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Report 1397

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1 Wageningen Livestock research

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Samenvatting NL In dit rapport wordt het effect van het reguliere, tussensegment en Beter Leven één ster vleeskuikensysteem op broeikasgasemissies, landgebruik en fosfaatefficiëntie berekend door middel van een levenscyclusanalyse. Alle processen, inclusief opfok van de kuikens, tot en met de slachterij worden meegenomen. Per schakel in de keten worden de effecten getoond. Ten slotte, worden de resultaten bediscussieerd en aanbevelingen gegeven.

Summary UK
In this report, the impact of the conventional, Dutch Retail Broiler and Better Life one Star broiler production systems on greenhouse gas emissions, land use, and phosphorus excretion are estimated by using a life cycle assessment. All processes, including the breeding stage, until slaughterhouse stage were included. The impact is shown per stage in the chain. Finally results are discussed and recommendations are provided.

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Table of contents

Summary

In the Netherlands, several broiler production systems exist. These broiler systems differ in breed, stocking density and type of feed, which results in different impacts on animal welfare, economic, and environmental sustainability.

In this report, the environmental sustainability of three different broiler production systems, namely, Conventional, Dutch Retail Broiler (DRB) and Better Life one Star (BLS) is analysed. In other reports the economic and animal welfare aspects of sustainability are analysed.

The impact of the three above mentioned broiler production systems is analysed on greenhouse gas (GHG) emissions, land use, and phosphorus excretion by using a life cycle assessment (LCA). All processes and related environmental impacts were included until the slaughterhouse stage, because no differences between the production systems after this stage were expected. Environmental impacts were expressed per hen (rearing period), per egg to hatchery (laying period), per egg hatched (hatchery), per kg live weight (broiler farm and slaughterhouse), or per kg filet (slaughterhouse), depending on the stage of the chain. Feed compositions in all stages were based on performance objectives and nutritional recommendations published by the genetic companies.

In the rearing and laying period, BLS had the lowest land use and phosphorus excretion. For GHG emissions, BLS was most efficient in the rearing period and DRB in the laying period. However, the contribution of the breeding stage to total impact on farm or slaughterhouse stage was limited.

At farm and slaughterhouse stage (Table I), the conventional production system was most efficient for land use and phosphorus excretion. The conventional production system had the lowest feed conversion rate and therefore the lowest impact. For GHG emissions, however, BLS production system had the lowest impact when emissions from land use change (LUC) were included.

Emissions from LUC had a major impact on GHG emissions. For this study, soy (oil and meal) sourced from Brazil was used which has a high impact on LUC. Conventional and DRB broilers had a higher amount of soy in the diets and therefore a higher impact of LUC. When LUC emissions are excluded or when soybean products were sourced from a country with low LUC emissions, the conventional broiler production had the lowest GHG emissions. Therefore, it is important to show results with and without LUC and showing the origin of feed ingredients.

This study showed that feed production and feed conversion rate are most important parameters for the environmental impact. Most mitigation options to reduce the environmental impacts can be found in these two parameters. The impact of these can be improved by reducing the impact during feed production (cultivation and processing) or by composing a diet with a lower environmental impact considering the trade-off with the feed conversion rate or vice versa. Changing the origin of feed ingredients to countries with a low LUC can reduce the GHG emissions of a product. However, with equal or increasing demand of crops, this may not reduce GHG emissions on a global level and only displace emissions between sectors. In addition, for every mitigation performed, the impact on the economic performance and animal welfare, and the impact on other (livestock) sectors should be considered.

Table I *Environmental impacts of different broiler production systems expressed per kg live weight slaughtered at slaughterhouse gate.*

	Conventional	DRB	BLS
Climate change exclusive LUC[1] (kg CO_2-eq)	1.38	1.58	1.75
Climate change inclusive LUC (kg CO_2-eq)	3.75	4.07	3.64
Land use (m^2a crop eq)	3.59	4.00	4.32
Phosphorus excretion (g P excreted)	3.02	3.80	5.01

1 LUC: land use change, i.e. deforestation

1 Introduction

The World population is expected to grow to 10 billion people in 2050. Feeding this population will be an enormous challenge, and this will have an enormous impact on natural resources such as water and land. To supply the human population and maintain our planet, food should be produced sustainably.

Sustainability can be divided in three dimensions: economic, social, and environmental. In the agricultural field, economic sustainability is associated with e.g. profitability, social sustainability with e.g. animal welfare, and environmental sustainability with e.g. climate change. Of these three pillars, environmental sustainability is increasingly seen as the most important, because without a life supporting systems (planet Earth), economies and societies cannot thrive (Fischer *et al.*, 2007). To maintain the life supporting system, this should stay within planetary boundaries. Currently, several environmental issues exceed the planetary boundaries, such as climate change, phosphorus and nitrogen flows (Steffen *et al.*, 2015).

The livestock sector is responsible for approx. 14.5% of human induced greenhouse gas (GHG) emissions in the World. The poultry sector is responsible for 8% of these GHG emissions (Gerber *et al.*, 2013).
Food production worldwide is responsible for 14.8 Gt CO_2eq per year, which is 25-30% of the total GHG emissions (IPCC, 2019). Agriculture contributed 10-12%, land use (deforestation) 8-10 %, and beyond farm gate (e.g. storage and processing) 5-10%.
In the Netherlands, GHG emissions were 196.3 Tg CO_2eq in 2020, from which 17.7 Tg CO_2eq from the agricultural sector (RIVM, 2022). The contribution of the poultry sector is small, because most emissions of the poultry sector in the Netherlands take place outside the Netherlands, mainly because of production of feed ingredients. Climate change and other environmental issues are a worldwide issue, and hence the poultry sector in the Netherlands can contribute to a reduction of GHG emissions and other environmental issues worldwide. Therefore a life cycle assessment (LCA) is needed to estimate the impact of broiler production on the environment. An LCA includes all processes and related environmental impacts in the chain to produce a product, i.e. broiler meat.

In the Netherlands, several broiler production systems exist to produce broiler meat. In this project, three different production systems are analysed: Conventional, Dutch Retail Broiler ('Kip van Morgen') (DRB), and Better Life one star (BLS):

1. the conventional broiler farming system using so-called fast growing broilers housed at maximum stocking densities (in the Netherlands: 39-42 kg/m2) and with indoor housing only, representing the majority of broiler chicken farming in the Netherlands in 2021, called in the report conventional;
2. systems according to the farming standards of 'Kip van Morgen', i.e. a slower growing chicken breed with a maximum daily growth of 50 g and a stocking density of 38 kg/m^2 or lower, and provision of environmental enrichment in the house but no veranda or outdoor range, called in this report Dutch Retail Broiler (DRB);
3. free range indoor ('Beter Leven 1 star'), using a slower growing breed (slaughter age at least 56 days), a stocking density of 25 kg/m2, a covered outdoor run/veranda and environmental enrichment, called in the report Better Life one Star (BLS)

These different production systems might have an impact on the economic, environmental, and social sustainability. The goal of this study was to estimate the impact of these different production systems on the environmental sustainability. Therefore, an LCA was performed including most parts of the broiler chain. In two other reports, the economic (Van Horne, 2020) and animal welfare (de Jong et al., 2022) are analysed. Details about the method and results of GHG emissions in this report are also published in Mostert et al. (2022).

2 Material and methods

A spreadsheet based model was developed in Excel to estimate the environmental impacts of the broiler production systems. Each production system had a different broiler breed, namely Ross 308 (conventional), Ranger classic (DRB), and Hubbard JA 257 (BLS).The model consists of two parts. The first part estimates the production parameters for the whole chain until the slaughterhouse and the second part estimates the environmental impacts by using LCA. In this report the calculations are based on biological performance objectives and nutritional recommendations published by the genetic companies.
Figure 1 shows the processes to estimate the environmental impacts at different stages of the chain. The processes are described below in more detail.

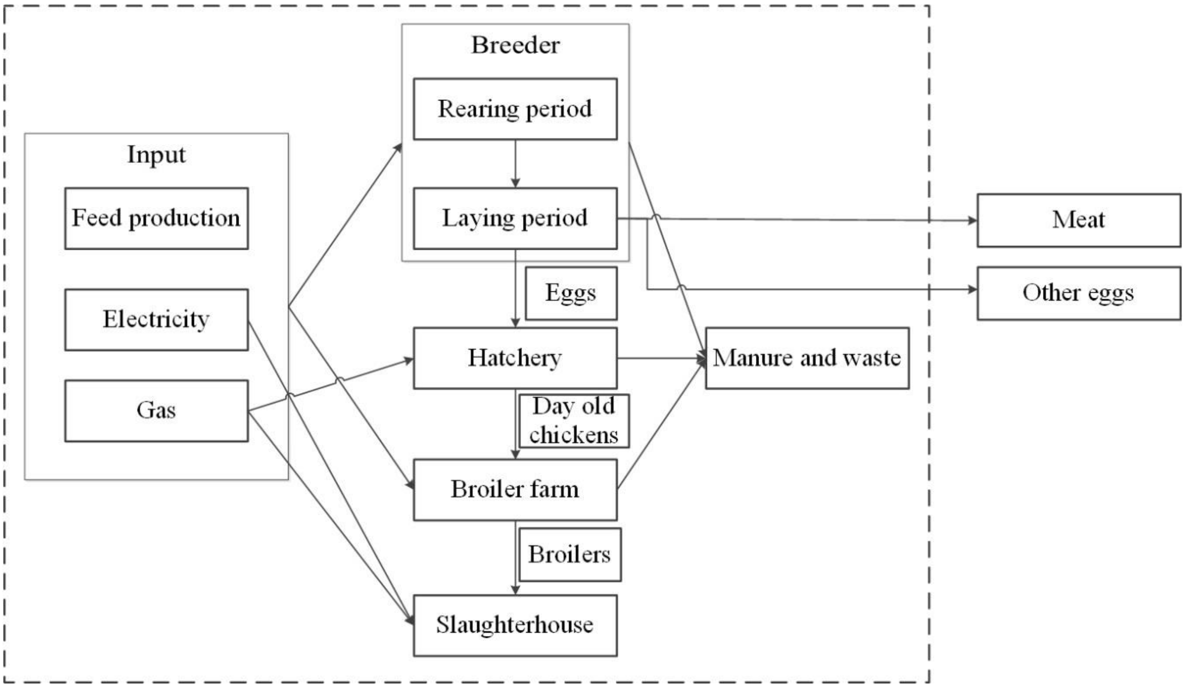

Figure 1 *System boundary of stages and processes included of the broiler chain to estimate the environmental impacts of broilers (Mostert et al., 2022)*

2.1 Production parameters

2.1.1 Parent stock 1-20 weeks of age (rearing period)

The production parameter input can be found in Table 1. One rearing diet was composed for every production system based on the advice of breeding companies for diet composition (Appendix 1). Nutritional recommendations for the conventional (Ross 308) and DRB production systems (Ranger Classic) are the same. In the field 3 or 4 rearing diets are used. In this study no differentiation in composition of the diets were made in week 1-20; environmental figures of the grower diet are used for the full rearing period with males and females receiving the same diets. Selection of feed ingredients for the diets were based on economic optimisation and nutritional recommendations. Prices of feed ingredients were average prices of the years 2017 and 2018 (LEI, 2019). It was assumed that feed intake of dead males and females was half of the total feed intake. Data about energy use (costs for energy per hen housed) was only available for the conventional production system and was assumed to be equal for the other production systems. Based on energy prices (0.13€/kwh and 0.55€/m^3 gas) energy use was estimated.

Table 1 *Production input parameters to estimate the environmental impact of parent stock 1-20 weeks of age (rearing period) of different broiler production systems*

	Conventional	DRB	BLS	Source
Chicken start (chicken/m^2)	9.5	9.5	9.5	KWIN-V, 2018
Mortality and selection (%)	9	5	4	Performance Objectives Aviagen / Hubbard[a]
Chicken to laying period (chicken/m^2)	8.6	9.0	9.1	
Feed intake (females only)				
Starter 1 (0-20 days) kg	0.57	0.54	0.46	Performance Objectives Aviagen / Hubbard[a]
Starter 2 (21-34 days) kg	0.55	0.54	0.54	Performance Objectives Aviagen / Hubbard[a]
Grower (35-104 days) kg	4.32	3.74	3.75	Performance Objectives Aviagen / Hubbard[a]
Pre Breeder (105 – 139 days) kg	3.28	2.56	2.4	Performance Objectives Aviagen / Hubbard[a]
Weight hen at 20 weeks (kg)	2.34	1.97	1.59	Performance Objectives Aviagen / Hubbard[a]
Feed intake (males only)				
Starter 1 (0-20 days) kg	0.61	0.61	0.62	Performance Objectives Aviagen / Hubbard[a]
Starter 2 (21-34 days) kg	0.7	0.7	0.71	Performance Objectives Aviagen / Hubbard[a]
Grower (35-104 days) kg	5.4	5.4	5.45	Performance Objectives Aviagen / Hubbard[a]
Pre Breeder (105 – 139 days) kg	3.22	3.22	3.25	Performance Objectives Aviagen / Hubbard[a]
Male weight at 20 weeks (kg)	3.04	3.04	3.08	Performance Objectives Aviagen / Hubbard[a]
Electricity (€/100 chicken housed)	10	10	10	KWIN-V, 2018
Gas (€/100 chicken housed)	31	31	31	KWIN-V, 2018

a Performance objectives: Aviagen, 2016, 2018; Hubbard 2019
Parent males for the broiler breeds were the following: Ross male (Ross 308), Ross male (Ranger Classic), Hubbard M22 (Hubbard JA257).
Parent females for the broiler breeds were the following: Ross 308 female (Ross 308), Ranger female (Ranger Classic), Hubbard JA57 (Hubbard JA257).

2.1.2 Parent stock >20 weeks (laying period)

The production parameter input can be found in table 2. A diet was composed for every production system based on breeding companies recommendations (Appendix 1). Diets for breeds in the conventional and DRB production systems are the same. In the field 1, 2 or 3 breeder diets are used. In this study no differentiation in composition of the diets was made in week 20-60/65; environmental figures of Breeder 1 diet were used for the full production period with males and females receiving the same diets. Selection of feed ingredients for the diets were based on economic optimisation and nutritional recommendations. Prices of feed ingredients were average prices of the years 2017 and 2018 (LEI, 2019). Data about energy use was only available for conventional production system and therefore assumed to be similar in all production systems. BLS, however, have a longer laying period (65 weeks instead of 60 weeks), and therefore the energy use per hen was increased with the increased fraction in length of days. It was assumed that feed intake of dead chickens was half of the total feed intake.

Table 2 *Production input parameters to estimate the environmental impact of parents >20 weeks of age of different broiler production systems*

	Conventional	DRB	BLS	Source
Number of hen at start (hen/m^2)	7	7	7.6	KWIN-V, 2018
Mortality and selection (%)	8	8	6	Performance Objectives Aviagen / Hubbard[a]
Mating ratio (%)	8.0	8.0	8.0	Performance Objectives Aviagen / Hubbard[a]
Depletion age (weeks)	60	60	65	Performance Objectives Aviagen / Hubbard[a]
Total eggs per hen housed (#)	177	184	233	Performance Objectives Aviagen / Hubbard[a]
Non hatching eggs per hen housed (#)	8	11	13	Performance Objectives Aviagen / Hubbard[a]
Total hatching eggs per hen housed (#)	169	173	221	Performance Objectives Aviagen / Hubbard[a]
Feed intake (females only)				
Pre breeder 20-23 weeks (kg)	3.4	2.6	2.2	Performance Objectives Aviagen / Hubbard[a]
Breeder 24-60 weeks (kg)	41.9	37.1		Performance Objectives Aviagen / Hubbard[a]
Breeder 24-65 weeks (kg)			35.6	Performance Objectives Aviagen / Hubbard[a]
Weight hen at depletion age (kg)	4.08	3.27	2.24	Performance Objectives Aviagen / Hubbard[a]
Feed intake (males only)				
Pre breeder 20-23 weeks (kg)	2.9	2.9	2.9	Performance Objectives Aviagen / Hubbard[a]
Breeder 24-60 weeks (kg)	34.8	34.8		Performance Objectives Aviagen / Hubbard[a]
Breeder 24-65 weeks (kg)			40.2	Performance Objectives Aviagen / Hubbard[a]
Weight male at depletion age (kg)	5.00	5.00	5.05	Performance Objectives Aviagen / Hubbard[a]
Electricity (€/100 chickens)	56	56	62	KWIN-V, 2018
Gas (€/100 chickens)	18	18	20	KWIN-V, 2018
Price meat (€/kg chicken)	0.4	0.4	0.4	KWIN-V, 2018
Price per hatched egg €/egg)	0.185	0.185	0.185	KWIN-V, 2018
Price non hatching egg (€/egg)	0.02	0.02	0.02	KWIN-V, 2018

a Aviagen, 2016, 2018; Hubbard 2019

Parent males for the broiler breeds were the following: Ross male (Ross 308), Ross male (Ranger Classic), Hubbard M22 (Hubbard JA257).

Parent females for the broiler breeds were the following: Ross 308 female (Ross 308), Ranger female (Ranger Classic), Hubbard JA57 (Hubbard JA257).

2.1.3 Hatchery

The production parameter input can be found in table 3. It was assumed that most of the energy use was gas. The amount of gas in m^3 was estimated with a gas price of 0.55 €/m3. The environmental consequences of unhatched eggs were placed in this stage.

Table 3 *Production input parameters to estimate the environmental impacts of the hatchery of different broiler production systems.*

	Conventional	DRB	BLS	Source
Depletion age (weeks)	60	60	65	Performance Objectives Aviagen / Hubbard[a]
Hatchability (%)	83.7	84.3	84.4	Performance Objectives Aviagen / Hubbard[a]
Chicks per hen housed (#)	142	146	186	Performance Objectives Aviagen / Hubbard[a]
Energy costs(€/1000 chickens)	12.5	12.5	12.5	KWIN-V, 2018
Gas use (m^3/1000 chickens)	22.7	22.7	22.7	Based on energy costs

a Aviagen, 2016, 2018; Hubbard 2018.

2.1.4 Broiler farm and slaughterhouse

Input data of the production parameters on the broiler farm and slaughterhouse can be found in table 4. Production input parameters were based on the performance objectives of the genetic companies.
Diets are formulated on breeding company recommendations. Selection of feed ingredients for the diets were based on economic optimisation and nutritional recommendations. Prices of feed ingredients were average prices of the years 2017 and 2018 (LEI, 2019). Because the environmental impact of the different diets was different, it was assumed that dead of broilers occurred at 4 four different days evenly divided over the production period for every breed (e.g. for conventional at day 5, 15, 25, 35). The number of dead broilers at every day was assumed to be ¼ of the total dead broilers. Subsequently feed intake of different type of diets until these days were estimated.

Table 4 *Production input parameters to estimate the environmental impacts of the broiler farm of different broiler systems*

	Conventional	DRB	BLS	Source
Production period(d)	38	49	56	Performance Objectives Aviagen / Hubbard[a]
Density, maximum (kg/m^2)	42	38	25	
Electricity per chicken delivered (kWh)	0.18	0.23	0.28	Van Horne, 2020
Gas per chicken delivered (m^3)	0.07	0.10	0.13	Van Horne 2020
Slaughter weight (g)	2527	2449	2389	Performance Objectives Aviagen / Hubbard[a]
Composition broiler (kg of live weight)				Performance Objectives Aviagen / Hubbard[a]
Breast (%)	25.0	20.7	19.2	Performance Objectives Aviagen / Hubbard[a]
Thigh (%)	13.1	12.8	13.0	Performance Objectives Aviagen / Hubbard[a]
Drumstick (%)	9.8	9.7	9.9	Performance Objectives Aviagen / Hubbard[a]

	Conventional	DRB	BLS	Source
Leg meat (%)	16.4	15.5	16.1	Performance Objectives Aviagen / Hubbard[a]
Wings (%)	8.7	8.7	8.7	Based on personal communication Plukon
Eviscerated (%)	73.4	72.0	71.4	
Mortality (%)	3.5	3.0	2.5	KWIN-V, 2018
Dead on arrival (%)	0.11	0.09	0.04	Personal communication Plukon
Feed intake				Performance Objectives Aviagen / Hubbard[a]
Starter (g/chicken/cycle)	304	244	373	
Grower 1(g/chicken/cycle)	771	585	783	
Grower 2 (g/chicken/cycle)	1340	981	1029	
Finisher (g/chicken/cycle)	1457	2650	2799	
Total per chicken (kg)	3.87	4.46	4.98	
FCR (kg feed/kg weight)	1.53	1.82	2.09	
FCR incl mortality (kg feed/kg weight)	1.55	1.84	2.11	

a Hubbard 2017; Aviagen, 2018; Aviagen, 2019.

The main input in the slaughterhouse was energy use for slaughtering and cooling. It was assumed that the slaughter process was the same for all production systems. Gas use in the slaughterhouse was 3.5 m^3/ton live weight and electricity use was 95 kWh/ton live weight (personal communication Plukon). It was assumed that transport to the slaughterhouse was by lorry with a distance of 150 km. Prices of breast meat to perform economic allocation were based on personal communication from Plukon.

2.2 Environmental impacts

The impact of the three different broiler systems on GHG emissions, agricultural land use occupation potential (named land use), and phosphorus excretion was estimated. An LCA was performed to estimate the impact on GHG emissions, land use. Most processes from cradle to slaughterhouse were included (Figure 1). Processes excluded were transport of eggs and chickens until the farm gate in the Netherlands, packaging of products and manure processing. These were excluded because of lack of data, or an expected low impact, or minor differences between the different production systems. Phosphorus excretion was based on amount of P excreted on the farms in the Netherlands. The environmental impacts were estimated for every stage of the chain and summed to compare the impact on farm and slaughterhouse level. For every stage in the broiler chain, impacts related to feed production, on farm manure management, and energy use were estimated. The environmental impact of manure after it has left the parent and broiler farm was not included, because different options of manure treatment and application exist, such as incineration, composting, or direct use as fertilizer. No differences in manure treatment between the production systems are expected and no effect in differentiation between the different production systems. Feed products from the diets were matched with the available feed products in Feedprint, version 19.00, including the country of production (Vellinga et al., 2013) (Appendix 2). If no specific country was selected or available, the default value in Feedprint was selected. If the feed product was not available in Feedprint, a similar product was selected (Appendix 1). Environmental impacts of energy use at the feed mill was included based on Feedprint. The environmental impacts were expressed per hen (Parent stock 1-20 weeks), per egg to hatchery (Parent stock >20 weeks), per egg hatched at hatchery (hatchery), per kg live weight (broiler farm), per kg live weight slaughtered, and per kg breast (slaughterhouse). To express the environmental impacts in the functional units after parent stock 1-20 weeks, number of parents and hatching eggs at the breeder farm and hatchery needed to produce the functional unit at that stage in the chain were calculated backwards. Because broilers have multiple outputs, an economic allocation was performed to estimate the impact per egg and per kg breast. Economic allocation is recommended by the LEAP guidelines for poultry supply chains (FAO, 2016), when system expansion or physical allocation is not possible. In economic allocation, emissions are allocated to different (co)products based on the economic value of these products.

2.2.1 Greenhouse gas emissions

GHG emissions (CO_2, CH_4, and N_2O) along the broiler chain were estimated and expressed in kg CO_2-equivalents based on their equivalent factor for 100 years Global Warming Potential: 1 for CO_2, 34 for biogenic CH_4, 36.75 for fossil CH_4, and 298 for N_2O (IPCC, 2013).

Feed production
Emissions of feed production were based on Feedprint, version 19.00 (Vellinga et al., 2013) and included emissions from crop cultivation, processing, drying, pelleting of feed ingredients, transport to the feed mill and farm, and production of inputs (e.g. fertilizer, energy) (Appendix 2). Calculations of GHG emissions in Feedprint are based on Product Environmental Footprint Category Rule (PEFCR) for feed (PEFCR, 2018). Land use change (LUC) was based on Feedprint that estimated LUC with the PAS2050 method, which is recommended to use. LUC estimates the GHG emissions from LUC occurring no more than 20 years ago. This consist of GHG emissions and removals from vegetation and soil carbon stocks changes and is amortized during a period of 20 years. At broiler farms of the DRB and BLS production systems, 20 kg lucerne artificially dried per 1000 broilers was given.

Manure on farm
Emissions of manure were based on national inventory reports and IPCC (2006) and included direct N_2O, and indirect N_2O (i.e. N_2O derived from volatilization of NH_3 and NO_x) and CH_4. First nitrogen excretion and Total Ammoniacal Nitrogen (TAN) were estimated based on nitrogen intake and nitrogen retained for growth and eggs production, according to the following formulas:

N excreted= N intake from feed –N retained
Where:
N intake is estimated based on kg feed intake (Table 4) and N content of the diets (Appendix 2)
N retained is based on kg N retained in meat and eggs (Appendix 2) (CBS, 2018)

TAN was estimated by first multiplying N intake with the N digestibility (Appendix 2) and second subtracting the N retained.

Direct N_20 Emissions (IPCC 2006) were estimated by:

N excreted x EFN_2O x 44/28
Where:
EFN_2O is emission factors in kg N_2O-N/kg N (0.001)
44/28 conversion from N_2O-N to N_2O

NH3-N was estimated by:
TAN x EFNH3-N
Where
$EFNH_3$-N is emission factor NH_3 for parents and broilers (Table 5)

NOx-N was estimated by:
N excreted x $EFNO_x$
Where:
$EFNO_x$ is emission factors in kg NO_x-N/kg N (0.001)

Indirect N_2O emissions (IPCC 2006) due to volatilisation were estimated by:
(NH_3-N+NO_X-N) x $EFNH_3NO_x$ x 44/28
Where:

$EFNH_3NO_x$ is emission factor for N2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised) ; default value is 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilised)

Emissions of NH_3-N were based on national inventory reports (Bruggen et al., 2018). Emission factors were based on the following housing systems: other low emissions housing for parent stock 1-20 weeks, floor housing with manure aeration from above for parent stock> 20 weeks, and mixed air ventilation, heaters and fans for broiler farms.

Table 5 *Emissions factors of NH3-N of parent stock 1-20 weeks, parent stock >20 weeks, and broiler farms.*

	1-20 weeks	>20 weeks	Broiler farm	Source
EF NH3 (%/TAN)	20.3	21.2	5.5	Bruggen et al., 2018

Methane emissions were estimated by the following formulas:

VS x Bo x MCF x methane density
Where:
VS is volatile solids (kg)
Bo is maximum methane production potential (0.34 m^3 CH_4/kg VS) for the manure
MCF is methane conversion factor for livestock category and manure management system
Methane density is 0.67 kg/m^3 CH_4

Volatile solids was simplified estimated based on the method used in the GLEAM model (FAO, 2013)
$DM \times (1- ME_{feed}/GE_{feed}) \times (1-0.3)$
Where:
DM is dry matter intake (kg)
ME_{feed} is metabolic energy of feed (MJ)
GE_{feed} is gross energy of feed (MJ)
0.3 is ash content of manure

Energy use was based on the production of an average energy mix and based on ELCD database (kg CO_2eq/ MJ).
Transport for feed was included in the feed emissions. Only transport from broiler farm to slaughterhouse was included. It was assumed that this was 150 km with an average weight per lorry of 13,500 kg.

2.2.2 Land use

Agricultural land is limited and the amount of this land used to produce a product explains the efficiency of the concept. Land use is expressed in m^2a crop eq and was based on diet compositions (Appendix 1) and land used to produce the crops from Feedprint, version 19.00 (Appendix 2) (Vellinga et al., 2013). Surfaces of buildings were assumed to be minor and therefore excluded.

2.2.3 Phosphorus excretion

The efficiency of phosphorus was estimated at all farm stages. Phosphorus is mined and is a limited resource in the World. To show the efficiency of phosphorus use of broiler chickens in the Netherlands, losses of phosphorus during feed production was excluded. Phosphorus excretion is calculated as:

P excreted= P intake from feed –P retained
Where:
P intake is estimated based on kg feed intake (Table 1, 2, 4) and P content of the diets (Appendix 1)
P retained is based on kg P retained in meat and eggs (Appendix 2) (CBS, 2018)

3 Results

Results are shown per environmental impact category and subsequently per stage in the chain. Because of the importance of LUC in GHG emissions, these results are estimated with and without the impact of LUC.

3.1 Greenhouse gas emissions

Results of GHG emissions until broiler farm gate are described and discussed in Mostert et al. (2022) and therefore only summarized here. Table 6 shows the impact of different production systems and breeds of the parent stock (1-20 weeks) on GHG emissions. The conventional system has per hen the highest impact followed by the breeds of DRB and BLS. Main impact is from feed production and because of the higher feed intake of breeders in the conventional system, the impact of feed production is also higher.

Table 6 *Greenhouse gas emissions (kg CO_2-eq) for parent stock farms (1-20 weeks) per hen (Mostert et al., 2022).*

	Conventional	DRB	BLS
Feed production	5.74	4.82	4.55
Land use change	1.30	1.09	1.06
Energy on farm	2.17	2.08	2.06
Manure on farm	0.38	0.32	0.34
Total	9.59	8.31	8.01
Total excl LUC[1]	8.29	7.22	6.95

1 LUC: land use change, i.e. deforestation.

Table 7 shows the impact of different production systems and breeds of parent stock older than 20 weeks of age (laying phase) on GHG emissions. Feed production and LUC were the main contributors for all breeds. DRB production system had. When LUC is excluded, BLS had the lowest impact per egg delivered to hatchery.

Table 7 *Greenhouse gas emissions (kg CO2-eq) per egg delivered to hatchery at the laying period (> 20 weeks) (Mostert et al., 2022).*

	Conventional	DRB	BLS
From parent stock 1-20 weeks	0.06	0.05	0.04
Feed production	0.17	0.15	0.11
Land use change	0.13	0.11	0.17
Energy on farm	0.03	0.02	0.02
Manure on farm	0.01	0.01	0.01
Total	0.40	0.34	0.35
After allocation	0.37	0.33	0.34
Total excl LUC[1]	0.26	0.22	0.17
After allocation excl LUC	0.24	0.21	0.17

1 LUC: land use change, i.e. deforestation.

Table 8 shows the impact of different production systems and breeds at the hatchery on GHG emissions. After the hatchery stage, BLS production systems had the lowest GHG emissions per egg hatched.

Table 8 *Greenhouse gas emissions (kg CO_2-eq) per egg hatched at hatchery (Mostert et al., 2022).*

	Conventional	DRB	BLS
From parents >20 weeks	0.37	0.33	0.34
losses due to unhatched eggs	0.07	0.06	0.06
Energy use at hatchery	0.06	0.06	0.06
Total	0.51	0.45	0.46
Total excl LUC[1]	0.35	0.31	0.26

1 LUC: land use change, i.e. deforestation.

Table 9 shows the impact of different production systems and breeds at the broiler farms on GHG emissions. Main impact is from feed production and LUC. Including or excluding LUC gives different results. When LUC is included, BLS is most efficient per kg live weight, whereas by excluding LUC conventional is most efficient per kg live weight. LUC results mainly from soybean meal and soy oil produced in Brazil in the diets of the broilers. The percentage of these ingredients in the diets is lower in BLS production system and therefore the contribution of LUC lower.

Table 9 *Greenhouse gas emissions (kg CO_2-eq) per kg live weight at broiler farm (Mostert et al., 2022).*

	Conventional	DRB	BLS
Breeding	0.15	0.14	0.14
Hatchery	0.05	0.05	0.05
Feed production	0.99	1.14	1.27
Land use change	2.30	2.43	1.80
lucerne	0.00	0.01	0.01
energy on farm	0.12	0.16	0.21
manure on farm	0.04	0.05	0.06
Total	3.65	3.98	3.55
Total excl LUC[1]	1.29	1.49	1.66

1 LUC: land use change, i.e. deforestation.

Table 10 shows the impact of different production systems and breeds at the slaughterhouse on GHG emissions. At slaughterhouse, results per kg liveweight have a minor difference at broiler farm level due to dead on arrival. Expressing the GHG emissions per kg breast meat (filet) showed that conventional is most efficient including or excluding LUC. Including or excluding LUC showed different results for the breeds of DRB and BLS.

Table 10 *Greenhouse gas emissions (kg CO_2-eq) of different broiler production systems expressed per kg live weight slaughtered and kg breast meat at slaughterhouse gate.*

	Conventional	DRB	BLS
Breeding	0.15	0.14	0.14
Hatchery	0.05	0.05	0.05
Feed production	0.99	1.14	1.27
Land use change	2.31	2.43	1.80
Lucerne	0.00	0.01	0.01
Energy on farm	0.12	0.16	0.21
Manure on farm	0.04	0.05	0.06
Total at broiler farm	3.66	3.98	3.55
Transport to slaughterhouse	0.01	0.01	0.01
Energy at slaughterhouse	0.08	0.08	0.08
Total	3.75	4.07	3.64
Total excl LUC[1]	1.38	1.58	1.75
Total/ kg breast meat after allocation	10.88	14.94	14.81
Total/ kg breast meat after allocation excl LUC	4.00	5.81	7.14

1 LUC: land use change, i.e. deforestation.

3.2 Land use

Table 11 shows the land use for all stages in the broiler chain. Land use is based on type of feed and feed conversion rate. In the breeding stage BLS production system is most efficient per hen and per egg, because more eggs per hen are produced. At broiler farm and slaughterhouse, conventional is most efficient per kilogram live weight and per kg breast meat (filet), because feed conversion rate is lowest.

Table 11 *Land use (m^2a crop eq) in parent stock farm (1-20 weeks, rearing period), parent stock farm (>20 weeks, laying period), hatchery, broiler farm and slaughterhouse expressed per hen, egg, egg hatched, kg live weight, kg live weight slaughtered, and kg breast meat.*

	Conventional	DRB	BLS
Parent 1-20 weeks (per hen)	17.52	14.72	13.56
Parent > 20 weeks (per egg)			
From parent stock 1-20 weeks	0.10	0.09	0.06
parent stock >20 weeks	0.55	0.48	0.37
Total	0.66	0.56	0.44
After allocation	0.62	0.54	0.42
Hatchery (per egg hatched)			
From parent stock >20 weeks	0.62	0.54	0.42
losses due to unhatched eggs	0.12	0.10	0.08
Total	0.74	0.64	0.50
Farm (kg live weight)			
Breeding	0.25	0.23	0.18
Hatchery	0.05	0.04	0.03
Farm	3.28	3.73	4.11

	Conventional	DRB	BLS
Total	3.58	3.99	4.32
Slaughterhouse (kg live weight slaughtered)			
Breeding	0.25	0.23	0.18
Hatchery	0.05	0.04	0.03
Farm	3.28	3.73	4.11
Total	3.59	4.00	4.32
Total/ kg breast meat after allocation	10.41	14.67	17.61

3.3 Phosphorus excretion

Table 12 shows the P excreted for different stages in the broiler chain. In the breeding stage, BLS has the lowest P excretion per hen and per egg. On broiler farm and slaughterhouse level, conventional has the lowest P excretion per kg live weight. Feed intake and output (hen, eggs, meat) determined which broiler production system was most efficient at the different stages.

Table 12 *Phosphorus excretion (g P excreted) in parent stock (1-20 weeks, rearing period), parent stock (>20 weeks, laying period), hatchery, broiler farm and slaughterhouse expressed per hen, egg, hatched egg, and kg live weight slaughtered.*

	Conventional	DRB	BLS
Parent stock week 1-20 weeks (per hen)	50.74	42.68	38.83
Parent stock > 20 weeks (per egg)			
From parent stock 1-20 weeks	0.30	0.25	0.18
parent stock >20 weeks	1.19	1.02	0.84
Total	1.49	1.26	1.01
After allocation	1.41	1.20	0.98
Hatchery (per egg hatched)			
From parent stock >20 weeks	1.41	1.20	0.98
losses due to unhatched eggs	0.27	0.22	0.18
Total	1.68	1.43	1.16
Farm (kg live weight)			
Breeding	0.58	0.51	0.42
Hatchery	0.11	0.09	0.08
Farm	2.33	3.20	4.51
Total	3.02	3.80	5.01
Slaughterhouse (kg live weight slaughtered)			
Breeding	0.58	0.51	0.42
Hatchery	0.11	0.09	0.08
Farm	2.33	3.20	4.51
Total	3.02	3.80	5.01

4 Discussion

This is the first study in the Netherlands that estimated the environmental impacts of the different broilers systems with very detailed diet composition and feed ingredients emissions for all chains in the sector. In this report GHG emissions, land use, and phosphorus excretion were estimated for the conventional, DRB and BLS production systems. Including organic chicken was not yet possible, because of lack of data about the environmental impacts of organic feed production.

Comparing the impact of the different broiler systems at different stages of the broiler chain on different impact categories showed different results in the chain. This showed the importance of including the whole chain and including several environmental impact categories to show trade-offs. GHG emissions, land use, and phosphorus excretion are important indicators for environmental sustainability.

Land use and phosphorus excretion showed similar results. At the breeding stage, per hen produced and per hatched egg at hatchery, BLS was most efficient for these impact categories. At the farm and slaughterhouse stage, conventional broiler production had the lowest environmental impact for all these impact categories. Feed production was the most important contributor for all categories. Feed conversion rate was the lowest for the conventional chicken and therefore the conventional chicken was most efficient per kilogram live weight.

Comparing the impact of the different broiler systems on GHG emissions at different stages of the broiler chain showed the importance of including or excluding LUC. Because of the high contribution of LUC to the total emissions, LUC is reported separately. The results of GHG emissions are discussed in Mostert et al. (2022) and therefore we only summarize that discussion.

Although the feed intake of DRB and BLS is higher than conventional, the total emissions of BLS can be lower than DRB and conventional production systems. Including or excluding emissions from LUC, or origin of soy products had a major impact on the results. The contribution of LUC was high because of the high amount of soybean products from Brazil in the diet. The lower amount of soybean meal and soy oil in the diets of the DRB and BLS, especially at broiler stage, makes the impact of LUC lower. Excluding emissions from LUC or sourcing soy products from a country with low LUC emissions (Mostert et al. 2022) showed that the conventional production system had the lowest impact.

The impact of LUC is based on PAS2050, which means that the impact of LUC on GHG emissions is based on LUC in the last 20 years. This means that soy products have emissions from LUC if there is no guarantee that land use change (e.g. deforestation) occurred more than 20 years ago. Currently, there are many discussions about the calculation method and inclusion of land use change emissions. The GHG protocol, for example, is developing new guidelines to account for GHG emissions from land use management and land use change.

In this report we also expressed emissions per kg breast meat and we also included the slaughterhouse stage. Breast of the chicken is the most important part of the chicken in the Netherlands. The conventional production system had the highest percentage of breast per kilogram liveweight (Table 4). The conventional production system was the most efficient per kg breast when LUC was included or excluded. Economic allocation was used to show the impact per kilogram of breast. Price of breast was higher for BLS than for conventional, while the prices for other parts of the broiler were comparable. As a consequence more emissions are allocated to breast for the BLS than for the conventional broiler. Economic allocation might give different results in other years, because it is related to the market. Ideally, no allocation, biophysical allocation or system expansion was performed. This was not possible (in case of biophysical) or would result in several assumptions (in case of system expansion) making results less reliable.

Comparing results of LCA studies with each other is difficult. Other studies that estimate the impact on broiler meat had a different feed conversion rate, slaughter age, and emissions from feed production (Leinonen et al., 2012; Tallentire et al., 2018). However, these studies also showed that emissions from feed production and feed conversion rate are important for the impact on GHG emissions. Comparing broiler chickens to other agricultural sectors will have the same issues. Studies estimating the environmental impacts are performed in different years, have different background data, and have different assumptions.

Moreover the nutritional value of a product and functional unit might be different when comparing with other sectors. These two issues make it difficult to compare.

Uncertainty of results

A lot of production input data were provided by chain partners. However, some specific data were lacking, resulting in uncertainty of the results. No specific data about energy use for the different production systems were available for the breeding stage, broiler and hatchery stages. However, the contribution of energy to the total environmental impact is low and therefore this may not have affected the conclusions.

On-farm emissions of manure were based on IPCC calculation methods and national inventory reports. Data about on-farm emissions of N_2O, NH_3 could be improved by measuring these on farm for different productions systems.

Information on composition of diets was very detailed, but based on performance objectives. In practice, variations in diets compositions can be found. Moreover feed conversion rate and slaughter weight can vary between and within production systems. Mostert et al. (2022) did several scenarios for GHG emissions and showed that there might be overlap in GHG emissions between the different production systems due to variation in feed intake and slaughter weight. Therefore primary data about feed intake, origin and type of feed ingredients, and slaughter weight are required. In this study, feed compositions of the different diets were based on economic optimalisations. Optimizing diets based on other criteria (e.g. land use, GHG emissions, etc.) may give different diets and consequently different results. This may give trade-offs between criteria. Therefore including additional constraints for selection of feed ingredients to increase the environmental sustainability is complex and these constraints should be developed carefully (Mostert et al., 2022).

Recommendations

This study showed that feed production and feed conversion rate are most important parameters for the environmental impact of different Dutch broiler production systems. Most mitigation options to reduce the environmental impacts will be in these two elements. The impact of these can be improved by composing a diet with a lower environmental impact, while considering the trade-off with the feed conversion rate or vice versa.

The impact of a change for other sectors is not estimated in this study and should be included when mitigations are analysed. To analyse this, a consequential LCA could be performed, by including all the consequences of a change. This, however, requires a lot of data and assumptions and consequently uncertainty.

Composing a diet with a lower environmental impact by including more by-products, can be complicated when consequences on the world market can be expected. When there are several outputs from a product (e.g. soybean meal, oil, expeller) economic allocation is performed to allocate the emissions over the products. A by-product can have a low environmental impact because of the low economic value. When many producers include this by-product to reduce their environmental impact, the demand can increase, and consequently the price and the environmental impact will also increase. However, total emissions have not been changed.

Moreover, changing to soybean products from a different country (thus no LUC emissions) may reduce the GHG emissions of Dutch poultry sector. However, if total worldwide soybean demand remains similar, emissions are displaced between sectors. In addition, the impact on total emissions by replacing soybean products with different feed ingredients is uncertain as these different feed ingredients should also be available or extra land is required to cultivate those.

Most products that have a nutritional value are already used. A reduction by changing feed ingredients therefore can be achieved by, changing the feed ingredient to a different (livestock) sector that is more efficient in converting this to human food, by including new waste streams (e.g. animal meal or swill) with a low impact, or by reducing the impact of feed production (cultivation and processing). In all cases, consequences of different choices on environmental impacts and on other sectors at different scales should be considered.

Moreover, for all mitigation options that reduce the environmental impacts, trade-offs with economic and social (i.e. animal welfare) sustainability should be avoided, which means that the overall impact of sustainability should be assessed.

5 Conclusions

This study showed that the impact on greenhouse gas emissions, land use, and phosphorus excretion of different Dutch broiler production systems differ at several stages of the broiler chain. Information about feed composition and emissions were available at several stages of the broiler chain, which makes this study very detailed and results reliable. At the slaughterhouse stage per kilogram live weight slaughtered, the conventional chicken was the most efficient, except for climate change when LUC was included (Table 13). A different origin of soybean products and including or excluding LUC can give other conclusions about the impact on greenhouse gas emissions. Therefore it is important to show results with and without LUC and showing the origin of feed ingredients. Changing the origin of feed ingredients to countries with a low LUC can reduce the GHG emissions of your product. However, with a same or increasing demand for crops, this solution may have no contribution to a change in climate change on world level.

This study showed that feed production and feed conversion rate are most important parameters for the environmental impact. Most mitigation options to reduce the environmental impacts can be found in these two parameters. The impact of these can be improved by reducing the impact during feed production (cultivation and processing) or by composing a diet with a lower environmental impact considering the trade-off with the feed conversion rate or vice versa. For every mitigation performed, the impact on the economic performance and animal welfare, and the impact on other (livestock) sectors should be considered.

Table 13 *Environmental impacts of different broiler production systems expressed per kg live weight slaughtered at slaughterhouse gate.*

	Conventional	DRB	BLS
Climate change exclusive LUC (kg CO_2-eq)	1.38	1.58	1.75
Climate change inclusive LUC (kg CO_2-eq)	3.75	4.07	3.64
Land use (m^2a crop eq)	3.59	4.00	4.32
Phosphorus excretion (g P excreted)	3.02	3.80	5.01

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Appendix 1

Diet composition (%/kg) and nutritional constraints of the rearing period (weeks 1-20) and laying period (weeks> 20) of the conventional (Ross 308), Dutch Retail Broiler (Ranger Classic) and Better Life one Star (Hubbard JA 257) broiler production systems (Mostert et al., 2022).

Broiler breed[a]	Ross308, Ranger Classic Weeks 1-20	Ross308, Ranger Classic Weeks >20	Hubbard JA257 Weeks 1-20	Hubbard JA257 Weeks >20
Corn	44.40	41.88	29.85	32.34
Wheat	9.95	24.87	24.03	30.36
Sunflower seed meal	0.00	14.86	4.94	10.93
Limestones		6.53		7.12
Soybean meal 48.5-50% CP	0.00	5.33	0.00	14.48
Rapeseed extr. pou	2.75	2.49	6.97	0.00
Soy bean oil crude	0.50	1.49	0.50	2.16
Bonephosphate (DCP)	1.11	0.70	0.68	1.03
Prophorce sa exclusive	0.60	0.60	0.60	0.60
px SLF-1ZC 0.25%	0.30	0.30	0.30	0.30
Salt stone	0.24	0.27	0.15	0.25
L-lysine sulphate 55%	0.29	0.25	0.32	0.13
L-methionine 99%	0.12	0.13	0.05	0.11
Xyl/Fyt-mix 0.10%	0.10	0.10	0.10	0.10
Sunfl.extracted 29	16.92	0.07	8.65	0.00
L-threonine 99% powder	0.08	0.06	0.01	0.00
Na bicarbonate	0.05	0.05	0.05	0.05
Cholin chlorid 75% liquid	0.04	0.04	0.04	0.04
Barley	2.99	0.00	2.99	0.00
Nutricell pellet	4.00	0.00	4.00	0.00
Lime fine	0.82	0.00	0.93	0.00
Wheat grits	14.77	0.00	14.87	0.00
Nutrients of diet				
ME Poultry (Kcal)	2600	2800	2600	2800
Gross energy (MJ)	16.04	15.50	16.12	15.55
Crude Protein (%)	13.11	14.94	14.47	16.80
Moisture (%)	11.31	10.87	11.32	10.79
Undigestible CP(%)	2.43	2.39	2.80	2.52
Digestible Lys (%)	0.52	0.6	0.59	0.69
Calcium (%)	0.90	3.00	0.86	3.30
Available Phosphorus (%)	0.42	0.35	0.36	0.41

[a] Parent males for the broiler breeds were the following: Ross male (Ross 308), Ross male (Ranger Classic), Hubbard M22 (Hubbard JA257)
Parent females for the broiler breeds were the following: Ross 308 female (Ross 308), Ranger female (Ranger Classic), Hubbard JA57 (Hubbard JA257)

Diet composition (%/kg) of the conventional production system (Ross 308) for starter, grower 1, grower 2, and finisher diets (Mostert et al., 2022).

Ingredient	Starter (day 0-10)	Grower 1 (day 11-20)	Grower 2 (day 21-30)	Finisher (day 31-38)
Wheat	22.96	24.88	34.83	44.78
Corn	34.83	33.25	19.14	14.93
Breadmeal	0.00	1.99	7.96	7.96
Oats	0.00	0.00	0.00	0.00
Soybean meal 48.5-50% CP	29.30	27.74	22.65	22.16
Potato protein	1.50	0.00	0.00	0.00
Rapeseedmeal 00	0.00	0.00	2.99	1.99
Fieldbeans (white)	4.98	4.98	4.98	0.66
Sunflower meal 35-38% CP	0.00	0.00	0.00	0.00
Nutricell pellet	1.00	1.00	1.00	1.00
Soy bean oil crude	1.70	2.98	3.80	4.04
Lime fine	0.94	0.84	0.79	0.75
Bonephosphate porcine (DCP)	1.11	0.76	0.53	0.38
Na bicarbonate	0.15	0.15	0.15	0.15
Salt stone	0.27	0.24	0.14	0.14
L-lysine sulphate 55%	0.37	0.35	0.33	0.35
L- methionine 99%	0.34	0.30	0.26	0.23
L-threnine 99% powder	0.13	0.12	0.10	0.10
Valine 40% PX	0.05	0.05	0.01	0.01
Cholin chlorid 75% liquid	0.04	0.04	0.04	0.04
Broiler premix 0.3%	0.30	0.30	0.30	0.30
Wheat enzyme	0.03	0.03	0.03	0.03
Fytase	0.02	0.02	0.02	0.02
Nutrients of diet				
ME Poultry (Kcal)	3000	3100	3150	3200
Gross energy (MJ)	16.67	16.96	17.22	17.24
Crude Protein (%)	22.3	20.67	20.05	19.09
Moisture (%)	11.58	11.47	11.3	11.31
Undigestible CP (%)	3.04	2.84	2.92	2.77
Digestible Lysine (%)	1.25	1.12	1.04	0.98
Calcium (%)	0.96	0.84	0.78	0.72
Available Phosphorus (%)	0.48	0.42	0.39	0.36

Diet composition (%/kg) of the Dutch Retail Broiler production system (Ranger Classic) for starter, grower 1, grower 2, and finisher diets (Mostert et al., 2022).

Ingredient	Starter (day 0-10)	Grower 1 (day 11-20)	Grower 2 (day 21-30)	Finisher (day 31-49)
Wheat	27.36	27.00	34.83	44.78
Corn	33.44	34.04	22.60	16.77
Breadmeal	0.01	1.99	7.96	7.96
Oats	0.00	0.00	0.00	0.00
Soybean meal 48.5-50% CP	26.68	25.24	21.32	19.65
Potato protein	1.50	0.00	0.00	0.00
Rapeseedmeal 00	0.00	0.00	1.49	1.00
Fieldbeans (white)	4.98	4.98	4.98	2.82
Sunflower meal 35-38% CP	0.00	0.00	0.00	0.00
Nutricell pellet	1.00	1.00	1.00	1.00
Soy bean oil crude	1.35	2.57	3.13	3.55
Lime fine	0.95	0.85	0.81	0.77
Bonephosphate porcine (DCP)	1.12	0.78	0.56	0.39
Na bicarbonate	0.15	0.15	0.15	0.15
Salt stone	0.27	0.24	0.14	0.14
L-lysine sulphate 55%	0.37	0.35	0.33	0.34
L- methionine 99%	0.31	0.28	0.24	0.21
L-threnine 99% powder	0.12	0.11	0.09	0.09
Valine 40% PX	0.03	0.05	0.00	0.01
Cholin chlorid 75% liquid	0.04	0.04	0.04	0.04
Broiler premix 0.3%	0.30	0.30	0.30	0.30
Wheat enzyme	0.03	0.03	0.03	0.03
Fytase	0.02	0.02	0.02	0.02
Nutrients of diet				
ME Poultry (Kcal)	3000	3100	3150	3200
Gross energy (MJ)	16.54	16.82	17.02	17.08
Crude Protein (%)	21.40	19.76	19.13	18.24
Moisture (%)	11.67	11.56	11.42	11.41
Undigestible CP (%)	2.93	2.72	2.73	2.60
Digestible Lysine (%)	1.19	1.07	0.99	0.93
Calcium (%)	0.96	0.84	0.78	0.72
Available Phosphorus (%)	0.48	0.42	0.39	0.36

Diet composition (%/kg) of the Better Life one Star production system (Hubbard JA257) for starter, grower 1, grower 2, and finisher diets (Mostert et al., 2022)

Ingredient	Starter (day 0-14)	Grower 1 (day 15-25)	Grower 2 (day 26-35)	Finisher (day 36-56)
Wheat	21.01	27.89	34.83	44.78
Corn	34.83	34.83	32.43	18.02
Breadmeal	0.00	1.99	0.21	7.96
Oats	4.81	1.06	0.00	0.00
Soybean meal 48.5-50% CP	23.33	18.90	15.16	10.14
Potato protein	0.00	0.00	0.00	0.00
Rapeseedmeal 00	0.00	0.00	2.99	5.97
Fieldbeans (white)	4.98	4.98	3.67	4.98
Sunflower meal 35-38% CP	4.98	4.98	4.98	3.05
Nutricell pellet	2.00	1.00	1.00	1.00
Soy bean oil crude	0.94	1.44	2.02	2.13
Lime fine	0.76	0.68	0.60	0.48
Bonephosphate porcine (DCP)	0.94	0.65	0.53	0.24
Na bicarbonate	0.15	0.15	0.15	0.15
Salt stone	0.27	0.23	0.26	0.11
L-lysine sulphate 55%	0.33	0.43	0.45	0.39
L- methionine 99%	0.25	0.26	0.22	0.17
L-threnine 99% powder	0.06	0.10	0.09	0.08
Valine 40% PX	0.00	0.05	0.05	0.00
Cholin chlorid 75% liquid	0.04	0.04	0.04	0.04
Broiler premix 0.3%	0.30	0.30	0.30	0.30
Wheat enzyme	0.03	0.03	0.03	0.03
Fytase	0.02	0.02	0.02	0.02
Nutrients of diet				
ME Poultry (Kcal)	2900	3025	3058	3100
Gross energy (MJ)	16.46	16.57	16.67	16.80
Crude Protein (%)	20.25	18.83	18.00	17.24
Moisture (%)	11.59	11.62	11.63	11.58
Undigestible CP (%)	2.86	2.66	2.68	2.71
Digestible Lysine (%)	1.05	1.00	0.95	0.85
Calcium (%)	0.85	0.75	0.70	0.60
Available Phosphorus (%)	0.45	0.40	0.38	0.34

Appendix 2

Products used and ingredients selected in FeedPrint (Mostert et al., 2022)

Product name	Ingredient FeedPrint
Corn	Maize Ukraine
Wheat	Wheat France
Sunflower seed meal	Sunflower seed meal, CF 160-200
Limestones	Chalk grit
Soybean meal 48.5-50% CP	Soybean meal, CF 0-45, CP >480 Brasil Crush NL
Rapeseed extr. pou	Rape seed meal solvent extracted, CP 0-380
Soy bean oil crude	Fat/oil, Soya oil Brasil
Bonephosphate (DCP)	Monocalciumphosphate
Prophorce sa exclusive	Lactic acid (100% liquid)
px SLF-1ZC 0.25%	Mineral mix
Salt stone	Salt
L-lysine sulphate 55%	L-Lysin HCL
L-methionine 99%	DL-Methionin
Xyl/Fyt-mix 0.10%	Fytase 1 (max 0.20%)
Sunfl.extracted 29	Sunflower seed meal, CF >240
L-threonine 99% powder	L-Threonin
Na bicarbonate	Sodiumbicarbonate
Cholin chlorid 75% liquid	Vitamin mix
Barley	Barley
Nutricell pellet	Oats husk meal
Lime fine	Chalk (finely milled)
Wheat grits	Wheat middlings
Breadmeal	Bread meal
Oats	Oats grain
Potato protein	Potato protein, ash 0-10
Rapeseedmeal 00	Rape seed meal solvent extracted, CP 0-380
Fieldbeans (white)	Horse beans white
Sunflower meal 35-38%CP	Sunflower seed meal, CF 160-200
Nutricell Pallet	Oats husk meal
Valine 40% PX	L-Valin
Cholin chlorid 75% liquid	Vitamin mix
Broiler premix 0.3%	Mineral mix
Wheat enzyme	Mineral mix
Fytase	Fytase 1 (max 0.20%)
Lucerne	Lucerne (alfalfa) artificially dried
Scenario	
Soybean meal 48.5-50% CP	Soybean meal, CF 0-45, CP >480 USA Crush NL
Soy bean oil crude	Fat/oil, Soya oil USA

Environmental impact per feed ingredient for greenhouse gas emissions and land use. (Mostert et al., 2022).

Product	Climate (luc) (g CO2 eq/kg)	Climate (exc luc) (g CO2 eq/kg)	Climate (incl luc) (g CO2 eq/kg)	Landuse areal (m^2a crop eq/kg)
Maize Ukraine	112	535	647	1.9
Wheat France	30	416	445	1.3
sunflower seed meal, CF 160-200	19	467	486	3.5
Chalk grit	0	519	519	0.0
Soybean meal, CF 0-45, CP >480 Brasil Crush NL	4119	599	4718	3.1
rape seed meal solvent extracted, CP 0-380	300	502	802	1.8
Fat/oil, Soya oil Brasil	12734	1688	14423	9.6
Monocalciumphosphate	0	575	575	0.0
lactic acid (100% liquid)	32	3168	3200	1.6
Mineral mix	8	1093	1101	0.3
salt	0	180	180	0.0
L-Lysin HCL	56	6437	6493	1.9
DL-Methionin	0	3050	3050	0.0
Fytase 1 (max 0.20%)	112	12865	12977	3.8
sunflower seed meal, CF >240	16	403	419	2.9
L-Threonin	56	6437	6493	1.9
sodiumbicarbonate	1	490	491	0.0
Vitamin mix	52	6351	6403	1.8
barley	42	396	438	1.4
oats husk meal	1	232	233	0.9
chalk (finely milled)	0	1225	1225	0.0
wheat middlings	11	270	281	0.7
Bread meal	0	124	124	0.0
oats grain	2	497	498	2.1
potato protein, ash 0-10	0	1316	1316	1.8
Horse beans white	0	402	402	2.9
oats husk meal	1	232	233	0.9
chalk (finely milled)	0	1225	1225	0.0
L-Valin	52	6351	6403	1.8

Weight, N and P content of broilers (CBS, 2018)

	Weight (g)	N (g/kg live weight)	P (g/kg live weight)
Day-old chicken	42	25.8	2.5
Parent female 20 weeks	2200	33.4	4.9
Parent female end of life	3700	28.4	5.4
Parent male 20 weeks	3000	34.5	5.5
Parent male end of life	4800	35.4	5.7
Broiler	2373	28.3	4.4

Environmental impacts of different diets per kg feed for different breeds (Mostert et al., 2022).

	Climate (luc) (g CO2 eq/kg)	Climate (exc luc) (g CO2 eq/kg)	Climate (inc luc) (g CO2 eq/kg)	Landuse areal (m^2a crop eq/kg)
Ross308, Ranger Classic Weeks 1-20	130	575	705	1.8
Ross308, Ranger Classic Weeks >20	475	629	1104	2.0
Hubbard JA257 Weeks 1-20	131	561	691	1.7
Hubbard JA257 Weeks >20	919	629	1548	2.1
Conventional (Ross 308)				
Start	1470	675	2144	2.2
Grower 1	1567	663	2230	2.3
Grower 2	1457	625	2082	2.1
Afmest	1464	623	2086	2.0
DRB (Ranger Classic)				
Start	1317	661	1978	2.1
Grower 1	1413	653	2066	2.2
Grower 2	1317	616	1933	2.0
Afmest	1297	611	1908	2.0
BLK (Hubbard JA 257)				
Start	1128	631	1759	2.2
Grower 1	1011	633	1643	2.1
Grower 2	938	637	1575	2.1
Afmest	741	580	1320	1.8

To explore
the potential
of nature to
improve the
quality of life

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