



Development of the 'animal welfare' dimension within the Greenwell sustainability assessment model: 1. justification of the selection of indicators

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Report 1194



WAGENINGEN
UNIVERSITY & RESEARCH

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This research was conducted by Wageningen Livestock Research, commissioned and funded by the Ministry of Agriculture, Nature and Food Quality, Aviagen EPI, Belgabroed/Van Hulst, De Heus BV, and Plukon Food Group within the framework of the public-private partnership 'Greenwell' (TKI-AF-17023, project number BO-47-001-033)

Wageningen Livestock Research
Wageningen, September 2019

Report 1194

De Jong, Ingrid C., 2019. Development of the 'animal welfare' dimension within the Greenwell sustainability assessment model: 1. justification of the selection of indicators. Wageningen Livestock Research, Report 1194.

The current report describes the development of the 'animal welfare dimension' ('welfare assessment model') within the overall Greenwell sustainability model. As we apply the framework of Welfare Quality®, in which animal health is considered one of the aspects of animal welfare, the model also includes health indicators. The model has been developed according to two steps: definition of long-lists of indicators for the broiler breeder, hatchery, broiler on-farm and broiler end-of-life stage, and the selection of key indicators from these long-lists, as well as whether these need to be measured real-time or can be estimated by a representative sample or literature value.

Samenvatting NL. Dit rapport beschrijft de ontwikkeling van de dimensie 'dierenwelzijn' binnen het Greenwell duurzaamheid beoordelingsinstrument (ook wel 'welzijnsmodel' genoemd). Omdat het raamwerk van Welfare Quality® wordt toegepast, waarbinnen diergezondheid wordt beschouwd als onderdeel van dierenwelzijn, bevat het welzijnsmodel ook diergezondheidsindicatoren. Het model is in twee stappen ontwikkeld: eerst volledige lijsten van mogelijke indicatoren voor de ouderdierenfase, broederijfase, vleeskuikenfase primair bedrijf en vleeskuikenfase wat betreft vangen/transport/slachten, en vervolgens de selectie van de belangrijkste indicatoren uit deze lijst. Daarbij wordt tevens aangegeven of de indicatoren continu gemonitord moeten worden of dat een inschatting op basis van de literatuur of een steekproef kan volstaan.

This report can be downloaded for free at <https://doi.org/10.18174/500884> or at www.wur.nl/livestock-research (under Wageningen Livestock Research publications).

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Summary

One of the aims of the Greenwell project is to develop a model to assess the sustainability of broiler farming systems. Farming systems being defined as standardised housing and management procedures or requirements, including the use of pre-defined genetic strains or limitations on average daily weight gain for strains that are allowed. Such a sustainability model can be used to provide insight in differences between farming systems with respect to sustainability, to substantiate choices for farming systems, and to determine the effect of system adaptations (e.g., in resources, housing conditions) and their respective impact on overall sustainability. The ultimate goal of the Greenwell project is to develop a model that can be used for real-time data collection on sustainability aspects of broiler farming systems. Therefore, the model should not only provide insight in differences between farming systems with respect to sustainability aspects, but also provide insight in variation within broiler farming systems (between flocks and across time).

Here we describe the development of the 'animal welfare dimension' (also called 'welfare assessment model') within the overall Greenwell sustainability model. We applied the framework of Welfare Quality®, in which animal health is considered one of the aspects of animal welfare, and we preferred animal-based indicators over resource- or management-based indicators in the model. In the welfare assessment model, we included the following stages of the broiler production chain: (1) rearing and laying phase of broiler breeders (parent stock), (2) hatchery stage including day-old broiler chicken transport, (3) rearing of broilers on the farm until slaughter age, and (4) the end-of-life stage from catching the birds at depopulation until slaughter, including transportation to the slaughterhouse.

With respect to the selection of indicators to be included in the welfare assessment model, we first defined a longlist of indicators for each stage of the production chain. Earlier studies on sustainability of chicken farming included a very limited range of welfare indicators, usually based on data availability from literature or routinely collected farming chain data, but this may not fully represent the welfare issues in the farming chain and thus may not provide a complete picture of the actual welfare status. In our selection process, we aimed to cover all welfare aspects using the Welfare Quality® approach as a framework, using existing welfare assessment protocols where available. In the second step, we selected key-indicators from the longlist and we decided whether or not data should be collected real-time or values can be derived from literature or a representative sample. Criterion for selection of key-indicators was the impact of the proposed indicator on welfare (impact being defined as the result of duration and severity, according to standard risk assessment approaches as used by EFSA). Indicators were selected with an impact score of 4 and above (on a scale between 1 and 7). Further, indicators with an expected variation of 10% or larger within and between farming systems were selected for real-time data collection.

In chapter 4 the summarizing tables are presented showing the list of key-measures per farming stage and whether or not these indicators are currently collected routinely in the broiler production chain. It should be noted that the model can be subject to improvement as new indicators or techniques will be developed in the future, e.g., to replace resource- or management-based indicators that were included at the moment to overcome lack of data on animal-based indicators.

1 Introduction

One of the aims of the Greenwell project [1] is to develop a model to assess the sustainability of broiler farming systems. Farming systems being defined as standardised housing and management procedures or requirements, including the use of pre-defined genetic strains or limitations on average daily weight gain for strains that are allowed (see section 1.1.1 for examples). Such a sustainability model can be used to provide insight in differences between farming systems with respect to sustainability, to substantiate choices for farming systems, and to determine the effect of system adaptations (e.g., in resources, housing conditions) and their respective impact on overall sustainability. The ultimate goal of the Greenwell project is to develop a model that can be used for real-time data collection on sustainability aspects of broiler farming systems [1]. Therefore, the model should not only provide insight in differences between farming systems with respect to sustainability aspects, but also provide insight in variation within broiler farming systems (between flocks and across time).

In the current chapter, the development of the 'animal welfare dimension' (from now on called 'welfare assessment model') within the overall Greenwell sustainability model is described. As we apply the framework of Welfare Quality[®], in which animal health is considered one of the aspects of animal welfare [2], also indicators of health are included in the welfare assessment model.

1.1 Selection of farming stages and farming systems

The broiler farming chain consists of several stages: from multiplication to broiler farm and the subsequent transport and handling at the slaughter plant [3]. With respect to the welfare assessment model, we decided to include the following stages of the farming chain in the welfare assessment model: (1) rearing and laying phase of broiler breeders (parent stock), (2) hatchery stage including day-old broiler chicken transport, (3) rearing of broilers on the farm until slaughter age, and (4) the end-of-life stage from catching the birds at depopulation until slaughter, including transportation to the slaughterhouse. The broiler breeder stage (rearing and laying), the hatchery phase including transport to the broiler farm, and the end-of-life stage can each have a major impact on the welfare of (broiler) chickens [4-6], in addition to the rearing phase on the broiler farm itself [7]. Because the stages in the breeding pyramid before the broiler breeders (e.g. grandparents) represent a relatively small number of birds [3], we did not include these in the welfare assessment model. This does not exclude that the earlier stages may considerably affect the welfare potential of birds for the different systems in further stages in the farming chain, through genetic and epigenetic effects. Animal-based measures of welfare applied in the stages that are included in the assessment model likely include these genetic and epigenetic potentials.

Within the Greenwell project, we chose to compare the wide range of broiler farming systems that are currently present in The Netherlands [8], by selecting four systems that are supposed to represent the range between 'efficient in terms of production and costs', and 'including additional requirements supposed to provide a higher welfare level for the chickens' [8, 9]:

1. the conventional broiler farming system using so-called fast growing breeds housed at maximum stocking densities (in the Netherlands: 39-42 kg/m²) and with indoor housing only ('conventional'), representing the majority of broiler chicken farming in the Netherlands;
2. systems according to the farming standards of 'Kip van Morgen' [10], i.e. a slower growing chicken breed with a maximum daily growth of 50 g and a stocking density of 38 kg/m² or lower, and provision of environmental enrichment in the house but no veranda or outdoor range;
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 veranda and environmental enrichment, and
4. organic, using a slow growing breed (slaughter age of at least 70 days), a stocking density of 21 kg/m² and an outdoor range.

These systems were taken into account when estimating the variation between and within systems as further described in chapter 1.3.

1.2 Approach to develop a list of key-indicators

With respect to the selection of indicators to be included in the welfare assessment model, we first defined a longlist of indicators. Earlier studies on sustainability of chicken farming included a very limited range of welfare indicators, usually based on data availability from literature or routinely collected farming chain data [11-15], but this may not fully represent the welfare issues in the farming chain and thus may not provide a complete picture of the actual welfare status. In our selection process, we aimed to cover all welfare aspects using the Welfare Quality® approach [2] (see section 1.2) as a framework, using existing welfare assessment protocols where available. In the second step, we selected key-indicators from the longlist, based on criteria relevant for the current project (see chapter 1.3), and we decided whether or not data should be collected real-time or values can be derived from literature or a representative sample.

1.3 Guidance for reading

Section 1.2 presents the selection of welfare indicators of the longlists, section 1.3 presents the selection of key-indicators for the different farming stages and the applied methods for selection of these key-indicators, and section 1.4 presents summarizing tables per farming stage and information on routine data collection. After a short introduction of the methodology, in each chapter four tables are presented, one for each of the farming stages (parent stock, hatchery and day-old chicken transport, broiler chickens, end-of-life (catching, transport and slaughter)). The structure of the tables will be explained in the respective chapters. Please note that in each section we start with the broiler on-farm table, and subsequently present the parent stock, hatchery and end-of-life table. The reason for this is that the latter three tables are based on the broiler table; for the broiler on-farm stage welfare assessment protocols have already been developed, in contrast to the parent stock and hatchery phase. Therefore, where relevant, the parent stock and hatchery tables refer to the broiler table. See also section 1.2 in which we explain the process of indicator selection.

2 Longlists of animal welfare indicators

2.1 Introduction

The longlists of animal welfare indicators have been selected based on existing on-farm welfare assessment protocols for broiler chickens [16-18] or protocols to assess welfare during the process of catching, transport, stunning and killing (also called the 'end-of-life' phase) [17, 19]. In contrast to published assessment protocols for broiler welfare on-farm and during the end-of-life stage [16-19] there are no published welfare assessment protocols for the broiler breeder and hatchery stages. Therefore, for these stages, the Greenwell consortium developed the longlist by identifying the most important welfare issues using the risk assessment of Visser et al. [20] as a basis. The risk assessment for broiler and turkey meat farming [20] has also been used to add possible indicators to the longlist of the on-farm broiler and end-of-life stages. For all stages, lists were completed with indicators mentioned by the members of the Greenwell consortium (expert and stakeholder opinions).

For the animal welfare dimension within the Greenwell assessment model we chose to work according to the framework of the Welfare Quality® principles and criteria for animal welfare. Welfare Quality® applies the definition of animal welfare being a multidimensional concept, that embraces (1) freedom from suffering (e.g., prolonged pain, fear, hunger or thirst) (2) a high level of biological functioning (e.g., absence of disease, injuries, malnutrition), and (3) existence of positive experiences (e.g., comfort, contentment, expression of the species-specific behavioural repertoire). These dimensions should therefore, according to the Welfare Quality® consortium, be present in a welfare assessment protocol. Based on this approach Welfare Quality® developed a way of assessing welfare that covered all its different aspects: they defined 12 welfare criteria falling within four main principles of animal welfare (good feeding, good housing, good health, appropriate behaviour) [2]. For the scientific justification of the four principles and 12 criteria we refer to Blokhuis et al. [2]; Tables 1-4 below list these principles and criteria.

Another important aspect of the Welfare Quality® assessment protocol, that distinguished this protocol from earlier developed welfare assessment models, is the choice for animal-based indicators instead of resource-based or management-based indicators to assess welfare. Animal-based indicators are considered being more close to the experiences of the animal. However, in case no valid or feasible animal-based indicators were available, resource-based or management-based indicators were considered and included in existing assessment protocols such as Welfare Quality® [2]. With respect to the longlist of welfare indicators in the Greenwell project we preferred animal-based indicators over resource-based or management-based indicators. However, resource-based or management-based indicators were also listed as possible complements to the animal-based indicators, in case we expected that no feasible or insufficient valid animal-based indicators are available. Resource-based or management-based indicators were only selected in case there was an established relationship, published in scientific literature, with the specific animal-based indicator or criterion.

A few new animal-based indicators were considered by the Greenwell consortium and are included in the long-lists. One reason for adding new indicators in addition to indicators of existing models is that in existing welfare models, such as Welfare Quality®, indicators for some criteria are still lacking (e.g., for social behaviour in the Welfare Quality® broiler assessment protocol), or are subject to discussion between scientists because of lack of validity (e.g., Qualitative Behaviour Assessment and Touch Test in the Welfare Quality® broiler assessment protocol [21, 22]), and that new indicators of animal welfare are still being developed (e.g. in precision/smart farming). Indicators with reference to Welfare Quality® [17] in Tables 1 and 4 were already included in Welfare Quality®, the other indicators were derived from other assessment models or are new suggestions.

2.2 Tables presenting the longlists

Tables 1-4 present the longlists for respectively the on-farm stage of broiler chickens, the parent stock stage, the hatchery stage, and the end-of-life stage. As explained in section 1.1.1 we start with the broiler on-farm stage, as assessment protocols and welfare indicators have been best described for this stage [16-18]. Each table is structured as follows: Welfare Quality® principle, Welfare Quality® criterion [17], suggested indicator(s) (animal based and sometimes resource or management based indicators as indicated above), and justification for the choice of the respective indicator. The final column, justification, includes literature references on the relationship between the respective indicator and animal welfare, a short explanation (in case not based on existing assessment protocol), and some information on duration and/or prevalence, if relevant. It should be noted that only key-references are included.

Table 1 Long-list of indicators for **broiler welfare on-farm**, including the justification for each indicator. Principles and criteria refer to the framework of the Welfare Quality® assessment protocols [17].

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification	
Good Feeding	Absence of prolonged hunger	% emaciated chickens		[17]	
			Access to feed	Broiler chickens are usually fed (nearly) <i>ad libitum</i> , which is not supposed to lead to prolonged hunger. Chickens unable to reach the feeders are not included in this measure and are likely included in the culling/mortality figure	
			On-farm hatching	With on-farm hatching systems, broiler chickens usually have immediate access to feed post-hatch [23]. This seems most relevant during the first days post-hatch [6]	
			Rejection (condemnation) at the plant specific for cachexia (wasting syndrome)	[17]	
			Absence of prolonged thirst	% emaciated chickens	Prolonged thirst may lead to emaciation [24]
				Water consumption in test situation	The water consumption in a test situation when provided <i>ad libitum</i> water was related to the level of thirst, however, this test needs further development [25]
				Restriction(s) in water supply	[17]. Although restrictions in water supply (thus: no <i>ad libitum</i> provision) may be applied in practice by e.g. reducing water pressure or shutting down the water supply shortly on a daily basis, it is not considered to lead to prolonged thirst as long-term water restriction affects feed intake and thus growth rate [24]. Chickens unable to reach the drinkers are not included in this measure, but will likely be included in the culling/mortality figure
				On-farm hatching	With on-farm hatching systems broiler chickens usually have immediate access to water post-hatch [23], so the chickens are supposed not to suffer from thirst

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
				during the first days post-hatch. Chicks unable to reach the drinkers are not included in this measure but likely included in the culling/mortality figure.
			Rejection (condemnation) at the plant specific for cachexia	[17]
Good housing	Comfort around resting	Quality of sleep		As far as we know there is yet no feasible and valid measure of quality of sleep in chickens
		Proportion of broilers resting on an elevated structure		Chickens are highly motivated to rest on an elevated structure; this behaviour can be observed after 10-14 days of age [26]
		Proportion of chickens with dirty plumage		Dirty plumage is associated with poor litter quality which affects comfort when resting in the litter area [17]
		Proportion of chickens with footpad lesions		Footpad lesions are considered painful, and can therefore cause discomfort when resting/perching [27]
		Proportion of chickens with hock burn		Hock burns are considered painful, and therefore cause discomfort when resting [27]
		Proportion of chickens with breast irritation or blisters		Breast skin irritation and blisters are considered painful, and therefore cause discomfort when resting. Moreover, design of perches and other resting places may cause blisters when inappropriate [28].
		Breast bruises		Bruises negatively affect welfare [29, 30] and may cause discomfort when resting
		Red skin		A red skin might be caused by irritation from ammonia (Van Harn, pers. comm.) thus relate to air quality in the broiler house
		Thigh scratches		Thigh scratches are related to disturbance of sitting or resting birds [31]
			Presence of elevated resting areas (perches, platforms)	Chickens are highly motivated to rest on an elevated structure [32]
			Light schedule	The light schedule (light-dark period length and distribution over 24h) determines the sleep-wake rhythm of chickens [27], however, there is no information on the quality of sleep in relation to the light schedule
			NH ₃ concentration	High NH ₃ concentration in the air causes discomfort, it may irritate eyes and the respiratory system [27]
			Dust concentration	High dust concentration in the air cause discomfort, it may irritate the eyes and the respiratory system [17, 27]
			Litter quality	Poor litter quality may cause dirty plumage, footpad lesions, hock burn and breast irritation or blisters [17, 31].
	Thermal comfort	Proportion of broilers panting		Persistent panting indicates that the environmental temperature causes discomfort for the chickens [17], although it should be continuously monitored to assess thermal comfort

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
		Mortality caused by heat stress		In severe cases, when animals are unable to cope with heat stress, it may lead to mortality [33, 34]
		Proportion of broilers huddling		Persistent huddling indicates that the environmental temperature is too low [17]
		Proportion of chickens with dirty plumage		Dirty plumage is associated with poor litter quality and reduction in insulating capacity [17]
		Bird distribution in the house		An unequal distribution may indicate that in certain areas the climate causes discomfort for the birds [35], although an unequal distribution might also be a result of temperature/light zones and/or bird preferences
			Temperature and relative humidity in the house	The combination of environmental temperature and relative humidity determine thermal comfort; especially a combination of high humidity and high environmental temperatures cause discomfort and may lead to mortality [36]
			Possibility to choose between temperature zones	Broilers may choose the environment that best meets their thermal needs
			Litter quality	Poor litter quality affects thermal comfort of the chickens [17, 31]
			Presence of a cooling system	The presence of a cooling system may help broilers to cope with very high environmental temperatures
			Heating system	Thermal comfort may be related to the type of heating used in the house
	Ease of movement	Maximum stocking density (at any time in the laying cycle)		The stocking density determines the possibilities of the birds to move around and perform their species-specific behaviours [27], and the use of resources offered [37]
			Obstacles	The presence of obstacles may hamper behaviours such as running, flying, walking, jumping. This might conflict with presence of elevated resting areas (perches, platforms)
			Availability of extra floor space (such as platforms) on top of legally calculated space	According to the EU Directive 2007/43/EC 100% of the available floor space should be covered with litter. Additional space on top of this, such as platforms (without litter), provide extra space and reduce actual stocking density
Good health	Absence of injuries	Proportion of chickens with footpad dermatitis		Severe footpad lesions involve dermatitis and ulcerations and are considered painful [17, 38]
		Proportion of chickens with hock burn		Hock burn involves lesions on the hock area and are considered painful [17]
		Proportion of chickens with breast irritation and blisters		Skin irritations and breast blisters are considered painful [17]
		Proportion of chickens with locomotion		Gait abnormalities limit movement and may be painful [17, 39]

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
		problems (lameness)		
		Bruises		Bruises are considered painful [29]
		Wing fractures		Wing fractures are painful and limit movement [40]
		Leg fractures		Leg fractures are painful and limit movement [40]
		Scratches and wounds		Scratches and wounds are painful and a potential source of infection. Scabby hips are sometimes measured at the plant and are scratches or scabs at the hip area [41].
		Mortality		Mortality due to poor health, injuries or disease reflects poor animal welfare [7]
		Selection (culling of chickens for reason of disease or injuries)		Culling is a way of minimising suffering, although indicates a welfare problem in a flock [7]
			Rejections (condemnations) at the plant	At the slaughter plant, carcasses are rejected because of quality issues (smell, colour), diseases (hepatitis, serositis, etc.) or damage (fractures) [42]. As various causes for rejection are included into one figure in the Netherlands, it does not refer to specific health issues
	Absence of disease	Mortality		Mortality due to poor health, injuries or disease reflect poor animal welfare [7]
		Selection (culling of chickens for reason of disease or injuries)		Culling is a way of minimising suffering, although a high percentage of culling may indicate a welfare problem in a flock [7]
		Curative antimicrobials use		When treated curative, antimicrobials use (and number of treatments applied) is indicative for a health problem in a flock
			Rejection (condemnation) percentage at the plant	At the slaughter plant, carcasses are rejected because of quality issues (smell, colour), diseases (hepatitis, serositis, etc.) or damage (fractures) [42]. As various causes for rejection are included into one figure in the Netherlands, it does not refer to specific health issues.
	Absence of pain induced by management procedures	Pain due to inadequate handling or culling		Inadequate culling or handling can be painful [7]. There is currently no or feasible indicator of pain in chickens
		Proportion of chickens with footpad dermatitis		Footpad lesions are related to inadequate litter management and considered painful [43]
		Proportion of chickens with hock burn		Hock burns are related to inadequate litter management and bird weight/growth profile, and considered painful [44]
		Proportion of chickens with breast irritation and blisters		Breast irritations are related to inadequate litter management, blisters are related to inadequate flooring design, and considered painful [45]
		Proportion of chickens with locomotion		There is a relationship between management and lameness in

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
		problems (lameness)		broiler chickens [7]; lameness can be painful [39]
		Proportion of chickens with bruises		Inadequate handling [29] or housing design may cause bruises; bruises are considered painful [19]
		Proportion of chickens with wing fractures		Wing fractures can be related to inadequate handling [29] or housing and are painful [17, 19]
		Proportion of chickens with leg fractures		Leg fractures can be related to inadequate handling [29] or housing and are painful [19]
		Proportion of chickens with scratches and wounds		Inadequate management, such as feeding schedule and water availability, lighting schedule, may cause crowding which may result in scratches [24]. Scabby hips are measured at the plant and are scratches at the hip/thigh area.
Appropriate behaviour	Expression of social behaviour	Prevalence of injurious pecking behaviour		Injurious pecking behaviour (feather pecking, cloacal pecking) is a form of abnormal behaviour, and may lead to injuries, wounds and increased mortality [46]. There is no literature on the prevalence in broiler chicken flocks, although the prevalence is generally considered to be very low
		Prevalence of feather damage		Feather damage may be the consequence of injurious pecking behaviour [46]; however, also of inadequate system design causing feather abrasion [17]; a deteriorated feather cover may cause thermal discomfort [46]
		Proportion of chickens with scratches, wounds		Injuries may be caused by injurious pecking behaviour [17], although accidents and inadequate system design may also cause injuries. There is no literature on the prevalence of injurious pecking in broiler chicken flocks, although the prevalence is generally considered to be very low
			Rejection (condemnation) percentage at the plant	Skin damaged accompanied by ulcerations, or severe damage, may cause rejection at the plant [42]
			Provision of environmental enrichment	Environmental enrichment may reduce the risk for injurious pecking behaviour [47], and provide possibilities to hide from conspecifics [48]
			Light intensity and composition	Light intensity and composition affect social behaviours [49] although there is little known on the effects of light composition and wavelength on social behaviour of broiler chickens
	Expression of other behaviours	Proportion of time spent on species specific behaviours (e.g., dustbathing, foraging, preening, exploration)		It is generally assumed that the ability to perform species-specific behaviours such as dustbathing, foraging, and exploration is a sign of good welfare [2]

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
		Proportion of chickens with locomotion problems (lameness)		Lameness hampers the performance of behaviours [7]
			Provision of environmental enrichment	Environmental enrichment increases the opportunities to perform species-specific behaviours, such as exploration and pecking [32]
		Proportion of chickens with locomotion problems (lameness)		Lameness affects the ability of the bird to perform behaviours such as walking, running, jumping, etc. [27]
			Litter quality	Loose and friable substrate is required to perform dustbathing and foraging behaviour [50, 51]
			Presence of covered veranda and/or outdoor range	Both a covered veranda and an outdoor range provide a wider range of opportunities to perform diverse behaviours as compared to indoor housing only, where the outdoor range provides the most diverse environment [32]
			Light intensity, flicker frequency, composition, schedule	Chickens are able to see frequencies <120 Hz, although this is dependent on the light intensity [52, 53]. Light intensity and composition have a large effect on the behaviour of chickens [54-62]
	Good human-animal relationship	Expression of fear of humans, e.g. to inadequate handling or culling		Human/caretaker behaviour may cause stress in chickens [63]
		Assurewell flock behaviour score (calm, cautious, flighty)		[18]
			Stockperson training for handling and culling	Training of stockpersons may reduce stress due to inadequate handling [63]
	Positive emotional state	Experiences of positive emotions		Animals (including chickens) may perceive positive feelings. Although techniques are available to assess positive emotional states in chickens, this needs further development before application in practice [64, 65]. This also relates to play behaviour, which has been suggested as indicator of positive emotions but needs to be further validated in chickens [66]
		Expression of fear		Fear is a negative affective state and affects the welfare of animals [17, 67]
			Presence of environmental enrichment	Environmental enrichment may help to promote a positive affective state, by providing opportunities for species specific behaviours and by its rewarding properties [32]; however, this statement can be challenged as it can also be argued that this should be a basic requirement. Moreover, the effects can be marginal [68]

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
			Light intensity, flicker frequency, composition, schedule	Chickens are able to see frequencies <120 Hz, although this is dependent on the light intensity [52, 53]. Light intensity and composition have a large effect on the behaviour of chickens [54-62]
			Presence of covered veranda and/or outdoor range	Likewise as for environmental enrichment, a covered veranda or outdoor range may help to promote positive affective states by increasing opportunities for species specific behaviours and providing a more diverse environment [32]

Table 2 Longlist of welfare indicators for **rearing and laying phase of broiler breeders** (parent-stock phase), including the justification of the selection of indicators. Principles and criteria refer to the framework of the Welfare Quality® assessment protocols [17]. In case the justification is similar for broiler breeders and broiler chickens, we refer to Table 1 (broiler chickens). If an indicator relates to rearing or laying phase only this is mentioned in bold. All other indicators refer to both rearing and laying phase.

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
Good feeding	Absence of prolonged hunger	Time spent on stereotypic pecking behaviour (rearing)		The proportion of total time spent on stereotypic pecking after feeding is indicative of hunger in broiler breeders [69-71]. Relative feed control during the laying period is much lower than during rearing, especially after the peak of lay, and stereotypic behaviours are nearly absent, so this indicator relates mainly to the rearing period [72-74].
			Male and female genetic line/breed in combination with nutritional/feeding management strategies (rearing)	The extent to which feed control needs to be applied is dependent on the breed/genetic line that is used [72]. Although breeds with similar growth potential can differ in feelings of hunger due to different feeding schedules or ingredients. In general a lower growth potential and feed control or alternative management strategies can result in less feelings of hunger
	Absence of prolonged thirst	Water consumption in a test situation		The water consumption in a test situation when provided <i>ad libitum</i> water was related to the level of thirst in broiler chickens, however, this test needs further development and has not been validated for broiler breeders [25]
			Drained blood content	Drained blood content seemed to be indicative of thirst due to daily controlled water supply in broilers, but this indicator needs further development before application in practice and has not been validated for broiler breeders [75]
			Duration of water provision	There is no valid and feasible indicator of thirst in chickens or broiler breeders [24, 25, 75]. Restrictions in water supply can be measured as an alternative [17].
Good housing	Comfort around resting	Quality of sleep		As far as we know there is yet no feasible and valid measure of quality of sleep in chickens
		Proportion of breeders resting on an elevated structure		Broiler breeders show a strong prevalence to rest on an elevated structure [76-78]
		Proportion of breeders with dirty plumage		See Table 1 (broilers)
		Proportion of breeders with footpad dermatitis		See Table 1 (broilers); may cause discomfort when resting and/or perching. Footpad dermatitis is present in broiler breeders, is mainly related to litter quality (moisture, pH, NH3 content) and has shown to be more prevalent with larger slatted areas in the layer house [79]
		Proportion of breeders with hock burn		See Table 1 (broilers); may cause discomfort when resting. Hock burn was rare in broiler breeders in

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
				published data on the actual prevalence [79]
		Proportion of breeders with breast irritation/blisters		See Table 1 (broilers); breast blisters may cause discomfort when resting/perching. A single study showed that breast irritation was almost absent in breeders [79]. Inadequate design of perches or other elevated resting areas can cause breast blisters [28, 80]
		Proportion of breeders with bruises		See Table 1 (broilers). May cause discomfort when resting/perching
		Proportion of breeders with keel bone fractures		Keel bone fractures are painful and affect resting comfort as is shown in layers [81]. Keel bone fractures have shown to be prevalent in broiler breeders, but no relationship with perches was shown [76]
		Proportion of breeders with eye irritation		A prolonged too high ammonia concentration causes eye irritation [82]
			Presence of elevated resting areas (perches, platforms)	See Table 1 (broilers)
			Light/dark schedule	See Table 1 (broilers)
			NH ₃ concentration	See Table 1 (broilers)
			Dust concentration	See Table 1 (broilers)
			Litter quality	See Table 1 (broilers)
	Thermal comfort	Proportion of breeders panting		See Table 1 (broilers)
		Mortality caused by heat stress		See Table 1 (broilers). Occurs only in extreme situations
		Proportion of breeders huddling		See Table 1 (broilers)
		Proportion of breeders with dirty plumage		See Table 1 (broilers)
		Bird distribution in the house		See Table 1 (broilers)
			Temperature and relative humidity	See Table 1 (broilers)
			Choice between temperature zones	See Table 1 (broilers)
			Litter quality	See Table 1 (broilers)
			Presence of a cooling system	See Table 1 (broilers)
			Type of heating system	See Table 1 (broilers)
	Ease of movement	Maximum stocking density at any moment		See Table 1 (broilers); stocking density has been shown to affect the quality of mating behaviour in broiler breeders [83]
			Obstacles	The presence of obstacles may hamper behaviours such as running, flying, walking, jumping. This might be conflicting with 'presence of elevated resting areas (perches, platforms)'
			Feeder length per bird	Especially during rearing, there may be a severe competition for feed. Providing sufficient feeder space reduces the risk for injuries due to aggression around feeding [84]. All birds should be able to eat at the same time [85]
			Availability of extra floor space (such as platforms) on top of legally calculated space	See Table 1 (broilers)

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification	
Good health	Absence of injuries	Proportion of breeders with footpad dermatitis		See Table 1 (broilers)	
		Proportion of breeders with hock burn		See Table 1 (broilers)	
		Proportion of breeders with breast irritation/blisters		See Table 1 (broilers)	
		Proportion of breeders with locomotion problems (lameness)		See Table 1 (broilers). This includes all types of lameness in broiler breeder flocks during rear and lay [86, 87]	
		Proportion of breeders with bruises		See Table 3 (broilers)	
		Proportion of breeders with wing fractures		See Table 3 (broilers)	
		Proportion of breeders with leg fractures		See Table 3 (broilers)	
		Proportion of breeders with keel bone fractures		Keel bone fractures are painful and affect resting comfort as is shown in layers [[76]	
		Proportion of breeders with scratches and wounds		See Table 1 (broilers)	
		Mortality (proportion of breeders found dead)		See Table 1 (broilers)	
		Selection (proportion of breeders culled)		See Table 1 (broilers)	
				Breed/genetic line of males and females	Genetic selection for improvement of robustness with respect to lameness, footpad dermatitis, hock burn may lead to differences between genetic breeds/ lines [7, 88-90]
		Absence of disease		Mortality (proportion of breeders found dead)	
Selection (proportion of breeders culled)				See Table 1 (broilers)	
Curative antimicrobials use				See Table 1 (broilers)	
	Percentage of rejections (condemnations) at the slaughter plant			See Table 1 (broilers)	
Absence of pain induced by management procedures		Pain due to inadequate culling or handling		See Table 1 (broilers)	
		Proportion of breeders with footpad dermatitis		See Table 1 (broilers)	
		Proportion of breeders with hock burn		See Table 1 (broilers)	
		Proportion of breeders with breast irritation or blisters		See Table 1 (broilers)	

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
		Proportion of breeders with bruises		See Table 1 (broilers)
		Proportion of breeders with wing fractures		See Table 1 (broilers)
		Proportion of breeders with leg fractures		See Table 1 (broilers)
		Proportion of breeders with keel bone fractures		A major cause of keel bone fractures is collision with housing structures [81]
		Proportion of breeders with injuries (wounds, scratches)		See Table 1 (broilers)
		Proportion of breeders with problems (lameness)		See Table 1 (broilers)
		Mutilations		Mutilations are considered painful [91-93]; beak treatment may affect food and water consumption in the first days after treatment [92, 93]. There is no literature on the (long-term) effects of toe treatment.
			Breed/genetic line of males and females	Genetic selection for improvement of robustness with respect to lameness, footpad dermatitis, hock burn may lead to differences between genetic breeds/lines [7, 88-90]
Appropriate behaviour	Social behaviour	Prevalence of injurious pecking behaviour		Injurious pecking behaviour (feather pecking, cloacal pecking) is a form of abnormal behaviour, and may lead to injuries, wounds and increased mortality [46]
		Proportion of breeders with feather damage		Feather damage may be the consequence of injurious pecking behaviour (back, neck, tail) [46] and of frequent mating (back, thigh area) [72]; however, also of inadequate system design causing feather abrasion especially on neck, breast and belly [17]. The measure is therefore not related to abnormal social behaviour only. A deteriorated feather cover may cause thermal discomfort [46]
		Proportion of breeders with scratches and wounds		Injuries may be caused by injurious pecking behaviour (including the cloacal area) [17], by competition at the feeders [84] and by mating in case the feather cover is deteriorated [72], although accidents and inadequate system design may also cause wounds. Prevalence of the latter is estimated to be low. Injuries therefore not relate to social behaviour only
			Percentage of rejections (condemnations) at the slaughter plant	Skin damage accompanied by ulcerations, or severe damage, may result in rejections at the plant
			Male:female ratio (laying)	There is no literature on the relationship between male:female ratio and prevalence of injuries in broiler breeders; however, too many males, especially in the beginning of lay, may result in overmating and/or aggression, increasing the risk for injuries

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
			Availability of environmental enrichment	Environmental enrichment, such as vertical cover panels, may reduce the risk for injurious pecking behaviour [47], and provide possibilities to hide from conspecifics [48]
			Light intensity and composition	Light intensity and wavelengths affect social behaviours, such as the quality of the mating behaviour [49]
	Expression of other behaviours	Proportion of time spent on species-specific behaviours (e.g., foraging, dustbathing, preening, courtship behaviour)		See Table 1 (broilers). Courtship behaviour relates to the laying period only.
		Proportion of breeders with locomotion problems (lameness)		See Table 1 (broilers)
			Availability of environmental enrichment	See Table 1 (broilers)
			Ratio slatted floor: litter floor	Both slatted floor and litter area provide opportunities for species specific behaviour (e.g., resting, dustbathing, foraging), and the extent to which these can be performed is thought to be affected by the ratio between these. E.g., mating behaviour is largely performed in the litter area. However, as far as we know there is no scientific literature on this relationship available
			Litter quality	See Table 1 (broilers)
			Availability of covered veranda or outdoor range	See Table 1 (broilers)
			Light intensity, flicker frequency and composition	See Table 1 (broilers)
	Good human-animal relationship	Expression of fear of humans, e.g. to inadequate handling and culling		See Table 1 (broilers)
		Assurewell flock behaviour score (calm, cautious, fearful)		See Table 1 (broilers)
			Stockperson training for handling and culling	See Table 1 (broilers)
	Positive emotional state	Experience of positive emotions		See Table 1 (broilers)
		Expression of fear		See Table 1 (broilers)
			Availability of environmental enrichment	See Table 1 (broilers)
			Light intensity, flicker frequency and composition	See Table 1 (broilers)
			Availability of covered veranda or outdoor range	See Table 1 (broilers)

Table 3 Long-list of welfare indicators relating to welfare during the **hatchery phase of broiler chickens and the transport of day-old chickens to the broiler farm**, including a justification for each indicator. Principles and criteria refer to the framework of the Welfare Quality® assessment protocols [17]. Empty cells indicate the absence of potential indicators. In case the justification is similar for day old chicks and broiler chickens, we refer to Table 1 (broiler chickens).

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
Good feeding	Absence of prolonged hunger		Early feeding	A too long post-hatch feed deprivation or a combination of post-hatch feed deprivation and unfavourable environmental conditions may increase mortality (1st week and total mortality) [6]
	Absence of prolonged thirst		Water provision	Water deprivation post-hatch can cause dehydration [6]
Good housing	Comfort around resting	Proportion of chickens showing undisturbed resting (hatchery and transport)		Handling and transport conditions may disturb resting behaviour (Expert opinion in [20])
			On-farm hatching	Air quality (dust, gaseous concentrations), wind speed, temperature and humidity in the incubators may negatively affect chicken comfort and performance [94]. With on-farm hatching, wind speed and dust/gaseous concentrations are considered to be lower than in the hatchery. Furthermore, transport and handling are (nearly) absent which reduces the risk for disturbance while resting
	Thermal comfort	Cloacal temperature (hatchery and transport)		Cloacal temperature indicates whether or not the environmental temperature is appropriate
		Huddling (hatchery and transport crates)		Huddling indicates a too low environmental temperature [17]
	Ease of movement	Stocking density in crates (hatchery and transport)		Stocking density is generally used as a measure of available space to move around (e.g., [27])
Good health	Absence of injuries	Proportion of second-grade chickens (hatchery) and selection upon arrival at the farm (transport)		Malformed or injured chickens are euthanised upon selection in the hatchery. Good culling procedures may be beneficial for welfare [7], although high culling proportions indicate a welfare problem
		Dead-on-arrival (measured upon arrival at the broiler farm)		Transport is generally considered as a stressor for day-old chickens [95]. Injured or malformed chickens, in case selection was not carried out properly, may die during transport to the farm
	Absence of disease	Dead-on-arrival (measured upon arrival at the broiler farm)		Transport is generally considered as a severe stressor for day-old chickens [95]. Weak chickens, in case culling was not carried out properly, may not be able to survive during transport to the farm
		First week mortality		Day-old chick quality may affect health and thus 1 st week mortality, but rearing conditions on the farm may also affect this [96]
	Absence of pain induced by	Pain due to inadequate		There is currently no valid measure of pain in day-old chicks

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
	management procedures	culling or handling		
			Culling procedures, sexing, vaccinations, disinfection at the hatchery	Handling in the hatchery may cause pain and/or discomfort (e.g. selection of 2 nd grade chickens, vaccination, sexing (not very common in broiler flocks) and disinfection [94, 97-99])
			On-farm hatching	Disinfection and sexing are not carried out with on-farm hatching.
Appropriate behaviour	Expression of social behaviours			
	Expression of other behaviours	Proportion of time spent on species specific behaviours (eating, drinking, resting, active)		Resting, eating and drinking are behaviours that are predominantly observed in the first week after hatching [100]
			On-farm hatching	With on-farm hatching handling and transport are (nearly) absent, and continuous light is provided around hatching, thus chickens are able to perform their natural behaviours such as resting, eating and drinking [97].
	Good human-animal relationship	Expression of fear of humans, e.g. to inadequate handling or culling		There is currently no valid and feasible measure of fear in day-old chicks
		Dead-on-arrival (measured upon arrival at the broiler farm) (hatchery and transport)		Inexpertly or erroneous handling may cause injuries which may lead to increased mortality during transport; inadequate transport conditions may cause dead-on-arrival (expert opinion in [20])
	Positive emotional state	Experience of positive emotions		See table 1 (broilers)
		Expression of fear		See table 1 (broilers). There are currently no feasible methods to assess fear in day-old chicks.

Table 4 Long-list of indicators for **broiler welfare during the end-of-life stage (catching, transportation, stunning and killing)**, including the justification per indicator. Principles and criteria refer to the framework of the Welfare Quality® assessment protocols [17].

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
Good Feeding	Absence of prolonged hunger	Body weight loss		Prolonged feed withdrawal before slaughter causes hunger [101]. Broilers are feed withdrawn before transport to prevent contamination in the processing plant; contamination might cause risk for human health. The duration of feed withdrawal depends on farm management and duration of transport and lairage [17].
			Feed withdrawal time	The longer the feed withdrawal time, the higher the risk for/intensity of feelings of hunger [101]

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
	Absence of prolonged thirst	Body weight loss		Prolonged water withdrawal may cause thirst and dehydration. Broilers are water withdrawn shortly before catching; the duration depends on farm management and duration of transport and lairage [17]. High environmental temperatures during transport may increase the need for water
		Plasma chloride concentration		Plasma chloride concentration was the best indicator to measure effects of dehydration due to transport; concentration increases with increasing water deprivation duration [75]
		Dead-on-arrival		Severe dehydration may lead to mortality during transport [17]
			Water withdrawal time	The longer the water withdrawal time, the higher the risk for prolonged thirst [25]
Good housing	Comfort around resting	Discomfort because of driving the lorry (noise, movements, etc.)		Movements and noises during transport may be stressful and may cause discomfort [102]
			Stocking density in transport containers ¹	A too high stocking density may lead to discomfort for the birds [17], whereas a too low stocking density may increase the risk for injuries when driving [103]; as far as we know there is no literature on critical densities
Thermal comfort		Proportion of birds panting during loading, transport or in lairage		Prolonged panting is a sign of thermal stress, in this way the birds try to prevent overheating caused by too high environmental temperatures [17, 19]
		Proportion of birds huddling during transport or in lairage		Huddling is a sign of discomfort, in this way chickens try to prevent heat loss due to too low environmental temperatures [19]
		Dead-on-arrival		Thermal stress (especially heat stress, or extremely cold conditions) may be one reason of mortality during transport and in lairage [17, 104]
			Environmental temperature and relative humidity in the lorry and in lairage	The combination of temperature and relative humidity determine thermal comfort, together with the stocking density in the containers. Environmental temperatures may highly vary during loading, transport and in lairage [105].
			Stocking density in transport containers ¹	Stocking density in transport containers affects thermoregulation [105]
			M ³ available per bird in the lorry	Not only the two dimensional, but also the three dimensional space in the lorry determines thermal comfort; it affects ventilation and thus thermoregulation [105]
Ease of movement	Proportion of chickens (partially) sitting or standing on each other			Too little space in transport containers ¹ results in birds sitting or standing (partially) on each other, this may lead to injuries, and limited abilities to move [19]
			Stocking density in transport containers ¹	Too little space in transport containers may lead to injuries, limited abilities to move and death [19]; as far as we know there is no literature on critical densities, but minimum area per kg bird is defined in the EU Transport Regulation [106]
			M ³ available per bird in the lorry	Not only the two dimensional but also the three dimensional space affects the ability of the birds to move,

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification	
				although it is advised that broilers should not be able to stand when driving due to risk for falling and injuries. Broilers should be able to sit with the head raised during transport [106]	
Good health	Absence of injuries	% Broilers with trapped limbs (in transport containers ¹)		Trapped limbs are painful and prevent movement of the birds, and may cause injuries [19]. They are caused by inappropriate loading [107].	
		% Supine birds (in transport containers ¹)		Inappropriate loading may cause supine birds [107], this causes serious discomfort [19]	
		% Broiler with bruises		Inappropriate catching, (un)loading and shackling may cause bruises. These are painful for the birds [17, 19]. It has been shown that the majority of bruises is caused by inadequate catching procedures [107]	
		% Broilers with splayed legs		Splayed legs are painful; this can be caused by inadequate catching [107] or broilers not being fit for transport [19]	
		% Broilers with wing fractures and dislocations		Inappropriate catching, unloading and shackling may cause wing fractures and dislocations. These are painful for the birds [17, 19]. The majority of wing fractures and dislocations is caused by inadequate catching and handling [107]	
		% Broilers with leg fractures		Inappropriate catching, unloading and shackling may cause leg fractures. These are painful for the birds [19].	
		% broilers showing exhaustion		The combination of feed and water deprivation, stress due to catching and transport and/or extreme weather conditions may lead to exhaustion [105]	
		Dead-on-arrival %		Inadequate catching and handling may cause injuries and as a consequence dead-on-arrival [108]	
		Absence of disease	Dead-on-arrival %		Ill birds, unfit for transport, may die [19, 108, 109]
		Absence of pain induced by management procedures	Discomfort during stunning and killing (e.g., pre-stun shocks, wing flapping, vocalisations)		With electrical water bath stunning, pre-stun shocks may cause severe discomfort [17, 110]
		Effectiveness of stunning and killing (% broilers being unconscious)		Unconsciousness after stunning may cause severe discomfort; effective stunning causes epileptic seizure, which can be measured with the body posture (eyes open, no rhythmic breathing, neck arched, repeated tremor etc.); absence of tonic seizures, vocalisations, spontaneous eye blinking, wing flapping, corneal reflex and head shaking indicate ineffective stunning [17, 110, 111]	
		% Broilers with trapped limbs (in transport containers ¹)		Trapped limbs are painful and prevent movement of the birds, and may cause injuries [19]. They are caused by inappropriate loading [107].	
		% Supine birds (in transport containers ¹)		Inappropriate loading may cause supine birds [107], this causes serious discomfort [19]	
		% Broiler with bruises		Inappropriate catching, (un)loading and shackling may cause bruises. These are painful for the birds [17, 19, 105]. It has been shown that the	

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
		% Broilers with splayed legs		majority of bruises is caused by inadequate catching procedures [107] Splayed legs are painful; this can be caused by inadequate catching [107] or broilers not being fit for transport [19]
		% Broilers with wing fractures and dislocations		Inappropriate catching, (un)loading and shackling may cause wing fractures and dislocations. These are painful for the birds [17, 19]. The majority of wing fractures and dislocations is caused by inadequate catching and handling [107].
		% Broilers with leg fractures		Inappropriate catching, (un)loading and shackling may cause leg fractures. These are painful for the birds [19].
			Unloading before stunning	Unloading involves a risk for injuries; in some systems, stunning is done in containers and chickens are unloaded when being unconscious [112, 113]
			Unloading system	The unloading procedure, manually or tipping or tilting of containers, can increase the risk for injuries [112, 113]
			Shackling and shackling system	Shackling of conscious birds causes discomfort (e.g. to inversion) and increases the risk for injuries [112, 114]; in addition, shackle size in relation to bird size may cause discomfort
			System for stunning and killing	Gas stunning usually involves a lower risk of ineffective stunning [17, 111] although the induction phase may result in discomfort [113]
			Catching equipment	Crates involve a higher risk of injuries than containers, as it is related to more difficult loading and unloading; as far as we know there is no published information on this
			Catching method	Catching is one of the primary causes of injuries in the end-of-life phase [4]. The risk for injuries decreases when birds are not hold upside down on their legs, but kept in upright position and hold by their body with manual catching [115]; with mechanical catching, settings of the machine are important to reduce the risk for injuries [116]
	Expression of other behaviour ²	Behaviour in containers		Broilers should be able to sit and stand in upright position when motivated, although during transport it is advised that the container should not be of a height that allows birds to stand as this may result in falling and causing injury. The height should allow them to sit comfortably, with the head raised, during transport [106]
			Stocking density in containers	The stocking density in containers affects the ability of the broilers to move. As far as we know, there is no literature on critical densities although maximum stocking densities are defined in the EU Transport Regulation [106]
			M ³ available per broiler in the lorry	The three dimensional space affects the ability of the broiler to stand in an upright position, although during transport it is advised that the

Principle	Criterion	Indicator (animal-based)	Alternative/complementary resource-based or management-based indicator	Justification
				container should not be of a height that allows birds to stand as this may result in falling and causing injury. The height should allow them to sit comfortably, with the head raised, during transport [106]
	Good human-animal relationship	Expression of fear of humans		(Inappropriate) handling (during catching, (un)loading, shackling, stunning, such as dropping of containers, inversion, hanging by one leg, restraint) may cause fear and stress; broilers may show escape attempts and vocalise [117, 118]
			Catching crew and slaughter personnel training	Catching is one of the primary causes of injuries in the end-of-life phase [4]. Training of the catching crew may reduce the risk for fear and injuries. Training of slaughter personnel may reduce the risk for fear and injuries with unloading, shackling [106]
	Positive emotional state	Expression of fear (transport, lairage)		Noises, abrupt movements during transport, in lairage and the slaughter process (tipping, tilting of containers) may cause fear; broilers may show wing flapping, escape attempts and vocalise [117, 118]
		Flapping on the line and vocalisations		In systems with live shackling, flapping on the line and vocalisations indicate fear due to inversion and e.g. abrupt changes of direction [17, 110]
			Lay-out of shackling system (breast support, curves)	Discomfort due to shackling can be reduced by supporting the breast of the birds and excluding curves in the lines [112]

¹ Where containers are written, please read both containers and crates; ² During loading, transport, in lairage and the slaughter process species specific behaviours such as foraging and dustbathing cannot be performed; however, broilers should be able to stand, move and sit when motivated.

3 Selection of key-indicators

The long-lists for the different broiler farming chain stages provide a large number of possible welfare indicators that can be included in the Greenwell sustainability assessment model. Because it is not feasible to collect data for all indicators as suggested in the long-lists, in the second step, key-indicators for each farming stage were selected according to the criteria as described below.

3.1 Impact on welfare

First, the welfare impact of each indicator in the long list was determined according to the methodology described in the text box. To be included in the list of key-indicators, a moderate to severe welfare impact was used as threshold and indicators with a minor impact on welfare were excluded. This means that a threshold value of 4 on a scale from 1-7 for impact (from no impact to very severe impact, see text box below for explanation) was used as criterion for inclusion or exclusion from the key-indicator list.

To determine the impact on welfare

To determine the impact on welfare, the following criteria were applied according to Visser et al. [20] and based on the EFSA risk assessments [5, 7, 119, 120]:

- (1) Estimation of the severity of the welfare issue;
- (2) Estimation of the duration of the welfare issue.

For the definition of durations within the different chain phases we refer to [20]. Briefly, for each stage in the farming chain, definitions were provided for a short, moderate or long duration of the welfare issue. As an example, for the broiler stage, a short duration was defined as being less than 1 day, a moderate duration between 1-3 days and a long duration being more than 3 days exposure to the welfare issue [20].

Definition of severity of welfare issues are as follows according to EFSA [120]:

1. Absent = absence of pain, malaise, frustration, fear or stress;
2. Limited = small deviations from the normal situation that lead to pain, malaise, fear or agitation;
3. Moderate = moderate deviation leading to pain, malaise, fear, agitation, hormonal responses (e.g. adrenal), changes in behaviour such as locomotion responses and vocalisations;
4. Severe = severe deviations from the normal situation leading to pain, malaise, fear, agitation, hormonal responses (e.g. adrenal), changes in behaviour such as locomotion responses and vocalisations (reversible);
5. Very severe = extreme deviations leading to pain, malaise, fear, agitation and disease, death (irreversible).

(1) and (2) determine the total impact on welfare on a scale from 1-7 according to [20], as shown in the table below:

	Absent	Limited	Moderate	Severe	Very severe
Short	1	2	3	4	5
Medium	1	3	4	5	6
Long	1	4	5	6	7

Table Calculation of impact for specific welfare issues based on the severity (X-axis) and duration (Y-axis), according to Visser et al. [20]. Impact scores of 4 and higher were considered for inclusion in the Greenwell welfare assessment model.

3.2 Estimated variation within and between farming systems

Because of one of the aims of the Greenwell project was to use the assessment model also as a 'real time model' (based on data collected in the farming chain and being flock specific), priorities have been defined in the selection of indicators, to select which indicators should be measured real-time and which indicators can be derived from a literature value or random sample. The list of key-indicators should include indicators that are sensitive to variation *between* and *within* broiler farming systems. Indicators with impact on welfare but without sufficient variation can be included, but should not be collected real-time. In the latter case, either a value derived from the literature, or a representative sample (in case no information is present) will be collected. For the list of key-indicators, thresholds of 10% for variation of data within and between farming systems were defined, excluding variation due to seasonal effects and outliers with exceptional high or low values and occurring only once or twice per year. This means that in case of an expected variation less than 10% within and/or between farming systems, indicators are not included in the real-time collection. Variation was defined here as σ^2 and in this stage only estimated (calculations will follow in the next step when data will be collected). This is thus a rather rough and simple way to make a first selection of key-indicators. In case of resource-based or management-based indicators, it was estimated whether or not >10% of the farms varied with respect to presence or absence of a specific resource or management strategy.

3.3 Other considerations

As indicated earlier, animal-based indicators should be included where possible and only in case these were absent or not specific, resource-based or management-based indicators should be selected.

Indicators should be valid, i.e. they should measure the welfare issue. Sometimes many indicators for the same criterion were found. In case these were (considered to be) correlated, only one indicator was used as indicated in Tables 5-8 presented below. Indicators may also relate to multiple welfare issues. To be included in the key-indicator list, these indicators were preferred over indicators relating to a single welfare issue (if more than one indicator was presented for a certain criterion). This improves the feasibility and efficiency of data collection.

Finally, all welfare needs must be addressed. As we worked according to the Welfare Quality framework, we considered all welfare principles as defined by Welfare Quality® [17] equally important and representing the various needs of the animals. This means that the list of key-indicators should at least represent all four principles, unless the impact is estimated was lower than 4. Figure 1 illustrates the different steps in the approach to select key-indicators from the long-lists.

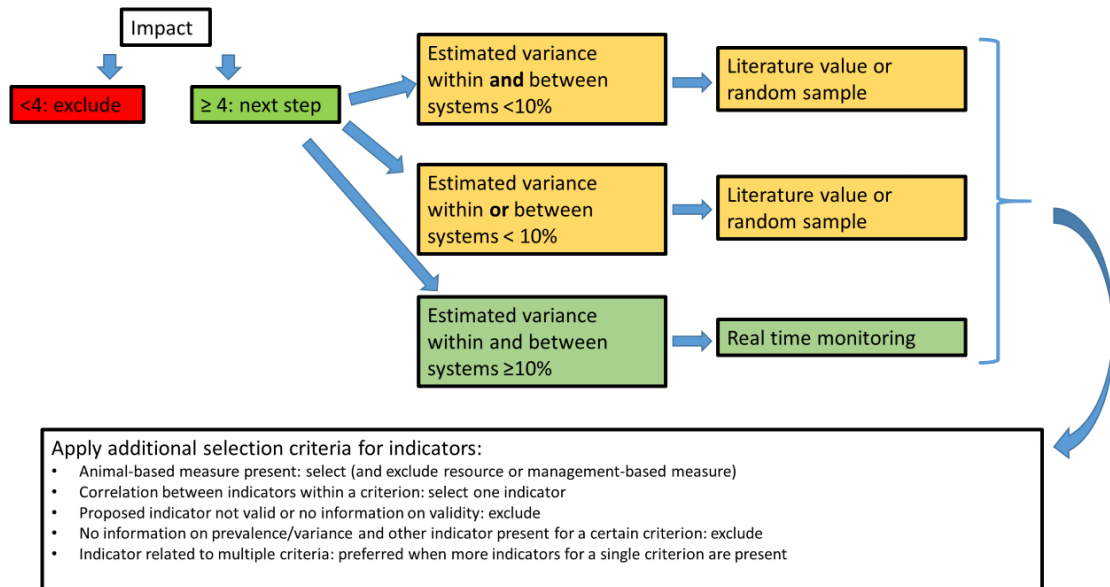


Figure 1 Decision tree for selection of key-indicators from the long lists as defined in Tables 1-4.

3.4 Tables presenting the short lists

Tables 5-8 below summarise the selection criteria to reduce the long-lists of indicators per stage into lists of key-indicators. Each table is built according to the following structure: Welfare Quality® criterion [17] , indicator (these are similar to the indicators in tables 1-4); impact [20], estimated variance within broiler farming systems, estimated variance between broiler farming systems, selection or deletion from the list of key-indicators with justification if necessary. Likewise as for tables 1-4, we start with the broiler on-farm stage and subsequently present the broiler breeder, hatchery and broiler end-of-life stage tables.

In case no impact was defined for a specific welfare issue in [20] we estimated the impact (expert opinion). In case we were not able to provide an estimation of the variance between or within farming systems, it is advised to first collect a random sample and to take a final decision of inclusion in the list/real time data collection afterwards.

Indicators that have been selected for inclusion in the list of key-indicators are presented in bold.

Table 5 Justification of selection of key-indicators for assessment of **broiler welfare on-farm**, based on the long-list as presented in Table 1. For each indicator, the (estimated) impact, the estimated variation within and between broiler systems, whether or not data are available, and the justification for selection or deletion from the list is presented. Selected indicators are presented in **bold**. Empty cells indicate that variation could not be estimated.

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
Absence of prolonged hunger	% emaciated chickens		4	<10%	<10%	Literature value or random sample
		(Duration of) access to feed	4			No Access to feed does not necessarily mean that individual chickens cannot suffer from hunger. Moreover, broiler chickens have usually more or less permanent access to feed.
		On-farm hatching	4	>10%	>10%	Yes This variable mainly relates to the first days post-hatch. In the absence of data on emaciation , it can be used as an alternative measure.
Absence of prolonged thirst	% emaciated chickens	Rejection at the plant specific for cachexia	4			No Rejection for cachexia currently not expressed in proportions, but only qualitative and included in the total rejection figure.
			4	<10%	<10%	Literature value or random sample
		Water access	4			No Access to water does not necessarily mean that individual chickens cannot suffer from thirst. Moreover, restricted water supply likely leads to reduced growth, thus, it is unlikely that broiler chickens may have limited water access during a long period [24].
Comfort around resting	Proportions of broilers resting on an elevated structure	On-farm hatching	4	>10%	>10%	Yes This variable only relates to the first days post-hatch. In the absence of data on emaciation , it can be used as an alternative measure.
		Rejection at the plant specific for cachexia	4			No Rejection for cachexia currently not expressed in proportions, but only qualitative and included in the total rejection figure.
			5⁵	<10%	>10%	Literature value or random sample

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
	Proportion of chickens with dirty plumage		4	<10%	>10%	No Dirty plumage is related to bad litter quality, which causes footpad dermatitis, hock burn and breast irritation [43]. These are included in the key-indicator list.
	Proportion of chickens with footpad dermatitis		6	>10%	>10%	Yes
	Proportion of chickens with hock burn		5	>10%	>10%	Yes
	Proportion of chickens with breast irritation/ blisters		5	<10%	<10%	Literature value or random sample
	Proportion of chickens with bruises		3-4 ³	<10%	<10%	No No literature available on the presence of bruises on broilers (on-farm) and other animal-based measures included
	Proportion of chickens with red skin		4 ⁴			No No literature available on the relationship between red skin and ammonia concentration
	% broilers with thigh scratches		4	>10%	<10%	Literature value or random sample
		Presence of elevated resting areas (perches, platforms)	5 ⁵			No Animal based measures selected as key-indicator and related to quality of resting areas and comfort around resting
		Light schedule	5 ⁵			No Insufficient literature available on the relationship between light schedule and comfort around resting in broiler chickens
		NH ₃ concentration	4 ⁴			No No literature available on the relation between ammonia concentrations and consequences for welfare in broiler chickens
		Dust concentration	4 ⁴			No No literature available on the relation between dust concentration and consequences for comfort around resting in broiler chickens
		Litter quality	4-6 ⁶			No There is a relationship between litter quality and types of contact dermatitis [43]; these are included as key-indicators

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
Thermal comfort	Proportion of chickens panting		4	>10%	<10%	No Although panting is indicative of heat stress, it should be continuously measured to get a reliable impression of heat stress. There are currently no feasible methods to continuously measure panting behaviour
	Mortality caused by heat stress		4	>10%	<10%	No Total mortality is included in the list of key-indicators and includes mortality due to heat stress
	Proportion of chickens huddling		3	<10%	<10%	No
	Proportion of chickens with dirty plumage		4	<10%	>10%	No Dirty plumage is related to bad litter quality, which causes footpad dermatitis, hock burn and breast irritation [43]. These are included in the key-indicator list.
	Bird distribution in the house		3 ⁷	<10%	<10%	No
		Temperature and relative humidity in the house	3-4			No Mortality due to heat stress included in total mortality figure
		Possibility to choose between temperature zones	3-4			No Relationship with thermal comfort needs to be established first
		Litter quality	4-6 ⁶			No There is a relationship between litter quality and types of contact dermatitis [43]. These are included as key-indicators
		Presence of a cooling system	4			No Mortality due to heat stress included in total mortality figure and selected as animal-based measure
		Heating system	3			No There is no literature on the relationship between heating system and comfort around resting
Ease of movement	Maximum stocking density (at any time in the production cycle)		5⁵	>10%	>10%	Yes
		Obstacles	5 ⁵			No No method available to record/score obstacles
		Availability of extra floor space	5 ⁵	<10%	<10%	No

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
		(such as platforms) on top of legally calculated space				Part of environmental enrichment, which is suggested as alternative measure for species specific behaviour and positive emotions (see below)
Absence of injuries	Proportion of chickens with footpad dermatitis		6	>10%	>10%	Yes
	Proportion of chickens with hock burn		5	>10%	>10%	Yes
	Proportion of chickens with breast irritation/blisters		5	<10%	<10%	Literature value or random sample
	Proportion of chickens with locomotion problems (lameness)		4-6³	>10%	>10%	Yes
	Proportion of chickens with bruises		3-4 ³	<10%	<10%	No No literature available on the presence of bruises on broilers (on-farm) and other animal-based measures included.
	Proportion of chickens with wing fractures or dislocations		4	<10%	<10%	No Likely included in selection figures, and thus in total mortality.
	Proportion of chickens with leg fractures		4	<10%	<10%	No Likely included in selection figures, and thus in total mortality.
	Proportion of chickens with injuries (scratches, wounds)		4	>10%	<10%	Literature value or random sample (scratches) Prevalence of wounds is observed to be very low in broiler chickens (de Jong, pers. comm.). Therefore, only scratches are included.
	Mortality		4	>10%	>10%	Yes
	Selection (culling of chickens for reason		4	>10%	>10%	No. Included in total mortality figure, which is included as key measure

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
	of disease and injuries)					
		Rejection (condemnation) percentage at the slaughter plant	5-7 ⁹	>10%	>10%	No Not only related to injuries
Absence of disease	Mortality		4	>10%	>10%	Yes
	Selection (culling for reason of disease or injuries)		4	>10%	>10%	No Included in total mortality figure, which is included as key measure
	Curative antimicrobials use		5-7⁹	>10%	>10%	Yes
		Rejection (condemnation) percentage at the slaughter plant	5-7 ⁹	>10%	>10%	No. Not only related to disease prevalence
Absence of pain induced by management procedures	Proportion of chickens with footpad dermatitis		6	>10%	>10%	Yes
	Proportion of chickens with hock burn		5	>10%	>10%	Yes
	Proportion of chickens with breast irritation/blisters		5	<10%	<10%	Literature value or random sample
	Proportion of chickens with lameness		4-6⁸	>10%	>10%	Yes
	Proportion of chickens with bruises		3-4 ³	<10%	<10%	No No literature available on the presence of bruises on broilers (on-farm) and other animal-based measures included
	Proportion of chickens with wing fractures or dislocations		4	<10%	<10%	No Likely included in selection figures, and thus in total mortality

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
	Proportion of chickens with leg fractures		4	<10%	<10%	No Likely included in selection figures, and thus in total mortality.
	Proportion of chickens with injuries (scratches, wounds)		4	>10%	<10%	Literature value or random sample (scratches) Proportion of wounds is observed to be very low in broiler chickens (de Jong, pers. comm.). Therefore, only scratches are measured.
Expression of social behaviour	Prevalence of injurious pecking behaviour		4	<10%	<10%	No Prevalence of injurious pecking behaviour is estimated to be very low in broiler chicken flocks
	Prevalence of feather damage		4			No Difficult to measure in broiler chickens due to molting and feather growth
	Proportion of chickens with wounds		4	<10%	<10%	No Proportion of wounds is observed to be very low in broiler chickens (de Jong, pers. comm.).
		Rejection (condemnation) percentage at the slaughter plant	5-7 ⁹	>10%	>10%	No. No valid indicator for injuries.
		Provision of environmental enrichment	5 ⁵	>10%	>10%	No Relationship between environmental enrichment and social behaviour has not been described for broiler chickens (in contrast to laying hens)
		Light intensity and composition	5 ⁵			No Currently insufficient information on the relationship between aspects of light and social behaviour
Expression of other behaviours	Proportions of time spent on species specific behaviours		5⁵	>10%	>10%	Yes
	Proportion of chickens with lameness (gait score)		4-6⁸	>10%	>10%	Yes
		Provision of environmental enrichment	5⁵	>10%	>10%	No In the absence of data on time spent on species specific behaviour, this could be registered as alternative measure. There is scientific evidence for the relationship between species specific behaviour and the provision of environmental enrichment [32].

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
		Litter quality	4-6 ⁶			No There is a relationship between litter quality and types of contact dermatitis [43], these are included as key-indicator.
		Presence of covered veranda and/or outdoor range	5 ⁵	>10%	>10%	No In the absence of data on time spent on species specific behaviour, this could be registered as alternative measure. There is scientific evidence for the relationship between species specific behaviour and the provision of a veranda or outdoor range [32].
		Light intensity, flicker frequency, wavelengths, program	5 ⁵			No Currently insufficient information on the relationship between many aspects of light and species specific behaviour; however, a relationship between species specific behaviour and presence of natural light has been shown [68, 121]. In the absence of data on species specific behaviour, natural light can be included as alternative measure.
Good human-animal relationship	Expression of fear of humans		2			No
	Discomfort due to inadequate handling		2 ¹⁰			No
	Discomfort due to inadequate culling		4	<10%	<10%	No No feasible indicator available
		Assurewell flock behaviour score (calm, cautious, fearful)	2 ¹⁰			No
		Stockperson training for handling and culling	2 ¹⁰			No
Positive emotional state	Experience of positive emotions		5 ⁵	>10%	>10%	No There are currently no valid and feasible measures to assess positive emotional state in broiler chickens.
	Expression of fear		2 ¹⁰			No
		Presence of environmental enrichment	5 ⁵	>10%	>10%	Yes In the absence of data on experience of positive emotions, this could be registered as alternative measure. A relationship between presence of environmental enrichment and positive emotions has been suggested [32].

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Justification for selection or exclusion from key-indicator list of Greenwell, or for taking a random sample or literature value instead of real-time monitoring
		Light intensity, flicker frequency, wavelengths, schedule	5 ⁵			Currently insufficient information on the relationship between aspects of light and the presence of positive emotions in chickens
		Presence of covered veranda and/or outdoor range	5 ⁵	>10%	>10%	Yes In the absence of data on experience of positive emotions, this could be registered as an alternative measure. Verandas and outdoor ranges provide environmental enrichment, which has been suggested to stimulate positive emotions in chickens [32].

¹ Impact score according to [20], apart from where a footnote is provided; ² Estimation based on expert/stakeholder opinion; an empty cell indicates that no estimation could be provided; ³ expert opinion; duration medium, severity limited to reasonable; ⁴ expert opinion; duration medium, severity reasonable; ⁵ impact factor of limited behavioural repertoire; ⁶ impact factors of dirty plumage to footpad dermatitis; ⁷ impact factor of hypothermia; ⁸ impact factors of limited activity to leg deformities; ⁹ impact factors of various diseases; ¹⁰ impact factor of fear of humans.

Table 6 Justification of selection of key-indicators for assessment of **broiler breeder welfare** (rearing and laying phase), based on the long-list as presented in Table 2. For each indicator, the (estimated) impact, the estimated variation within and between broiler systems, and the (justification for) selection or deletion from the list is presented (if necessary, in addition to Figure 3.1). Selected indicators are presented in **bold**. Empty cells indicate that variation could not be estimated.

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
Absence of prolonged hunger	Time spent on stereotypic pecking behaviour (rearing)		5	>10%	>10%	Yes
		Male and female genetic line/breed (rearing) and nutritional/feeding management strategies	5			No The level of feed control is breed dependent [72]. However, as within breeds there might be variation due to different feeding programs and management strategies, it is preferred to measure stereotypic behaviour and not register the breed. However, in the absence of data, the breed and feeding management (if known) can be registered.

Criterion	Indicator (animal-based)	Resource-based or management- based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
Absence of prolonged thirst	Water consumption in a test situation		5			No. Test needs to be further developed before implementation [25]
	Drained blood content		5			No. This indicator needs to be developed further before implementation.
		Duration of water provision	5			Yes
Comfort around resting	Quality of sleep		5 ³			No. No method available to determine quality of sleep.
	Proportion of breeders resting on an elevated structure		5³	<10%	<10%	Literature value or random sample
	Proportion of breeders with dirty plumage		2 (rear)-4 (lay)	>10%	<10%	No Dirty plumage is related to bad litter quality, which causes footpad dermatitis [43] which is included in the key-indicator list.
	Proportion of breeders with footpad dermatitis		6	>10%	>10%	Yes
	Proportion of breeders with hock burn		5	<10%	<10%	No Several other indicators included that relate to resting comfort; prevalence is estimated to be very low
	Proportion of breeders with breast blisters		5	>10%	>10%	Yes
	Proportion of breeders with bruises		3-4 ⁴	<10%	<10%	No No literature available on the prevalence of bruises in broiler breeders, but prevalence is estimated to be very low. Several other indicators related to resting comfort present.
	Proportion of breeders with keel bone fractures		5			No Currently no information on the prevalence. Several other indicators related to resting comfort present. Could be included in the future, if more information is present on the actual prevalence in broiler breeders.
	Proportion of breeders with eye irritation		4 ⁵			No No literature available on prevalence of eye irritation due to high ammonia concentrations in broiler breeders. Several other indicators related to resting comfort present.

Criterion	Indicator (animal-based)	Resource-based or management- based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
		Presence of elevated resting areas (perches, platforms)	5 ³			No Animal-based measures present.
		Light/dark schedule	5 ³			No Animal-based measures present.
		NH ₃ concentration	4 ⁵			No No literature available on the relationship between ammonia concentration and resting comfort. Animal-based measures present.
		Dust concentration	4 ⁵			No No literature available on the relationship between actual dust concentrations resting comfort. Animal-based measures present.
		Litter quality	2 (rear)-4 (lay)			No There is a relationship between litter quality and footpad dermatitis [43] which is included in the list of key-measures
		Proportion of breeders panting	3	>10%	<10%	No
Thermal comfort		Mortality caused by heat stress	6 ⁶	>10%	<10%	No Total mortality is included in the list of key-indicators and includes mortality due to heat stress
		Proportion of breeders huddling	3	>10%	<10%	No
		Proportion of breeders with dirty plumage	2 (rear)-4 (lay) ⁶	>10%	<10%	No Dirty plumage is related to bad litter quality, which causes footpad dermatitis [43] which is included in the key-indicator list.
		Bird distribution in the house	3			No
		Temperature and relative humidity	3			No
		Choice between temperature zones	3			No
		Litter quality	2 (rear)-4 (lay)			No There is a relationship between litter quality and footpad dermatitis [43] which is included in the list of key-measures
		Presence of a cooling system	3			No
		Type of heating system	3			No
Ease of movement	Maximum stocking density		5³			Yes

Criterion	Indicator (animal-based)	Resource-based or management- based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
		Obstacles	5 ³			No No method available to record/score obstacles
		Feeder length per bird	3-4 ⁷			No Results in scratches and wounds, which are included
		Availability of extra floor space (such as platforms) on top of legally calculated space	5 ³			No Alternative animal based-measure present
Absence of injuries	Proportion of breeders with footpad dermatitis		6	>10%	>10%	Yes
	Proportion of breeders with hock burn		5	<10%	<10%	No Other indicators for absence of injuries present; prevalence is estimated to be very low
	Proportion of breeders with breast irritation/blisters		5	>10%	>10%	Yes
	Proportion of breeders with locomotion problems (lameness)		4-6⁸	>10%	<10%	Literature value or random sample. No actual figures of prevalence of lameness in breeders available; includes all types of lameness during rear and lay
	Proportion of breeders with bruises		3-4 ⁴	<10%	<10%	No No literature available on the prevalence of bruises in broiler breeders; prevalence estimated to be very low
	Proportion of breeders with wing fractures or dislocations		4	<10%	<10%	No Likely included in selection by the farmer, and thus in total mortality. Prevalence estimated to be very low
	Proportion of breeders with keel bone fractures		5 ³			No Currently no information on the prevalence. Several other indicators related to absence of injuries present. Could be included in the future, if more information is present on the actual prevalence in broiler breeders
	Proportion of breeders with leg fractures		4	<10%	<10%	No Likely included in selection by the farmer, and thus in total mortality. Prevalence estimated to be very low

Criterion	Indicator (animal-based)	Resource-based or management- based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
	Proportion of breeders with injuries (scratches, wounds)		3-4	>10%	<10%	Literature value or random sample Large wounds have an impact of 4
	Total mortality (incl. culling)		4	>10%	>10%	Yes
	Selection (culling)		4	>10%	>10%	No Selection is included in the total mortality figure
		Male and female line/breed	4-6 ⁸			No There is no scientific literature on the relationship between breed and lameness.
Absence of disease	Total mortality (incl. culling)		4	>10%	>10%	Yes
	Selection (culling)		4	>10%	>10%	No Selection is usually included in the total mortality figure
	Curative antimicrobial use (rear and lay)		4-6⁹			Yes Determine variance based on data.
		Proportion of rejections (condemnations) at the slaughter plant	4-6 ⁹	>10%	>10%	No Not only related to diseases [42]
Absence of pain induced by management procedures	Pain due to inadequate handling or culling		2-4			No No indicator for pain available
	Proportion of breeders with footpad dermatitis		6	>10%	>10%	Yes
	Proportion of breeders with hock burn		5	<10%	<10%	No Other indicators for absence of pain induced by management procedures present; prevalence is estimated to be very low
	Proportion of breeders with breast blisters		5	>10%	>10%	Yes

Criterion	Indicator (animal-based)	Resource-based or management- based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
	Proportion of breeders with bruises		3-4 ⁴	<10%	<10%	No No literature available on the prevalence of bruises in broiler breeders; prevalence estimated to be very low
	Proportion of breeders with wing fractures or dislocations		4	<10%	<10%	No. Likely included in selection by the farmer, and thus in total mortality
	Proportion of breeders with leg fractures		4	<10%	<10%	No. Likely included in selection by the farmer, and thus in total mortality.
	Proportion of breeders with keel bone fractures		5 ³			No. Currently no information on the prevalence. Several other indicators related to absence of pain induced by management procedures present. Could be included in the future, if more information is present on the actual prevalence in broiler breeders
	% breeders with injuries (wounds, scratches)		3-4	>10%	<10%	Literature value or random sample Impact factor of large wounds is 4.
	Proportion of breeders with locomotion problems (lameness)		4-6⁸	>10%	<10%	Literature value or random sample No actual figures of prevalence of lameness in breeders available. This includes all types of lameness during rear and la
	Mutilations		3-5	<10%	>10%	Literature value or random sample Breeding companies routinely collect actual data on applied mutilations; these can easily be collected real-time
		Breed/line of males and females	3-5			No Animal based measure included.
Social behaviour	Prevalence of injurious pecking behaviour		3-5 ¹⁰	>10%	<10%	No Consequences (injuries and wounds) are included. In severe cases, it can lead to mortality and culling, which is also included.
	Proportion of breeders with feather damage		4-5	>10%	>10%	No Not only related to social behaviour.
	Prevalence of scratches and wounds		3-4	>10%	<10%	Literature value or random sample Large wounds have an impact factor of 4
		Percentage of rejections	4-6 ⁹	>10%	>10%	No Not related to injuries only [42] and other indicators included

Criterion	Indicator (animal-based)	Resource-based or management- based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
		(condemnations) at the slaughter plant				
		Male:female ratio (lay)	3-5 ¹⁰	<10%	>10%	No Animal based indicator included
		Availability of environmental enrichment	5 ³			No Animal based indicator included
		Light intensity and composition	5 ³			No. The relationship between light intensity, composition and social behaviour is currently not clear. Animal based indicator included
Species specific behaviour	Proportions of time spent on species specific behaviours		5³	<10%	>10%	Literature value or random sample High variation expected, dependent on enrichment and overall management. Random sample preferred
	Proportion of breeders with locomotion problems (lameness)		4-6⁸	>10%	<10%	Literature value or random sample No actual figures of prevalence of lameness in breeders available. This includes all types of lameness during rear and lay
		Availability of environmental enrichment	5³			No Alternative measure of proportion of time spent on species specific behaviours; in the absence of data, the availability can be registered , as breeders generally make good use of elevated resting areas [76, 77] and other enrichments [32]
		Ratio slatted floor: litter floor	5 ³	<10%	<10%	No No literature on relationship with welfare
		Litter quality	2 (rear)-4 (lay)			No There is a relationship between litter quality and footpad dermatitis [43] which is included in the list of key-measures
		Availability of covered veranda or outdoor range	5³	<10%	<10%	No In the absence of data on species-specific behaviour a literature value or random sample can be used. Usually, there is a relationship between the presence of a covered veranda or outdoor and the behaviour of breeders [32]
		Light intensity, flicker frequency, composition	5 ³			No Relationship between light intensity, flicker frequency and composition and species specific behaviour currently unclear
Good human- animal relationship	Expression of fear of humans, e.g. with inadequate handling or culling		2 ¹¹	<10%	<10%	No

Criterion	Indicator (animal-based)	Resource-based or management-based indicator	Impact ¹	Estimated variance within broiler farming systems ²	Estimated variance between broiler farming systems ²	Inclusion (yes) or exclusion (no) from the key-indicator list of Greenwell (real time monitoring), or for taking a random sample or literature value instead of real-time monitoring
	Assurewell flock behaviour score (calm, cautious, fearful)		2 ¹¹			No Measure has not been validated yet.
		Stockperson training for handling and culling	2 ¹¹			No There is no literature on the relationship between training and welfare.
Positive emotional state	Experience of positive emotions		5 ³	>10%	>10%	No Currently no feasible methods to assess positive emotions in commercial flocks
	Expression of fear		2 ¹¹	<10%	<10%	No
		Availability of environmental enrichment	5³			Yes Affects positive emotions [32] and included because of absence of available animal-based measures
		Light intensity, flicker frequency, composition	5 ³			No Affects behaviour but little scientific evidence on actual relationship with positive emotions
		Availability of covered veranda or outdoor range	5³	<10%	<10%	Literature value or random sample Affects positive emotions [32] and included because of absence of available animal based measures

¹ Impact score according to [20], apart from where a footnote is provided; ² Estimation based on expert/stakeholder opinion; an empty cell indicates that no estimation could be provided; ³ impact factor of limited behavioural repertoire; ⁴ expert opinion; duration medium, severity limited to moderate; ⁵ impact of non-infectious respiratory diseases; ⁶ expert opinion; duration moderate, very severe; ⁷ impact factor of (small) scratches and wounds; ⁸ impact factors of limited activity to skeletal deformities; ⁹ impact factors of various diseases; ¹⁰ impact factors of feather damage to injuries; ¹¹ impact factor of fear of humans.

Table 7 Justification of selection of key-indicators for assessment of **broiler welfare during the hatchery phase (including transport of day-old chickens to the farm)**, based on the long-list as presented in Table 3. For each indicator, the (estimated) impact, the estimated variation within and between broiler systems and the (justification for) selection or deletion from the list is presented (if necessary, in addition to figure 3.1). Selected indicators are presented in **bold**.

Criterion	Indicator (animal-based)	Resource- or management based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
Absence of prolonged hunger		Early feeding	5	>10%	>10%	Yes
Absence of prolonged thirst		Water provision	5	>10%	>10%	Yes
Comfort around resting	Proportion of chicks showing undisturbed resting (hatchery and transport)		5			Literature value or random sample Prevalence unknown; likely random sample required
		On-farm hatching	5	>10%	>10%	No Included in assessment protocol for broiler chickens on-farm. In the absence of data on undisturbed resting, on-farm hatching can be registered as an alternative
Thermal comfort	Cloacal temperature (hatchery and transport)		4	<10% (hatchery) <10% (transport)	<10% (hatchery) <10% (transport)	Literature value or random sample
	Huddling (hatchery and transport crates)		4	<10% (hatchery) <10% (transport)	<10% (hatchery) <10% (transport)	No Cloacal temperature is included as animal based measure; chicks showing huddling likely have a too low cloacal temperature
Ease of movement	Stocking density in crates (hatchery and transport)		3-4 ³ (depending on transport duration)	<10%	<10%	No. There is no literature on the relationship between stocking density in transport crates and welfare of day-old chickens; a too low stocking density may cause injuries during transport whereas a too high stocking density may cause discomfort, however, there is no literature on thresholds

Criterion	Indicator (animal-based)	Resource- or management based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
Absence of injuries	Proportion of second-grade chickens (hatchery) and selection upon arrival at the farm (transport)		4-5 ⁴	>10%	<10%	No. Second grade chickens may include other reasons for culling (such as quality), and this is therefore not a related to absence of injuries only
	Dead-on-arrival (measured upon arrival at the broiler farm)		4-5 ⁴	<10%	<10%	No Injured chickens are considered to be included in the selection for second-grade chickens
Absence of disease	Dead-on-arrival (measured upon arrival at the broiler farm)		4-5 ⁴	<10%	<10%	No Ill chickens are considered to be included in the selection for second-grade chickens
		First week mortality	4-5 ⁴	>10%	>10%	No Inadequate environmental conditions on-farm can also cause first week mortality [96], and first week mortality is therefore not a specific measure for absence of disease in day-old chicks
Absence of pain induced by inadequate handling or management procedures	Pain due to inadequate handling or culling		2-5 ⁵			No No method to measure pain in day old-chicks available
		Culling procedures, sexing, vaccinations, disinfection at the hatchery	2-5⁵ (disinfection)			Literature value or random sample Sexing rarely occurs in the Netherlands and Belgium. Other procedures are also reported as stressful events [98, 99] Relationship with absence of pain only reported for disinfection [94]. Culling, if performed adequately, involves only slight discomfort.
		On-farm hatching	5	>10%	>10%	No In the absence of data, it can be registered. Included in protocol for on-farm broiler welfare. With on-farm hatching, handling is minimised and disinfection is not performed [23]

Criterion	Indicator (animal-based)	Resource- or management based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
Expression of other behaviours	Proportion of time spent on species-specific behaviours (eating, drinking, resting, active)		5	>10%	<10%	Literature value or random sample.
		On-farm hatching	5	>10%	>10%	No In the absence of data, on-farm hatching might be registered as this increases possibilities to perform species-specific behaviours
Good human-animal relationship	Expression of fear of humans		2			No
	Dead-on-arrival (measured upon arrival at the broiler farm)		4-5⁴	<10%	<10%	Literature value or random sample
Positive emotional state	Expression of positive emotions		5			No No feasible method available
	Expression of fear		2			No

¹ Impact score according to [20], apart from where a footnote is provided; ² Estimation based on expert/stakeholder opinion; an empty cell indicates that no estimation could be provided.

³ Expert opinion: limited severity – moderate to long duration; ⁴ Expert opinion: moderate to severe effect on welfare – moderate duration); ⁵ Expert opinion: limited to severe effect on welfare – short to moderate duration

Table 8 Justification of selection of key-indicators for assessment of **broiler welfare during the end-of-life stage**, based on the long-list as presented in Table 4. For each indicator, the (estimated) impact, the estimated variation within and between broiler systems, , and the justification for selection or deletion from the list is presented. Selected indicators are presented in **bold**. Empty cells indicate that variation could not be estimated.

Criterion	Indicator (animal-based)	Resource or management-based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
Absence of prolonged hunger	Body weight loss		5	>10%	<10%	Literature value or random sample
		Feed withdrawal time	5	>10%	<10%	No In the absence of data on body weight loss, feed withdrawal time can be registered as alternative
Absence of prolonged thirst	Body weight loss		5	>10%	<10%	No Only in extreme situations body weight loss will occur [75]
	Plasma chloride concentration		5			No This measure needs further development before it can be applied in practice
	Dead-on-arrival		6 ³	>10%	>10%	No Only in extreme situations related to thirst
		Water withdrawal time	5	>10%	<10%	Literature value or random sample
Comfort around resting	Discomfort because of driving the lorry (noise, movements, etc.)		5 ⁴	>10%	<10%	No No feasible and valid indicator available
		Stocking density in transport containers	5 ⁴	<10%	<10%	Random sample or literature value. Variation estimated to be low, as minimum requirements are defined in legislation.
Thermal comfort	Proportion of birds panting during transport or in lairage		4	>10%	<10%	No Thermal stress increases the likelihood for dead-on-arrival, which is included as key-indicator
	Proportion of birds huddling during		3	>10%	<10%	No Huddling is very difficult to measure in transport containers, so no valid measure available

Criterion	Indicator (animal-based)	Resource or management-based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
	transport or in lairage					
	Dead-on-arrival (DOA)		6³	>10%	>10%	Yes More often related to heat stress than to cold stress
		Environmental temperature, relative humidity in the lorry and in lairage	3-4	>10%	<10%	No Animal-based measure (dead-on-arrival) is included as key-indicator
		Stocking density in transport containers	3-4			No Animal-based measure (dead-on-arrival) is included as key-indicator
		M ³ available per bird in the lorry	4			No Animal-based measure (dead-on-arrival) is included as key-indicator
Ease of movement	Proportion of chickens (partially) sitting or standing on each other		5 ⁴			No Difficult to measure on the lorry and expected to be related to the stocking density in the container (number of broilers and kg per container)
		Stocking density in transport containers	5⁴	<10%	<10%	Random sample or literature value. Variation estimated to be low, as minimum requirements are defined in legislation
		M ³ available per bird in the lorry	5 ⁴			No No literature on the relationship between three dimensional space and ease of movement; in addition, possibility for standing implicates a risk for injuries [106]
Absence of injuries	% Broilers with trapped limbs (in the transport containers)		6⁵	>10%	<10%	Random sample or literature value. Prevalence is estimated to be very low [107]
	% Supine birds (in transport containers)		6⁵	<10%	<10%	Random sample or literature value. Difficult to measure. Prevalence is estimated to be very low [87]
	% Broilers with bruises		5-6⁵	>10%	>10%	Yes
	% Broilers with splayed legs		6⁵			Random sample or literature value Prevalence is estimated to be very low [107]

Criterion	Indicator (animal-based)	Resource or management-based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
	% Broilers with wing fractures and dislocations		6	>10%	>10%	Yes (upon arrival at the plant) Highest prevalence of all injuries, and a high variation between and within systems; most fractures occur during catching [107, 122, 123]
	% Broilers with leg fractures		6			Random Sample or literature value. Prevalence estimated to be lower than for wing fractures. Most fractures occur during catching [107, 122]
	Dead-on-arrival %		6³	>10%	>10%	Yes
Absence of disease	Dead-on-arrival %		6³	>10%	>10%	Yes
Absence of pain induced by management procedures	Discomfort during stunning and killing (e.g., pre-stun shocks, wing flapping, vocalisations)		4			No Difficult to measure in a commercial plant, therefore stunning system included instead of the animal-based measure.
	Effectiveness of stunning and killing (% broilers being unconscious)		4			No Difficult to measure in a commercial plant. Gas stunning being more effective than electrical water bath stunning [17, 112], therefore stunning system included instead of the animal-based measure.
	% Broilers with trapped limbs (in the transport containers)		6⁵	>10%	<10%	Random sample or literature value. Prevalence is estimated to be very low [107]
	% Supine birds (in transport containers)		6⁵	<10%	<10%	Random sample or literature value. Difficult to measure. Prevalence is estimated to be very low [87]
	% Broilers with bruises		5-6⁵	>10%	>10%	Yes
	% Broilers with splayed legs		6⁵			Random sample or literature value Prevalence is estimated to be very low [107]

Criterion	Indicator (animal-based)	Resource or management-based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
	% Broilers with wing fractures and dislocations		6	>10%	>10%	Yes (upon arrival at the plant) Highest prevalence of all injuries, and a high variation between and within systems; most fractures occur during catching [107, 122, 123] although fractures may also occur because of unloading and handling
	% Broilers with leg fractures		6			Random Sample or literature value. Prevalence is estimated to be lower than for wing fractures. Most fractures occur during catching [107, 122] although fractures may also occur because of unloading and handling
		Unloading before stunning	3 ⁶			No
		Unloading system	3 ⁶			No
		Shackling system	5			Yes Consciousness or unconsciousness at shackling determines the discomfort as a result of shackling. Although there is variation in discomfort with live shackling, e.g. due to speed or abrupt movements, this is difficult to measure (Gerritzen, pers. comm.)
		System for stunning and killing	4			Yes Discomfort due to stunning and killing is estimated to be related to the type of stunning system
		Catching equipment	6 ⁷			No Injuries due to catching are included.
		Catching method	6 ⁷			No Injuries due to catching are included
Expression of other behaviours	Behaviour in containers		5 ⁴			Literature value or random sample
		Stocking density in containers	5⁴	<10%	<10%	No In the absence of data , stocking density can be registered as an alternative
		M ³ available per bird in the lorry	5 ⁴			No No literature on the relationship between m ³ available per bird and behaviour; in addition, the possibility to stand implicates a risk for injuries [106]
Good human-animal relationship	Expression of fear of humans		5			No Difficult to measure; alternative indicators (injuries due to catching, resource/management based indicators) are included.
		Catching crew and slaughter personnel training	5			No No literature on the relationship between training and fear of humans

Criterion	Indicator (animal-based)	Resource or management-based indicator	Impact ¹	Estimated variation within broiler farming systems ²	Estimated variation between broiler farming systems ²	Justification for selection or deletion from key-indicator list of Greenwell, or for taking a random sample instead of real-time monitoring
Positive emotional state	Expression of fear		5			No Difficult to measure. Resource-based or management-based indicators (e.g., shackling, tilting) are included.
	Flapping on the line and vocalisations		5 ⁸			Yes This may indicate discomfort at live shackling.
		Lay-out of shackling system (breast support, curves)	4			No Shackling as such implicates a welfare risk and is registered. Although the system may alleviate discomfort, no shackling is a larger improvement [112]

¹ Impact score according to [20], apart from where a footnote is provided; ² Estimation based on expert/stakeholder opinion; an empty cell indicates that no estimation could be provided;

³ Impact score of unfit broilers; ⁴ Impact score of disturbed resting; ⁵ Impact score of other injuries, only for small bruises, a lower impact score is assigned; ⁶ Impact score of handling; ⁷ Impact score of injuries due to catching; ⁸ Impact score of fearfulness

4 Summarizing tables

For ease of reading, summarizing tables for each farming stage are presented in Tables 9-13, again starting with the broiler on-farm stage. In these tables each indicator is only presented once and it is indicated whether or not real-time collection should be performed. In addition the tables present information on routine data collection and methods applied.

Table 9 Summarizing table presenting the key indicators for **broilers on-farm**. It is indicated whether or not the indicators are routinely collected and if yes, what methods are applied in practice. The final column indicates to which Welfare Quality® criterion/criteria each variable is linked.

Indicator	Real-time or literature value/random sample	Routinely collected?	Method of routine data collection	Linked to welfare criterion/ criteria:
Proportion of emaciated chickens	Literature value or random sample	No	% flocks with on-farm hatching suggested as alternative indicator (but only relates to the first days after hatching); registered by hatchery and slaughter plant	Absence of prolonged hunger Absence of prolonged thirst
Proportion of chickens with footpad dermatitis	Real-time	Yes	% of chickens with no, mild or severe footpad dermatitis at slaughter ¹	Comfort around resting Absence of injuries Absence of pain induced by management procedures
Proportion of chickens with hock-burn	Real-time	Yes	% of chickens with hock burn at slaughter ²	Comfort around resting Absence of injuries Absence of pain induced by management procedures
Proportion of chickens with breast irritation or blisters	Literature value or random sample	Yes	% of chickens with breast irritation at slaughter ²	Comfort around resting Absence of injuries Absence of pain induced by management procedures
Proportion of chickens with (thigh) scratches	Literature value or random sample	Yes	% chickens with scratches at slaughter ²	Comfort around resting Absence of injuries Absence of pain induced by management procedures
Maximum stocking density (at any moment in the production cycle)	Real-time	Yes	Registered upon slaughter at food chain information form, but limits also set by welfare regulation and concept requirements	Ease of movement
Proportion of chickens with lameness	Real-time	No		Absence of injuries Absence of pain induced by management procedures Expression of other behaviours behaviour
Total mortality	Real-time	Yes	% mortality (including culling) per flock. Registered by the farmer and data collected by the slaughter plant on food chain information form	Absence of injuries Absence of disease
Curative antimicrobials use	Real-time	Yes	% flocks with or without antimicrobials. Registered by the farmer and data collected by the slaughter plant on food chain information form	Absence of disease
Proportion of time spent on species specific behaviours	Real-time	No	% flocks with environmental enrichment, presence of natural light and covered veranda/outdoor range has	Expression of other behaviour Positive emotional state

Indicator	Real-time or literature value/random sample	Routinely collected?	Method of routine data collection	Linked to welfare criterion/criteria:
			been suggested as alternative indicators and are registered by the slaughter plant	
Presence of environmental enrichment	Real time	No		Positive emotional state (alternative for expression of other behaviour)
Presence of covered veranda/outdoor range	Real time	No		Positive emotional state (alternative for expression of other behaviour)

¹ according to National welfare regulations each flock at stocking densities ≥ 39 kg/m² should be scored; slaughter plants may voluntarily register this for each flock; ² standard quality control measures at the slaughter house (<https://docplayer.nl/25574586-Ikb-kip-bijlage-9-beoordelingssysteem-vleeskuikens.html>)

Table 10 Summarizing table presenting the key indicators for the **broiler breeder stage** (rearing and laying phase). It is indicated whether or not the indicators are routinely collected and if yes, what methods are applied in practice. The final column indicates to which Welfare Quality® criterion/criteria each variable is linked.

Indicator	Real-time or literature value/random sample	Routinely collected?	Method of routine data collection	Linked to welfare criterion/criteria:
Prevalence of stereotypic pecking behaviour (rearing)	Real-time	No	Male/female genetic line/breed including alternative feeding/nutritional management strategies is suggested as alternative indicator and linked to the farming system	Absence of prolonged hunger
Duration of water provision	Real-time	No		Absence of prolonged thirst
Proportion of breeders resting on an elevated structure	Literature value or random sample	No		Comfort around resting
Proportion of breeders with footpad dermatitis	Real-time	Yes	4-point scale: score 1, 2, 4, 5 (middle score not used) for increasing evidence of footpad dermatitis in a flock. Qualitative scoring upon slaughter ¹ .	Comfort around resting Absence of injuries Absence of pain induced by management procedures
Proportion of breeders with breast blisters	Real-time	Yes	4-point scale: score 1, 2, 4, 5 (middle score not used) for increasing evidence of breast irritation or blisters in a flock. Qualitative scoring upon slaughter ¹ .	Comfort around resting Absence of injuries Absence of pain induced by management procedures
Maximum stocking density	Real-time	No		Ease of movement
Proportion of breeders with locomotion problems (lameness)	Literature value or random sample	No		Absence of injuries Absence of pain induced by management procedures Species-specific behaviour
Total mortality (incl culling)	Real-time	Yes	% hens found dead and culled % males found dead and culled Separately for rear and lay Registered by the hatchery and nutrition company	Absence of injuries Absence of disease Absence of pain induced by management procedures
Curative antibiotics use	Real-time	Yes	% flocks treated with antibiotics (rear and lay). Registered by the hatchery and nutrition company	Absence of disease

Indicator	Real-time or literature value/random sample	Routinely collected?	Method of routine data collection	Linked to welfare criterion/criteria:
% of breeders with injuries (scratches, wounds)	Literature value or random sample	No		Absence of injuries Absence of pain induced by management procedures Social behaviour
% flocks with mutilations	Real-time	Yes	% flocks with beak treatment (males and females) or toe treatment (males). Registered by the breeding company.	Absence of pain induced by management procedures
Proportion of time spent on species-specific behaviours	Real-time	No	% flocks with environmental enrichment and covered veranda/outdoor range has been suggested as alternative indicator .	Species-specific behaviour Positive emotional state

¹ Voluntarily quality control program by the slaughter plant

Table 11 Summarizing table presenting the key indicators for the **hatchery stage** (including day-old chick transport). It is indicated whether or not the indicators are routinely collected and if yes, what methods are applied in practice. The final column indicates to which Welfare Quality® criterion/criteria each variable is linked.

Indicator	Real-time or literature value/random sample	Routinely collected?	Method of routine data collection	Linked to welfare criterion/criteria:
Early feeding in the hatchery	Real-time	Yes	% flocks with early feeding in the hatchery (hatchery registration)	Absence of prolonged hunger
Water provision in the hatchery	Real-time	Yes	% of flocks with water provision in hatchery (hatchery registration)	Absence of prolonged thirst
Provision of chickens showing undisturbed resting	Real-time	No	% of flock on-farm hatched has been suggested as alternative indicator	Comfort around resting
Cloacal temperature (hatchery and transport)	Literature value or random sample	No		Thermal comfort
Culling procedures, sexing, vaccinations, disinfection at the hatchery	Literature value or random sample	No	% of flock on-farm hatched has been suggested as alternative indicator	Absence of pain induced by management procedures
Proportion of chickens showing species-specific behaviour	Real-time	No	% flocks with on-farm hatching suggested as alternative indicator	Expression of other behaviour
Dead-on-arrival	Literature value or random sample	No		Good human-animal relationship

Table 12 Summarizing table presenting the key indicators for the **end-of-life stage for broiler chickens** (catching until slaughter). It is indicated whether or not the indicators are routinely collected and if yes, what methods are applied in practice. The final column indicates to which Welfare Quality® criterion/criteria each variable is linked.

Indicator	Real-time or literature value/random sample	Routinely collected?	Method of routine data collection	Linked to welfare criterion/criteria:
Body weight loss	Literature value or random sample	No	In the absence of data, feed withdrawal time can be registered as alternative indicator	Absence of prolonged hunger
Water withdrawal time	Literature value or random sample	No		Absence of prolonged thirst

Indicator	Real-time or literature value/random sample	Routinely collected?	Method of routine data collection	Linked to welfare criterion/ criteria:
Stocking density in transport containers	Literature value or random sample	No		Comfort around resting Ease of movement
Dead-on-arrival	Real-time	Yes	% Dead-on-arrival (DOA) routinely collected by the slaughter plant ¹	Thermal comfort Absence of injuries Absence of disease
% broilers with trapped limbs (in transport containers)	Literature value or random sample	No		Absence of injuries Absence of pain induced by management procedures
% Supine birds (in transport containers)	Literature value or random sample	No		Absence of injuries Absence of pain induced by management procedures
% broilers with bruises	Real-time	Yes	% broilers with bruises on breast, wings, legs measured as part of quality control ²	Absence of injuries Absence of pain induced by management procedures
% broilers with splayed legs	Literature value or random sample	No		Absence of injuries Absence of pain induced by management procedures
% broilers with wing fractures and dislocations (after transport)	Real-time	No		Absence of injuries Absence of pain induced by management procedures
% broiler with leg fractures (after transport)	Random sample or literature value	No		Absence of injuries Absence of pain induced by management procedures
Shackling system	Real-time	No	Consciousness or unconsciousness when shackling is dependent on stunning system and can be registered	Absence of pain induced by management procedures Good human-animal relationship
System for stunning and killing	Real-time	Yes	Registered by the plant	Absence of pain induced by management procedures
Behaviour in transport containers	Literature value or random sample	No	Stocking density in transport containers can be registered as alternative indicator	Expression of other behaviours

¹ should be selected ante-mortem by regulation ² standard quality control measures at the slaughter house (<https://docplayer.nl/25574586-Ikb-kip-bijlage-9-beoordelingssysteem-vleeskuikens.html>)

5 Discussion

The current report presents the subsequent steps taken in the Greenwell project [1] to develop a list of key-indicators for animal welfare that can be applied in the sustainability assessment model for broiler farming systems. This includes the four stages in the farming chain, i.e. broiler breeders, hatchery, broiler on-farm and broiler end-of-life stage. There is thus far no generally applied approach to select the indicators that are used to assess animal welfare as part of sustainability. E.g., for broiler chickens on-farm behavioural observations and physiological indicators of stress have been used [15], but also a more extended set of indicators based on the 'five freedoms' [14], whereas others used a limited list based on published data [12] or routinely collected data in different countries [13], or even an overall welfare estimation per farming system [124]. For comparison of sustainability between laying hen farming systems, Van Asselt et al. [11] selected data based on the four principles of the Welfare Quality® poultry protocol [17], although they were only able to use a very limited set of indicators in their calculations for the animal welfare dimension. Here, we also chose to apply the Welfare Quality® [17] as a framework to select possible indicators for welfare in the four selected stages of the farming chain. The rationale behind our approach was that Welfare Quality® has been based on the 'five freedoms', and that all aspects of animal welfare are taken into account when applying the framework of four welfare principles and 12 welfare criteria [2]. We are however aware of the fact that any other approach could also have resulted in a similar set of indicators. Further, in line with Welfare Quality® we intended to include as much as animal-based indicators as possible instead of resource- or management-based indicators, as these are supposed to best reflect the actual welfare state of the animal [2].

For broiler chickens on-farm and the end-of-life stage several assessment protocols exist [16-19], but this is not the case for the hatchery and broiler breeder stage. In addition, as there might have been developments since the publications of existing protocols that require reconsideration of indicators or inclusion of new welfare indicators, we decided to critically review existing broiler on-farm and end-of-life stage protocols and start with a longlist of possible welfare indicators. For the broiler breeder and hatchery stage we started from scratch with similar long-lists. As this inevitably led to a set of indicators which is not feasible to collect in practice, the next step was to select a list of key-indicators. Until here, we followed more or less a similar approach as Van Asselt et al. for laying hens [11]. In Van Asselt et al. [11] the key-indicators were selected based on the following features: measurability, sensitive to variation between housing systems, data availability and being as broad as possible. In contrast to [11], in the current report, data availability was not included as primary selection criterion. Because our welfare assessment model is considered as a starting point and should be improved or completed when possible, we decided also to select key-indicators in case no data are available yet. In case we expected that there would be lack of data, alternative resource- or management- based indicators were included as a temporary solution to overcome the gaps in data and to provide the overall picture of welfare. We however emphasise that we preferred selection of animal-based indicators over resource- or management-based ones as indicated in chapter 1.

Compared to existing assessment protocols for the broiler on-farm and end-of-life stage [16-19], the Greenwell list of key-indicators contains few additional indicators, mainly where existing protocols lack indicators for welfare criteria. E.g., for broiler chickens on-farm, this is the case for the principle 'appropriate behaviour'. We feel that in this way we will meet as much as possible the multidimensional aspect of animal welfare that will help us to get insight in variation between and within farming systems.

Additional criteria for selection of indicators from the long-list were the estimated impact on welfare and sensitivity to variation between and within systems. This led to a list of key-indicators in the current document with at least a moderate impact on welfare according to [20] and based on scientific publications. Indicators that were expected to be sensitive to variation between and within farming systems were selected for real-time assessment. These indicators will likely be sensitive to housing

and management, and thus offer opportunities for welfare improvement and turning trade-offs between welfare and other sustainability dimensions into opportunities for synergistic effects. Other relevant welfare indicators that were not or less sensitive to variation within and/or between farming systems can be included by taking a representative sample or literature value. Thus, these will be included in the welfare assessment model to provide the overall picture of welfare in all its dimensions [2], but do not need to be sampled on a real-time basis. It should be noted that in this stage we only estimated the within and between farming system variation. As soon as data are available, these should be checked for the actual variation and this may lead to an update of the list of key-indicators with respect to sampling frequency.

The next step in the development of the welfare assessment model will be data collection and calculation of indicator scores, as well as an overall welfare score for each of the four selected farming systems. These results will be published in a separate report, which will also cover items such as critical values for indicators with respect to welfare, actual variation for the various indicators and sensitivity of the final welfare assessment model.

5.1 Conclusions

The current report presents the approach of the Greenwell project, to develop a welfare assessment model for broiler farming systems. Based on the Welfare Quality® framework, long-lists of welfare indicators for four farming stages (broiler breeders, hatchery, broilers on-farm and broilers end-of life stage) were used to select a list of key welfare indicators for each stage. It should be noted that the model can be subject to improvement as new indicators or techniques will be developed in the future, e.g., to replace resource- or management-based indicators that were included at the moment to overcome lack of data on animal-based indicators.

6 Acknowledgements

Rick van Emous, Marien Gerritzen, Marc Bracke (Wageningen Livestock Research) and the Greenwell consortium are acknowledged for reviewing the current report.

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