

Environmental impacts of dairy farming in Lembang, West Java

Estimation of greenhouse gas emissions and effects of mitigation strategies

Working Paper No. 221

CGIAR Research Program on Climate Change,
Agriculture and Food Security (CCAFS)

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A. P (Bram) Wouters
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RESEARCH PROGRAM ON
**Climate Change,
Agriculture and
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Abstract

The demand for milk and dairy products is growing in Indonesia. At the same time, Indonesia has committed itself to substantially reduce national greenhouse gas (GHG) emissions. Low-emission strategies are required to sustainably increase milk production of the Indonesian dairy sector. Objectives of this study were to estimate the current level of GHG emissions and land use of dairy farms in Lembang District, West Java, and evaluate the potential effects of feeding and manure management interventions on GHG emissions and land use. A life cycle assessment was used to estimate cradle-to-farm gate GHG emissions and land use of an average dairy farm in Lembang District, using data from a survey of 300 dairy farmers in Lembang in 2016. Total GHG emissions were 33 ton CO₂e. per farm/year, and emission intensity was 1.9 kg CO₂e per kg of fat and protein corrected milk (FPCM) and 8.8 kg CO₂e per kg live weight. Total estimated land use was 2.1 ha per dairy farm, which was equal to 1.2 m² per kg FPCM and 5.6 m² per kg live weight. Hotspots of GHG emissions were rumen enteric fermentation (CH₄), manure management (CH₄ and N₂O; especially discharged manure), and off-farm feed production (CH₄, N₂O and CO₂; especially rice straw). Feeding and manure management interventions evaluated in a scenario analysis in this study changed total GHG emissions by -12 to +24%, and GHG emission intensity by -1 to -14%. Total land use changed by -6 to +22%, and land use intensity (i.e., land use per kg FPCM or life weight) by 0 to -11%. Largest reductions in GHG emission intensity were found in the scenarios with maize silage feeding, improved manure management, and an increased amount of roughage in the diet. We concluded that improvement of feeding and manure management can reduce GHG emissions and land use of dairy farms in Lembang District. As results were based on scenario analysis, the mitigation potential of interventions should be validated in practice.

Keywords

Dairy cattle; greenhouse gases; climate change mitigation; feeding; manure management.

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1. Introduction

The demand for dairy products in Indonesia has increased sharply over the past decades, and consumption is expected to continue to grow. Projections show that regional consumption in Southeast Asia is expected to grow by 13% between 2017 and 2026 (OECD/FAO, 2017). In addition, the government of Indonesia aims to increase domestic milk production to about 40% of national industrial demand by 2021 to increase its self-sufficiency and reduce dependency on imports. This increase in demand for dairy products may offer opportunities for Indonesian dairy farmers to increase milk production and income, and improve their livelihoods.

Dairy farming in Indonesia is concentrated on Java, particularly in West and East Java, and takes place on small-scale, zero-grazing dairy farms. Most farms have little land for forage production, and productivity is below potential due to poor feeding, poor reproduction and animal health problems (De Vries and Wouters, 2017). This situation leads to challenges of obtaining sufficient and good quality fodder and recycling of manure as a fertilizer. Forage supply throughout the year is a challenge in regions with high livestock stocking densities, both in terms of quantity and quality. On many farms, waste management is poor, and manure pollutes water streams and rivers, while only a small part of manure is used to fertilize crop production. These challenges are common to many regions with a high livestock density in Southeast Asia.

Greenhouse gas emissions from Indonesian dairy farms

Total GHG emissions in Indonesia were 1.4 gigaton CO₂e in 2000 (including land use change), with a considerable contribution from deforestation and land use change (Indonesian Ministry of Environment, 2010). Agriculture contributed 5% of Indonesia's total emissions. Dairy farming contributes to global warming via emissions of methane (CH₄) from enteric fermentation and manure management, nitrous oxide (N₂O) from manure management and fertilizer application, and carbon dioxide from energy use (CO₂).

To date, there are few studies that have estimated GHG emissions of Indonesian dairy production. Permana et al. (2012) estimated that GHG emissions from dairy cattle in Indonesia were 671 gigagram CO₂e per year (CH₄ and N₂O emissions from enteric

fermentation and manure management only). More recently, Taufiq et al. (2016) reported on emission intensity: 2.3 kg CO₂e per litre of milk among small-scale dairy farms in Pangalengan, West Java, and 1.5 kg CO₂e per litre of milk in a 'modern' farm using a life cycle assessment (LCA).

The Government of Indonesia has committed itself to reduce national greenhouse gas (GHG) emissions by 29-41% compared to the business-as-usual scenario by 2030 (NDC, 2016). For agricultural sectors, Indonesia aims to realize a reduction in GHG emissions by increasing anaerobic digestion of cattle manure and provision of feed supplements to cattle, among other measures (NDC, 2016).

Milk production volume and GHG emissions

An increase in milk production can be realized in two ways: by increasing number of cattle or by increasing productivity per head. Increasing the number of cattle is inherently associated with increases in GHG emissions, whereas an increase in productivity per head will most likely lead to a smaller or no increase in GHG emissions, depending on the measures taken. Improved feeding and manure management are measures known to increase productivity and potentially reduce GHG emission intensity of cattle production systems (Opio et al., 2013).

To our knowledge, no LCA studies have evaluated feeding and manure management strategies to reduce GHG emissions from dairy farms in Indonesia. Our study conducted a survey of 300 dairy farmers in Lembang District, West Java, to identify characteristics of dairy farms and the constraints and opportunities for increasing productivity of farms (De Vries and Wouters, 2017). Lembang District has a high population density (2,390 people per km² in 2014), and a predominantly hilly landscape at an elevation between 1,312 and 2,084 m. Dairy farms are mostly small-scale, zero-grazing farms with an average herd size of 6 heads. Based on survey results and stakeholder meetings, a number of feeding and manure management options for improving productivity of dairy herds in Lembang have been suggested: increasing the amount of roughage in the feed ration, feeding a better quality conserved feed in the dry season, balancing feed rations according to nutritional requirements of cows, continuous water provision, reducing discharging of manure, and recycling of manure as a fertilizer for feed and food production. These interventions are in line with best practices guidelines for dairy farming (FAO and IDF, 2011).

Objectives

Objectives of the present study were to i) estimate current GHG emissions and land use of an average dairy farm in Lembang District, West Java, ii) identify hotspots of GHG emissions and land use, and iii) evaluate the potential effects of feeding and manure management interventions on the reduction of GHG emissions and land use.

2. Materials and Methods

2.1 Scope of the LCA study

This study focused on small-scale dairy farms in Lembang District, West Java. Three hundred dairy farms were randomly selected from a list of 4,361 farms delivering milk to the largest dairy cooperative in Lembang; KPSBU Jabar (De Vries and Wouters, 2017). We evaluated GHG emissions of an average dairy farm in this district to estimate overall effects of strategies across the general population of dairy farms in Lembang.

2.2 LCA approach

The global warming potential and land use of dairy value chains in Lembang were quantified following LCA. LCA evaluates the use of resources and emission of pollutants or other negative impacts along a production chain, according to ISO 14040 and 14044 (ISO, 2006). In this study, the LCA approach was based on international Livestock Environmental Assessment and Performance (LEAP) Partnership Guidelines for Animal Feed and Large Ruminants (FAO, 2015a, b). These guidelines, developed by the LEAP partnership, reflect a common vision among partners to the initiative, including farmer organizations representing smallholders. The LEAP guidelines can be applied to smallholder farming systems, while enabling consistent and science-based environmental assessments, with a view to reduce the environmental footprint of animal products.

The Global Livestock Environmental Assessment Model (GLEAM) framework (MacLeod et al., 2017) was used to calculate environmental impacts using a LCA. The LCA in this model, which is defined in ISO standards 14040 and 14044 (ISO, 2006), simulates the interaction of activities and processes involved in livestock production and the environment. GHG emissions were assessed based on current IPCC Guidelines (2014), mainly working at Tier 2

level. The IPCC Tier 2 method was used for estimating enteric methane emissions and nitrogen and phosphorus excretions in the model.

In this study, we considered the environmental impact categories global warming potential (GWP) and land use. For GWP characterization, factors of 1, 28, and 265 were used for CO₂, CH₄ and N₂O, respectively (IPCC, 2014).

2.2.1 System boundaries, functional units, and allocation

System boundaries of the dairy production system evaluated in this study are shown in Figure 1. All processes were assessed up to the farm gate (i.e., cradle-to-farm gate; including production of farm inputs and on-farm production activities, but excluding transport of animals and products to market or processing plants, processing, refrigeration, packaging, transport to retail distributor, and consumer). LCA can be performed in two ways: consequential or attributional. Consequential LCA aims at quantifying environmental consequences of a change in a production system or a change in product demand (Thomassen et al., 2008). In this study, we used attributional LCA, which aims at quantifying the environmental impact of the main product of a system in a status quo situation. GHG emissions related to land use and land use change (LULUC) were not included in the LCA.

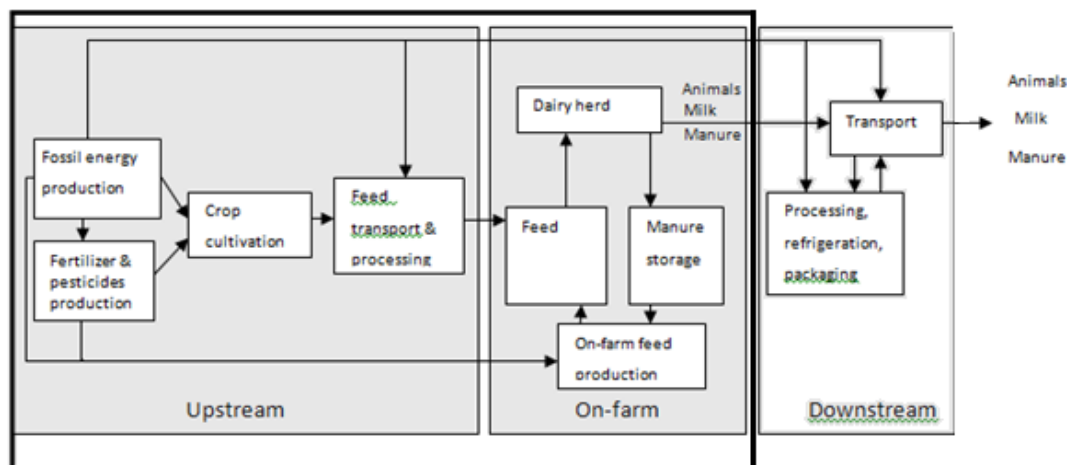


Figure 1: Cradle-to-farm gate system boundaries for the life cycle assessment of Lembang dairy value chains (downstream process not included)

GHG emissions were estimated in two ways:

- total GHG emissions at the value chain level (cradle-to-farm gate);

- GHG emission intensity, i.e., GHG emissions per kg milk or per kg live weight.

The allocation method used for emissions related to feed production was economic or digestible fraction allocation, depending on the type of feed ingredient (MacLeod et al., 2013). For allocation of emissions to milk and live weight, a causal relationship allocation was used, as this is the method preferred by International Dairy Federation (IDF) (Thoma et al., 2013).

2.2.2 Customizing the GLEAM model to the Indonesian context

In the GLEAM model, default IPCC emission factors (Tier 2) are used to estimate CH₄ and N₂O emissions related to different manure management systems (IPCC, 2014; MacLeod et al., 2017). IPCC does not provide default emission factors for discharged manure. Discharging manure is very common in Indonesian dairy farming systems (De Vries and Wouters, 2017). In most farms, manure is flushed to outside the cow barn several times per day. In some farms, manure is first entered in a bio-digester before being discharged to the environment.

In this study, we assumed the following emission factors for discharged manure:

- For manure discharged daily from barns, CH₄ and N₂O emission factors of ‘anaerobic lagoon’ were used (IPCC, 2014) with a leaching factor of 100%.
- For manure discharged after anaerobic digestion (discharged digestate), the methane conversion factor of anaerobic digestion was used for CH₄ emissions, and the emission factor of daily discharging of manure for N₂O (see previous bullet).

2.3 Data Inventory

2.3.1 Primary data collection

Primary data used in the LCA analysis were mainly based on results of a survey of 300 dairy farms in Lembang, as described in De Vries and Wouters (in press). Farms in this survey were small-scale, zero-grazing farms with an average herd consisting of 4 adult cows and 2 young stock, and an average milk production of 4,415 kg milk per cow/year. Most farms were specialized dairy farms (84%), and in nearly all farms the main purpose of keeping cattle was to produce milk for sale. Few farmers had other sources of income. Farmers owned/rented small areas of land for production of fodder or food crops, implying a very high stocking

density (on average 46 livestock units/ha). Sixteen percent of the farms were managed by female farmers. More details can be found in De Vries and Wouters (in press).

Primary data and data sources used in the LCA are shown in Table 1 and 2. Herd characteristics, herd performance, feed rations, and manure management were mainly based on De Vries and Wouters (in press), and databases kept by the local dairy cooperative KPSBU Jabar in Lembang. Live weights of cattle and absolute quantities of feed and fodder fed to cattle were based on data collected in on-farm measurements at 50 dairy farms (Verweij, 2017), which were selected from the list of farms in the survey described in De Vries and Wouters (in press). For some aspects of herd performance, additional data were collected from literature (Table 1).

Table 1. Primary data used in LCA analysis: average herd composition, herd performance, and share of cattle manure per destination

Variable	Value	Source
Lactating cows (number)	3.4	De Vries and Wouters, 2017
Dry cows (number)	0.5	"
Young stock (number)	2.0	"
Bulls (number)	0.2	"
Live weight adult cows (kg)	503.3	Verweij, 2017
Death rate, perinatal (%)	22.0	Opio et al., 2013
Death rate, older (%)	4.2	De Vries and Wouters, 2017; expert opinion
Age at first calving (months)	31.0	Anggraeni and Rowlinson, 2005a, b
Fertility rate (%)	75.0	Opio et al., 2013
Replacement rate (%)	15.0	De Vries and Wouters, 2017; expert opinion
Annual milk yield/cow (kg)	4415	KPSBU Lembang (300 farms)
Milk fat (%)	4.0	" (all KPSBU farms)
Milk protein (%)	2.9	" (all KPSBU farms)
Manure management:		
Discharged (%)	55.5	De Vries and Wouters (in press)
Solid storage (%)	4.0	"
Daily spread (%)	13.7	"
Digester (%)	10.4	"
Sold (exit livestock) (%)	15.2	"

The composition of the feed ration assumed in this study (Table 2) was based on results of the survey of De Vries and Wouters (in press) and Verweij (2017). The reason for combining results is that the survey only included relative shares of different types fodder fed, whereas absolute amounts of feed and fodders were quantified in on-farm measurements in the study of Verweij (2017).

Table 2. Assumed feed ration (kg fresh/animal/day)

Feed ration	Feed supply (kg fresh/animal/day)		
	Lactating cows	Dry cows	Young stock
Rainy season (245 days)			
fresh cut grass (road side)	12.0	13.2	6.7
fresh cut grass (home grown)	20.2	22.3	11.3
rice straw	5.8	6.4	3.2
maize silage	0	0	0
tofu waste	13.9	8.2	5.4
cassava waste (pommace)	11.3	6.7	4.4
brewers spent grain	0.3	0.2	0.1
rice bran	0.2	0.1	0.1
compound feed	6.5	5.0	2.3
Dry season (120 days)			
fresh cut grass (road side)	7.0	7.7	4.0
fresh cut grass (home grown)	11.9	13.0	6.8
rice straw	12.1	13.2	6.9
maize silage	0	0	0
tofu waste	1.37	6.4	4.2
cassava waste (pommace)	11.5	5.4	3.5
brewers spent grain	0.3	0.2	0.1
rice bran	0.2	0.1	0.1
compound feed ¹	6.9	5.0	2.3

¹ Compound feed was assumed to be 0.3 kg higher than report for the dry season, to obtain similar production levels in dry and wet season in the ISNM model.

Composition of the compound feed and production location were derived from the dairy cooperative KPSBU Lembang (2016). Two types of compound feed were used in KPSBU dairy farms:

- Quality A¹: wheat pollard (80%), corn gluten feed (13%), dregs of soy sauce (3%), CaCO₃ (3%);

¹ For the calculation of the carbon footprint of compound feed we used a slightly simplified composition: wheat pollard (80%), corn gluten feed (13%), dregs of soy sauce (7%).

- Quality B²: wheat pollard (40%), corn gluten feed (13%), dregs of soy sauce (3%), CaCO₃ (3%), rice bran (7%), palm oil dregs (23%), coffee hulls (6.7%), and corn tumpi (3%).

According to the survey (De Vries and Wouters, 2017), the type of compound feed used on dairy farms in Lembang was 32% of quality A, and 68% of quality B. Farmers did not change the type of compound feed in different seasons.

2.3.2 Secondary data collection

Assumptions for nutritional values of feed ingredients are shown in Table 3. To determine nutritional values of feed ingredients, feed samples were taken from farms in Lembang in 2016 (not necessarily farms in the baseline survey or farm assessment) and analyzed in EUROFINS laboratory. For some feedstuffs, values were based on expert opinion or Feedipedia (see Table 3 footnote). Dry matter content of fresh cut grass (road-side and home grown) was assumed to be 25% lower in the rainy season than the dry season (pers. comm. Bram Wouters, August 2017). Metabolic energy and total digestible nutrients (TDN) were calculated based on organic matter (OM) and organic matter digestibility (OMD), and nitrogen content was based on crude protein content.

² For the calculation of the carbon footprint of compound feed we used a slightly simplified composition: wheat pollard (46%), corn gluten feed (15%), dregs of soy sauce (4%), rice bran (8%), palm oil dregs (27%)

Table 3. Assumed nutritional values of feed ingredients

Feed ration	Dry matter content ¹	Nutritional value ^{2,3,4} per kg DM			
	(%)	CP (%)	OM (%)	OMD (%)	GE (MJ)
fresh cut grass (road side)	11.1	11.7	85.4	60.7	16.0
fresh cut grass (home grown)	11.3	14.9	83.3	74.0	17.4
rice straw	28.6	4.0	79.9	38.0	15.5
maize silage	31.5	8.0	93.2	72.0	19.1
tofu waste	12.5	20.7	96.9	79.6	19.7
cassava waste (pommace)	13.1	1.7	96.3	79.6	17.7
brewers spent grain	23.5	29.3	97.0	67.7	19.7
rice bran	90.2	12.7	90.6	63.8	20.2
compound feed	86.0	17.0	93.0	74.8	18.9

¹ Dry matter content of fresh cut road side grass was assumed to be 14.8% in the dry season. Dry matter content of fresh cut home grown grass was assumed to be 15.0% in the dry season.

² CP = Crude Protein, OM = Organic Matter, OMD = Organic Matter Digestibility, GE = Gross Energy

³ Sources: expert opinion (DM% maize silage and tofu waste; OMD% maize silage and cassava waste; CP% rice straw, maize silage, and compound feed), Feedipedia (DM%, CP% and OM% of cassava waste and rice bran; OMD% rice bran; GE of all feed ingredients, except road-side grass; P content cassava waste and rice bran), EUROFINS laboratory analyses (other values).

⁴ Except for dry matter content of fresh cut grass, nutritional values of feed ingredients were assumed to be the same in the rainy season and the dry season.

Assumptions for crop yields, fertilizer use and pesticide use were based on national statistics (Bandan Pusat Statistik), FAOSTAT, primary data from the survey in Lembang (De Vries and Wouters, 2017), expert opinion, and literature (Table 4). Other secondary data was collected from: IPCC guidelines (IPCC, 2014; default values, coefficients, and emission factors for calculation of emissions from animals, feed, and manure), GLEAM databases (Opio et al., 2013), EcoInvent (using Simapro; energy use of road transport, modelling field work emissions), FeedPrint (Vellinga et al., 2012; data for field work emissions, energy use and allocation of processing crops), and the dairy cooperative KPSBU (market prices). For calculation of methane emissions of rice cultivation, we assumed pre-flooding, continuous irrigation (via canals systems), no animal manure as a fertilizer, and 200 days of cultivation per year (pers. comm. Huib Hengsdijk, November 2017).

Table 4. Assumed crop yields, fertilizer use, and pesticide use

	Gross yield (kg dry matter/ha)	Synthetic fertilizer (kg/ha/year)			Animal manure (kg N/ha/year)	Pesticides (kg/ha)
		N	P2O5	K2O		
Grass (road side) ¹	7 500	-	-	-	-	-
Grass (home grown) ^{1,2}	15 000	277	-	-	243	-
Whole crop maize ^{1,3}	25 000	150	-	-	209	-
Rice ⁴	10 997	202	10	-	-	2
Wheat ⁵	2 360	39	25	22	29	3
Corn ⁶	4 954	82	-	-	2	2

Data sources:

¹ pers. comm. Bram Wouters, Aug. 2017 (yield)

² SIDPI baseline survey (fertilization)

³ Pers. comm. Bram Wouters, Aug. 2017 (yield, fertilization); MSc thesis L. Gautier (fertilization whole crop maize KPSBU model farm, Lembang)

⁴ Badan Pusat Statistik (average rice yield Indonesia 2011-2015); IRRI, 2004 (fertilization, pesticides)

⁵ FAOSTAT (2014; wheat yield Australia); Norton and VanderMark, 2016; IPNI, 2011; Vellinga et al., 2012 (fertilization, pesticides)

⁶ FAOSTAT (2014; maize yield); FAO, 2005 (fertilizer use).

2.4 Mitigation scenarios

The following locally suitable strategies for improving feeding and manure management were identified in farmer and stakeholder workshops in Lembang District in 2016 and 2017 and from existing knowledge about potential contribution to climate change mitigation:

- increasing the utilization of manure;
- selling cattle manure;
- increasing the amount of roughage in the ration;
- balancing rations;
- fodder conservation (maize or grass silage);
- improved feed/water trough.

Effects of individual feeding and manure management interventions on milk yield, GHG emissions, and land use were simulated for an average dairy farm in Lembang. A herd model ('ISNM model'; Snijders et al., 2013) was used to estimate effects of changes in the feed ration on milk yield. Manure management interventions were not expected to have a (direct)

effect on milk yield. The GLEAM model was used to quantify effects of interventions on GHG emissions and land use. We did not test combinations of interventions.

Interventions and assumptions made for the different scenarios are explained in the following paragraphs and summarized in Table 5.

2.4.1 Increasing utilization of manure

The survey among dairy farmers in Lembang (De Vries and Wouters, 2017) showed that 84% of farmers are discharging manure into the environment. The discharging of manure causes high GHG emissions, both as CH₄ and N₂O. Part of cattle manure is applied on land located closer than 500m to the barn, which covers about half of the on-farm land used for fodder production. On land located further away from the barn or land that is difficult to reach, farmers apply synthetic fertilizer (mainly urea) more often than cattle manure because cattle manure is liquid and thus difficult to handle and transport.

Replacing (part of the) urea by cattle manure can contribute to reducing GHG emissions because it reduces the emissions from manure discharging and from the production and application of synthetic fertilizer.

In this scenario, we evaluated effects of increasing the utilization of cattle manure as a fertilizer. Because of the practical difficulties of using slurry, farm yard manure (FYM) was used because it is easier to handle and transport, and costs little for farmers to apply manure on land located further away from the barn.

In this scenario,

- The amount of discharged manure is reduced and used as organic fertilizer (FYM);
- The organic fertilizer (FYM) is used to (partly) replace urea;
- This is expected to lead to lower GHG emissions related to discharged manure and production and application of urea.

The following assumptions were made for manure management and fertilizer application:

- Total nitrogen excretion of 430 kg N per farm/year, with 190 kg excreted in dung and 240 kg excreted in urine. This estimate is based on the Tier 2 method in IPCC guidelines (IPCC, 2014), thus accounting for diet composition and excretion in milk

produced. This corresponds to 93 kg N per adult cow per year, and 28 kg N per young stock per year (dung and urine together).

- Destinations:
 - 238 kg N discharged (56%; Table 1), with 105 kg N in dung, and 133 kg N in urine.
 - 126 kg N used as fertilizer (29%), corrected for 20% N loss for slurry and 40% N loss for FYM, of which: daily spread of fresh slurry (52 kg N) or digestate (36 kg N), and solid manure (assuming FYM; 10 kg N)
 - 65 kg N sold (15%).
- The average farm applies 277 kg N/ha/y via urea (46% N), and 343 kg N/ha/y via animal manure on 0.28 ha of land (0.26 ha for fodder production, 0.03 ha for food crops; SIDPI baseline survey). A plant-available N coefficient of 1.0 and 0.4 was assumed for urea and cattle manure, respectively; hence 277 and 137 kg plant-available N/ha/y for urea and animal manure.
- For the intervention, we assumed all fresh feces were collected from discharged manure with a ratio of feces/urine of 50/50, thus reducing discharged manure by 50% (urine still being discharged). Collected fresh feces were stored on a heap as FYM. With an initial amount of 105 kg N in the collected fresh feces (see assumptions above), we assumed 25 kg plant-available N would be available in the total amount of FYM (40% N loss during storage, plant available N coefficient of 0.4). Produced FYM can replace 25 kg of current urea N applied (i.e., 9%).

2.4.2 Selling cattle manure

The survey among dairy farmers in Lembang (De Vries and Wouters, 2017) showed that limited space for storing manure is a major constraint to avoiding discharge of manure on dairy farms. Selling fresh cattle manure can be a solution; farmers can either sell manure directly to vegetable or flower farms or to middle men. Also, farmer groups in Lembang showed interest in setting up a compost facility with their farmer group, as compost can be sold at a higher price compared to slurry and FYM. Selling part of the cattle manure can contribute to reducing GHG emissions related to discharging of manure. Possible mitigating effects of using cattle manure in other sectors (e.g., replacing synthetic fertilizer, soil C

sequestration) were not included as these were outside the boundaries of the system studied (dairy chain).

In this scenario, feces are no longer discharged but stored on a compost heap, after which the compost is sold (urine is still discharged).

2.4.3 Increased roughage

The farm assessment among 50 dairy farmers in Lembang (Verweij, 2017) and other Indonesian projects investigating nutrition of dairy cattle showed that amounts of roughage fed to lactating cows are often far below potential intake. Insufficient dry matter intake from roughage negatively affects milk production.

Increasing the amount of roughage fed can increase absolute GHG emissions from dairy cattle due to an increase in CH₄ from enteric fermentation and an increased amount of manure produced. On the other hand, the increase in milk yield can dilute GHG emissions, leading to lower GHG emissions per unit of milk or meat when milk yield increases more strongly than GHG emissions.

In this scenario,

- Amount of home-grown grass fed to lactating cows was increased in the ISNM model to reach maximum potential forage intake (Zemmelink et al., 2003).
- We evaluated how increasing the amount of home-grown grass in the ration affects milk yield, GHG emissions and land use.

2.4.4 Balanced rations

Especially in the situation of scarce feed resources, there is scope for enhancing milk production by more efficient use of existing feed resources. Feeding dairy cows according to their individual requirements can increase milk production and fertility and leads to lower costs of feed inputs. The survey among dairy farmers in Lembang (De Vries and Wouters, 2017) showed most farmers in Lembang do not adjust feed rations to milk yield and lactation stage of cows.

Balanced rations can contribute to a lower GHG emission intensity due to an increase in productivity, leading to lower GHG emissions per unit of milk or meat.

In this scenario,

- We evaluated effects of adjusting feed rations per cow to individual cow requirements depending on her milk yield and lactation stage (balanced rations).
- We assumed no changes in the feed ration of the total herd, because some (lower yielding) cows would require less, while other (higher yielding) cows more of certain feed ingredients.
- We assumed a 5% higher annual milk yield per cow (assumption based on expert judgment).

2.4.5 Ad libitum water provision

The survey among dairy farmers in Lembang (De Vries and Wouters, 2017) revealed that in half of the farms cows do not have continuous access to drinking water. Lactating cows require sufficient amount and quality of drinking water for milk production. The required amount of drinking water and the effect on milk yield depends on various factors, such as milk production level, water intake from moisture in feeds, and ambient temperature and humidity.

Ad libitum water provision can contribute to a lower GHG emission intensity due to an increase in productivity, leading to lower GHG emissions per unit of milk or meat.

In this scenario, we assumed ad libitum water provision would increase milk production by 0.5 kg per cow/day in the dry season. This amount was based on subjective estimates by dairy farmers in another project in Indonesia.

2.4.6 Maize silage

The survey among dairy farmers in Lembang (De Vries and Wouters, 2017) showed that shortages of green fodder in the dry season are compensated by increased amounts of rice straw and compound feed in the dairy ration. This was also found by Fella et al. (2009). Because rice straw is of low nutritional quality, farmers increase the amount of compound feed in the dairy ration to maintain milk production levels. This strategy has several negative side effects:

- Rice straw has a low palatability causing a lower forage intake by ruminants.
- Feed costs per kg of milk increase due to the relatively high price of concentrates.

- Feeding high amounts of compound feed can lead to problems in rumen and cow health (such as abomasal displacement, acidosis, and poorer reproductive performance).
- The relatively high carbon footprints of compound feed and rice straw increase GHG emissions from animal feeding.

In the baseline survey we found a small, but significant, difference in the amount of compound feed fed in the dry and wet seasons, probably because in 2016 the dry season was less pronounced than in other years. Data on the amount of compound feed sold to these 300 farms by the dairy cooperative KPSBU in 2016 showed the same result. Milk production levels were the same in the dry season and the rainy season (KPSBU data). To obtain the same milk production in wet and dry season from the ISNM model, we assumed a slightly higher amount of compound feed in the dry season in our analyses (0.3 kg).

Replacing rice straw and compound feed by whole crop maize silage can contribute to lower GHG emissions because the production of whole crop maize silage has a lower carbon footprint than rice straw and compound feed, and the improved digestibility of the ration reduces GHG emissions from enteric fermentation.

In the first scenario ('maize silage', same milk yield as baseline):

- We evaluated the effects of replacing part of the rice straw and compound feed fed to lactating cows with whole crop maize silage.
- The amount of dry matter intake from whole crop maize silage was determined based on similar milk production per cow as the baseline scenario in the ISNM model.

In the second scenario ('maize silage+', higher milk yield by maximizing forage intake):

- We evaluated the effects of replacing part of the rice straw and compound feed in the dry and wet seasons with whole crop maize silage on milk yield, GHG emissions and land use.
- The amount of dry matter intake from whole crop maize silage was determined by maximizing the potential forage intake, thus realizing higher milk production per cow.

Table 5. Summary of assumptions in scenarios compared to the baseline scenario, for manure management system, feed ration, and milk yield

Scenario	Manure management system	Feed ration (kg fresh per lactating cow/d)	Milk yield (kg/cow/y)
1. Increasing utilization of manure	- Reduction in discharged manure to 27.7%; - Increase in solid storage to 31.7%; - Reduction in urea N to 252 kg urea N/ha; - Increase in N from animal manure to 368 kg N/ha.	-	-
2. Selling manure	- Reduction in discharged manure to 27.7%; - Increase in compost to 27.7%.	-	-
3. Increased roughage	-	- Home-grown grass increased to 73 and 41 kg in the wet and dry season.	+1766 ^a
4. Balanced ration	-	-	+220 ^b
5. Ad libitum water provision	-	-	+60 ^b
6a. Maize silage	-	- Rice straw reduced to 2.9 kg in both seasons; - Compound feed reduced by 0.5 kg in both seasons; - Maize silage increased by 4.5 and 6.1 kg in wet and dry season.	-
6b. Maize silage+	-	- Rice straw reduced to 2.9 kg in both seasons; - Compound feed reduced by 0.5 kg in both seasons; - Maize silage increased by 15.6 and 17.3 kg in wet and dry season.	+552 ^a

^a Increase in milk yield based on modeling result (ISNM model).

^b Increase in milk yield based on assumption.

3. Results and discussion

3.1 Baseline GHG emissions and land use

Total estimated GHG emissions of an average dairy farm (including upstream emissions, i.e., cradle-to-farm gate) in Lembang was 33 ton CO₂e/year. Estimated GHG emission intensity was 1.9 kg CO₂e/kg fat and protein corrected milk (FPCM) and 8.8 kg CO₂e/kg live weight.

Total estimated land use was 2.1 ha per dairy farm (including on-farm and off-farm land used for feed production, excluding stables and other land). Estimated land use per kg FPCM was 1.2 m², and 5.6 m² per kg live weight (based on causal relationship allocation), which is relatively low compared to other studies (De Vries and De Boer, 2010; De Vries et al., 2015).

3.2 Hotspots analysis

In total farm GHG emissions, the most important greenhouse gas in terms of CO₂e was CH₄, followed by CO₂ and N₂O (Figure 2).

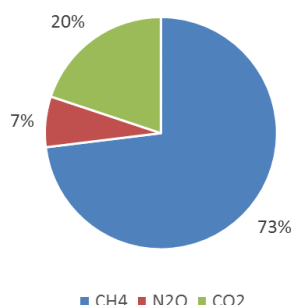


Figure 2. Relative contribution of different types of greenhouse gases (CO₂e/farm/year).

As shown in Figure 3, the most important sources of total farm GHG emissions were rumen enteric fermentation (CH₄; 40%), followed by manure management (CH₄ and N₂O; 29%), and feed production (CH₄, N₂O, and CO₂; 28%).

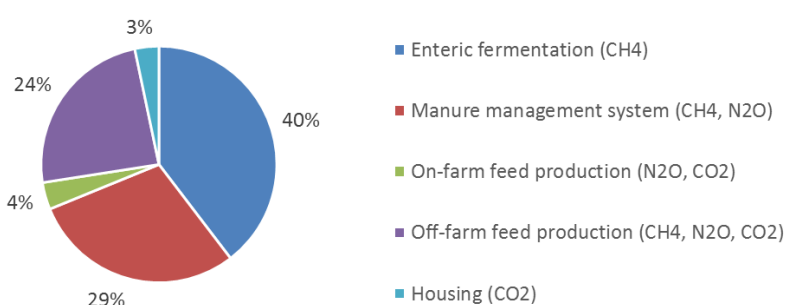


Figure 3. Sources of total GHG emissions (CO₂e/farm/year).

The most important source of emissions related to manure management systems (MMS), including storage and treatment, was discharged manure (accounting for more than 80% of emissions from MMS).

Most emissions related to feed production occurred off-farm, as more than 80% of the ingredients in the feed ration (dry matter) were produced off-farm. CO₂ emissions from energy use contributed most to total emissions from on- and off-farm feed production (Figure 4). Energy is used for production of inputs (synthetic fertilizer and pesticides), field work, transport, and processing of feed ingredients. N₂O emissions were caused by synthetic and organic fertilizer application, leading to direct (N₂O) and indirect (via leaching of NO₃, and

volatilization of NH_3 and NO_x) nitrogen losses. CH_4 emissions occurred during rice cultivation (Figure 4).

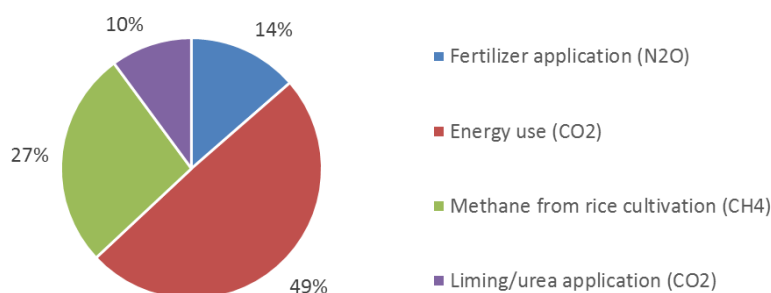


Figure 4. Sources of greenhouse gas emissions from feed production ($\text{CO}_2\text{e}/\text{farm}/\text{year}$).

Rice straw contributed most to total emissions from feed production (Figure 5). The relatively high emissions from rice straw are caused by CH_4 emissions from rice paddies and CO_2 emissions related to cultivation and processing of rice. Part of these emissions were allocated to rice straw (using digestible fraction allocation between rice grain and rice straw) and rice bran (using economic allocation between flour and bran; Vellinga et al., 2012). Emissions of home-grown grass were relatively high because we assumed high fertilization rates, leading to relatively high nitrogen losses. Emissions of compound feed result mainly from high energy use (CO_2) for the two main ingredients: corn gluten feed and wheat pollard. Corn gluten feed requires relatively significant energy for processing and drying, and wheat pollard (derived from Australian wheat) has a high energy use from production (inputs, field work, transport, processing) combined with relatively low yields per ha.

Feed ingredients with the highest emissions per kg product (DM) were rice straw (0.9 kg $\text{CO}_2\text{e}/\text{kg DM}$), compound feed (0.4-0.5 kg $\text{CO}_2\text{e}/\text{kg DM}$), rice bran (0.4 kg $\text{CO}_2\text{e}/\text{kg DM}$), and home-grown grass (0.3 kg $\text{CO}_2\text{e}/\text{kg DM}$). Emissions of wet by-products were low (<0.1 kg $\text{CO}_2\text{e}/\text{kg DM}$) because no upstream emissions were allocated to wet by-products (Vellinga et al., 2012).

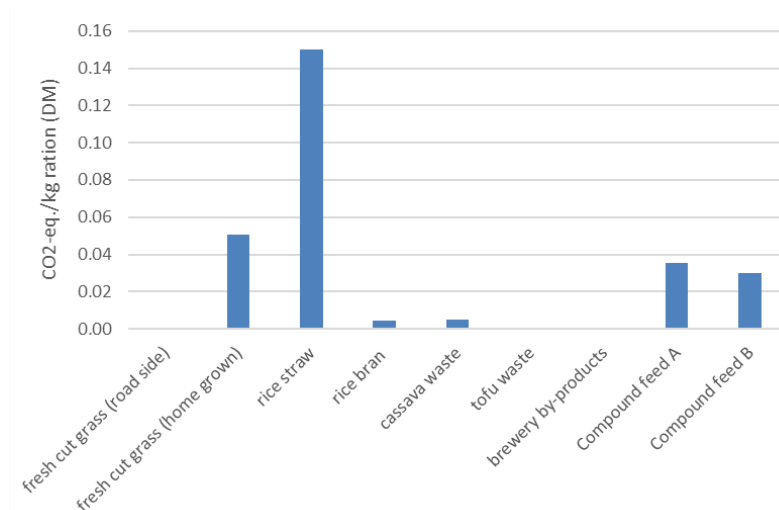


Figure 5. Contribution of feed ingredients to GHG emissions of the total feed ration (in dry matter; DM).

Regarding land use, most land was used for production of compound feed (51%), grass (home grown and roadside; 33%) and rice straw (12%; based on allocation of land for rice production between rice grain and straw). Compound feed used more land than other feed ingredients because of its large share in the ration (about 35% of total DM intake), relatively low yields per ha compared to forages, and high allocation fractions compared to other by-products.

3.3 Effects of interventions on GHG emissions and land use

In the scenario analysis, feeding and manure management interventions showed different effects on total GHG emissions and emission intensity (Figure 6). Total farm GHG emissions reduced in the scenarios of improved manure management and maize silage feeding compared to the baseline emissions, increased with increased roughage feeding, and remained about the same with balanced rations and ad libitum water provision. GHG emission intensity (i.e., emissions per kg FPCM) reduced in all scenarios; the largest reductions were found in the scenarios with improved manure management, increased roughage, and maize silage feeding. Total land use decreased or remained about the same in most scenarios, except for increased roughage. However, as milk yield increased more strongly than land use, land use per kg FPCM decreased by more than 10% with increased feeding of roughage. Effects are discussed in more detail below.

It should be noted that milk yield was based on assumptions (scenarios on improved manure management, maize silage (no change), balanced rations (+5%) and ad libitum water provision (0.5kg milk/cow/day)) or on modelling results (increased roughage provision and maize silage+ scenario). Also, emissions related to land use and land use change (LULUC) were not included in the calculation of GHG emissions.

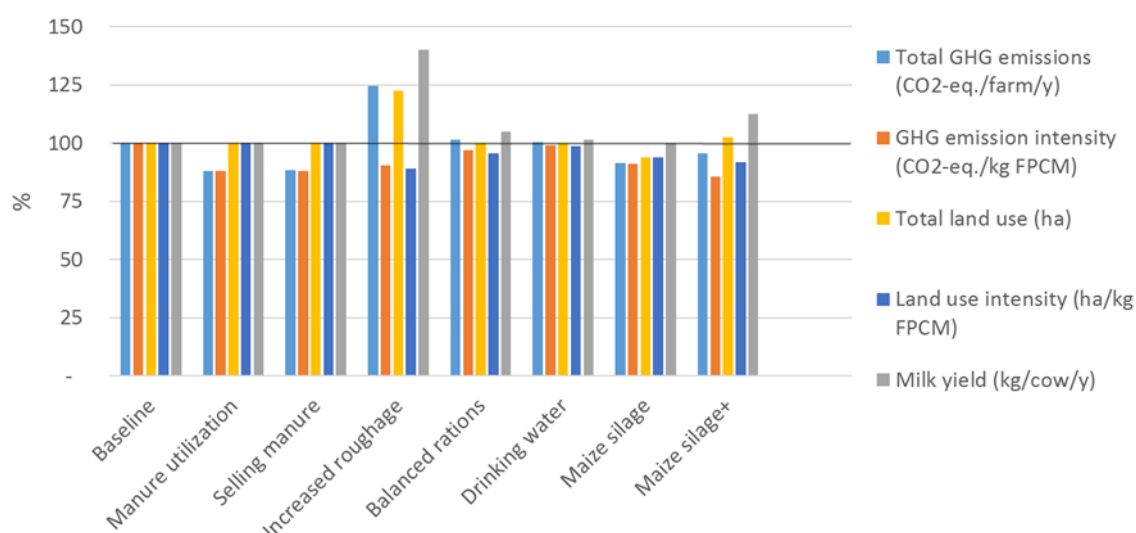


Fig. 6. Estimated effects of feeding and manure interventions on milk yield, GHG emissions, and land use.

3.3.1 Increasing utilization of manure

Utilizing FYM for application on land for fodder production reduced both total farm GHG emissions and GHG emission intensity (emissions per kg FPCM) by 12% (Figure 6). The reduction in GHG emissions was due to lower emissions related to discharged manure (CH_4 and N_2O) and lower emissions related to production and application of urea (CO_2 and N_2O). Although emissions related to production and application of FYM increased, net GHG emissions reduced due to the strong reduction in GHG emissions from avoided discharge of manure and avoided urea.

In our analysis, we assumed no effects on milk yield or land use. However, replacing urea by organic fertilizer could lead to increased forage yields in the longer-term due to other benefits of animal manure (e.g. increased organic matter and micro-nutrients). This could lead to higher milk yields due to increased forage availability, a lower land use per kg milk, and a

lower GHG emission intensity. Using cattle manure for application on land for fodder production is expected to be cost-effective (Ndambi and De Vries, 2017).

Some constraints should be taken into account:

- The amount of manure available on farms may be too much compared to the amount of land available, and thus could lead to over-fertilization. In this case, surplus FYM should be sold (or composted and sold, see 3.3.2 Selling manure).
- Farmers indicated that a lack of space for storing manure was a main constraint for improving manure management (baseline survey). In this case, slurry should be collected (e.g. in sacks) and sold directly (e.g. to traders).

3.3.2 Selling manure

Composting manure and selling the compost reduced both total farm GHG emissions and GHG emission intensity by 12% (Figure 6). The reduction in GHG emissions resulted mainly from lower emissions related to discharged manure (CH_4 and N_2O).

Selling manure could contribute to reduced emissions in other sectors if the cattle manure replaces synthetic fertilizer in those chains. Moreover, it could help to improve soil quality, and hence soil productivity, and contribute to soil carbon sequestration. These effects are not included in current analyses because they are outside the boundaries of the system studied (dairy chain). Selling manure does not affect milk yield or land use, unless it leads to changes in current fertilization practices.

3.3.3 Increased roughage

Feeding approximately 3.5 times more home-grown grass in the ration of lactating cows increased total farm GHG emissions by 24% (Figure 6). The increase in emissions was caused by an increase in CH_4 from: enteric fermentation due to a higher roughage intake and more fibre in the diet (lower digestibility) and increased amount of manure produced per animal thus increased emissions from (currently improper) manure management. Additionally, the increase in land area for the production of additional grass required field inputs (e.g., fertilizer), which are accompanied by GHG emissions (e.g., synthetic fertilizer production and application).

Though increasing the amount of grass in the diet increased total farm emissions, it reduced GHG emission intensity by 9% because the increase in milk production has a diluting effect on GHG emissions, even including the additional GHG emissions caused by the intervention. Hence, the increase in milk production was stronger than the increase in GHG emissions caused by the intervention.

Land use increased by 22% due to the additional land required for grass production, but land use per kg FPCM decreased by more than 10% because milk yield increased more than land use. An increase in land use is undesirable because land is scarce in Java, and an expansion of agricultural land may drive deforestation (Gollnow and Lakes, 2014; LULUCF emissions were not included in current LCA analyses). Especially in the dry season, farmers already have problems obtaining sufficient green fodder. To solve this problem, two possible solutions could be explored. First, current grass yields and quality could be increased through good agricultural practices (fertilization, timing of harvesting, etc.). Second, farmers in Lembang have indicated abundant grass is available during the wet season which can be ensiled and used as grass silage in the dry season. In both cases land use does not increase, but total farm emissions will still increase due to the increase in emissions from enteric fermentation and manure.

3.3.4 Balanced rations

Balancing rations increased total farm GHG emissions by 1%, as cows with higher production produce more manure. At the same time, balanced rations reduced GHG emission intensity by 3% due to higher milk yields (Figure 6). Land use remained the same and land use per kg FPCM slightly decreased. In an Indian study by Garg et al. (2013), enteric methane emissions per kg milk reduced by 15-20% due to balanced rations. The smaller impact of feeding balanced rations in this study is because baseline milk yields were much lower in the Garg et al. study, and the increase in milk production was higher in the Garg et al. study than the assumed increase in this study (2-14% versus 5%). It should be noted that the effects of balanced feeding on milk yield might differ from our assumption; further, the effects could differ among farms depending on the current milk production level. This should be evaluated in practice in Indonesia.

3.3.5 Ad libitum water provision

We assumed an increase of 0.5 kg milk production per cow in the dry season through ad libitum water provision. The increase in milk production reduced GHG emission intensity by 1% (Figure 6). Total GHG emissions and land use remained the same. Effects of ad libitum water provision on milk yield might differ from this assumption, and effects could differ among farms, depending on the situation. This should be evaluated in practice in Indonesia.

3.3.6 Maize silage

'Maize silage' scenario

Replacing nearly 60% of the rice straw and 8% of the compound feed fed to lactating cows with 5 kg whole crop maize silage per lactating cow per day reduced total farm GHG emissions and GHG emission intensity by 9% (Figure 6). In this scenario, the amount of maize silage in the ration was determined based on a similar milk yield per cow as in the reference scenario. GHG emissions were lower because maize silage has a lower carbon footprint than rice straw and compound feed (0.1 versus 0.9 and 0.4 kg CO₂e/kg DM, respectively). Additionally, emissions from enteric fermentation and manure management decreased due to a lower feed intake and higher digestibility of the ration. Land use reduced by 6% because maize silage required less land than rice straw and the ingredients of compound feed (consisting mainly of wheat pollard, corn gluten feed, and palm oil dregs).

'Maize silage+' scenario

In this second scenario ('maize silage+') the amount of whole crop maize silage in the ration was increased to maximum potential forage intake of 16 kg maize per lactating cow/day (Zemmelink et al., 2003). This caused an increase in milk yield of 13%. Total farm GHG emissions decreased by 4%, and GHG emission intensity decreased by 14%. Land use increased slightly (2%) due to the additional land required for maize production, but land use per kg FPCM decreased by 8% because milk yield increased more than land use.

4. General discussion

This study investigated the current level of GHG emissions and land use of small-scale dairy farms in Lembang, West Java, hotspots of GHG emissions and land use, and the effects of improved feeding and manure management on emissions and land use.

We found total GHG emissions to be 33 ton CO₂e. per farm per year, and emission intensity was 1.9 kg CO₂e per kg FPCM and 8.8 kg CO₂e per kg live weight. Total estimated land use was 2.1 ha per dairy farm, which was equal to 1.2 m² per kg FPCM and 5.6 m² per kg live weight. These results are generally in line with results of Opio et al. (2013) and Gerber et al. (2013). Methane emissions from manure management in our study were larger than in Opio et al. (2013) because discharged manure was not considered in Opio et al. (2013). Emission intensity results in this study were lower than the 2.3 kg CO₂e/litre FPCM found in a LCA study among dairy farms in Pangalengan by Taufiq et al. (2016), partly due to higher milk production in our study (12 litre versus 10 litre/cow/day).

A number of methodological aspects should be considered when interpreting results of our study:

- Results from the baseline survey were mostly based on subjective answers from farmers, which may have led to less reliable or less accurate results. To more accurately estimate emissions, data should be collected with on-farm measurements.
- In the absence of emission factors in IPCC guidelines, we made assumptions for emission factors of discharged manure (fresh slurry and digestate). As discharged manure was a major source of emissions and reduction of discharged manure was an intervention in our study, assumptions about the emission factor of discharged manure influenced our results. Estimating methane and direct and indirect nitrous oxide emissions from discharged manure is difficult, and requires further investigation to accurately estimate effects of improved manure management on farms.
- GHG emissions were estimated for an average dairy farm in Lembang. This was a suitable method to predict overall effectiveness of mitigation strategies in the SIDPI project on Lembang dairy herds, but a large variation may be expected in the characteristics of farms (De Vries and Wouters, 2017). This will influence the

effectiveness of interventions in individual dairy farms. Therefore, evaluation of GHG emissions and mitigation options should be carried out for a number of distinct types of farms, especially with regard to land base, feed ration, and manure management system.

- Carbon sequestration and emissions related to land use and land use change and forestry (LULUCF) were not included in our analyses.
- Scenario analyses were used to estimate potential effectiveness of various feeding and manure management interventions on mitigation of GHG emissions. Assumptions in these scenarios and mitigation effects should be validated in practice.

Hotspots of GHG emissions

The most important sources of GHG emissions were rumen enteric fermentation, followed by manure management and feed production. High enteric methane emission per kg milk were mainly caused by poor quality of feed rations and herd performance (milk yield, reproduction). With regard to emissions from manure management, discharging of manure caused more than 80% of GHG emissions from manure management systems. This implies reduction of discharged manure is important for reducing GHG emissions, but also for other environmental and social impacts (pollution of ground and surface water, public health, nuisance). As emission factors for discharged manure were based on assumptions, methods for estimating emissions of discharged manure need to be improved. GHG emissions related to synthetic fertilizer use on land located further away from the cow barn showed there are opportunities to reduce GHG emissions by replacing synthetic fertilizer with animal manure. With regard to feeding, rice straw and compound feed were associated with relatively high carbon footprints due to the GHG emissions associated with production of rice, poor nutritional quality of rice straw, and high energy use of compound feed.

Mitigation of GHG emissions

All scenarios for improved feeding and manure management evaluated in this study resulted in reduced GHG emission intensity (i.e., emissions per kg milk or beef). We expect that implementing combinations of feeding and manure management interventions will lead to even larger reductions. Mitigation options evaluated in this study are in line with mitigation options suggested by Gerber et al. (2013) and with best practices guidelines for dairy farming (FAO and IDF, 2011).

In two feeding interventions (increased roughage and maize silage feeding), GHG emission intensity decreased, but total GHG emissions increased. The increase in total emissions is (partly) due to the increase in milk yield per animal, which is associated with absolute increases in GHG emissions per animal, as a higher milk yield requires a higher feed intake, which causes an increase in CH₄ from enteric fermentation and higher manure production, and thus more emissions from manure per animal. Targeting reductions in both total GHG emissions and GHG emission intensity will be crucial considering the projected increases in milk volumes in Indonesia.

Replacing rice straw and compound feed with maize silage resulted in the largest reduction in GHG emission intensity. Two points should be considered when interpreting this result. First, the reduction in GHG emissions from dairy farms due to omission of rice straw in the diet does not mean the emissions of rice straw are not present anymore, but the emissions are no longer allocated to the dairy sector. Emissions avoided by not using rice straw were about 1.6 ton CO₂e. This was less than the mitigation of GHG emissions in this scenario (2.9 ton CO₂e), which suggests this intervention is still effective in reducing total GHG emissions. Secondly, whereas use of rice straw in fact does not require additional land (being a crop residue), whole crop maize silage does require additional land. Hence, as with GHG emissions, omission of rice straw from the diet does not imply less land is used, but that the land is no longer allocated to the dairy sector. If the reduction in land use from omitted rice straw (about 0.12 ha) would be not be taken into account, total land use would reduce only slightly due to this intervention. In this context, technical solutions that can improve the nutritional quality and digestibility of rice straw are promising, such as fungi treatment of rice straw (e.g. Tuyen et al., 2013), and are expected to contribute to reduction of GHG emissions when evaluated at a higher scale.

The second largest reduction in GHG emission intensity found was through improved manure management. The effect of improved manure management is expected to be larger than found in this study because carbon sequestration and effects of utilizing cattle manure in other sectors were not taken into account (system boundaries of the LCA were limited to the dairy chain). Animal manure might replace synthetic fertilizer in other sectors, which can have additional benefits for reducing GHG emissions at a regional scale (i.e., regional nutrient

cycling). Additional methods to estimate GHG emissions at a regional level or multi sector approach are required.

Sustainable intensification

Feeding and manure management interventions evaluated in this study aimed to produce more from the same resources while reducing negative impacts on the environment, also known as sustainable intensification. Resource use efficiency is particularly important for small-scale farmers in developing countries, who are often coping with resource scarcity. In the peri-urban situation of West Java, where there is limited availability of feed and land, improving resource use efficiency is key to increasing milk production in a sustainable way. For feeding interventions, this means improved efficiency of feed production and feed conversion of animals to milk and meat. For manure management, this implies improved nutrient-use efficiency, including recycling of animal waste. Besides feeding and manure management, animal health plays an important role in efficiency of animal production. Interventions proposed in this study might not only contribute to a reduction in GHG emissions, but also limit the amount of land used by dairy farming systems as a result of improved resource-use efficiency. Additionally, improvements in manure management and fertilization can reduce other environmental problems, such as pollution of ground and surface water, public health problems, and nuisance.

5. Conclusions

Total estimated GHG emissions of an average dairy farm in Lembang District, West Java, were 33 ton CO₂e/year, which was equal to 1.9 kg CO₂e per kg FPCM, and 8.8 kg CO₂e/kg live weight. Total estimated land use was 2.1 ha per dairy farm, which was equal to 1.2 m² per kg FPCM, and 5.6 m² per kg live weight.

Hotspots of GHG emissions were rumen enteric fermentation, manure management (especially discharged manure), and off-farm feed production (especially rice straw). Of all feed ingredients, compound feed contributed most to total land use.

Feeding and manure management interventions evaluated in the scenario analyses in this study changed total GHG emissions by -12 to +24%, and GHG emission intensity (i.e., emissions per kg FPCM or life weight) by -1 to -14%. Total land use changed by -6 to +22%,

and land use intensity (i.e., land use per kg FPCM or life weight) by 0 to -11%. Largest reductions in GHG emission intensity were found in scenarios with maize silage feeding, improved manure management, and an increased amount of roughage in the diet. The largest reduction for land use intensity was found in the scenarios with improved feeding.

References

- De Vries M, De Boer IJM. 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science* 128: 1-11.
- De Vries M, Van Middelaar CE, De Boer IJM. 2015. Comparing environmental impacts of beef production systems: A review of life cycle assessments. *Livestock Science* 178: 279-288.
- De Vries M, Wouters AP. 2017. Characteristics of small-scale dairy farms in Lembang, West Java. Wageningen Livestock Research, Report 1076. Wageningen UR, The Netherlands.
- FAO. 2005. Fertilizer use by crop in Indonesia. Rome: Food and Agriculture Organization of the United Nations.
- FAO. 2015a. Environmental performance of large ruminant supply chains – Guidelines for Assessment (Draft version). Rome: Food and Agriculture Organization of the United Nations.
- FAO. 2015b. Environmental performance of animal feeds supply chains – Guidelines for Assessment. Rome: Food and Agriculture Organization of the United Nations.
- FAO, IDF. 2011. Guide to good dairy farming practice. Animal Production and Health Guidelines. No. 8. Rome: Food and Agriculture Organization of the United Nations.
- FAOSTAT. 2014s. Available from: <http://www.fao.org/faostat/>
- Fella A, Permana IG, Despal. 2009. Differences nutrition quality of forage during wet and dry seasons and their impact on milk production and quality in Barunagri village, Lembang Regency. MSc thesis. Bogor Agricultural University, Indonesia. Available from: <http://repository.ipb.ac.id/handle/123456789/59787>
- Garg MR, Sherasia PL, Bhandari BM, Phondba BT, Shelke SK, Makkar HPS. 2013. Effects of feeding nutritionally balanced rations on animal productivity, feed conversion efficiency, feed nitrogen use efficiency, rumen microbial protein supply, parasitic load, immunity and enteric methane emissions of milking animals under field conditions. *Animal Feed Science and Technology* 179: 24–35.
- Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Rome: Food and Agriculture Organization of the United Nations.
- Gollnow F, Lakes T. 2014. Policy change, land use, and agriculture: The case of soy production and cattle ranching in Brazil, 2001–2012. *Applied Geography* 55: 203-211.

- Indonesian Ministry of Environment. 2010. Indonesia Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC). Ministry of Environment, Republic of Indonesia, Jakarta.
- IPCC. 2014. IPCC 2006 Guidelines for National Greenhouse Gas Inventories prepared by the National Greenhouse Gas Inventories Programme, Eds: Eggleston HS, Buenida L, Miwa K, Nagara T, Tanabe K. (eds). Updated 2014. IGES, Japan.
- ISO. 2006. Environmental management. The ISO 14000 family of international standards ISO standard collection on CD-rom. Geneva, Switzerland.
- MacLeod MJ, Gerber P, Mottet S, Tempio G, Falcucci A, Opio C, Vellinga TV, Henderson B, Steinfeld H. 2013. Greenhouse gas emissions from pig and chicken supply chains – A global life cycle assessment. Rome: Food and Agriculture Organization of the United Nations.
- MacLeod MJ, Vellinga TV, Opio C, Falcucci A, Tempio G, Henderson B, Makkar H, Mottet A, Robinson T, Steinfeld G, Gerber PJ. 2017. Invited review: A position on the Global Livestock Environmental Assessment Model (GLEAM). *Animal* 9: 1-15.
- Ndambi OA, De Vries M. 2017. Financial Incentives for Manure Management Solutions in a Peri-Urban Context. In: Proceedings Tropentag 2017, “Future Agriculture: Socio-ecological transitions and bio-cultural shifts.”
- NDC. 2016. First Nationally Determined Contribution - Republic of Indonesia. Indonesia.
- OECD/FAO. 2017. “Dairy and Dairy Products”, in OECD-FAO Agricultural Outlook 2017-2026. Paris: OECD Publishing.
- Opio C, Gerber P, Mottet A, Falcucci A, Tempio G, MacLeod MJ, Vellinga TV, Henderson B, Steinfeld H. 2013. Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment. Rome: Food and Agriculture Organization of the United Nations.
- Snijders PJM, van der Meer HG, Onduru DD, Ebanyat P, Ergano K, Zake JYK, Wouters AP, Gachimbi LN, van Keulen H. 2013. Effects of cattle and manure management on the nutrient economy of mixed farms in East Africa: A scenario study. *African Journal of Agricultural Research* 8: 5129-5148.
- Taufiq FM, Padmi T, Rahardyan DB. 2016. Life cycle assessment of dairy farms. *Reviews on Environmental Health* 31: 187-190.
- Thoma G, Jolliet O, Wang Y. 2013. A biophysical approach to allocation of life cycle environmental burdens for fluid milk supply chain analysis. *International Dairy Journal* 31: 41-S49.
- Thomassen MA, Dalgaard R, Heijungs R, de Boer IJM. 2008. Attributional and consequential LCA of milk production. *The International Journal of Life Cycle Assessment* 13: 339-349.

- Tuyen DV, Phuong HN, Cone JW, Baars JJP, Sonnenberg ASM, Hendriks WH. 2013. Effect of fungal treatments of fibrous agricultural by-products on chemical composition and in vitro rumen fermentation and methane production. *Bioresource Technology* 129: 256 - 263.
- Vellinga TV, Blonk H, Marinussen M, van Zeist WJ, de Boer IJM. 2012. Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization. Wageningen: Wageningen Livestock Research and Blonk Consultants.
- Verweij JW. 2017. Manure management at smallholder dairy farms in Lembang, Indonesia. MSc thesis. Wageningen: Wageningen University and Research.
- Zemmelink G, Ifar S, Oosting SJ. 2003. Optimum utilization of feed resources: model studies and farmers' practices in two villages in East Java, Indonesia. *Agricultural Systems* 76: 77-94.



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