highest gaseous N loss, followed by N lost through denitrification (N_2), and N_2O for all the studied farms. The table also shows that intensive Dutch farms have had higher NH_3-N losses than their corresponding extensive farm. In Kenya, a similar pattern can be observed except for one intensive farm that has shown lower NH3-N losses (8 kg N ha^{-1}) than the extensive farm with 15 kg N ha^{-1}.

Table 13. Corrected whole farm N balance Per ha on-farm

	kg N ha^{-1} yr^{-1} (on-farmland)								
			Gaseous N losses						
	Total N input	Total N output	NH_3-N	N_2O-N	NO_x-N	N_2-N	Total G losses	Output N + G. N Losses	**Corrected N surplus**
NL-I1 (2.7)	481	223	68	12	3	32	114	337	**144**
NL-I2 (2.0)	271	85	54	9	2	24	90	175	**96**
NL-E (1.4)	99	25	26	1	0	3	31	55	**44**
NL Average	284	111	49	7	2	20	78	189	**95**
K-VI (35)	1844	1332	118	11	8	79	217	1549	**294**
K-I1 (8.3)	602	113	8	1	1	5	14	127	**475**
K-I2 (8.3)	631	129	68	3	2	20	94	223	**408**
K- E (2.8)	243	97	15	1	1	8	25	122	**121**
K Average	830	418	52	4	3	28	87	505	**325**

4.4.3.3. *Corrected whole-farm N balance per ha on+off-farm*

Table 14 shows results of corrected whole-farm N balances and gaseous N losses expressed per ha on+off-farm. The same ranking for the corrected whole-farm N surpluses per ha on-farm was maintained by the Dutch farms when the total land was included. The pattern is similar for the Kenyan farms except for the very-intensive farm, which has shown a deficit (negative) balance. The same ranking for the NH_3 losses per ha on-farm was maintained when the NH_3-N losses were expressed per ha on+off-farm.

Table 14. Corrected whole-farm N balance per ha on+off-farm

	kg N ha^{-1} yr^{-1} (on+off-farm)								
			Gaseous N losses						
	Total N input	Total N output	NH_3-N	N_2O-N	NO_x-N	N_2-N	Total G losses	N Output + G. losses	Corrected N surplus
NL-I1 (2.7)	291.34	135.36	40.9	7.2	1.7	19.1	68.9	204.3	**87.1**
NL-I2 (2.0)	192.71	60.66	38.5	6.6	1.3	17.3	63.8	124.4	**68.3**
NL-E (1.4)	85.27	21.24	22.7	1.0	0.2	2.4	26.3	47.5	**37.7**
NL Average	190	72	34	5	1	13	53	125	**64**
K-VI (35)	69.63	50.31	42.4	0.4	0.3	3.0	46.1	96.4	**-26.8**
K-I1 (8.3)	130.47	24.46	1.4	0.1	0.1	0.9	2.4	26.9	**103.6**
K-I2 (8.3)	131.65	26.96	11.8	0.6	0.4	3.5	16.2	43.2	**88.5**
K- E (2.8)	90.00	35.94	3.9	0.3	0.2	2.2	6.6	42.6	**47.4**
K Average	105	34	15	0	0	2	18	52	**53**

4.4.4. Chain-level N balance

Error! Reference source not found. shows chain level (from cradle to farm-gate) N surplus per 3 different FUs and NUE for intensive and extensive dairy farms in Kenya and the Netherlands

4.4.4.1. Chain-level N balance per kg FPCM

A slightly lower chain-level N surplus per tonne FPCM is recorded for the intensive farms in the Netherlands (12.5, and 12.1 kg N tonne $FPCM^{-1}$) than the extensive farm (13.4 kg N tonne $FPCM^{-1}$). Also, the very intensive farm of Kenya had a lower chain level N surplus, unlike the other two intensive farms that had a higher N surplus (55.8 and 37.4 kg N tonne $FPCM^{-1}$) than the extensive farm (34.3 kg N tonne $FPCM^{-1}$).

4.4.4.2. Chain-level N balance per ha on-farm

The extensive system had less chain level N surplus by more than half in the two countries. A chain level N surplus of 289 and 206 kg N per ha on-farm are recorded for the intensive Dutch farms compared to 81 for the extensive system. In Kenya, all intensive farms also had higher chain-level N surpluses that ranged from 906 to 1860, while the extensive farm had only 310 kg N per ha. It can also be observed from the averages of the two countries that Kenyan farms had a very high chain-level N surplus per ha on-farm.

4.4.4.3. Chain-level N balance per ha on+off-farm

This pattern for the chain level N per ha was almost maintained when expressed per ha total land used (on+off-farm ha) for the Dutch farms, and to a lesser extent in the Kenyan cases except for the very intensive farm that showed lower than the corresponding extensive farm.

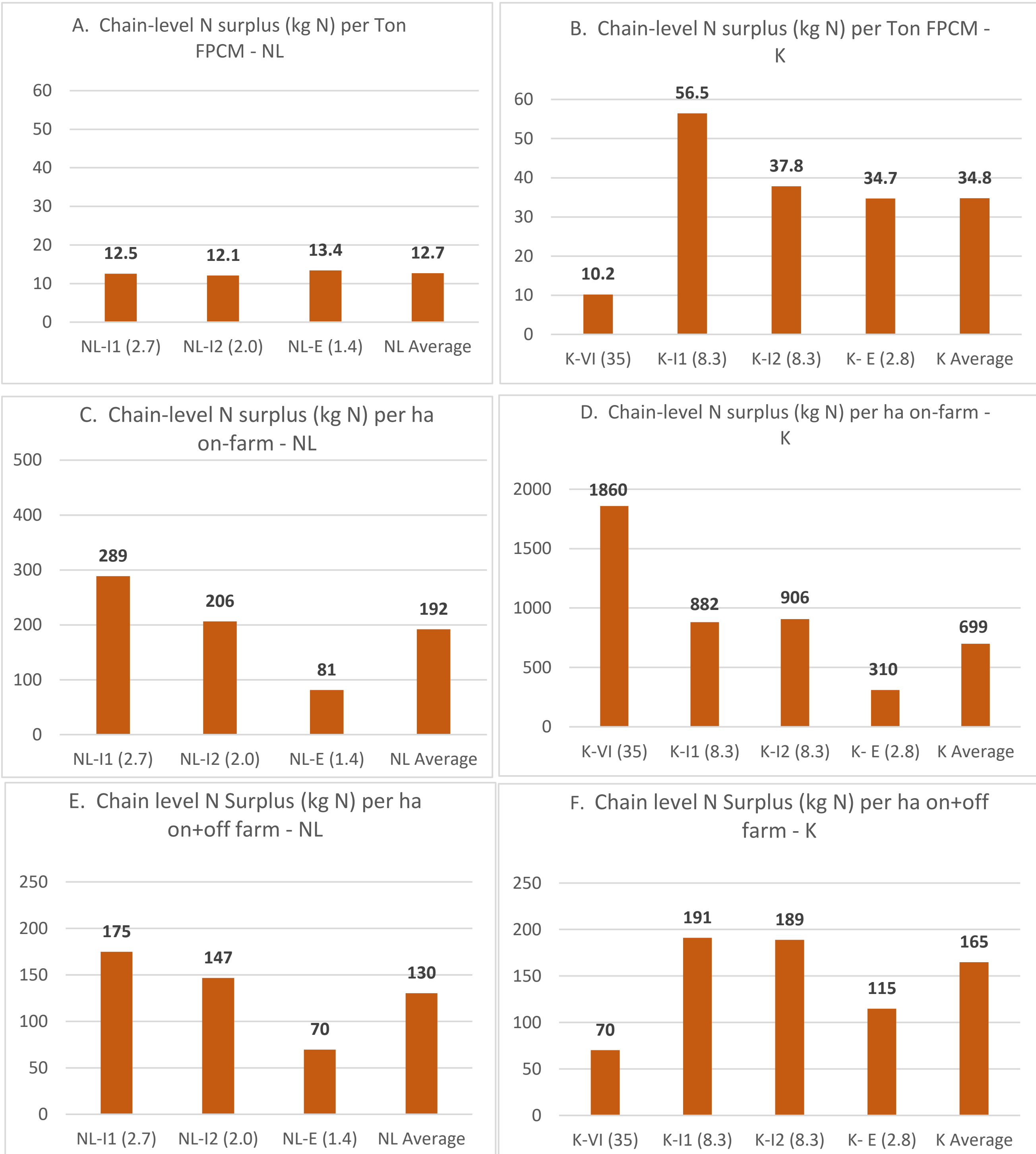


Figure 11.Chain-level N balance

4.4.5. Nitrogen use efficiencies (NUEs)

4.4.5.1. Whole farm NUE

Results of the whole farm NUEs in Figure 12 show that intensive farms in the Netherlands had higher NUEs (46% and 30%) than their counterpart extensive farm (25%). However, the whole farm NUE results of the Kenyan farms have not maintained a clear pattern. The very-intensive farm had the highest NUE (72%), followed by the extensive farm, which had a 40% NUE, while the other 2 extensive farms had lower NUEs.

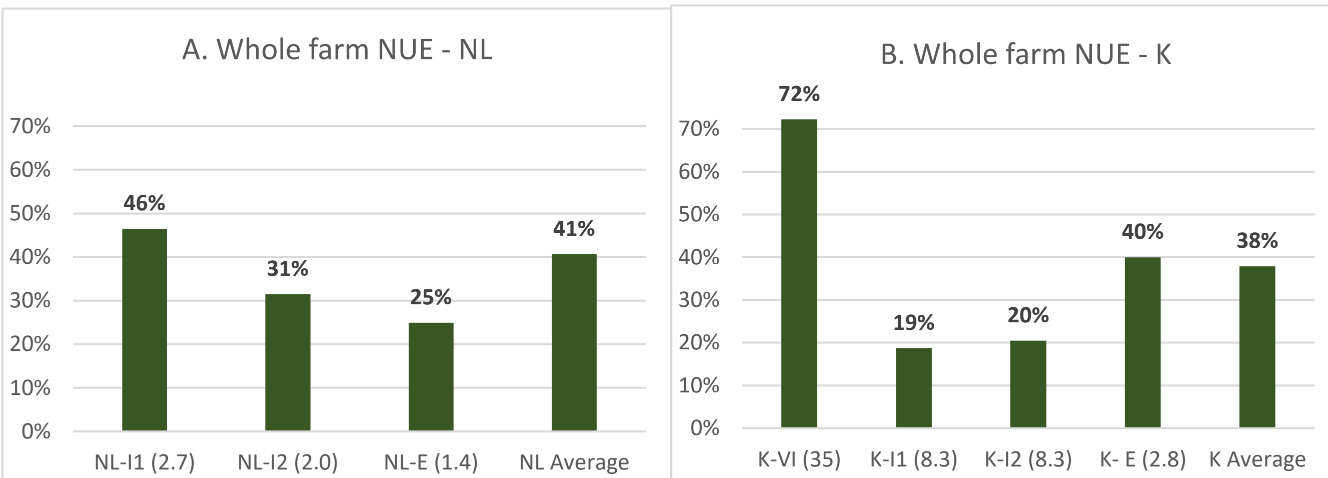


Figure 12. Whole-farm NUE

4.4.5.2. Chain-level NUE

The chain level NUE results of the intensive farms shown in Figure 13 were higher than their corresponding extensive farms, as the case is in the whole farm NUE results shown in Figure 12. It's worth mentioning that the chain level NUE of the Kenyan intensive farms show low figures concerning their respective whole-farm NUE.

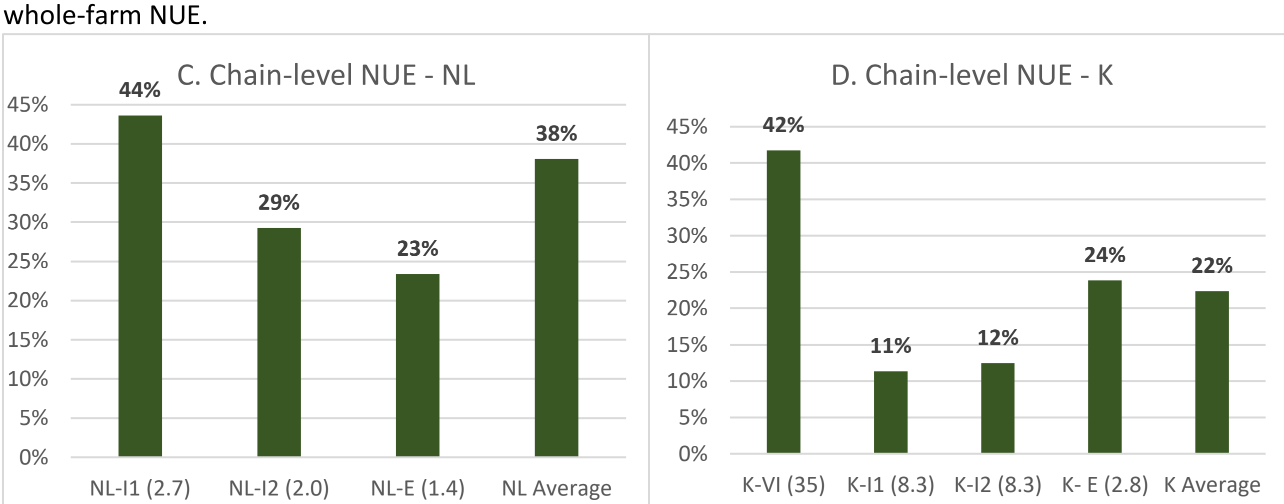


Figure 13. Chain-level NUE

5. DISCUSSION

The current study quantified and compared the GHG and nitrogen emissions of the intensive and extensive dairy production systems from production and land use perspectives. Although the study is based on a limited number of farms, it provided a clear overview of the situation in studied production systems of the Netherlands and Kenya. Under the following subheadings, the results of the studied indicators are discussed and compared with the findings of other researchers while putting into account the inevitable differences in methodologies. As outlined by the ISO (2006), results from various LCA can be compared only with caution. Moreover, direct comparisons were made between farms within each country/region (as much as possible) since comparisons (such as those based on nutrient balances) can only be justifiable if some major farm characteristics are comparable (Schröder et al., 2003).

5.1. GHG emissions

The LCA results of this study indicate lower GHG emissions per kg FPCM for the Dutch intensive farms (1.16 – 1.23 kg CO_2-eq) compared to the extensive farm (1.45 kg CO_2-eq). This corresponds with the study of Thomassen et al. (2008) in finding lower GHG emissions (1.4) for the intensive (conventional) farms and higher (1.5) for organic (extensive) farms per kg FPCM. Nevertheless, their figures for the Dutch farms are slightly higher than those of the current study. Even though the same LCA principles have been applied, there were considerable methodological differences between the two studies, such as the factors used. For instance, our study used the updated external feed production emission factors from FeedPrint (2020), which was not available for Thomassen et al. (2008). The low emissions per kg FPCM of intensive dairy farms were anticipated since the intensive farms produce larger quantities of milk which is achieved through the importation of nutrients from elsewhere. On the contrary, Bos et al. (2014) reported 5-10% higher GHG for the organic (extensive) production system compared to the conventional (intensive) farms. Although the same study indicated that there is no bulk of evidence for organic farms having lower GHG per kg FPCM than the conventional, it could be attributed to the productivity assumption of the organic farm model they used and the fact that the organic farm in the current study produced lower milk per cow than the average, typical Dutch organic farm.

A major difference between the two systems in this study lay in the category of enteric fermentation emissions, where the intensive Dutch farms have shown at least 12% lower emissions than the extensive farm. In general, higher rates of methane are released from diets that are high in roughage relative to diets high in starch. This will tend to result in higher emissions from extensive systems, as their diets tend to be high in roughage and low in concentrates. It is also partially due to the low productivity of the extensive system. As the intensity of animal production grows, so does the amount of methane emitted per unit of livestock product, which means two cows producing 5,000 litres of milk will generate more methane than one cow producing 10,000 litres (Shepherd et al., 2003). Emissions due to external feed production did not represent a major point of difference between the two systems, even though organic farms had slightly lower emissions of this category. The category of manure and fertilizer management, however, has shown major difference with the extensive farm having clearly lower emissions; this could be due to the lower nitrogen inputs as the extensive Dutch farm didn't use any chemical fertilizers and the relatively lower feed intake than the high producing cows of the intensive farm.

The Dutch intensive farms included in this study report GHG emissions, together with the results of some other environmental performance indicators through the Annual Nutrient Cycling Assessment (ANCA) tool, known as "Kringloopwijzer in Dutch". The tool benchmarks the performance of participating farms (Marion de Vries et al., 2020). Although the ANCA outcome is quite comparable to our results for GHG kg $FPCM^{-1}$, they were slightly (~12%) lower (1.01 and 1.14 shown in Annex A), particularly emissions in the category of enteric fermentation. It has been observed that the ANCA tool calculates enteric CH_4 differently and based on the Dutch net energy system for dairy cattle, called 'VEM' instead of the gross energy (GE) used in IPCC's enteric methane formula. The characterization factor for methane usually arises major differences; however, our study and the ANCA used the same factor (34) of the ReCipe midpoint method. Other differences lie in the factors used for calculating emissions from manure and fertilizer management. The ANCA calculations of Nitrogen excretion were mostly based on the Dutch NEMA model (Marion de Vries et al., 2020).

The ANCA was introduced parallel to legislation through the Dutch dairy supply chain organisation (ZuivelNL). Since 2016, the use of ANCA is mandatory, according to an agreement between the dairy processing companies and the farmers union (Klages et al., 2020). However, many organic farmers do not sell milk to ANCA-requiring companies. Based on the observations of the researcher and the response of an organic farmer, one of the main reasons for not being willing to report through the ANCA is that ANCA uses kg FPCM as a functional unit to calculate greenhouse gas emissions. Given the low milk production of extensive (organic) farms, this will translate that organic farmers are producing at a high cost to the environment. The same farmer believes that the organic farmers pay a lot of attention to the environment by keeping close to nature, such as providing cows free access to the pasture, not using synthetic fertilizers and pesticides and importing less concentrates; however, their effort is not reflected when kg FPCM is used as a functional unit for calculating GHG emissions. The use of both product-based (GHG per kg FPCM) and area-based (GHG per kg FPCM) indicators or a scoring system that considers both indicators would have addressed this issue.

The Kenyan dairy systems investigated in this study release fewer greenhouse gases per kg FPCM (1.5 – 3.5) than reported by the frequently cited FAO and GDP (2018) study, which provides an average value of 6.7 kg CO_2 kg FPCM for Sub-Saharan Africa for the year of 2015. This could be attributed to the herd structure, breed, and the use of concentrates. Milking cows of exotic or crossbreeds comprised the herd structure of the studied Kenyan farms. Moreover, all these farms have purchased concentrates or high-quality by-products that significantly contribute to increasing milk production. Different allocation methods applied can also generate differences. In this study, functions considered included the economic value of milk, meat and manure. Our findings correspond with Weiler et al. (2014), who investigated livestock's multifunctionality in a case of smallholder milk production in Kenya's Kaptumo district (20 farmers). They reported 1.6 (0.8–2.9) (economic function allocation); 2.0 (0.9–4.3) (food allocation); 1.1 (0.5–1.7) (livelihood allocation); (kg CO_2eq kg $FPCM^{-1}$) and concluded that inclusion or exclusion of multiple functions of cattle had a significant impact on the values of milk CF and, as a result, on mitigation options. Livelihood and food allocations require deeper information on how farmers value their animals and the reasons for keeping them. Since this was not fully available, the current study used the economic allocation only. De Vries and de Boer, (2010) noted that when social values of cattle were taken into account, the final carbon footprint of milk production in Kenya's free grazing management system was at the level of the more intensive (larger) systems of Kenya, and the specialized milk production systems in the Western countries.

Although the Dutch dairy farms have shown a decreasing GHG with higher livestock units per ha, it can be observed from the Kenyan data that high intensity, based on livestock density (LU/ha), does not necessarily lead to lower GHG per kg FPCM, since one intensive Kenyan farms (with 8.3 LU/ha stocking density) have shown comparable GHG emissions to the extensive farm (with 2.8 LU/ha stocking density), while high intensity based on the kg Milk per ha demonstrated lower GHG emissions per kg FPCM for both Dutch and Kenyan contexts in agreement with Gerber et al. (2011), who noted that increasing yields decreased greenhouse per kg of output (FPCM) with a significant relationship between productivity and greenhouse gas emissions per kg of milk (Figure 14).

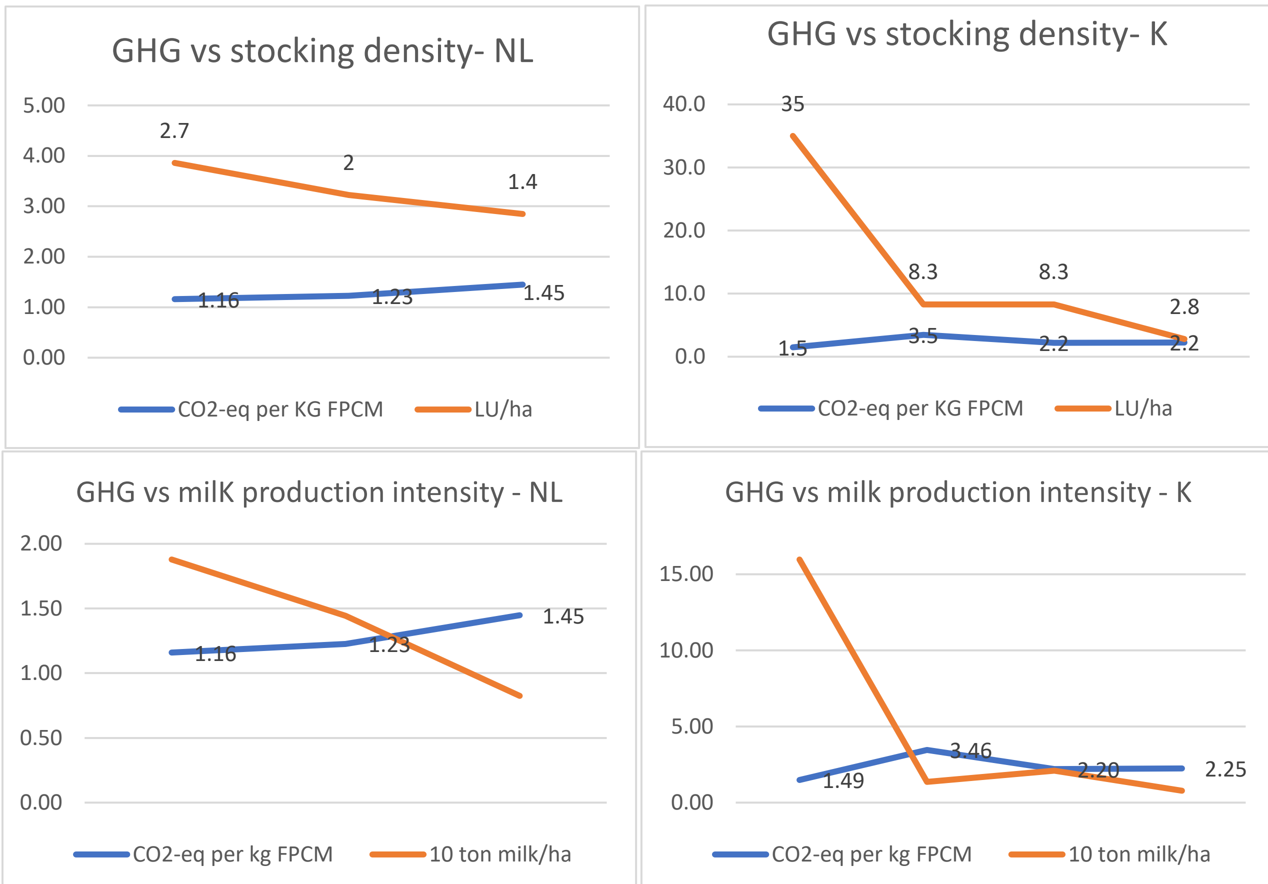


Figure 14. Relationship between GHG per kg FPCM and intensity (livestock density and milk production intensity)

The results of this study also show that extensive farms have lower GHG per ha on-farm than intensive farms. This is in agreement with the meta-analysis of Tuomisto et al. (2012), who noted that organic (extensive) farming in Europe has lower environmental impacts per unit of production area than conventional (intensive) farming. Also, an LCA study conducted in New Zealand has shown a similar pattern (14,570, 12,660 and 10,950, and kg CO_2-equivalents/ha for high, medium and low-intensity farms, respectively) (Ledgard et al., 2016). However, a significant part of the emission from intensive dairy systems are those impacts generated outside the farm boundaries. Yan et al. (2011) argues that including only on-farm area in an LCA is not satisfactory for assessing impacts since arable land used to produce purchased feed, which could be located anywhere in the world, will also be accountable for environmental consequences in the milk production life cycle. Several questions arise if we must account for the land used outside the farm; Ross et al., (2016) wonders whether productive areas of land be adjusted in LCA to homogenize their productivities across different locations in the same way as milk yields can be adjusted according to their fat and protein contents to achieve functional equivalence? In our studies, extensive systems tend to show lower impact both when considered on-farm and off-farm areas (with some exceptions in the Kenyan cases). However, based on the Ross et al. (2016) argument of correcting off-farmland for crop productivity differences in feed production of the two systems would no longer be reflected in GHG per hectare (since this leads to similar off-farm feed emissions), but rather in the other (downstream) system-specific elements like animal genetics, ration formulation and other farm-management characteristics. Another question could be, what would be the outcome if the extensive farms use a large portion of their land for growing concentrate feeds? The theoretical answer could be a lower enteric fermentation and higher milk production; however, it's worth noting that most extensive farms of the Netherlands (including the studied extensive farm) practice organic systems, which necessitates more grazing hours, and no synthetic fertilizer. The dairy farms in Kenya are not practising organic production; however, extending their farm area is difficult because they keep animals in the urban and preurban areas and the idea of moving out to the remote areas (where there is access to grazing land) may not be economically viable due to the transportation and infrastructure issues (electricity, network, veterinary services etc).

Relationship between expressing impacts per ha of land and per unit of milk

Although this study didn't statistically examine the relationships between greenhouse gas emissions (GHG) per kg FPCM and per ha of each system, the results tend to show that GHG per ha-on-farm increases with low GHG per kg FPCM (Figure 15); however, there is a need to study further by including extensive farms with higher milk production than the studied one. According to the research of Casey and Holden (2005) there is no substantial association between GHG per unit product and GHG per unit land. Ross et al., (2016) propose the use of dual FU to measure the outcome of trade-offs, for example, an improvement in emissions intensity using energy corrected milk as the FU being accompanied by a deterioration when using land-total, when assessing conversion from one production system to another.

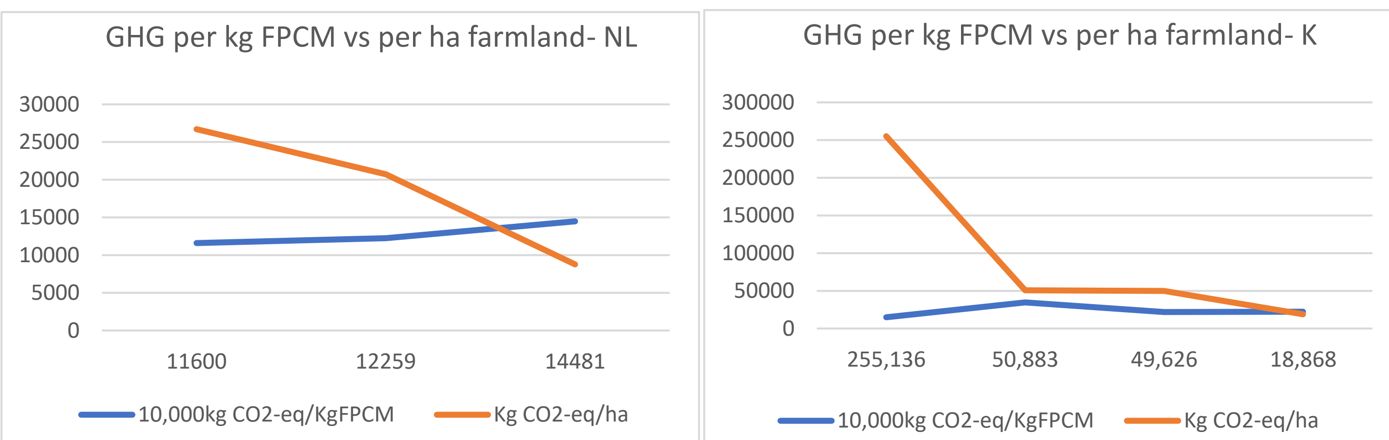


Figure 15. Relationship between expressing GHG per ha of land and per unit of milk

5.2. Nitrogen emission intensity

5.2.1. Marine eutrophication

Several researchers evaluated marine eutrophication potential (MEP) of dairy systems using the FU kg $FPCM^{-1}$ or energy-corrected milk as the FU kg $FPCM^{-1}$ (ECM). Kg NO_3^--eq and g N-eq are two popular reporting units of MEP. The MEP values in this study are within the range reported by Mu et al. (2017), who estimated values between 1.7 and 19.4 g N eq kg $FPCM^{-1}$ (8.1 ± 4) when on-farm activities were taken into account. The study did not show much difference in MEP per kg FPCM values for the intensive and extensive Dutch farms. A Norwegian study adopting as the FU 1 kg ECM provided estimates ranging from 9.3 and 12.1 g N eq., mainly attributed to forage production; the companies were partially pasture-based. Two Kenyan farms with medium intensity have shown higher EP than the extensive Kenyan farm; this could be due to the low milk production per cow. However, the very intensive farm had the least MEP; this is in line with the results of Modupeore (2011), which shows that a zero-grazing system had the least eutrophication potential (EP) per kg FPCM.

Few studies provided EP estimates on an area basis. The current study shows a higher MEP per ha on-farm and per ha on+off-farm for the intensive Dutch farms. The same explanation for intensive farms having higher GHG emissions on an area basis applies for the MEP per ha as well.

5.2.2. Nitrogen balances

The intensive and extensive whole-farm N surpluses per ha on-farm in the present study (257, 186 for the intensive farms and 75 kg N ha^{-1} yr^{-1} for the extensive farm) are in line with Flaten et al. (2018), who reported 2.6 times higher median N surpluses for intensive farms (199 vs 77 kg N/ha). In the literature, there are different ways to calculate N surplus depending on the purpose of the study, level of available information and assumptions of the researcher. Whole farm/farm gate N surpluses and soil surpluses were the most frequently used types. In most cases, the soil N surplus ha−1 is higher if the milk production ha−1 is higher (Figure 16). The higher amount of nitrogen ha−1 in purchased feed on more intensive dairy farms is not compensated by a comparable amount of nitrogen ha−1 in the outputs milk and meat plus export of animal manure (Daatselaar et al., 2015). There are limited assessments of product-based N indicators, such as surplus per kg FPCM, compared to the abundance of research reporting farm-gate N surplus per hectare. Dalgaard et al. (1998) used data from 16 organic and 14 conventional dairy farms to show that the farm-gate N surplus on organic and conventional farms was 22 and 29 kg N/tonne milk, respectively. However, the current study shows a lower N surplus per kg FPCM for both Dutch systems (at least by half) without showing a major difference between the two systems. When corrected the N surplus per ha (including the gaseous losses as an N output), the surpluses were much less, although the intensive Dutch farms still show higher N surplus. In literature, there are few studies that have considered gaseous N losses when conducting whole-farm N surplus. Thomassen and de Boer (2005) made corrections for NH_3-N volatilization and found a surplus of 82.2 kg N ha^{-1} yr^{-1} average N surplus in kg /ha for organic farms. While the value of N surplus for organic/extensive farms (44 kg N ha^{-1} yr^{-1}) of our study is two times higher than Thomassen and de Boer (2005), it's important to note that direct comparisons between the two studies might not be appropriate due to the possible methodological differences. In general, if the main aim of the N balance is to find out the leaching N potential, corrected whole-farm N surplus or soil-level surplus would make much sense than leaving whole-farm N surplus without identifying the type of losses.

The current study didn't study the soil N surplus due to limited information obtained from the internal N flows of participating farms.

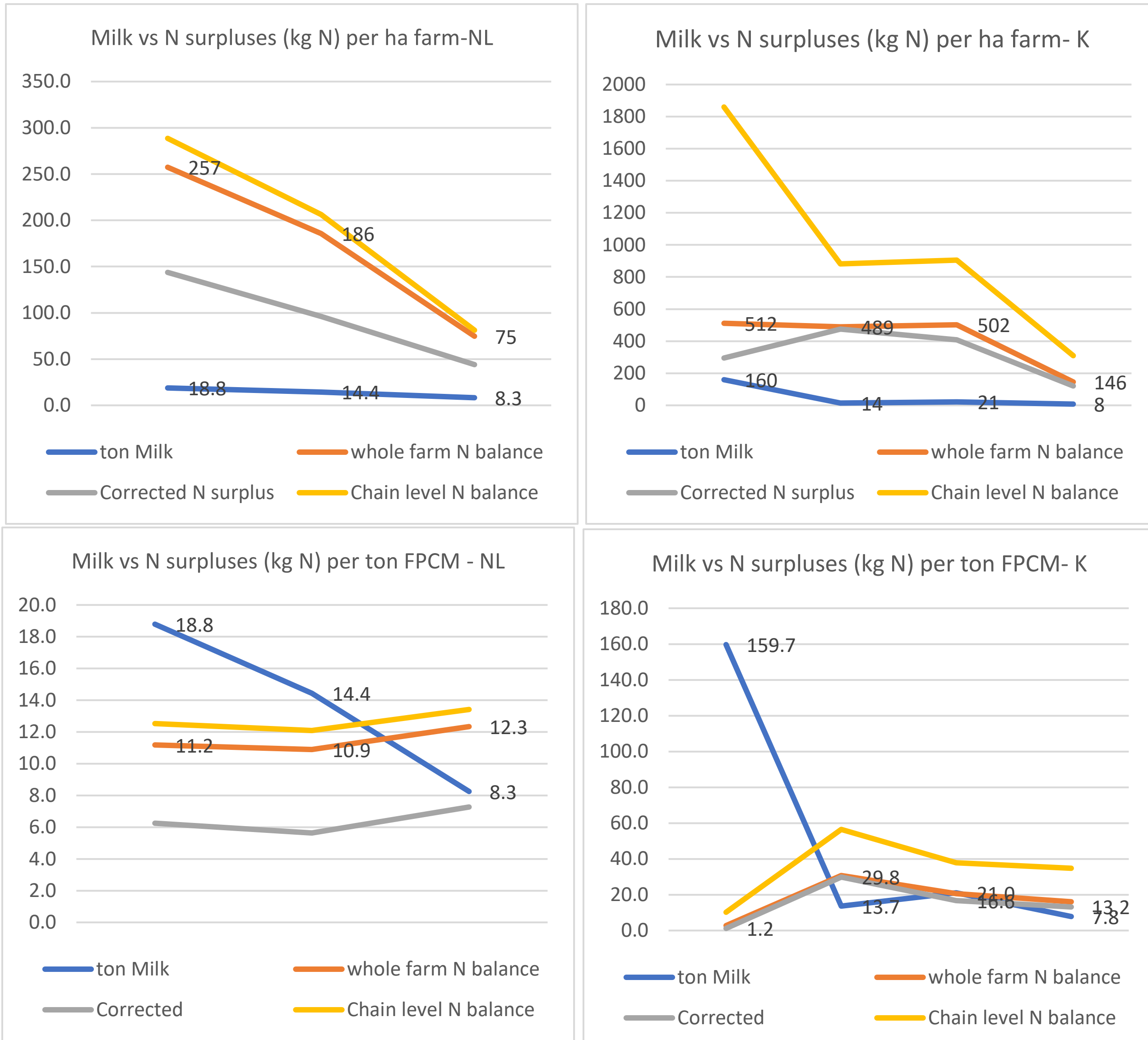


Figure 16. Milk production per ha vs N surpluses per ha and vs per tonne FPCM

At the chain level, the concept of NB is similar to that of N footprint (i.e., accounting for all the losses along the chain). For example, Leip et al. (2013) looked at the nitrogen footprint of 12 different food categories and found that dairy products from cows, lambs, and goats had N footprints ranging from 10 to 45 kg N per tonne of product. The current study recorded a range of 12.5, 12.1 and 13.4 kg N tonne $FPCM^{-1}$ for Dutch farms, counting from the most intensive to the least intensive farm.

To our best knowledge, all N balances reported on an area basis in the literature accounted for the farmland (on-farm), unlike the greenhouse gas reporting, where the study of Ross et al. 2016 considered land-total (on+off farm). This is not surprising as the focus of whole-farm N balances is to measure the potential loss of nutrients at the local level because nutrient losses through leaching have more local effects whereas GHG in the atmosphere may be considered much more global.

5.2.3. Nitrogen use efficiencies (NUEs)

In intensive dairy farms, a greater reliance on purchased feed might enhance efficiency because the farmer has more options when purchasing roughage. The roughage composition is more decided if a dairy farm is (more than) self-sufficient in roughage. Furthermore, when buying roughage, intensive dairy farms prevent the nitrogen losses that come with crop cultivation and during manure application by exporting manure off-farm (Daatselaar et al., 2015). This is not easy for extensive farmers who rely on feed grown inside their farmland and depend on manure as fertilizer. Our study confirms this as it shows that the whole farm NUEs of intensive farms in the Netherlands are higher (46% and 30%) than their counterpart extensive farms (25%). In Kenya, a similar pattern can be observed when compared to the very intensive with the extensive farm. However, the two (medium) intensive farms have shown relatively low NUE. This could be attributed to the low milk export of these farms.

The chain level NUEs kept showing the same trend (although slightly lower) as for the whole-farm NUEs, this was not expected; however, the fact that we used same factors for both intensive and extensive farms when calculating the off-farm input (N losses due to feed and fertilizer production) which might not be precise might have masked some information. Therefore, there is a need to find a way to estimate off-farm N losses for both systems since organic/extensive farm source their inputs from organic feed processors (who in turn only process feed that has no chemical fertilizer inputs) unlike the intensive conventional farms. There is also a need for a database that gives (crop and country) specific factors for off-farm N losses while considering the different feed production systems.

5.3. General discussion

There is lack of comparative whole-farm studies in which GHG emissions of Nitrogen surpluses in intensive and extensive farming systems in Kenya are calculated or measured. On the other hand, there are few studies that compared the conventional and organic systems of the Netherlands. Further studies could support the results found here and include other dimensions such as economic and social aspects.

6. CONCLUSION

This study was conducted to provide the Professorship Dairy Value Chains of the Van Hall Laresntein University of Applied Sciences a broader insight about the environmental impact of milk production by comparing GHG and N emission intensities among different dairy farming systems from production and land-use perspectives. In this part, conclusions are made based on the main research question and sub-questions.

6.1. GHG emission intensities

There were considerable differences in the level of GHG emission among the studied extensive and intensive farms. When expressed per Kg FPCM, a lower impact has been recorded for the intensive farms in the Netherlands (1.16 and 1.23 Kg CO2-eq) compared to the corresponding extensive farm (1.45 Kg CO2-eq). When expressed per kg FPCM, lower GHG emissions for the Dutch intensive farms (1.16 – 1.23 Kg CO2-eq) compared to the Dutch extensive farm (1.45 Kg CO2-eq) was recorded. In Kenya the GHG emissions ranged from 1.5 to 3.5± 0.8 kg FPCM. Only the very-intensive farm showed lower GHG per Kg FPCM (1.50 kg CO2-eq) compared to the extensive farm (2.2 Kg CO2-eq) When expressed per ha farmland, intensive farms in the Netherlands had 26,710 Kg and 20,722 Kg CO2-eq ha^{-1} on-farm (three times and two times higher than the extensive farm, respectively), while the very-intensive farm in Kenya had 255,136 Kg CO2-eq ha^{-1} (14 times higher GHG emissions of the respective extensive farm). When off-land is accounted for, the difference in GHG emission intensity falls dramatically than when expressed per ha on-farm only; nevertheless, the intensive farms of both countries still had higher GHG emissions per ha on+off farm.

6.2. Nitrogen emission intensities

A wide range of N-related indicators has been applied including the marine eutrophication potential of the studied systems, whole-farm N balances, corrected whole-farm N balances and chain level N balances expressed in Kg FPCM, per ha on-farm and per ha on+off-farmland used. The outcome can be summarised as follows:

- Similar marine eutrophication potential (MEP) per kg FPCM has been recorded for intensive farms in the Netherlands (2.5 and 2.32 g N-eq) compared to the extensive farm (2.5 g N-eq.). Both included on-farm and off-farm MEP. The pattern is not clear-cut for the farms in Kenya. The on-farm MEP ranged from 0.1 - 0.8 g N-eq. When expressed per ha, MEP values for the Dutch farms ranged from 40 - 70 g N-eq. In Kenya the very-intensive farm had 7 times high MEP per ha than the extensive farm. Considering the off-farm land, the pattern was quite similar.
- Results of the whole farm N balances are usually reported as per ha basis and rarely as per kg FPCM. The Dutch farms had a whole-farm N surplus of 257, 186 and 75 Kg N ha^{-1} yr^{-1} counting from the most intensive to the least intensive farm, respectively. On the other hand, the whole farm N surplus of the Kenyan farms ranged from 146 to 512 Kg N ha^{-1} yr^{-1}. When expressed per Kg FPCM, the trend was for the Dutch farms was opposite, but the difference was minor (11.2 and 10.9 Kg N tonne FPCM-1 yr^{-1}) when compared with the extensive farm (12.3 Kg N tonne FPCM-1 yr^{-1}). The pattern was similar for Kenya, except for one intensive farm.

- When whole farm N balance is corrected for the gaseous N losses, a similar pattern has been maintained as the uncorrected N balance. Major gaseous N losses recorded were in a form of ammonia. Intensive farms had clearly higher corrected-N-surplus per ha than extensive ones.
- Chain level N surplus per ha on-farm of Dutch farms didn't show much difference than whole-farm N surplus. When the total land is accounted for, a large difference has been observed between Kenyan farms.
- whole farm NUEs of the intensive farms in the Netherlands were higher NUEs (46% and 30%) than their counterpart extensive farm (25%). However, the whole farm NUE results of the Kenyan farms have not maintained a clear pattern, but the very intensive farm had the highest NUE (72 %).
- Chain level NUEs of the Dutch farms followed similar trend to that of whole farm NUE (varying between 23% and 44%). This was also true for the Kenyan farms, although very low efficiencies have been recorded for some farms (11%).

6.3. General conclusions

- The results indicate that almost all environmental performance indicators differed between the intensive and extensive systems.
- Intensive farms in the Netherlands tend to show better performance in all product-based indictors except for the MEP per kg FPCM where it was almost comparable to that of extensive farm
- The extensive farms show better performance in all area-based indicators (GHG, MEP, whole-farm N balance, corrected N balance and chain-level N balance per kg ha on farm and per ha on+off farm).
- the results tend to show that GHG per ha-on-farm increases with low GHG per kg FPCM
- Intensive farms in the Netherlands had both higher N surplus per ha and nitrogen use efficiencies at farm level. This means a farm with a greater nitrogen use efficiency can nevertheless pollute the environment locally due to the high N surplus per ha.
- Although many studies discussed about the possibility of applying N balances at chain level, only one study that actually measures both farm and chain level N balances has been found.
- The environmental issues surrounding intensive and extensive farming in Kenya are much more confusing than the Dutch farms.
- There is lack of comparative studies in which Nitrogen surpluses in intensive and extensive farming systems in Kenya are calculated or measured.

7. RECOMMENDATIONS

Based on the conclusions of this research work, the following recommendations are provided to two relevant parties: The Professorship Dairy Value Chains (research commissioner) and the Kenyan Ministry of Agriculture, accordingly.

To Professorship Dairy Value Chains:

- A more representative and detailed assessment considering both GHG and nitrogen-related impacts from different perspectives are necessary to understand the extent of environmental pressure for the different dairy production systems.
- When developing nutrient cycle assessment tools/software such as "the ANCA", developers should put into consideration the use of both product (Impact per kg FPCM) and area-based indicators, i.e., impact per ha farmland and per ha total land (including off-farm land for feed cultivation).
- Further studies are recommended to understand the relationship between impacts per kg FPCM and per ha and the possibility of developing a scoring system that joins the product and area-based indicators or testing the effectiveness of using dual-functional units.
- Further studies on the chain level nutrient balances and efficiencies, including establishing homogenised and easy to apply methodology for estimating off-farm N inputs (N losses due to production of external feed and fertilizers), could help in understanding the situation.
- When comparing dairy production systems in developing countries, researchers should be careful with the use of terms such as intensive and extensive, as there are no clear-cut distinctions available (when making classification, both intensities based on livestock units per ha, and milk production per ha should be considered).
- More comparative research on environmental impacts of milk production in Kenya, other than GHG such as N balances, acidification and eutrophication potentials are needed to establish a baseline for the different production systems.

To Ministry of Agriculture, Kenya:

- The agricultural extension department of the Kenyan Ministry of Agriculture may utilize the local knowledge institutes and partner with international organizations in developing simplified environmental performance assessment (such as LCA and nutrient balance) tools that are suitable for the Kenyan/Sub-Saharan Africa context.
- Farmers could also be trained on proper farm record keeping and the use of assessment tools to minimize environmental impacts of milk production.
- When setting policies for dairy production in Kenya, larger grazing land should be given priority to encourage newly forming farms to acquire more land before they start production

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ANNEXES

Annexe A. GHG emission report of the ANCA tool

Table 15. GHG emissions of the Dutch farms based on the outcome of the ANCA "the KringloopWijzer"

	NL-I1 (g CO_2-eq kg FPCM-1)	NL-I2 (g CO_2-eq/ kg FPCM)	NL-E (g CO_2-eq/ kg FPCM)
Emission from rumen fermentation	491	480	N/A
Emission from stored manure	162	112	N/A
Emissions from feed production	94	94	N/A
Emissions from energy sources	31	52	N/A
Emissions from import sources	235	406	N/A
Total	**1,012**	**1,145**	**N/A**

Annexe B. Nitrogen flows report of the ANCA tool

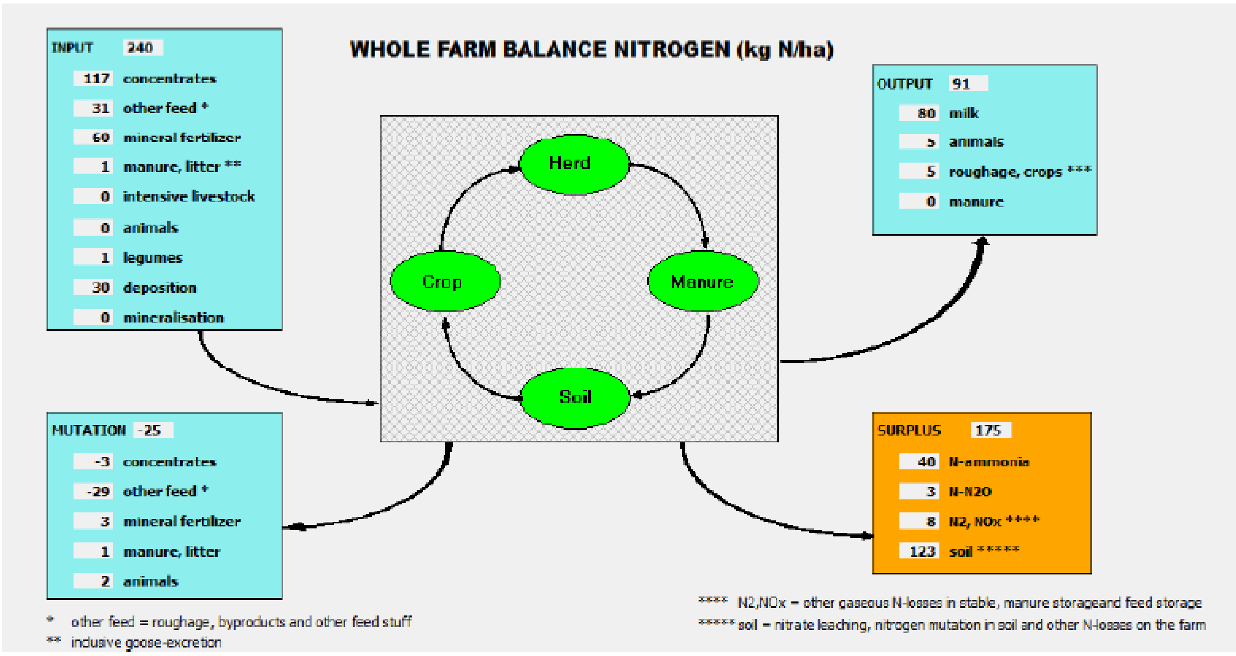

Figure 17. Whole-farm N balance of a Dutch intensive farm (NL-I2) based on the output of the ANCA

Source: ANCA report of the farm, 2021

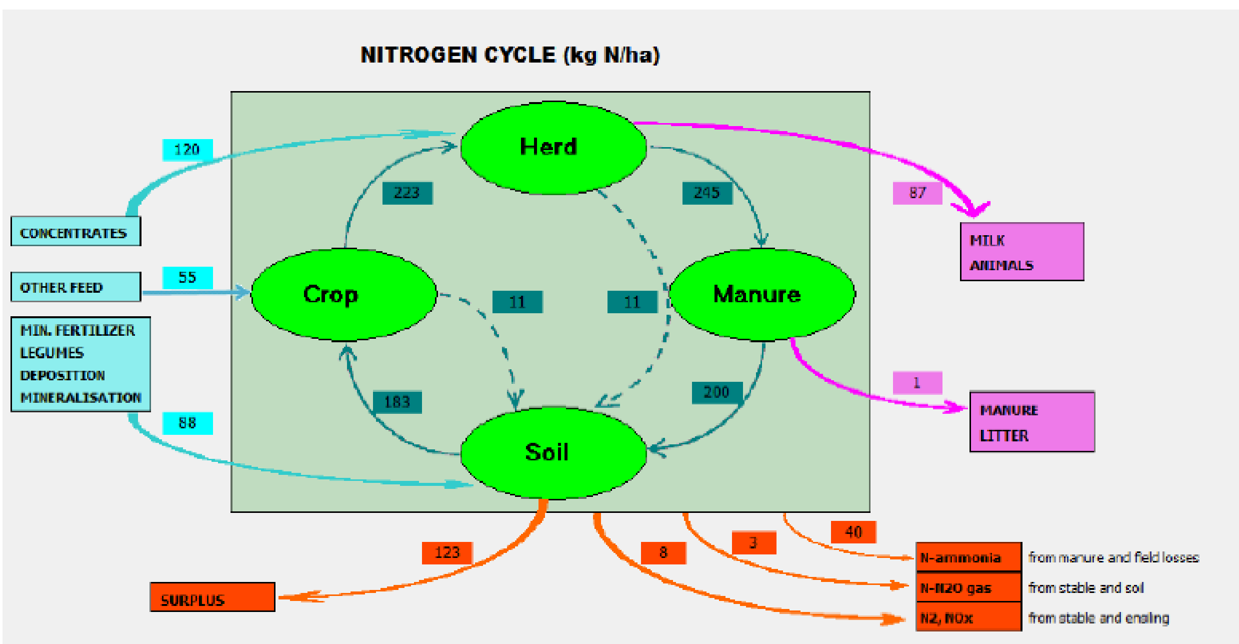

Figure 18. Nitrogen flow indicating N surplus (soil) for a Dutch intensive farm (NL-I2) based on the ANCA output

Source: ANCA report of the farm, 2021

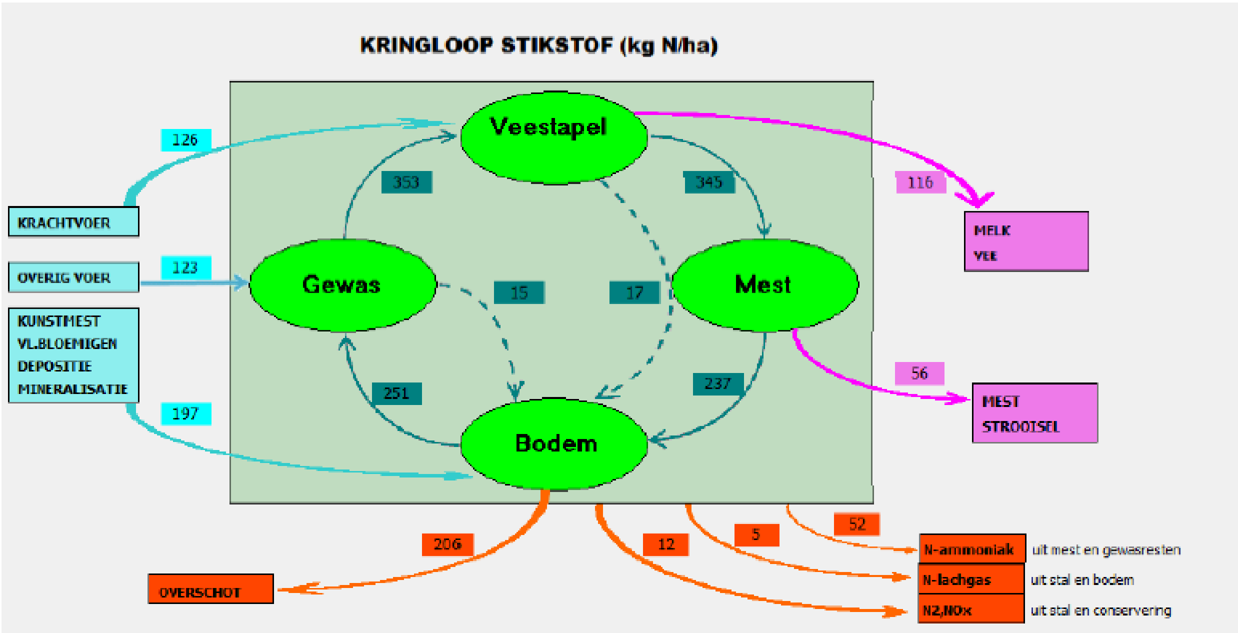

Figure 19. Nitrogen flow indicating N surplus (soil) for a Dutch intensive farm (NL-I1) based on the ANCA output