How to House a Hen

Assessing sustainable development

of egg production systems

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Chapter 1
General Introduction

1.1 Background of the study

Sustainability or sustainable development (SusD) is stated as a core element of many government policies, research projects, and corporate strategies (Cornelissen, 2003). Due to the widespread use and the different meanings given to the term 'sustainability', it is discarded as a buzz-word sometimes. There is, however, a common essence in using the term, which originates from the most often quoted definition from the World Commission on Environment and Development (WCED): "SusD meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations" (Brundtland, 1987). Subsequently, in scientific literature many authors gave their own definition, with the result that there is no generally agreed definition. Everybody has a notion of what SusD means in his or her circumstances (Bell and Morse, 2003), although not many people can define it. That is probably the main reason for all these definitions, and clearly stresses that SusD is a 'soft' problem, which means that objectives are unclear and solutions are not initially available (Bell and Morse, 1999). Therefore, it is necessary to first define SusD in broad terms, and, subsequently, come to a more precise and context specific definition with regard to time and space.

In order to define SusD within this thesis, two core elements have been identified. The first element is that "SusD is not a fixed state of harmony, but rather a process of change … consistent with future as well as with present needs" (Brundtland, 1987). This means that we cannot define a sustainable system or product, but that it is necessary to monitor SusD of a process (Cornelissen, 2003). The second element is that SusD relates to economic, ecological, and societal (EES) issues (e.g., Brundtland, 1987; Fresco and Kroonenberg, 1992; Spedding, 1995; Park and Seaton, 1996; Hardi and Zdan, 1997; de Boer and Cornelissen, 2002; Bell and Morse, 2003). Within the domain defined by these core elements, researchers have to find out what people think about SusD in a specific situation. A specific situation can be, e.g., a regional development plan, a sector of industry, or an animal production system. A participatory approach can help to obtain people's opinions, which means that all relevant stakeholders of a certain system are involved in the development of the research project, government policy, or corporate strategy (e.g., Hardi and Zdan, 1997; Bell and Morse, 1999; LNV, 2002; Bell and Morse, 2003; Keijzers, 2003; SER, 2003; LNV, 2005).

In this thesis a methodology to assess SusD of animal production systems will be further developed and applied. For the application we have chosen a case study on egg production, because the upcoming ban on the battery-cage system in 2012 (EC, 1999) forces farmers to change to an alternative, more animal-friendly production system in the near future. At the start of the project, in 2000, more than 75% of the eggs in the Netherlands were produced by hens in battery cages (PVE, 2004). Nowadays, this number has gone down to 56% (Luesink, 2005). This means that many farmers still have to choose an alternative. A decision to introduce a new production system should not be based on one single issue, e.g., animal welfare, as was the case with the ban on the battery cage. In order to prevent future shortcomings on other aspects, the selection of new production systems must consider all EES issues, which together determine the contribution to SusD.

1.2 Objective of the study

The objective of this study is to further develop and apply a methodology to assess the contribution of animal production systems to SusD. Here, a methodology means not a fixed method, which always will lead to a certain type of outcome. It is a general approach, in which different methods are applied. Methodology development and selection of applied methods are based mainly on literature and on earlier work from the Animal Production Systems group, as reflected in the academic course material of the group and in some PhD-theses (e.g., Eilers, 2002; Cornelissen, 2003). The practical use of the methodology is tested in the case study on egg production systems.

1.3 General approach

Assessment of the contribution of animal production systems to SusD implies four steps: (1) description of the situation; (2) identification and definition of relevant EES issues; (3) selection and quantification of suitable sustainability indicators (SI); and (4) final assessment of the contribution to SusD (e.g., Bell and Morse, 1999; de Boer and Cornelissen, 2002). The first step requires that you have to define and describe the system that is subject of study, in our case the egg production system. Stakeholders, who represent the internal and surrounding components (i.e., the context) of a system, are identified. These stakeholders are involved in the second step, the identification and definition of relevant EES issues. This step can be supplemented with information from literature. During the third step, issues are made measurable by selecting SI, which are quantified. For the case study, this means that data have to be collected in the field, i.e. on farm, from different egg production systems, characterized by differences in housing system. The fourth step encompasses the final assessment, which means that all information is combined to determine the final contribution of the system to sustainable development.

1.4 Outline of the thesis

The outline of the thesis follows the four steps of the mentioned methodology.

Chapter 2 describes the first two steps of the methodology, the description of the situation, and the identification and definition of relevant EES issues. This chapter starts with a short overview of the historical development of housing systems for egg production, followed by a description of the system under study. Subsequently, we identified stakeholders, based on a flowchart of the egg production system, and invited them for a workshop to identify the relevant EES issues. The results from the workshop, supplemented with literature review, resulted in a list of EES issues for further research.

Chapter 3 describes an example of the selection of appropriate SI. This is illustrated with the issue animal welfare, because this issue cannot be assessed easily on a large number of commercial farms. Furthermore, animal welfare is an important issue, as it was the main reason for banning the battery cage. The most easily applicable method to assess animal welfare is the animal needs index (Striezel, 1994). This method, however, is an environment-based method, which means that it scores features of the environment and management. Before being applied as a final SI, this method, therefore, had to be validated with animal-based methods, which score animals' responses to the environment and management more directly (Sandøe et al., 1997).

Chapter 4 describes an in-depth study on the incidence of *Salmonella* contaminations of laying hens, the main threat regarding food safety in egg production. Objective of the analysis was to identify risk factors associated with *Salmonella* infection in laying hens, like housing system, flock size, or season. In contrast to the original plan, collecting data on all issues on the same group of farms, this study was based on an existing data set. The main shortcomings of this approach are that data on different issues cannot be collected from the same farms, and that not for all issues data sets are available. The main advantage is that data from more farms and over a longer period are available. We resorted to this approach, because during spring and summer 2003 it was not possible to visit farms, due to the Avian Influenza outbreak in the Netherlands. Fortunately, the Avian Influenza outbreak was controlled quite soon, so on-farm data collection could take place in spring and summer 2004.

Chapter 5 describes the third step of the methodology, the selection and quantification of suitable SI for all issues. We compared commercial farms with the four housing systems for laying hens that were most common in the Netherlands, i.e., the battery-cage system, the deep-litter system with and without outdoor run, and the aviary system with outdoor run.

Chapter 6 presents an ethical reflection on the whole methodology, with special emphasis on the fourth step of the methodology, the final assessment of the contribution to SusD. We did not accomplish this step fully, but we chose to select five indicators to show the consequences of different choices with regard to integration. Main discussion points are the way of selection of issues and indicators, the level of aggregation, which is determined mainly by the final users of the results, and, who should determine the reference values and weighing factors, in case aggregation is used.

Chapter 7 discusses the results of the case study and formulates the main conclusions. Main discussion points are the context specific character of assessment of SusD; the selection of issues and SI, with special attention for some neglected issues; and the (future) use of the methodology and results, with special attention for the level of aggregation of final results, and the level of participation of stakeholders.

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Chapter 2
Identifying sustainability issues using participatory SWOT analysis: A case study of egg production in the Netherlands

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Abstract

This paper demonstrates how participatory strengths, weaknesses, opportunities and threats (SWOT) analysis can be used to identify relevant economic, ecological and societal (EES) issues for the assessment of sustainable development. This is illustrated by the case of egg production in the Netherlands. Participatory methods are used to facilitate the exchange of ideas, experiences and knowledge of all relevant stakeholders and to create a basis for implementation of the final results. It can be concluded that the combination of a brainstorming session and SWOT analysis with a heterogeneous group of stakeholders constitutes a useful tool to order and structure these listed aspects and to identify relevant issues for sustainable development. Final selection of EES issues from the SWOT analysis, however, required additional reviewing of the literature and consultation with experts from specific fields. Final EES issues selected in the case study of Dutch egg production include animal welfare and health, environment, quality, ergonomics, economics, consumer concerns, and knowledge and innovation.

2.1 Introduction

Since the Second World War, egg production in the Netherlands has intensified due to an increase in farm size, animal productivity, and the number of animals per unit of labour. Intensification was mainly caused by large-scale introduction of battery cages around 1960 (Blokhuis and Haye, 1986). Introduction of battery cages, however, resulted in societal criticism directed mainly at the welfare of laying hens. Public concern for animal welfare in the Netherlands and other northern European countries stimulated development of new production systems, such as enriched-cage systems; alternative systems, with or without outdoor run; and organic egg production systems (EC, 1999a; b).

In Europe, this public concern resulted in legislation favouring the application of 'animal-friendly' production systems and, finally, in a ban on battery cages from January 2012 (EC, 1999a). An example of an alternative, 'animal-friendly' system is the aviary system (Groot Koerkamp, 1998). Compared with battery cages, however, the aviary system has several adverse consequences, such as higher ammonia emission (Groot Koerkamp, 1998), higher energy costs for lighting (van Horne, 1994), and worse working conditions for the producer (van den Top et al., 1995). Research is generally focused on only one of the consequences, e.g., the environmental impact of poultry production (Groot Koerkamp, 1998; de Boer et al., 2000), economic performance of poultry systems (van Horne, 1996), or assessment of animal welfare (Gunnarsson, 2000). A decision to introduce new production systems, however, must be based on their combined economic, ecological and societal performance, i.e., on their contribution to sustainable development (de Boer and Cornelissen, 2002).

Assessment of the contribution of animal-production systems to sustainable development implies four steps (e.g., Bell and Morse, 1999; de Boer and Cornelissen, 2002):
(1) description of the (problem) situation;
(2) identification and definition of relevant economic, ecological and societal (EES) issues;
(3) selection and quantification of suitable sustainability indicators; and
(4) aggregation of indicator information into an overall contribution to sustainable development.

The aim of this paper is to demonstrate how participatory strengths, weaknesses, opportunities and threats (SWOT, Balamuralikrishna and Dugger, 1995) analysis can be used to identify relevant EES issues for assessment of sustainable development (step 2). This aim is illustrated by the case of egg production in the Netherlands. To demonstrate this aim, however, we first describe the (problem) situation of the case study (step 1), which requires knowledge about the historical development of the egg production sector.

2.2 Historical overview

2.2.1 Political developments

Laying hens have been housed in single cages since the 1920s. The expansion in the use of battery cages, however, started in the UK in the 1950s, when more than one hen was kept per cage (Brambell, 1965). In the Netherlands, it was not before the 1960s that cages were introduced on a large scale, because until then they had been too expensive for small farms (Ketelaars, 1992).

In 1965, the Brambell Committee wrote a report on the welfare of animals kept under intensive livestock-husbandry systems (Brambell, 1965), in which it objected to strict confinement of hens in cages (among other things). But the Committee also noted that the only real alternative to the cage system was the deep-litter system, which had two shortcomings. First, it is essential that the litter is always dry, which is difficult to achieve in practice. Second, the hen is not provided with protection from other hens. With these shortcomings in mind, the Committee concluded that a modified battery system might be as good as or better than loose housing, so prohibition of the battery cage was not justified at that time (Brambell, 1965). In 1975, a committee in the Netherlands also recommended constructing a modified battery cage that met the demands of animal welfare, profitability and labour conditions (Verkaik, 1975).

In 1979, the Minister of Agriculture of the Netherlands discussed a possible ban on battery cages, and the Council of Ministers of Agriculture of the European Community ordered research on the possibilities of such a ban in Europe. In 1980, they reached agreement only on minimum demands for dimensions of cages. Area per hen was set at 400 cm^2 , which increased to 450 cm^2 in 1988 for newly built cages, and in 1995 for all cages (Ketelaars, 1992). In July 1999, it was laid down that from January 2003 all battery cages must have at least 550 cm^2 per hen and no new battery cages should be built or brought into service. From January 2012, in

Europe all battery-cage systems will be prohibited, and only enriched-cage and alternative (loose-housing) systems will be allowed (EC, 1999a).

2.2.2 Technical developments

In England, Bareham (1976) published the design of an experimental cage for six layers, containing a laying nest with litter, which had to be used for laying eggs as well as for scratching and dustbathing. Research until 1983 resulted in a type of enriched cage with economic results that could almost equal those of battery cages if problems with the sandboxes were to be solved. Too many eggs were laid in sandboxes, which led to high numbers of second-grade eggs, and much sand was lost from the sandboxes. Other problems were concerned with labour conditions, poor surveyability, and difficulties with catching hens (Blokhuis and Haye, 1986). Due to the disappointing results with enriched cages, researchers began to develop an animal-friendly and economically feasible loose-housing system. This resulted in the tiered-wire-floor system, an aviary-type system (Anonymous, 1988). During the following years, the enriched-cage and aviary systems have been further developed in research and by commercial parties. Simultaneously, several types of aviary systems were brought into practice.

2.3 Materials and methods

Relevant EES issues were identified using participatory SWOT analysis. To perform a participatory SWOT analysis, a meeting was organized with participants from the egg production sector in the Netherlands. Participants were representatives from relevant stakeholder groups, i.e., the farmers' union, feed industry, retailers, non-governmental organizations, policy makers and researchers. Participatory methods were used to facilitate the exchange of ideas, experiences and knowledge of all relevant stakeholders and to create a basis for implementation of the final results (Chambers et al., 1989).

2.3.1 Identification of stakeholders

A diverse and representative SWOT analysis can be obtained only if a heterogeneous group of stakeholders is involved. Involving different stakeholders in a SWOT analysis maximizes the chances of completing a list of relevant EES issues. In addition, it is important to reach consensus among all stakeholders on which items to include in the analysis of production systems. Stakeholders are defined as 'those individuals or groups who depend on the organization to fulfil their own goals, and on whom, in turn, the organization depends. Typically, they include shareholders, customers, suppliers, banks, employees and the community at large' (Johnson and Scholes, 1997).

In the case study the organization was the egg production system, as depicted in Figure 2.1. Relevant inputs, outputs, subsystems and flows were presented in the flowchart. Not only material flows, but also non-material flows (e.g., information) were included, because the analysis was focused on a broad identification of the parties involved. After completing the flowchart, stakeholders were identified who could represent the different components. For some components, researchers working in that specific field were also included. In this way, a heterogeneous group of stakeholders was obtained. We chose to include only those components, and thus stakeholders, that were closely related to the primary production system (marked by the dotted line in Figure 2.1), because these components are particularly influenced by the introduction of new housing systems. In total, 18 participants were invited for the meeting. These participants represented the animal-nutrition sector, the animal-protection society, environmental-protection groups, extension services, farmers, financiers/banks, the ministry of agriculture, the product board, retail and industry (3) and veterinarians. Next to these direct representatives of stakeholders, researchers with experience in animal nutrition, animal welfare (2), environmental impact, labour conditions, organic agriculture, and systems research were invited as well.

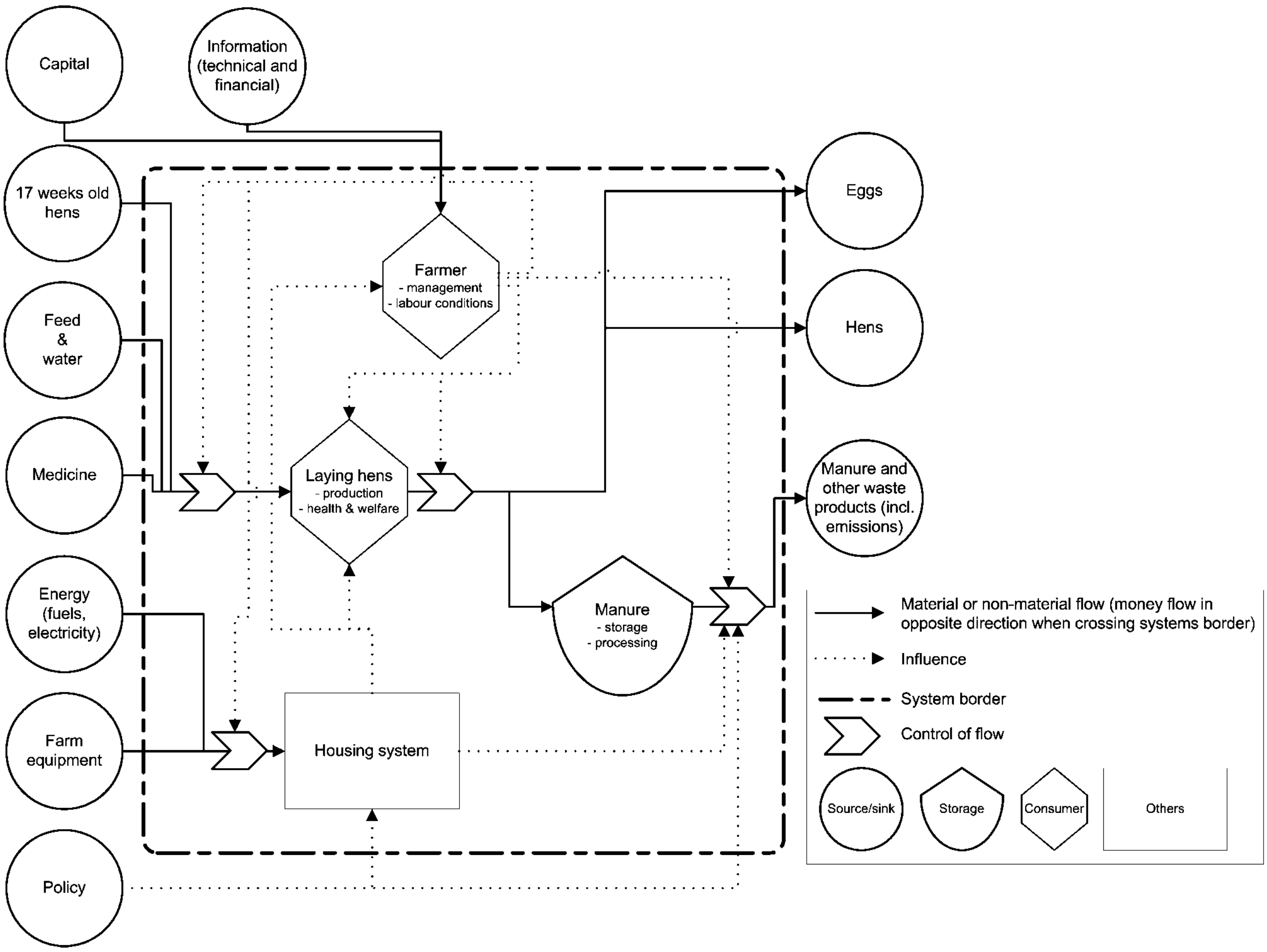

Figure 2.1. Flowchart of the egg production system.

2.3.2 Participatory SWOT analysis

The participatory SWOT analysis started with a brainstorming session to list relevant aspects for sustainable development of Dutch egg production in general. Brainstorming is a recognized idea-generating technique, in which any idea that comes up is recorded (Phillips et al., 1999). By using this method, it is possible to collect all important aspects before participants start a discussion on details. During the brainstorming session, aspects were clustered into issues. These clustered issues were the starting point for the SWOT analysis of the current situation regarding egg production in the Netherlands. Because over 75% of the hens were still kept in battery cages (PVE, 2002), this meant that the SWOT analysis was mainly directed at battery-cage systems.

Subsequently, a participatory SWOT analysis was used to order and structure clustered issues, by determining their internal or external character and their positive or negative contribution. A participatory SWOT analysis, therefore, considers the case study's internal strengths and weaknesses, as well as its external opportunities and threats (Figure 2.2). An easy distinction between internal and external issues is the influence of the farmer (Eilers et al., 2001). If the farmer can influence the issue, e.g., the feeding regime, it is internal, if not, e.g., governmental policy, it is external. In addition, the internal situation should only be discussed on the basis of what exists now. The external environment, however, should take into account the actual situation as well as probable trends (Horn et al., 1994).

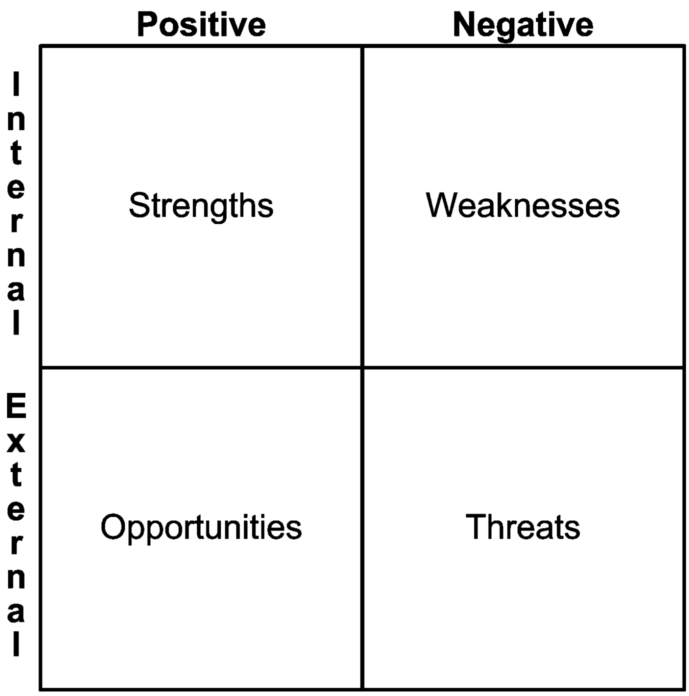

Figure 2.2. SWOT analysis.

2.3.3 Selection of EES issues from SWOT

Not only weaknesses and threats are relevant with respect to sustainable development, but strengths and opportunities should also be included. Current strengths and opportunities must be maintained regarding sustainable development of production systems. EES issues for assessing sustainable development were selected after a review of literature and consultation with experts on some topics. As a result, SWOT issues could be split or merged into EES issues. The result of this procedure was a list of EES issues (Figure 2.3) that could be used to define measurable indicators for sustainable development.

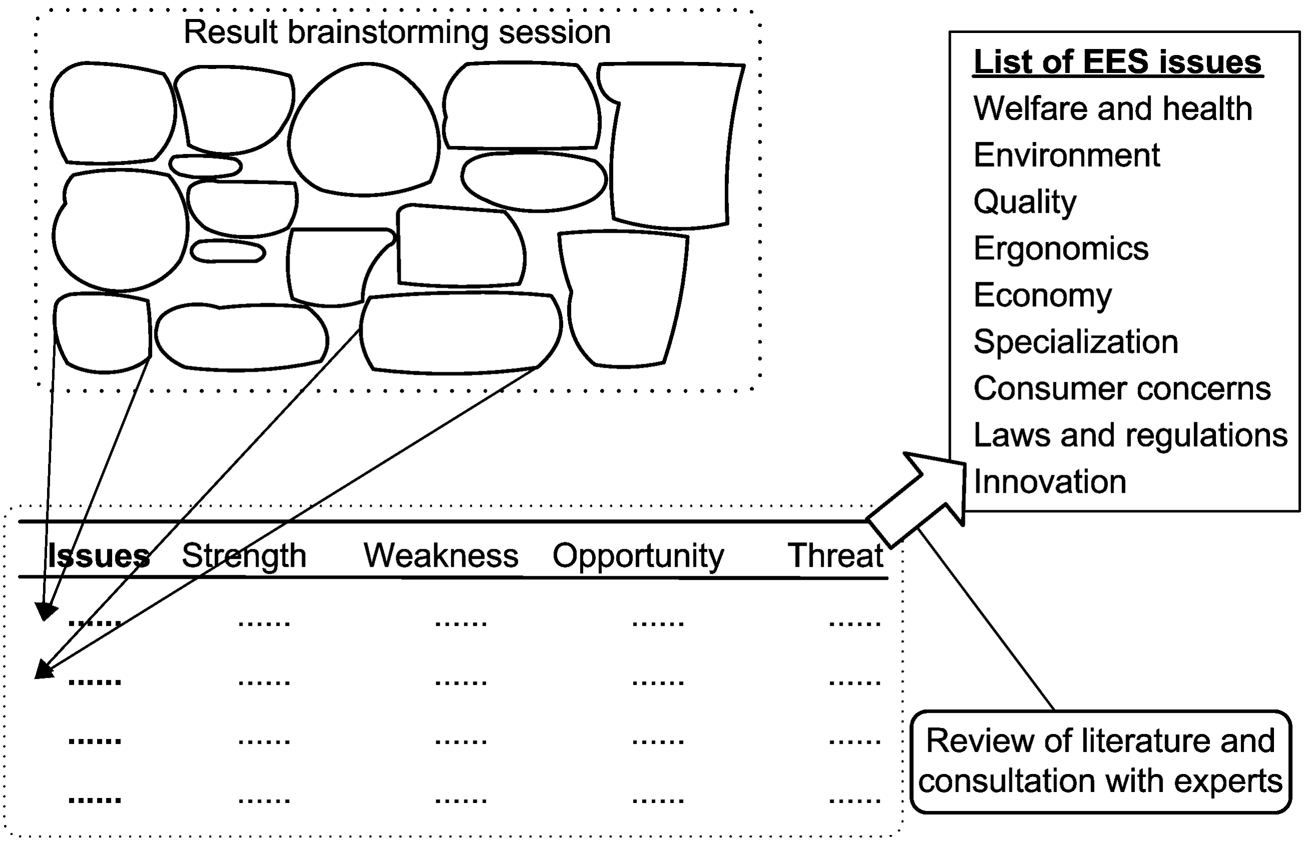

Figure 2.3. From participatory SWOT analysis to list of issues.

2.4 Results and discussion

2.4.1 Participatory SWOT analysis

Figure 2.4 shows clustered aspects, as put forward by different participants. These clusters were called 'SWOT issues', as these issues were the starting point for the participatory SWOT analysis. For each SWOT issue, participants determined its position in the SWOT analysis by agreeing on the issue's internal or external character and on the positive or negative contribution of the battery-cage system to the SWOT issue (Table 2.1).

Figure 2.4. Results of brainstorming session.

2.4.2 Identification of EES issues

EES issues were selected on the basis of the results of the participatory SWOT analysis, subsequent literature review and expert consultation. This procedure means that the following discussion is a combination of the knowledge of participants and experts, and information from the literature.

Welfare and health

Societal concerns about animal welfare started the discussion on production systems for laying hens and finally resulted in legislation to prohibit battery-cage systems. This discussion was mainly directed at the narrow confinement, lack of opportunities to perform species-specific behaviour, such as nesting and dustbathing, debeaking, and lack of access to outdoor runs (Table 2.1). The Farm Animal Welfare Council (1992), however, stated that these were not the only aspects a production system has to comply with. The Council formulated five freedoms: freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury or diseases; freedom to express normal behaviour; and freedom from fear and distress. In accordance with these five freedoms, animal health is part of animal welfare and, therefore, they are discussed together as one issue. Considering animal health, the lower chance of infection, due to less contact with manure and contact with only a few hens, is almost always presented as one of the strengths of cage systems. A weakness of cage systems that has to be taken into account, however, is the risk of osteoporosis (Table 2.1).

Table 2.1. Result of participatory SWOT analysis of battery-cage systems.

SWOT issue	Strength	Weakness	Opportunity	Threat
Animal welfare	Small group size	Narrow confinement No opportunities for species specific behaviour Debeaking still necessary No outdoor runs		
Animal health	Low disease incidence Epidemiologically favourable group size	Osteoporosis		
Lifespan		1 year production is quite short Killing day-old cocks		
Environment	Low emissions Low dir. energy use Good quality manure Little noise	Long-distance transport of feed No land available for manuring		
Animal feed	No use of medicine in feed	Use of by-products is low		
Quality	High external and internal quality	Too little certification	Introduce quality assurance (e.g., HACCP) Tracking & tracing	Low ‘emotional quality’
Ergonomics	No floor eggs to collect	Dust and endotoxines Red mites		Diminishing availability of pesticides
Economy	Low cost price			‘Trade marks’ only within EU
Specialization	High degree of specialization	Dependency on chain partners	Improved communication with chain partners	
Consumer concerns				Bad communication Bad image Lack of transparency
Laws and regulations				Tendency to move ahead faster than EU Spatial planning
Innovation	High level of knowledge and expertise			Effect on image when alternative systems become industrialized

The last SWOT issue closely related to animal health and welfare is lifespan. Laying hens are usually kept for one production cycle and are slaughtered at the age of about 77 weeks (KWIN, 1999). To take a hen into the next production cycle, however, it must moult, which is usually achieved by depriving it of water and feed for some days. Because of legislation on animal welfare, one must supply animals with sufficient and appropriate feed and water (LNV, 1999) and therefore this way of bringing about moulting is not allowed. The lifespan of cocks is even shorter, as they are killed as day-old cocks.

Because the SWOT issues, animal welfare, animal health and lifespan are so closely related to each other, they are merged into one issue, i.e., welfare and health. This means that all aspects mentioned here have to be taken into account when searching for one or more indicators for animal welfare and health.

Environment

Environmental issues mentioned during the meeting were related to emissions, energy use, feed production and manure application (Table 2.1). The most important emission from poultry houses is ammonia. It contributes to acidification and eutrophication (Cowling et al., 1998). Ammonia emission per hen from the stable is relatively low in cage systems, but increases with increasing surface area per hen, and with the introduction of litter and free-range systems (alternative systems with outdoor run). Daily removal of manure from the belts, a thin layer of dry litter, and a good climate in the hen house can reduce ammonia emission (Groot Koerkamp, 1995). Considering ammonia emission, however, it is not only the emission from the stable (including storage) that must be taken into account, but also emission during the spreading of manure on the field. This field emission contributes over 40% to the total ammonia emission from poultry production (Pain et al., 1998).

Energy use influences global warming and exhaustion of natural resources. It can be divided into direct and indirect energy use (Pimentel, 1992). Direct energy use (with energy supplied as fuel, gas or electricity directly on the farm) is considered to be rather low for all types of egg production systems. Indirect energy use (energy used to produce equipment and other goods and services that are used on the farm) is high, and is mainly caused by imports of grains for feed production. Opportunities to diminish indirect energy use are scarce, because it is difficult to use large amounts of by-products, especially waste products, in poultry feed (El Boushy and van der Poel, 1994, Table 1, Animal feed).

Leaching of nutrients from the soil causes eutrophication. Leaching occurs from the field, mostly outside the farm, on which the manure is spread and from the outdoor run. Leaching from the outdoor run is a bigger problem when hens stay close to the house (Appleby and Hughes, 1991) and, consequently, manure is not evenly divided over the outdoor run. When the run is made more attractive by providing bushes or shelters, the hens, and thus the manure, will be spread more widely over the outdoor run.

Aquatic and terrestrial ecotoxicity of pesticides is also an environmental problem. Use of pesticides in feed production, however, is difficult to estimate, because most feed is grown abroad and data are hard to obtain.

In conclusion, environmental pollution can be divided into different aspects, such as acidification, eutrophication, global warming, aquatic and terrestrial ecotoxicity, and land use. As can be noted from this discussion, the environmental impact of feed production and manure application contributes considerably to the environmental impact of egg production. Therefore, environmental impact assessment should not be restricted to the farm level, but should also include the impact of inputs and outputs.

Quality

Quality of eggs encompasses three main aspects: 'emotional' quality, external egg quality, and internal egg quality, the last one including food safety. Emotional quality refers to the feelings and thoughts of the consumer about the product, concerning, e.g., the welfare of the hens or environmental pollution by the system. Emotional quality is discussed further in the paragraph on 'consumer concerns'. Certification, quality-assurance schemes, and tracking and tracing (Table 2.1) are means to ensure quality, but are not considered as sustainability issues themselves.

External quality characteristics include egg shape, shell strength, percentage of ridged and cracked eggs, and cleanliness. In battery-cage systems, external egg quality is considered to be high, due to good systems of egg collection (Table 2.1). The proportion of cracked and broken eggs, however, is higher in battery-cage systems than in alternative systems (Leyendecker et al., 2001). Due to the relatively high occurrence of floor eggs (eggs laid outside laying nests), the proportion of dirty eggs, however, is higher in alternative than in battery-cage systems (van Niekerk, 1992b). The summed proportions of dirty eggs, and cracked and broken eggs is higher for alternative than for battery-cage systems (van Niekerk and Ehlhardt, 1995; Leyendecker et al., 2001). Particularly in organic systems, there are also problems with the colour or quality of the shell, possibly caused by viral infections (McCracken and Adair, 1993; McMartin, 1993).

Internal quality characteristics can be divided into sensory quality and food safety. Sensory characteristics are, e.g., yolk colour, smell and taste, and blood and meat spots. Internal egg quality is influenced mainly by farm management, especially feed characteristics, and, therefore, does not differ considerably between egg production systems (van Niekerk, 1992a). Food safety appeared to be the most important aspect of internal quality. Food safety is threatened by residues of medicines after veterinary treatment or contamination in feed, and by microbial contamination. Medicines, however, are rarely used in egg production (Table 2.1, Animal feed), because of the high likelihood of drug residues in the egg (Rougoor et al., 1994). One of the most frequently occurring microbial contaminations is salmonella. At the end of the production period, about 11.5% of the flocks are infected, but even from an infected flock, only one in 1,000 eggs is contaminated (PVE, 2001). From this research, no information on differences between production systems is available. De Boer and Wit (2000) found that less than 0.3% of the eggs in the shops were contaminated. Due to these small numbers nothing can be said about differences between production systems.

In conclusion, external quality and food safety are the most important aspects of the issue quality.

Ergonomics

One of the general definitions of ergonomics is: ‘Ergonomics attempts to design products, technical systems, and tasks in such a manner that safety, health, welfare, and efficient functioning of people is supported’ (van Scheijndel and Voskamp, 2000). For egg production systems, this means that they must be constructed so the farmer or worker can work in a safe, healthy, welfare-friendly and efficient way. From the stakeholder meeting it became clear that the most important factors included ambient conditions, e.g., dust, endotoxins and red mites, and working posture, especially with regard to collecting floor eggs (Table 2.1).

One weakness of all production systems is the high dust and endotoxin concentrations in the house. These concentrations are higher in alternative systems compared with battery-cage systems (Drost et al., 2002), probably due to the presence of litter and free-moving birds. Another factor that must be considered is the presence of the red mite *(Dermanyssus gallina*e) in the different systems (Mårtensson and Lundqvist, 1991). Red mites can cause itching in hens as well as in farmers, so they influence working conditions for the farmers. A threat has been identified in the diminishing availability of ways to deal with vermin (e.g., pesticides, insecticides).

The most important physical problem that farmers experience is pain in the lower back (Ellen et al., 2002), which can be an indication of bad working posture. There are, however, indications that not only physical factors, but also psychosocial factors play an important role (Ellen et al., 2002). The research by Ellen et al. (2002) was carried out in a situation with predominantly battery-cage systems for laying hens. In aviary systems, however, the risks of bad working posture are even greater, due to the gathering of floor eggs and removal of dead hens, especially from underneath the tiers (Drost et al., 2002). Another problem in non-cage systems is that working between the loose-housed hens is less safe, resulting in more injuries and physical problems (van den Top et al., 1995).

Hence ergonomics, with special attention to working posture and ambient conditions such as dust, endotoxins and red mites, have to be regarded as a sustainability issue.

Economics

Labour income is defined as the difference between revenues and costs – excluding costs of labour of the family (van den Tempel and Giesen, 1992). Revenues are a combination of number of eggs and trade prices, which depend on the system in which the eggs are produced. Differences in trade prices are possible due to marketing standards, as established in EU laws (EC, 1999b; 2001), which distinguish between eggs produced in battery, alternative, free-range and organic systems. This differentiation, however, only applies to the EU, so it is expected to be difficult to obtain the higher prices on the world market (Table 2.1). The costs depend on many aspects, among which is the degree of specialization (see next paragraph).

Another economic aspect is farm continuity, which depends on either the resilience of the farm in hard times or the possibility of obtaining extra financing when necessary. The labour income of the last few years and the balance between equity and foreign capital mainly determine farm continuity (van den Tempel and Giesen, 1992). In the end, labour income realized in the past also determines the balance between equity and foreign capital to a large extent. This leads to the conclusion that labour income is the most important economic issue, which should be taken into account when assessing sustainable development.

Specialization

The high degree of specialization in the egg production sector is seen as a strength (Table 2.1), because it provides opportunities to perform better due to more knowledge of a specific part of the production chain and due to costs being divided over larger units. Other advantages for specialized farms are that all time and expertise can be spent on one part of the production chain, and that there are possibilities for cooperation with other specialized farmers, such as arable farmers. Also, from the point of view of logistics, it is favourable to have large specialized farms. There are more possibilities for specialized farms working together on a regional level than for individual mixed farms. Cooperation can lead to higher profits and higher production, without a higher environmental burden (Bos and Van De Ven, 1999).

Specialization, however, is not a sustainability issue, because it does not contribute to the sustainable development of the sector. It can influence many issues, such as economic and environmental performance, but it is not a prerequisite for sustainable development and therefore will not be taken into account in our in-depth analysis.

Consumer concerns

The often stated (e.g., Aarts et al., 2001) contradiction between the wishes of consumers and citizens is seen as a threat. This discrepancy is attributed mainly to bad communication between the sector and consumers (Table 2.1). Most stakeholders saw possibilities in better communication when putting in place eggs from 'new' systems on the market. However, whether an egg is sold or not still depends on people's willingness to pay.

A related problem is the image of egg production in general (Table 2.1). In most systems, the public does not see the chickens; the only things they are aware of are closed buildings, noise of ventilators and the (bad) odour. With closed systems and technical measures (e.g., artificial manure drying), however, at least the noise pollution (Table 2.1, Environment) and ammonia emissions can be kept low. Whether the ammonia emission-reduction measures also influence odour emission is not clear yet (Ogink and Groot Koerkamp, 2001). A disadvantage of these closed systems, however, is the lack of transparency in the production chain (Table 2.1), which causes a big gap between the image consumers have (the 'emotional quality' of the egg) and the actual situation on the farm (Aarts et al., 2001). This can result in very negative as well as very positive images. A specific issue mentioned in the stakeholder meeting was the killing of day-old cocks (Table 2.1, Lifespan), which possibly is unknown to most consumers, but is an everyday practice that could really harm the image of the sector.

Consumer concerns, and especially the image of the different types of eggs, have to be taken into account in an analysis on sustainable development, because, in the end, consumers are the ones who buy the products.

Laws and regulations

The baseline for most (agricultural) laws is European legislation, but some member states (among them the Netherlands) have tended to move ahead faster (Table 2.1), e.g., introducing a total ban on cage systems. Some participants consider this as a threat, because it will be difficult, or even impossible, to exclude cage eggs produced in other countries from the market. This will diminish the competitiveness of the Dutch egg production sector unless marketing activities succeed in creating a big market for non-cage eggs.

Regulations on spatial planning (Table 2.1) are also seen as a threat, because agriculture has to compete with nature, cities and industry for land use. This will become even more of a problem for free-range systems, because they have a higher direct land use.

Laws and regulations, however, are not an issue with regard to sustainable development, but they form the framework wherein different systems can develop.

Knowledge and innovation

The knowledge and expertise level around the conventional cage system is high because there is more than 30 years of experience with this system (Table 2.1). When new systems are introduced, other knowledge is needed. For example, in alternative systems, where animals are housed in larger groups, more animal-directed management is needed. Solutions sometimes can be found in technical developments, but during the development of new systems, a too technical development should be avoided because that would again cause a negative, industrial image (Table 2.1).

Knowledge about how to manage a specific system is necessary to attain good results in economic, ecological and societal terms. Therefore, knowledge and innovation are considered to be a sustainability issue.

2.5 Conclusions

A brainstorming session with a heterogeneous group of stakeholders provides an easy start for a SWOT analysis, through quick listing of relevant aspects for sustainable development. A participatory SWOT analysis subsequently appeared to be a useful tool to order and structure these listed aspects and to identify relevant issues for sustainable development. Final selection of EES issues from a SWOT analysis, however, requires additional reviewing of the literature and consultation with experts from specific fields. EES issues selected for the case study of Dutch egg production included welfare and health, environment, quality, ergonomics, economics, consumer concerns, and knowledge and innovation. From this result, it can be concluded that to assess the contribution of egg production systems to sustainable development, not only animal welfare, but also many other EES issues need to be taken into account.

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Chapter 3
On-farm assessment of laying hen welfare: a comparison of one environment-based and two animal-based methods

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Abstract

Methods available to assess animal welfare at farm level are based on a range of welfare parameters, which can be divided into two categories, environment-based and animal-based parameters. The first category describes features of the environment and management, which can be considered prerequisites for welfare. The second category records animals' responses to that particular environment and management more directly. Objective of this study was to validate a mainly environment-based method, the animal needs index (ANI), with animal-based methods: behavioural observations and feather condition scores (FCS). The study was conducted on 20 commercial laying hen farms, 10 farms with battery cages and 10 farms with deep-litter systems. During a 1-day visit on each farm, the ANI was assessed, FCS was scored, and behavioural observations were performed. Instantaneous scan sampling and continuous focal sampling were used to assess the time spent on different behaviours and the occurrence of event behaviours. Data from behavioural observations and FCS were reduced with principal factor analysis. This resulted in two factors for each method. Significant positive correlations were found between the ANI, on the one hand, and 'movement' and 'comfort', two factors from behavioural observations, on the other hand. A significant negative correlation was found between the ANI and 'wing damage' (from FCS). The results of this study show that the ANI is valid and sensitive enough to show differences in animal welfare between housing systems, whereas differences in welfare within housing systems cannot be shown. In conclusion, the ANI is an appropriate method for assessment of laying hen welfare on a large number of farms with different housing systems.

3.1 Introduction

During the last decades, several new housing systems for laying hens have been developed. The main focus in developing these systems was improvement of animal welfare. Large-scale introduction of alternative housing systems, however, should not be based on animal welfare only, but on their contribution to sustainable development, which encompasses economic, ecological and societal issues (de Boer and Cornelissen, 2002). On-farm quantification of sustainability indicators is an approach to assess the contribution of (animal-friendly) production systems to sustainable development. In order to show significant differences in contribution of various housing systems to sustainable development, it is necessary to quantify the within and between housing systems variation for each indicator. Hence, for each issue relevant for sustainable development, we need an indicator that can be quantified easily on a large number of farms. Although it is necessary to determine sustainability indicators for all relevant issues (Mollenhorst and de Boer, 2004), this paper focuses on animal welfare only.

In developing new housing systems, focus has been so much on increasing space allowance and environmental enrichment, that other aspects of animal welfare were neglected. Problems with feather pecking and cannibalism, for instance, can be larger in alternative systems than in battery cages (Savory, 1995; Koene, 1997; Green et al., 2000; McAdie and Keeling, 2000; Pötzsch et al., 2001). Therefore, it is still doubtful whether these new systems improve the welfare of hens as much as supposed. A careful assessment of the welfare of hens in these new systems is necessary.

Methods available to assess animal welfare at farm level are based on a range of welfare parameters, which can be divided into two categories, environment-based and animal-based parameters (Johnsen et al., 2001). This corresponds with the division in design and performance criteria (Rushen and de Passillé, 1992). The first category describes features of the environment and management, which can be considered prerequisites for welfare. The second category records animals' responses to that particular environment and management more directly (Sandøe et al., 1997). Disadvantage of most animal-based parameters is that recording is difficult and demands considerable resources (e.g., time and money), whereas quantifying environment-based parameters is quite easy and demands less resources (Bartussek, 2001; Johnsen et al., 2001).

Few methods exist that assess animal welfare at farm level, and even less focus on laying hens (see reviews by e.g., Rushen and de Passillé, 1992; Bracke et al., 1999; Johnsen et al., 2001). The only comprehensive on-farm assessment method for laying hen welfare used in practice is the animal needs index (ANI), of which two types are available (ANI-200, Sundrum et al. (1994) and ANI-35L, Bartussek (1999)). This method is based mainly on environment-based parameters, even though an animal-based parameter, feather condition, is included.

In order to validate the ANI for assessing animal welfare, animal-based methods were sought, which were applicable in on-farm situations without disturbing the hens too much and within reasonable costs. Feather condition scores (FCS, Bilcík and Keeling, 1999) and behavioural observations comply with these criteria. Until now, similar evaluation studies were published for veal calves and dairy cows only. Bokkers and Koene (2001) showed significant correlations between the ANI and behavioural and slaughter data for veal calves. Alban et al. (2001) found a relation between the ANI and animal health data for dairy cows. These results indicate the validity of the ANI in general. Objective of this study was to validate the ANI-200 for laying hens with behavioural observations and FCS, based on data from 20 commercial laying hen farms, of which half had a battery-cage system and half a deep-litter system.

3.2 Materials and methods

3.2.1 Data collection

Data were collected on 20 commercial laying hen farms, 10 farms with battery-cage systems and 10 farms with deep-litter systems. The battery-cage systems were ordinary cages without perches, litter or laying nests. Number of birds per cage differed slightly between farms, dependent on the size of the cage. Six farms housed five birds per cage, three farms six per cage, and one farm seven birds per cage. At least 450 cm^2 of cage floor was available per hen, but already many complied with the new EU norm of 550 cm^2 per hen (EC, 1999). In the deep-litter systems, at least one third of the floor surface was covered with litter and the remaining part consisted of slatted floor and nest boxes. Feed and water was provided on the slatted floor. In seven out of ten deep-litter systems elevated perches were available. Seven to nine hens were housed per m^2.

Farms were selected randomly from the members of a farmers' union in the southern and eastern part of The Netherlands. The majority of all egg producing farms in The Netherlands is member of this union. Per farm only one flock in one stable was used for data collection. The major selection criterion was that hens should be brown-feathered. Other characteristics of the observed flocks are given in Table 3.1.

Two persons visited each farm once for a whole day. The day was divided up into four sessions of 100 minutes each for data collection, two in the morning and two in the afternoon (Figure 3.1). During the three sessions of behaviour/ANI, one person performed behavioural observations, while the other person gathered information about housing system and management to quantify the ANI. For FCS both observers were needed.

Table 3.1. Characteristics of observed flocks included in the sample (median (range)).

Characteristic	Deep litter (n = 10)	Battery cage (n = 10)
Strain	Bovans (1)	Bovans (2)
	Hisex (2)	Hisex (1)
	Hyline (1)	
	ISA (3)	ISA (2)
	Lohmann (2)	Lohmann (5)
	Unknown (1)	
Age (in days)	354 (122-491)	288 (161-420)
Flock size	4470 (2995-21459)	27841 (13431-41580)
Mortality rate (% per week)	0.11% (0.02-0.16)	0.08% (0.02-0.30)

Time	8:30-10:10		10:30-12:10		13:00-14:40		15:30-17:10
Method	*Behaviour / ANI*		*Behaviour / ANI*		*FCS*		*Behaviour / ANI*
Deep litter	N1 P1 L1 F1		P2 L2 F2 N2		40-50 hens		L3 F3 N3 P3
Battery cage	C1 C2 C3 C4		C5 C6 C7 C8		8 cages		C9 C10 C11 C12

Figure 3.1. Schedule for an observation day (N = area in front of nest boxes; P = perch area; L = litter area; F = feeding area; C = cage).

3.2.2 Behavioural observations

For deep-litter systems, the whole stable was divided up into four different functional areas, i.e., the area in front of nest boxes, the perch area, the litter, and on the slats near feeding and drinking facilities. Within each functional area, observation plots (1.5 m^2) were selected randomly for each session. For battery-cage systems, the observed cages were selected randomly.

The three sessions of behavioural observations consisted of four time blocks of 25 minutes each. These time blocks were used to do observations in the different functional areas in a deep-litter system or in the different cages in a battery-cage system (Figure 3. 1). Each time block started with 5 minutes for walking to the observation plot, followed by an adaptation period of 5 minutes. After the adaptation period, the observations started with 5 minutes instantaneous scan sampling (Martin and Bateson, 1993, pp. 85-87, 90-91). Instantaneous scan sampling was used to assess the time spent on different behaviours. All hens present in an observation plot or cage were observed every minute and behaviours were scored (see Table 3.2 for ethogram). Subsequently, the second hen from the left in the observation plot or cage was selected and observed for 10 minutes continuously using focal sampling (Martin and Bateson, 1993, pp. 84-85, 88-90). Continuous focal sampling was used to measure frequencies of event behaviours (see Table 3.3 for summary of ethogram). When the selected hen disappeared out of sight, again the second hen from the left was selected and observed for the remaining time. A hand-held computer programmed with The Observer® software (Noldus Information Technology, Wageningen, The Netherlands) was used during focal sampling observations.

Table 3.2. The ethogram of instantaneous scan sampling.

Label	Description
Stand	Standing idle, no contact body to floor
Sit	Sitting idle, body on floor
Walk	Walking from place A to B
Forage	Scraping over floor with foot, pecking on floor
Eat	Eating from feeding trough
Groom	Cleaning itself with beak or feet, feather ruffling, preening
Drink	Drinking water from drink nipple/ trough
Dustb	Laying down in substrate and making fluttering movements
Other	Behaviour not mentioned in this ethogram

Table 3.3. Summary of ethogram of continuous focal sampling.

Label	Full name	Description
FP gent. [1]	Gentle feather pecking	Gentle pecking on feathers of other hens
FP sev. [1]	Severe feather pecking	Severe pecking on feathers of other chicken. Can result in wounding the other bird; large head movement
Dustb. [2]	Dustbathing	Lay down in substrate and make fluttering movements
Groom [2]	Grooming	Cleaning itself with beak or feet, feather ruffling, preening
Stretch [2]	Stretching	Stretching wing and/ or leg
Wing flap [2]	Wing flapping	Making movements/ flapping with the wings
Aggressive	Aggressive behaviour	Pecking on head, fighting, sparring
Beakp.	Beak pecking	Pecking at beak of another bird
Vocal alarm	Vocal alarm	Making alarm calls
Vocal gakel	Vocal gakel	Making pre laying sounds

[1] Merged to ‘feather pecking’

[2] Merged to ‘comfort behaviour’

3.2.3 Feather condition score

The feather condition score (FCS) of Bilcík and Keeling (1999) was used to assess damage to feathers of hens. This method assesses feather condition on 11 body parts on a scale from 0 (intact feathers) to 5 (completely denuded). Skin injuries were scored for the whole body at once on a scale from 0 (no injuries or scratches) to 4 (wounds bigger than 2 cm in diameter). In a deep-litter system, about 40 to 50 hens were driven together with a small fence, and scored. In a battery-cage system, hens from eight cages were scored, which resulted in total in about the same number of observed hens as in a deep-litter system.

3.2.4 Animal needs index (ANI)

The ANI-200 for laying hens (Striezel, 1994) is a scoring method for housing systems. Based on the needs of an animal, points are given for housing conditions, management factors, and feather condition in eight different categories. These categories are locomotion, feeding and drinking, social, resting, comfort and nesting behaviour, and management with respect to hygiene and care. More points are given for favourable circumstances. Four to eight aspects are scored in each category and summed up. In the category ‘locomotion’ points are given for the number of hens per m^2 usable area, availability of perches and some characteristics of the outdoor run. In the category ‘comfort’ points are given for quality of litter, feather condition of hens, and possibilities to use the outdoor run. In the category ‘hygiene’ points are given for again quality of litter, frequency of removal of manure from the stable, odour in the stable, availability of daylight in the stable, presence of ectoparasites and also some characteristics of the outdoor run. The sum of all categories gives the final ANI score, which can be used to judge a housing system. This score judges prerequisites for animal welfare, but does not involve behavioural observations. Therefore, it does not actually assess animal welfare directly. Initially, the ANI for laying hens was developed for alternative and organic systems. In this study, however, we also used it to score battery-cage systems.

3.2.5 Statistical analysis

Statistical analyses were conducted using SAS (SAS Institute Inc., 1996). Data from behavioural observations and FCS were aggregated to farm level in order to compare them with ANI scores. For the deep-litter system, scan sampling data of all four functional areas within one observation session were summed up into a total number of hens performing each of nine behaviours. Subsequently, for each observation session, the percentage of hens performing each of nine behaviours was calculated. Finally, percentages of three observation sessions were averaged per farm.

For the battery-cage system, scan sampling data of each cage were summed up, and used to calculate the percentage of hens performing each of nine behaviours. Subsequently, cage percentages were averaged per observation session, and, finally, per farm.

For the deep-litter system, focal sampling data of all four functional areas within one observation session were weighted against the number of hens in the scan sampling just before the focal sampling observation. Subsequently, weighted data were averaged per observation session, and, after that, frequencies of behaviours of three observation sessions were averaged per farm.

For the battery-cage system, focal sampling data of the four cages within one observation session were averaged per observation session, and finally, averaged per farm.

For the deep-litter system, FCS data of all individual hens were averaged per farm. For the battery-cage system, FCS data of hens in the same cage were averaged, and, subsequently, cage values were averaged per farm.

In order to approach a normal distribution, percentages per farm from scan sampling were transformed with an arcsine (square root)-transformation. For focal sampling, two clusters of behaviours were formed. These clusters were called ‘feather pecking’, including gentle and severe feather pecking, and ‘comfort behaviour’, including dustbathing, grooming, stretching and wing flapping (Table 3.3). Subsequently, frequencies per farm were transformed with a square root transformation.

FCS data were influenced by age of the hens, due to cumulative damage. In all analyses with regard to FCS, age was included in the model to correct for the age effect.

Differences between housing systems concerning behavioural pattern and pattern of feather damage were first assessed by multivariate analysis of variance (MANOVA). When MANOVA showed a significant difference between housing systems, all single items were tested with a linear model (Proc GLM). Also (total) ANI scores were tested with a linear model on differences between housing systems. The model used for the analysis was

$$Y_{ij} = \mu + \alpha_i + b \times age + e_{ij}$$

with i = 1 or 2 for deep-litter resp. battery-cage system; j =1, ..., 10; age = age of hens in days.

As behavioural observations were not significantly influenced by age, this parameter was not estimated in the analysis of scan and focal sampling data.

To compare environment- and animal-based methods, farm data of behavioural observations and FCS were reduced by principal factor analysis (Proc Factor with method = principal, priors = one, rotate = varimax). Scree-plot and Kaiser-Guttman criterion were used to determine the number of factors (Sharma, 1996). Factors were named after the variable or variables with the highest positive loading. The linear model was, again, used to determine influence of age and housing system on factor scores. Spearman correlation coefficients were calculated between factor scores to determine relationships between different assessment methods. Age correction was applied to all correlations.

3.3 Results

MANOVA analysis of scan sampling data showed that time-budget differed significantly between both housing systems (Wilks' Lambda $F_{9,10} = 53.6$, $P < 0.001$; Figure 3. 2). In battery cages, hens spent more time on standing ($F_{1,18} = 58.7$, $P < 0.001$; 71% versus 47%) and eating ($F_{1,18} = 6.7$, $P < 0.05$; 24% versus 14%). In a deep-litter system, hens spent more time on walking ($F_{1,18} = 253.8$, $P < 0.001$; 17% versus 0.2%), sitting ($F_{1,18} = 10.5$, $P < 0.01$; 8.4% versus 1.7%), grooming ($F_{1,18} = 15.8$, $P < 0.001$; 6.4% versus 1.9%) and foraging ($F_{1,18} = 41.0$, $P < 0.001$; 5.2% versus 1.0%).

MANOVA analysis of focal sampling data also resulted in significant differences between both housing systems (Wilks' Lambda $F_{6,13} = 26.2$, $P < 0.001$; Figure 3. 3). Comfort behaviour was performed more in a deep-litter system ($F_{1,18} = 68.7$, $P < 0.001$; 0.0047 s^{-1} versus 0.0021 s^{-1}), and beak pecking was performed less in a deep-litter system ($F_{1,18} = 6.8$, $P < 0.05$; 0.0004 s^{-1} versus 0.0021 s^{-1}). A tendency to a higher incidence of feather pecking in a battery-cage system was observed ($F_{1,18} = 4.05$; $P = 0.059$).

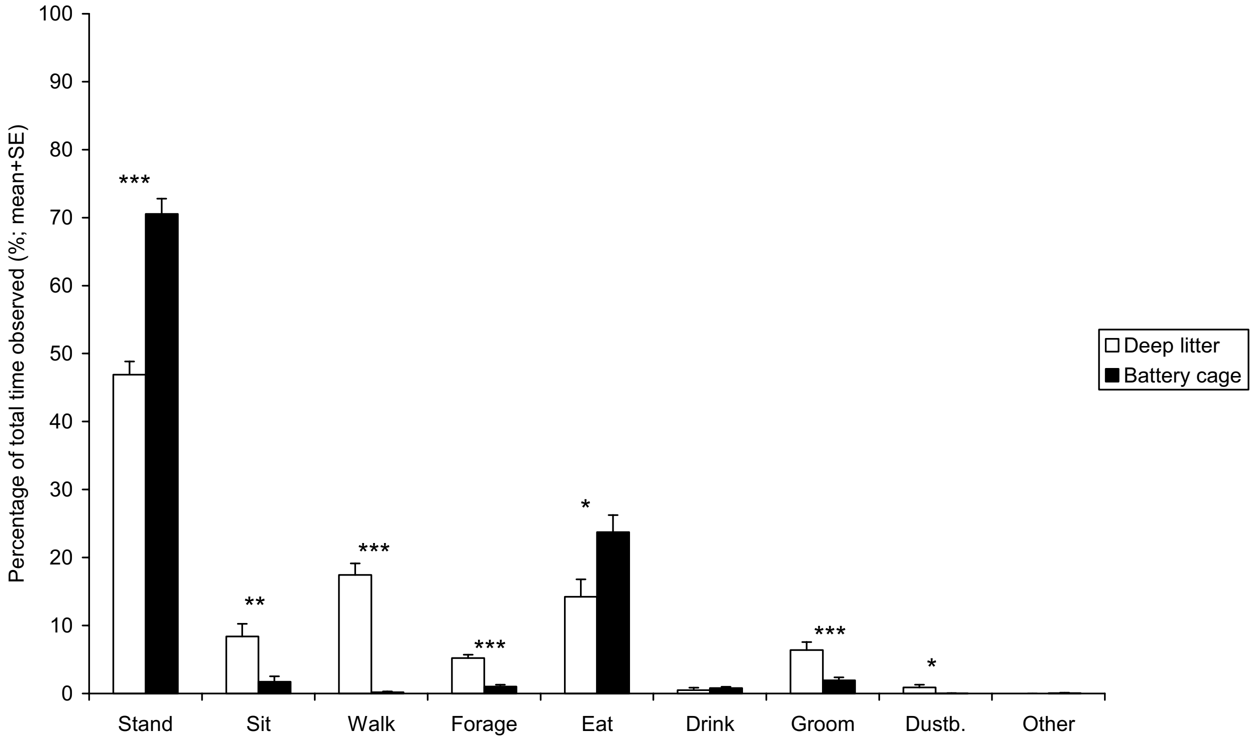

Figure 3.2. Percentage of time spent on different (state) behaviours in deep-litter and battery-cage systems, measured by instantaneous scan sampling (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; $F_{1,18}$).

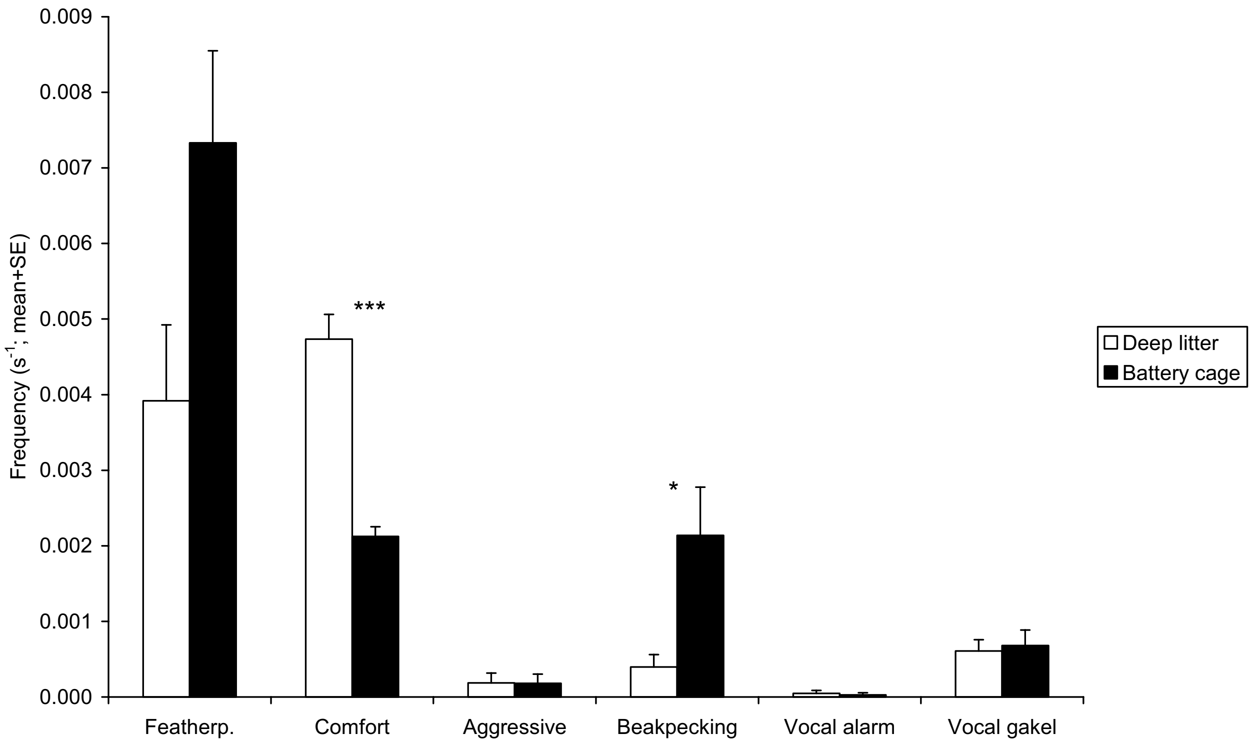

Figure 3.3. Frequency of different (event) behaviours in deep-litter and battery-cage systems, measured by continuous focal sampling (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; $F_{1,18}$).

Table 3.4. Feather Condition Scores per housing system (mean ± S.E.M.) and probabilities for differences between housing systems (general linear model, $F_{1,17}$).

Body part	Deep litter	Battery cage	F-value	P > F
Head	2.06 (0.27)	0.83 (0.20)	18.91	< 0.001
Neck	2.88 (0.40)	2.22 (0.43)	0.01	0.909
Back	1.77 (0.40)	1.40 (0.32)	0.06	0.810
Rump	1.77 (0.49)	0.90 (0.17)	1.33	0.265
Tail	2.59 (0.28)	2.58 (0.26)	3.04	0.100
Belly	2.08 (0.57)	1.03 (0.24)	1.39	0.255
Leg	1.65 (0.51)	0.96 (0.15)	0.71	0.412
Wing	1.00 (0.12)	1.56 (0.16)	19.43	< 0.001
Covert	1.32 (0.20)	1.29 (0.19)	1.10	0.310
Breast	2.14 (0.31)	2.64 (0.42)	8.76	0.009
Underneck	3.29 (0.37)	1.55 (0.43)	17.47	< 0.001
Total FCS	22.55 (3.49)	16.95 (2.74)	0.19	0.668
Injury	0.05 (0.02)	0.01 (0.01)	4.69	0.045

Table 3.4 shows FCS per housing system. FCS was significantly influenced by age of the hens ($F_{1,17}$ = 26.94, P <0.001). Total FCS (sum of all body parts) increased with 0.083 ± 0.016 (estimate ± S.E.) points per day. Scores for different body parts, except legs and injuries, increased significantly with age. Total FCS did not differ between housing systems. However, the pattern of damage over the body did differ between housing systems (MANOVA, Wilks' Lambda $F_{11,7}$ = 7.33; P <0.01). Analysis per body part also showed significant differences between housing systems. Wing and breast were more damaged in a battery-cage system, whereas head and underneck were more damaged in a deep-litter system. In the deep-litter system also more injuries were found, although the total number of injuries was low.

Results of the ANI (Table 3.5) differed significantly between housing systems, with a higher score for a deep-litter system compared to a battery-cage system (47.7 ± 2.08, resp., 35.7 ± 1.97; $F_{1,17}$ = 31.18, P < 0.001; b = -0.039). All categories except 'social' and the management factors 'hygiene' and 'care' are lower for a battery-cage system. The higher score for 'social' is mainly caused by smaller group size in a battery-cage system, whereas higher score for management factors is mainly caused by better opportunities for climate control, hygienic measures, and technical equipment.

Principal factor analysis resulted in two factors for each method (Table 3.6). Factors were named after the variable or variables with the highest positive loading. Factors for scan sampling were called 'movement' and 'eating and drinking', for focal sampling 'gakel/aggression' and 'comfort', and for FCS 'general damage' and 'wing damage'.

Table 3.5. Average ANI scores (range) per housing system.

Category	**Deep litter**	**Battery cage**
Locomotion	2.8 (0-4)	0 (0)
Feeding & drinking	6.9 (4-13)	5 (1-8)
Social	4.4 (2-8)	7.8 (6-10)
Resting	7.4 (2-14)	2.4 (0-3)
Comfort	7.9 (5-15)	1.9 (0-5)
Nest	4.5 (3-5)	0 (0)
Hygiene	5.2 (1-12)	6.7 (3-9)
Care	8.6 (3-14)	11.9 (7-16)
ANI	47.7 (37-57)	35.7 (27-46)

Table 3.6. Result of principal factor analysis for instantaneous scan sampling, focal continuous sampling, and Feather Condition Scores.

Method	**Factor loadings** [1]	**Factor name**	**Variance explained** [2] **(%)**
Scan 1	– Standing, walking, foraging, dustbathing, grooming	Movement	36.4
Scan 2	Eating, – sitting, drinking	Eating & drinking	27.4
Focal 1	Vocal gakel, aggressive, feather pecking	Gakel/aggression	28.1
Focal 2	– Beak pecking, comfort, vocal alarm	Comfort	27.1
FCS 1	Head, belly, underneck, rump, legs, back, neck, covert, tail	General damage	49.7
FCS 2	Wing, breast, covert, tail, back, neck	Wing damage	34.5

[1] All original variables with a factor loading > 0.50 are included in order of diminishing (absolute) correlation. Variables with negative correlation are preceded by –.
[2] Variance explained by varimax rotated factors.

All factors except 'eating and drinking' and 'gakel/aggression' were affected significantly by housing system. Only both factors of FCS, 'general damage' and 'wing damage', were affected significantly by age ($b = 0.0054$, $F_{1,17} = 15.75$, $P < 0.01$, resp., $b = 0.0067$, $F_{1,17} = 19.35$, $P < 0.001$). These significant effects were a justification for age correction on correlations.

Table 3.7 shows that for each of the three assessment methods one of the two factors correlated significantly with the ANI, when analysis was performed on all 20 farms. The factor 'movement' was positively correlated with the ANI ($r_s = 0.71$, $P < 0.001$), which means more movement (walking, foraging, dustbathing, and grooming) and less standing in systems with high ANI scores, i.e., a deep-litter system. 'Comfort' was positively correlated with the ANI ($r_s = 0.54$, $P < 0.05$), which shows that more comfort behaviour (i.e., dustbathing, grooming, stretching) and vocal alarm calls, and less beak pecking was observed in systems with high ANI scores. 'Wing damage' was negatively correlated with the ANI ($r_s = -0.81$, $P < 0.001$), which means that more damage at wing, covert, breast and tail was found in systems with low ANI scores (i.e., a battery-cage system). 'General damage' tended to correlate positively with ANI (r_s = 0.45, n = 20, P = 0.054; Table 3.7), which means that hens in a deep-litter system tended to have more damage on head, underneck, belly, legs, rump, and back. When scores for feather condition were left out of the ANI scores, the correlation even became significant (r_s = 0.74, n = 20, P < 0.001; not shown).

The last two columns of Table 3.7 show that above mentioned correlations are highly influenced by differences between housing systems. When farms were split into two types of housing system, significant correlations disappeared, with one exception, that in a battery-cage system 'gakel/aggression' appeared to be significantly correlated with the ANI (r_s = 0.80, P < 0.01).

Table 3.7. Correlation between the Animal Needs Index and factor scores.

	Animal Needs Index		
Factor	**All farms (n=20)**	**Deep litter (n=10)**	**Battery cage (n=10)**
Movement	0.71 ***	0.01	-0.08
Eating & drinking	-0.26	-0.16	0.07
Gakel/Aggression	-0.12	-0.29	0.80 **
Comfort	0.54 *	-0.66	-0.06
General damage	0.45	-0.49	-0.32
Wing damage	-0.81 ***	-0.51	-0.49

* P< 0.05; ** P< 0.01; *** P< 0.001.

3.4 Discussion

Objective of this study was to validate ANI-200 for laying hens. Therefore, the ANI was compared with behavioural observations and FCS. The ANI was computed at farm level. Consequently, behavioural observations and FCS data were aggregated to farm level. For the deep-litter system, scan sampling data of all four functional areas within one observation session were summed up into a total number of hens performing each of nine behaviours. Subsequently, for each observation session, the percentage of hens performing each of nine behaviours was calculated. In this way, we accounted for the different number of hens in the different functional areas in each observation session. For the same reason, this number of hens was also used as weighting factor for focal sampling data. Furthermore, in scan and focal sampling data, each functional area was assumed to be equally important.

Hens use different amounts of space for different behaviours, with wing flapping being the behaviour for which most space is used, followed by turning and preening (Dawkins and Hardie, 1989). Behaviours that require much space, like grooming and dustbathing in scan sampling, and comfort in focal sampling, are performed less in a battery-cage than in a deep-litter system. Reason for this could be that the restricted space in a battery cage prevents performing these behaviours. Other behaviours that were observed less in a battery-cage system with scan sampling were walking, foraging and sitting. This is in accordance with Koelkebeck and Cain (1984) and Mench et al. (1986), who observed less object pecking and walking, respectively, less locomotion in a battery-cage compared to a deep-litter system. There tended to be a higher incidence of feather pecking in the battery-cage system. This can be the result of redirected pecking due to lack of substrate for foraging or dustbathing (Blokhuis, 1986; Vestergaard and Lisborg, 1993).

The pattern of feather damage differed between housing systems, although the overall FCS score did not differ significantly. Hens housed in a deep-litter system had more damage on head and underneck. Damage to the head could be the result of aggressive pecking and damage to the underneck due to abrasion at feed troughs (Bilcík and Keeling, 1999). Hens in a battery-cage system had more damage on wings and breast, which also could be caused by abrasion (Bilcík and Keeling, 1999). According to Hughes and Michie (1982), however, even in a battery cage, most damage is caused by feather pecking by cage mates or hens from adjacent cages, rather than by abrasion.

As expected, the ANI showed quite clear differences between housing systems. Scores for the battery-cage system were overestimated, due to the fact that the ANI was not developed for a cage system (Sundrum et al., 1994). Therefore, a battery cage got zero points for several parameters, although negative scores would have been justifiable. This caused an underestimation of the difference between housing systems.

Principal factor analysis resulted in two factors per method, which made interpretation of correlations between methods easier. The positive correlations between ‘movement’ and ‘comfort’ on the one hand, and the ANI on the other hand, correspond with the idea that hens in a battery cage (low ANI score) lack opportunities to move around freely and are limited in their behaviour (Appleby and Hughes, 1991). The strong correlation between ‘wing damage’ and the ANI showed clearly the difference in pattern of feather damage in the different systems. Hens in a battery-cage system had more damage on wings, breast, and tail, while ANI score was lower for a battery-cage system. The tendency for ‘general damage’ to correlate positively with the ANI showed that hens in a deep-litter system (high ANI score) tended to have more damage to head, underneck, belly, legs, rump, and back. That this correlation even became significant when scores for feather condition were left out of the ANI, was due to the way feather condition is accounted for in the ANI and FCS. The ANI scores feather condition on first sight and on population level, while FCS scores feather damage more thoroughly and on individual hens. The battery-cage system got slightly more points for feather condition in the ANI, compared to deep-litter systems. Because the ANI score for battery-cage systems was already lower, the relative decrease is even bigger for battery-cage systems. Also the variation in final ANI scores for battery-cage systems decreases considerably. These changes mean that the contrast between the two systems becomes bigger and correlation becomes significant.

In a deep-litter system, the belly can be pecked easily when sitting on perches (Bilcík and Keeling, 1999), which possibly also counts for the legs. The back and rump can be pecked easily when hens are in other parts of the stable (Savory and Mann, 1997). In the battery-cage system, there are no perches and it is much more difficult to peck other hens on the topside of the body, due to the low cage construction. Therefore, feather damage of caged hens was concentrated on other parts of the body, like wings, breast, and tail. Besides pecking by cage mates, abrasion, due to contact with the cage material, and pecking by hens from adjacent cages possibly caused feather damage in caged hens.

Correlations within the two housing systems made clear that variations within housing systems could not be shown with the ANI. The only significant correlation of the ANI within housing systems was with 'gakel/aggression' in a battery-cage system. This means that when a battery-cage system scored more points on the ANI, there were also more problems with aggression and frustration, as gakels are an indication of laying behaviour in particular and more frustration in general (Zimmerman et al., 2000). When feather condition was left out of the ANI, this correlation, however, disappeared (data not shown). This points at a positive correlation between good feather condition (as scored in the ANI) and more 'gakel/aggression', which is confusing in this context.

Indicators for on-farm assessment have to comply with more criteria than only validity. Other criteria are that they are simple, sensitive and reliable. Furthermore, it has to be possible to determine a target value or trend, and data have to be available (Mitchell et al., 1995). Correlations between different factors proved the validity of the ANI for animal welfare assessment between housing systems. This is in accordance with Bokkers and Koene (2001) and Alban et al. (2001), who also found correlations between the ANI and some other, animal-based, parameters. In both studies, however, it is mentioned that environment-based parameters can assess prerequisites for animal welfare only. For good assessment of the animal welfare status, however, performance criteria have to be added, e.g., incidences of diseases and abnormal behaviour (Sundrum, 1997). Bock (1990) and Sandøe et al. (1997) mention the importance of management related parameters. They both demonstrate the influence of management on animal behaviour in addition to environment-based parameters. Hemsworth and Barnett (2000) mention influence of human-animal interactions on production and welfare, which can also be seen as a management factor. The ANI, however, consists mainly of environment-based parameters, and therefore has the advantage of data availability, because recording is quite easy and does not demand too much resources (Bartussek, 2001; Johnsen et al., 2001). Within the criteria that recording has to be easy and fast, the ANI includes even some management parameters and an animal-based parameter, namely feather condition. This feather condition score, however, is much less detailed than the FCS developed by Bilcík and Keeling

(1999). The lack of sufficient information on management and performance can be a reason for low validity of the ANI within housing systems. Due to the inclusion of some management and animal-based parameters, the ANI, however, showed to be sensitive enough to determine differences between housing systems. Furthermore, the reliability of the ANI is high, which means that assessment by different people results in the same scores (Ofner et al., 2000). ANI scores are also easy to understand, because the final score is between 0 and 200, with a higher score for higher/better welfare. The only difficulty is where to put the threshold for what stakeholders think is acceptable welfare. Results of behavioural observations, however, are more difficult to interpret. Within a behavioural repertoire, there is supposed to be an optimal duration and frequency for each single behaviour. Deviations to both sides of the optima can reduce animal welfare. It is difficult, however, to judge the impact of such deviations and to determine thresholds for acceptable welfare.

In conclusion, the ANI is valid and sensitive enough to show differences in animal welfare between housing systems for laying hens, whereas differences in welfare within systems cannot be shown. Together with the favourable results on other criteria for effective indicators, this leads to the conclusion that the ANI is an appropriate method for on-farm assessment of laying hen welfare between housing systems.

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Chapter 4
Risk factors for *Salmonella enteritidis* infections in laying hens

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Abstract

Contamination with *Salmonella enteritidis* (SE) is an important threat to food safety in egg production. Various risk factors exist for infection with and spreading of SE on a farm. A data set of regularly collected blood samples from hens at the end of lay was available for analysis. Data included information about infection with SE, date of sampling, housing system and flock size, and whether there were hens of different ages on the farm or in the house. Using this data set, our objective was to identify risk factors associated with SE infection in laying hens. Multiple logistic regression was used to assess the contribution of different variables. Results showed that bigger flocks increased the chance of infection with SE in all housing systems. The system with the lowest chance of infection was the cage system with wet manure. An outdoor run increased the chance of infection only at farms with all hens of the same age. The presence of hens of different ages on a farm was a risk factor for deep-litter systems only. This resulted in the highest chance of infection for a deep-litter system on a farm with hens of different ages. On a farm with all hens of the same age, however, a deep-litter system did not increase the chance of infection with SE compared with a cage system. The main risk factors associated with SE infection, therefore, were flock size, housing system, and farm with hens of different ages.

4.1 Introduction

In the 1950s and 1960s, the major concern in food production was food security, which means quantitative food supply. Nowadays, in Western Europe, food safety is highly important. The Codex Alimentarius Commission (2001) says about food safety that “everyone, including farmers and growers, manufacturers and processors, food handlers and consumers, has a responsibility to assure that food is safe and suitable for consumption.” Food safety from a farmer’s perspective, therefore, implies “the assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use” (Codex Alimentarius Commission, 2001). The subsequent partners in the handling chain and, finally, the consumers, in turn, are responsible for the right circumstances during storage and preparation.

In food safety, generally, three areas of risk are distinguished: microbiological, chemical, and physical contaminations (Codex Alimentarius Commission, 2001; Swabe et al., 2001). This paper focuses on microbiological contaminations, which are contaminations by micro-organisms that cause decay, produce toxins, and cause zoonoses. Decay-causing or toxin-producing micro-organisms, however, are of minor importance in table eggs (N. M. Bolder, 2004, Animal Sciences Group, WUR, Lelystad, The Netherlands, personal communication). Zoonoses are “infectious diseases naturally transmissible between vertebrates and man” (Bell et al., 1988). Foodstuffs of animal origin are the main source of zoonoses. Human salmonellosis, for example, originates from animals in about 96% of the cases (van Pelt and Valkenburgh, 2001). *Campylobacter* and *Salmonella* species are the most important zoonoses regarding poultry. They are major causes of gastroenteritis in humans (Mead et al., 1999; van Pelt et al., 2003). Eggs play a minor role in the distribution of *Campylobact*er; however, they are an important vector for transmission of *Salmonella* species, especially *Salmonella enteritidis* (SE) (van Pelt and Valkenburgh, 2001; Hald et al., 2002). Contamination with SE, therefore, is an important threat for food safety regarding egg production. Various risk factors exist for infection with and spreading of SE on a farm. Most studies focus on vectors for transmission of SE. Most important vectors are rodents, especially mice (Henzler and Opitz, 1992; Davies and Wray, 1995b; Kinde et al., 1996; Guard-Petter et al., 1997; Davies and Breslin, 2001; Liebana et al., 2003), but also flies (Olsen and Hammack, 2000) have been shown to contribute to the transmission of SE. The contribution of darkling beetles has also been mentioned (Davies and Wray, 1995a; Goodwin and Waltman, 1996); however, the evidence is quite weak (Davies and Wray, 1995a). Only few broad epidemiological studies are known. For broilers, risk factors for salmonella infection are large hatcheries and feed mills, a high number of houses on a farm, infection of the preceding flock, and rearing a flock in autumn (Angen et al., 1996), whereas for broiler breeders, risk factors are lack of hygienic measures and small feed mills (Henken et al., 1992). Due to these contradictory findings, the influence of the size of feed mills becomes unclear. For laying hens, risk factors are large flocks (Heuvelink et al., 1999) and airborne transmission (Gast et al., 1998). A thorough analysis on these risk factors could yield important insights in the real risk factors in different housing systems for laying hens.

A data set of regularly collected blood samples from hens at the end of lay was available for analysis. Data included information about infection with SE, date of sampling, housing system, and flock size, and whether there were hens of different ages on the farm or in the house. Using this data set, our objective was to identify risk factors associated with SE infection in laying hens.

4.2 Materials and methods

4.2.1 Data set

The Dutch Product Boards for Livestock, Meat, and Eggs (PVE, 2001) has monitored the presence of SE in laying hens since 1997 as part of an action plan to control and reduce SE in laying hens. Within this plan *Salmonella typhimurium* is also taken into account. The incidence of this specie is low in laying hens and, therefore, was not taken into further account in this paper.

Each flock of laying hens was monitored by taking blood samples at a maximum of nine weeks before the end of the laying period. A flock was defined as a group of hens in the same house. Blood samples were taken from 0.5% of the hens of each flock; a minimum of 24 and a maximum of 60 samples was collected. Samples were taken randomly throughout the house.

Each time, six samples were pooled into one sample for analysis. A positive result for one pooled sample was enough to declare a flock infected. All flocks were negative for SE at the end of the rearing period (about 17 weeks of age). When the previous flock in a house was positive, there was extra control on cleaning and disinfection with environmental swabs and on the control of vermin, which is obligatory as part of the action plan. Therefore, all stables were considered to be in the same clean status when new hens came in. The data set used in this study resulted from this monitoring program and covered from April 1998 until December 2002. The overall average percentage of infected flocks was 10.0% (n = 8,409).

Voluntarily, farmers could fill in a form to provide additional information about the flock (PVE, 2001). This form was completed for 2,508 flocks. The resulting data set contained information on SE status, month and year of sampling, housing system (i.e., battery cage with wet and dry manure, deep litter and aviary, with and without outdoor run), number of hens, vaccination against SE, and the presence of hens of different ages in the same house or on the farm. Of the 2,508 records, 324 records were incomplete and, therefore, removed. In addition, vaccinated flocks and flocks housed in aviaries were removed (Table 4.1). Vaccinated flocks were removed because blood analysis gives a positive result in all cases when certain vaccines are used. Therefore, vaccinated flocks must be tested on faeces instead of blood. This did not happen in all cases and, therefore, all vaccinated flocks were removed from the data set. Flocks housed in aviaries were removed because of the low number of these flocks. The final data set contained 1,912 records (Table 4.1) with an overall average of 10.0% of flocks being infected.

Table 4.1 Characteristics of the data set.

System	Complete records	Vaccinated flocks (%) [1]	Final data set [2]	FD [3] (%) [5]	HD [4] (%) [5]	NH [6] (SD)
Cage dry manure	615	40 (6.5)	575	396 (68.9)	15 (2.6)	25219 (13497)
Cage wet manure	406	19 (4.7)	387	203 (52.5)	26 (6.7)	12493 (11073)
Deep litter	769	89 (11.6)	680	346 (50.9)	28 (4.1)	4383 (3130)
Deep litter + run	331	61 (18.4)	270	111 (41.1)	4 (1.5)	6061 (3900)
Aviary	17	11 (64.7)				
Aviary + run	46	9 (19.6)				
Total	**2184**	**229 (10.5)**	**1912**	**1056 (55.2)**	**73 (3.8)**	**12527 (12771)**

[1] Percentage of number of complete records
[2] Number of records (flocks) used in final data set
[3] FD = Number of records (flocks) from farms with hens of different ages
[4] HD = Number of records (flocks) from houses with hens of different ages
[5] Percentage of number of records in final data set
[6] NH = Average number of hens per flock

4.2.2 Statistical analysis

Because the response variable (y = result of blood test at flock level) is a binomial trait, logistic regression was used (Neter, 1996). The response variable y has a Bernoulli distribution with expected values E(y):

$$E(\mathbf{y}) = \exp(ß'\mathbf{X}) / [1 + \exp(ß'\mathbf{X})] \quad (1)$$

where **y** = vector of result of blood test for n flocks; E(**y**) = vector of expected results of blood test, or the chance of infection; **X** = p × n matrix, where p is the number of variables in the model, and n is the number of flocks in the data set; and ß = vector of p coefficients.

The multiple logistic response function (1) can be made linear with the following transformation (Neter, 1996):

$$\mathbf{Y} = \ln [E(\mathbf{y}) / (1 - E(\mathbf{y}))] = ß'\mathbf{X} \quad (2)$$

This linearization makes it possible to analyze and interpret the regression analysis. Coefficients of the logistic regression model were estimated by maximum likelihood. PROC GENMOD of the SAS computer program (SAS Institute Inc., 1999) was used to fit the multiple logistic regression.

Converting coefficients of the logistic regression model to odds ratios (OR) can clarify interpretation. When **Y** = ß'**X** is rewritten to **Y** = $ß_0 + ß_1$**X**, it can be shown that $\exp(ß_1)$ is the OR of a potential risk factor (Henken et al., 1992; Neter, 1996). An OR greater than 1 means an increased chance of infection, whereas an OR less than 1 means a decreased chance. An OR of 2.3, for example, means a 2.3-fold increase in chance.

The full model contained all individual variables and potentially important interactions between housing characteristics. Interactions including house with hens of different ages (HD) were omitted, because of the low number of houses with hens of different ages (Table 4.1). An interaction between year and month could be expected, as the seasonal influence can differ between years. This interaction, however, could be considered as a random influence and, therefore, is included in the error term. The observation Y_{ijklmn}, therefore, can be described as

$$\begin{aligned} Y_{ijklmn} &= ß_0 + \text{year}_i + \text{month}_j + HS_k + FD_l + HD_m + ß_1 \times NH \\ &+ ß_{2k} \times (NH \times HS_k) + ß_{3l} \times (NH \times FD_l) + (HS_k \times FD_l) + e_{ijklmn} \end{aligned} \quad (3)$$

where $ß_0$ = intercept; year_i = effect of year i (i = 1, 1998; i = 2, 1999; ... i = 5, 2002); month_j = effect of month j (j = 1, January; j = 2, February; ... j = 12, December); HS_k = effect of housing system k (k = 1, deep litter with outdoor run; k = 2, deep litter; k = 3, cage system wet manure; k = 4, cage system dry manure); FD_l = effect of farm with hens of different ages (l = 1, yes; l =

2, no); HD_m = effect of house with hens of different ages (m = l, yes; m = 2, no); NH = number of hens (×1,000) of n^{th} flock (regression variable); $ß_1$ = regression coefficient of Y on NH; $ß_{2k}$ = regression coefficient of Y on the interaction between NH and HS_k; $ß_{3l}$ = regression coefficient of Y on the interaction between NH and FD_l; and e_{ijklmn} = error term of n^{th} flock (n = 1; ... n = 1,912).

Before coefficients were estimated, all variables and interactions were tested for their significant contributions to the model. The contribution of a variable to reduction of deviance (partial deviance) was tested by a chi-squared test with $\alpha < 0.05$ (Neter, 1996). This test resulted in elimination of interactions between number of hens × housing system, between number of hens × farm with hens of different ages, and the variables year and house with hens of different ages. The interaction of housing system × farm with hens of different ages was put into the model as a nested effect, in order to make a clear comparison between the various housing systems possible.

The parameters for the final model, therefore, were month, farm with hens of different ages, housing system (farm with hens of different ages), and number of hens. This resulted in the following final model:

$$Y_{jkln} = ß_0 + month_j + FD_l + HS_k(FD_l) + ß_1 \times NH + e_{jkln} \quad (4)$$

4.3 Results

Table 4.2 shows estimates for various coefficients of each variable in the final model. Each row represents one coefficient. To run the analysis, for each variable one coefficient must be set as a reference. This is the last coefficient per variable in Table 4.2. The reference situation, therefore, is a flock that is sampled in December, which came from a farm with all hens of the same age and was housed in a cage system with dry manure (Table 4.2). All other coefficients of a variable were relative to the reference value. The last column in Table 4.2 shows the chi-squared probability of each coefficient, which indicates whether an estimate was significantly different from the reference value. To determine mutual differences among estimates of all coefficients of each variable, additional analyses were performed with different reference situations (not shown in Table 4.2).

A sample taken in April had a significantly ($\alpha < 0.05$; OR = exp(0.909) = 2.48) higher chance of infection with SE than a sample taken in the reference month of December. For the reference system (i.e., cage system with dry manure), the difference between farms with and without hens of different ages was not significant. The difference between farms with and without hens of different ages was significant ($\alpha < 0.001$; estimate = 1.248; OR = 3.48) for the deep-litter system only.

Table 4.2 Results of the analysis for the final model.

	Degrees of freedom	Estimate	Standard error	Chi-squared	Prob. [1]
Intercept	1	-2.434	0.42	34.33	< 0.001
January	1	-0.265	0.46	0.33	0.568
February	1	0.337	0.40	0.70	0.404
March	1	-0.186	0.44	0.18	0.673
April	1	0.909	0.37	6.09	0.014
May	1	0.565	0.39	2.10	0.147
June	1	-0.002	0.42	0.00	0.996
July	1	-0.499	0.48	1.10	0.295
August	1	-0.178	0.42	0.18	0.669
September	1	0.508	0.38	1.79	0.181
October	1	-0.303	0.42	0.52	0.472
November	1	0.212	0.40	0.28	0.598
December	0	0.000	0.00	nd [2]	nd
Farm with hens of different ages	1	-0.250	0.27	0.87	0.351
Farm with all hens of the same age	0	0.000	0.00	nd	nd
Farm with hens of different ages					
Deep litter with outdoor run	1	0.208	0.38	0.29	0.589
Deep litter	1	0.739	0.27	7.57	0.006
Cage system wet manure	1	-0.328	0.33	0.98	0.323
Cage system dry manure	0	0.000	0.00	nd	nd
Farm with all hens of the same age					
Deep litter with outdoor run	1	0.003	0.38	0.00	0.995
Deep litter	1	-0.759	0.38	4.01	0.045
Cage system wet manure	1	-1.337	0.48	7.72	0.006
Cage system dry manure	0	0.000	0.00	nd	nd
Number of hens (×1000)	1	0.0195	0.0069	7.93	0.005

[1] Prob. = chi-squared probability

[2] nd = cannot be determined, because this coefficient is used as reference value

At a farm with all hens of the same age, a flock kept in a cage system with wet manure had a significantly ($\alpha < 0.01$; OR = 0.26) lower chance of infection with SE compared with a cage system with dry manure. At a farm with all hens of the same age, a deep-litter system also had a significantly ($\alpha < 0.05$; OR = 0.47) lower chance of infection with SE compared with a cage system with dry manure. The difference between a deep-litter system and a cage system with wet manure was not significant. At a farm with hens of different ages, however, a deep-litter system had a significantly higher chance of infection with SE compared with both types of cage systems ($\alpha < 0.01$; OR = 2.09 for cage with dry manure and OR = 2.91 (estimate = 1.067) for cage with wet manure). An outdoor run increased the chance of infection with SE significantly ($\alpha < 0.05$; estimate = 0.762; OR = 2.14) at farms with all hens of the same age. On farms with hens of different ages, no effect of outdoor run could be found. The factor number of hens increased the chance of infection with SE of a flock significantly ($\alpha < 0.01$; OR = 1.02 (per 1,000 hens)).

With the estimates from Table 4.2, the value of Y could be calculated for all combinations of month, housing system, farm with or without hens of different ages, and number of hens (equation 4). Interpretation of Y, however, is difficult. Therefore, the value of Y is transformed into the chance of infection with SE for a flock, using the logistic response function (1). Consider, for example, a flock that was sampled in July (–0.499), came from a farm with all hens of the same age (0.000), was housed in a deep-litter system with an outdoor run (0.003), and had 7,000 hens (7 × 0.0195 = 0.1365). These estimates, together with the general mean (–2.434), lead to

$$Y = \beta'\mathbf{X} = -2.434 - 0.499 + 0.000 + 0.003 + 0.1365 = -2.7935$$

Hence, with equation (1), this results in

$$E(y) = \exp(-2.7935) / [1 + \exp(-2.7935)] = 0.0577,$$

which means a 5.8% chance of infection with SE.

4.4 Discussion

4.4.1 Data set

The analyzed data set contained 1,912 flocks, from which additional information on, among others, housing system, was available. For each flock, the farmer provided this additional information voluntarily, which could have led to a biased data set. Bias occurs, for example, if farmers who do not provide this additional information have a higher incidence of infection with SE. The overall average percentage of infection, however, was equal in the original and final data sets (i.e., 10%). In addition, vaccinated flocks were excluded from the final data set, which could have led to underestimation of the chance of infection for housing systems in which more flocks were vaccinated, such as deep-litter systems (Table 4.1).

The management factor could not be taken into account in this study explicitly, because required data were lacking. Management, however, is an important factor, because most infections originate from the farm environment, which can be due to improperly cleaned and disinfected poultry houses or infected vermin at the farm (Henzler and Opitz, 1992; van de Giessen et al., 1994; Davies and Breslin, 2003; 2004). Henken et al. (1992) also showed the importance of hygienic measures in broiler breeder flocks. This problem could not be solved by including farm as a variable in the model with which differences in management between farms would be covered, because characteristics analyzed were defined at the flock level. Consequently, systematic differences in management among different housing systems were incorporated in the variable housing system. This made the variable housing system more a characterization of different production systems than of technical different housing systems only.

4.4.2 Model reduction

The variable year did not influence the results significantly and, therefore, was not included in the final model. This meant that the action plan to prevent and to eliminate SE, launched in 1997 (PVE, 2001), did not cause a reduction in SE incidence. Already in 2001 the action plan to prevent and eliminate SE became stricter (PPE, 2002). The effect of this change could not be derived from this analysis because the last data originated from 2002, and it takes longer to realize the effects of this change, as samples were taken at the end of the production period. Bouwknegt et al. (2004), however, found a significant decrease in *Salmonella* spp. in laying hens and a tendency for a decrease of SE from 1999 to 2002, suggesting that the control measures had a positive effect. They, however, only corrected for age and flock size and took faecal samples instead of blood samples.

The variable house with hens of different ages did not appear to contribute significantly to the chance of infection of a flock. This was possibly caused by the low number of houses with hens of different ages (see Table 4.1) and its relation with the variable farm with hens of different ages.

A significant influence of the variable month was found, which implicates that a seasonal trend could be present in the incidence of infections with SE in flocks of laying hens. From the current analysis, however, we could not conclude on the kind of trend present. A difficulty hereby was that flocks were sampled at the end of the laying period, whereas they could have been infected during the whole production period prior to the sampling date. The link between time of infection and sampling, therefore, was ambiguous. Bouwknegt et al. (2004) also did not find a seasonal trend, although they took manure samples of hens of different ages, which would give a better indication of the time of infection. For broiler flocks, however, Angen et al. (1996) found a significant effect of season on the incidence of *Salmonella enterica* infections with a higher incidence in the wet and cold season.

Only the interaction between housing system and farm with hens of different ages was significant in the model. This finding means that the effect of hens of different ages on a farm differed among the 4 housing systems.

4.4.3 Results from final model

At a farm with all hens of the same age, a flock kept in a cage system with wet manure had a significantly lower chance of infection with SE compared with a cage system with dry manure. A possible explanation could be that the manure in the cage system with dry manure was air-dried and that through this airflow salmonellae were transported. Gast et al. (1998) also mention that airborne transmission of SE is an important factor in spreading infections between cages.

A flock in a deep-litter system also had a significantly lower chance of infection with SE compared with a cage system with dry manure at a farm with all hens of the same age. At a farm with hens of different ages, however, a deep-litter system had a significantly higher chance of infection with SE compared with both types of cage systems. A possible explanation is that particles (e.g., manure) were transported easier from house to house in a deep-litter system, which resulted in a higher chance of infection with SE compared with a cage system with dry manure. This finding also corresponds with the significant difference between farms with hens of different ages and farms with all hens of the same age for deep-litter systems. The risk of more houses on a farm, which generally occurs on farms with hens of different ages, corresponds with the results of Angen et al. (1996) and Skov et al. (1999). They showed that having more broiler flocks on a farm increased the risk of infection with different *Salmonella* species. Also Davies and Breslin (2004) mentioned an increased risk on farms with multistage production and more houses.

The influence of an outdoor run is ambiguous, as the chance of infection with SE increased only at farms with all hens of the same age. An outdoor run possibly increases the risk of SE infection through vermin (e.g., mice and flies). This increased risk, however, only appeared in systems with a relatively low SE infection rate (i.e., deep-litter systems at farms with hens of the same age). The effect of number of hens was significant and showed that bigger flocks had a higher chance of infection with SE. This finding is in accordance with Heuvelink et al. (1999), who also found a significant higher incidence of *Salmonella* infections in bigger flocks.

The objective of this study was to identify risk factors associated with SE infection in laying hens. The main risk factors are flock size, housing system, and farm with hens of different ages. Bigger flocks increase the chance of infection with SE in all housing systems. The effects of housing system and farm with hens of different ages, however, interact with each other. The actual effect of a housing system on the chance of infection, therefore, is dependent on whether there are hens of different ages on the farm.

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Chapter 5
On-farm quantification of sustainability indicators: an application to egg production systems

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Abstract

On-farm quantification of sustainability indicators (SI) is an effective way to make sustainable development measurable. The egg production sector was used as a case study to illustrate this approach. The objective was to select SI for economic, ecological, and societal issues, and to analyze the performance on selected SI of different production systems. For the case study, we compared four egg production systems, characterized by differences in housing systems, which are most common in the Netherlands: the battery-cage system, the deep-litter system with and without outdoor run, and the aviary system with outdoor run. Based on a clear set of criteria, we selected SI for animal welfare, economics, environmental impact, ergonomics, and product quality. We showed that on-farm quantification of SI was an appropriate method to identify strengths and weaknesses of different systems. From this analysis it appears that the aviary system with outdoor run is a good alternative for the battery-cage system, with better scores for the aviary system on animal welfare and economics, but with worse scores on environmental impact.

5.1 Introduction

An often-quoted definition of sustainable development is the one of the World Commission on Environment and Development (WCED) that says, “Sustainable development meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations” (Brundtland, 1987). The ecological point of view dominated the discussion during the early phases of sustainable development concern. The WCED already recognized, however, that sustainable development is embedded in social structures and economy. Others (e.g., Clayton and Radcliffe, 1996; Hardi and Zdan, 1997) put more emphasis on the economic and societal aspects of sustainable development. Sustainable development, thus, encompasses economic, ecological, and societal (EES) aspects, which all need to be considered simultaneously (de Boer and Cornelissen, 2002).

Developing indicators for sustainable development can be an effective way to make such a complex concept measurable (Rigby et al., 2001). We defined an indicator as a tool to quantitatively measure an issue. In order to assess sustainable development of (animal) production systems, Mollenhorst and de Boer (2004) developed a four-step methodology: 1) description of the situation, 2) identification and definition of relevant EES issues, 3) selection and quantification of suitable sustainability indicators (SI) for each issue, and 4) final assessment of the contribution to sustainable development. During the first step, a production system, e.g., a farm, with its direct context is depicted. Based on this picture, stakeholders are selected, representing all components within the systems, and from the direct context. Subsequently, during step two, these stakeholders are involved in a participatory process to identify EES issues. This step can be supplemented with a literature review on the issues mentioned. During the third step, issues are made measurable by selecting SI, which are quantified. In order to show the significance of possible differences among indicator scores of various production systems in practice, it is necessary to quantify the within and between-system variation for each indicator. The fourth step encompasses the final assessment, which means that all information is brought together to determine the contribution of a particular animal production systems to sustainable development.

We applied this methodology to the egg production sector as a case study. The ban on the battery-cage system in the European Union (EC, 1999), mainly due to impaired hen welfare in these systems, forces farmers to change to alternative housing systems for egg production. Large scale introduction of more animal-friendly systems, however, requires a comparison of these systems in a wider EES context, which makes the egg production sector a good example of the approach to assess sustainable development. Mollenhorst and de Boer (2004) discuss the first two steps of this approach. This paper focuses on step 3, i.e. the selection and quantification of SI.

The objectives of this study were 1) to select SI for different EES issues, and 2) to analyze the performance on selected SI of different egg production systems, which are characterized by differences in housing system. For this case study, we compared the four most common housing systems in the Netherlands: the battery-cage system (BC), the deep-litter system with and without outdoor run (DLO resp. DL), and the aviary system with outdoor run (AO). We defined housing systems in accordance with European legislation (EC, 1999).

5.2 Materials and methods

5.2.1 Selected EES issues

Mollenhorst and de Boer (2004) concluded that in order to assess the contribution of egg production systems to sustainable development, animal health and welfare, economics, environmental impact, ergonomics, product quality, consumer concerns, and knowledge and innovation should be taken into account. One objective of this study was to analyze the performance on selected SI of different housing systems. In order to quantify the within and between-system variation for each SI, we collected data on a large number of farms, and, therefore, we quantified only issues for which SI were available and data were accessible on-farm. Therefore, we excluded the issues consumer concerns, and knowledge and innovation in this study.

5.2.2 Selection of SI

For each EES issue, we defined possible SI and subsequently selected final SI. Mollenhorst et al. (2005b) formulated criteria for selecting indicators based on Mitchell et al. (1995). Indicators have to be a) relevant, i.e., they have to express something about the issue, b) simple, i.e., they have to be understandable for users, and c) sensitive and reliable, i.e., they have to react to changes in the system, and different measurements must lead to the same outcome. Furthermore, d) it must be possible to determine a target value or trend, and e) data have to be accessible. In this study, we gathered data from finished flocks. The following sections describe the selection of SI for the EES issues, followed by a description of the selected SI and the data necessary to quantify it.

Animal health and welfare

The Farm Animal Welfare Council (1992) formulated 'five freedoms', that cover the animal's basic welfare needs, namely, 1) the freedom from hunger and thirst, 2) the freedom from discomfort, 3) the freedom from pain, injury or disease, 4) the freedom to express normal behaviour, and 5) the freedom from fear and distress. In accordance with these five freedoms, we considered animal health as an integral part of animal welfare. Table 5.1 lists possible SI for animal welfare.

Table 5.1. Selection of indicators for animal welfare.

Possible SI	Relevant	Simple	Sens./ reliable	Trend/ target	Data	Final SI
Behavioural observations	+	-	+	-	-	-
Animal Needs Index	+	+	0	+	+	Y
Feather condition score	+	+	+	+	-	-
Disease incidence	+	+	+	+	-	-
Clinical observations	+	+	+	+	-	-
Mortality rate	0	+	0	+	+	Y
Deviations from the egg production curve	0	0	+	+	+	Y
Medicine use	0	+	0	+	+	Y

+ suitable; 0 moderately suitable; - not suitable

Results from behavioural observations are the most relevant SI for freedom to express normal behaviour, but also for elements like freedom from discomfort, fear, and distress. Specialist, however, have to observe the hens during repetitive visits, which hampers data accessibility. Furthermore, wished and unwished behaviour are difficult to define, which hampers simplicity and the ability to define a target. An alternative SI is a scoring system, like the Animal Needs Index (ANI, Striezel, 1994). The ANI scores prerequisites for animal welfare by means of mainly environment-based and some animal-based parameters. Data on environment-based parameters, e.g., dimensions of the stable and facilities, like nests and perches, are easily accessible. Mollenhorst et al. (2005b) compared the ANI with behavioural observations to test its relevance and sensitivity. They concluded that ANI is an appropriate method for assessment of the between-system variation in laying hen welfare on a large number of farms. The ANI covers especially freedom to express normal behaviour, and only partly freedom from hunger and thirst, injury, and discomfort. The ANI divides the needs of an animal in eight categories: locomotion, feeding and drinking, social, resting, comfort and nesting behaviour, supplemented with management with respect to hygiene and care. In all categories different aspects are scored and summed (Mollenhorst et al., 2005b). Many parameters, like available space, are expressed per hen. In this study, we used the maximum number of hens present at a time. Furthermore, all ANI-scores were based on information provided by the farmer.

The third possible SI for animal welfare is the feather condition score. Feather pecking and cannibalism are considerable problems in laying hens (Savory, 1995; Koene, 1997; Green et al., 2000; McAdie and Keeling, 2000; Pötzsch et al., 2001). They can lead to bold (featherless) patches and injuries, sometimes resulting in death. The feather condition score of Bilcík and Keeling (1999) scores damage to feathers and skin injuries and is, therefore, a good SI for freedom from discomfort, pain, injury, fear, and distress. Data accessibility, however, again is a problem, because it requires observations by specialists in the house.

Other possible SI for animal welfare are disease incidence and results from clinical observations. They are the most relevant SI related to freedom from diseases, but are difficult to measure. Disease incidence was not registered regularly on farm, and clinical observations have to be done by a specialist during repetitive visits, which hampers data accessibility. Immunological and pathological assessments, which could replace clinical observations, are not routinely performed and are, therefore, also not relevant as SI in this study. Van de Ven (2002) searched for general illness symptoms for poultry diseases. These, however, are hard to define, because different diseases show different symptoms. The only general symptoms are behaviour and zootechnical parameters. Zootechnical parameters are, e.g., mortality rate, egg production, and feed intake. Behaviour has been discussed earlier and was not selected as final SI. Relevance and sensitivity for the zootechnical parameters are moderate, because they only indicate severe stages of illness or other problems, like cannibalism. On the other criteria, however, they score well. Therefore, we selected mortality rate, a simple indicator for seriously impaired welfare, and ‘deviations from the egg production curve’, a more sensitive, but less simple indicator, as SI. We used cumulative mortality rates from 21 to 68 weeks of age to make a fair comparison of mortality rates for all flocks. In order to assess ‘deviations from the egg production curve’, we fitted a curve through the weekly production data of each flock. The curve was adapted from Jolicoeur et al. (1988) in a way that it now contains an increasing and a decreasing phase. The adapted equation is:

$$Y_t = \frac{A}{(1 + \left(\frac{c_1}{t}\right)^{b_1} + \left(\frac{t}{c_2}\right)^{b_2})}$$

where Y_t is the laying percentage per present hen in week t; t is the age of the hens in weeks after hatching (t = 21,..,68); A gives an indication of maximum production; c_1 and c_2 are time-scale factors, determining the duration of the different phases; and b_1 and b_2 are dimensionless exponents, determining the rate of increase, respectively, decrease of the different phases. We estimated parameters A, b_1, b_2, c_1, and c_2 for each flock using iterative non-linear regression (Gauss-Newton method). We made a histogram of the sum of squared residuals of each flock to assess the difference in variation between normal and disturbed curves. From this histogram, we concluded that a sum of squared residuals up to 100 was caused by normal variation in data (e.g., caused by technical problems, feeding, or climatic factors), whereas a sum of squared residuals above 100 was assumed to be caused by illness. When the sum of squared residuals was above 100, we gave the week with the largest negative deviation weight zero to improve the fit. When this was not enough, we repeated the procedure till the sum of squared residuals was below 100. We used the number of weeks needed to reduce the sum of squared residuals to this point as an indicator for ‘deviations from the egg production curve’.

The last possible SI for animal welfare is medicine use, which also relates to freedom from diseases. Relevance and sensitivity of this SI are moderate, as it strongly depends on farmer’s management how quickly he uses medicine. On individual farms, it is, therefore, not a good SI, as using no medicine in case of disease can hamper animal welfare. For assessment among housing systems, as in this study, however, medicine use is a useful SI, as higher average medicine use points at a (conceived) health risk. We only inventoried of the type of medicines used, because data on amount of medicines used were not always available.

Economics

Labour income is the most important, and generally agreed, economic indicator to take into account when assessing sustainable development (Mollenhorst and de Boer, 2004; van Calker et al., 2005). Van den Tempel and Giesen (1992) defined labour income as the difference between revenues and costs, excluding costs of labour of the family. First, we calculated all revenues and costs per hen per year. Then, to get labour income per full time equivalent (FTE), we multiplied labour income per hen per year by the number of hens actually kept per FTE. Calculations were based on actual technical results and on standard prices for, e.g., eggs, hens, and feed for 2002 (KWIN, 2003). Additionally, we used KWIN (2003) as reference for missing data on, e.g., water and electricity use, and for percentages of depreciation, maintenance, and interest of production means.

Environmental impact

An assessment of environmental impact of animal production systems should encompass different impact categories, such as acidification, eutrophication, global warming, and the use of resources, such as land and fossil energy (de Boer, 2003). Feed production is one of the main sources of environmental impact in egg production systems (van Woudenbergh, 2004). Therefore, a method that assesses the on-farm impact only (i.e., input-output accounting (Thomassen and de Boer, in press)), is not sufficient. In this study, we used Life Cycle Assessment (LCA, Haas et al., 2000; de Boer, 2003) to quantify the environmental impact of egg production. LCA assesses the impact of all relevant production processes during the life cycle of the production of one kg of eggs. The impact of the production process of concentrates, for example, is ascribed to the production of eggs. Production processes included in this LCA computation are the production of concentrates, 17-week-old hens, litter, water and energy, and the production process at the farm itself. We used economic allocation, which means that the allocation of environmental impact of each production process to its main- and co-products was based on their economic value.

Environmental impact of the off-farm production processes of concentrates and litter was based on van Woudenbergh (2004), the impact of the production process of water was based on Brand and Melman (1993), and of energy on Michaelis (1998). The impact of 17-week-old hens was calculated, based on used concentrates (van Woudenbergh, 2004) and standard emission from the housing system (Oenema et al., 2000). To compute environmental impacts, we collected on-farm data on the amount and composition of concentrates, the amount of litter used, the number of 17-week-old hens purchased, and the amount of water and energy used. For missing data on, for example, water use, we used reference values (KWIN, 2003).

To compute the on-farm environmental impact, we collected data on the manure drying and ventilation system, the size of the outdoor run, and the average number of hens present. We used standard values for the emissions of NH_3, N_2O, NO_x and CH_4 from the different housing systems and manure storage facilities (Oenema et al., 2000; de Mol and Hilhorst, 2003; VROM, 2004). The nitrogen, after volatilization, and phosphorus dropped in the outdoor run was assumed to leach to the groundwater, because of the high manure load just outside the house (Hermansen et al., 2004).

Ergonomics

"Ergonomics is the study of work and working conditions in order to improve people's efficiency" (Oxford Advanced Learner's Dictionary of Current English, 5th Edition, 1995). Working conditions and exposure to these conditions, i.e. working hours, are possible SI for ergonomics. Assessment of working conditions, however, requires time consuming observations by specialists. Physical complaints can result from working conditions and exposure, and are easier to assess. Therefore, we assessed ergonomics by asking the farmers whether they had complaints during the last year. For this, we used part of an existing questionnaire (Anonymous, 1999), which was also used by Ellen et al. (2002). Complaints concerning the limbs and the respiratory system got special attention.

Product quality

Product quality encompasses external and internal egg quality (Mollenhorst and de Boer, 2004). For external egg quality, we selected the percentage second grade eggs as SI. Second grade eggs are all cracked, broken and dirty eggs selected on farm or at the egg packaging station. The most important aspect of internal egg quality is food safety. In food safety, generally, three risk areas are distinguished: microbiological, chemical, and physical contaminations (Codex Alimentarius Commission, 2001; Swabe et al., 2001). In eggs, the most important microbiological threat for food safety is Salmonella (Mollenhorst et al., 2005a). Therefore, we selected the *Salmonella enteritidis* (SE) status as SI. The SE status of all flocks at the end of the production period is known, because it is monitored by taking blood samples, as part of an action plan to control and reduce SE in laying hens (PVE, 2001). The most important chemical threats are dioxins and residues from medicines. Medicine use is regulated strongly to avoid residues in eggs and is, therefore, in principle not a risk factor for food safety. Furthermore, analysis on dioxins was too expensive to incorporate in this study, and, therefore, no SI was available on this issue. Physical contaminations are no issue regarding eggs at farm level.

5.2.3 Data collection

We sent 362 letters to farmers to inform them about the research project. Subsequently, we checked by telephone whether they were suitable to include in the sample. The main reasons to exclude farmers were that they had white feathered hens, quitted farming, or did not have the right system. This resulted in 167 suitable farmers, of which 106 were not willing to participate, because they did not like to, were too busy, or already indicated that they did not have enough data to answer all questions. Finally this resulted in a response rate of 37% (61 out of 167).

One researcher visited all 61 farms and collected the necessary data through a questionnaire. Table 5.2 shows that DL farms had relatively small farms and flocks, and DLO farms were considerably less specialized than the others. Farm visits took place from February until August 2004. Data were collected from the last flock finished in 2002, because most flocks were not run properly in 2003 due to the Avian Influenza outbreak in the Netherlands. Not all farmers were able to supply all necessary information. Therefore, in all tables and figures we mentioned the number of farms per housing system used in the analysis.

Table 5.2. Some characteristics of studied farms, flocks and farmers for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO). Standard deviations are given between brackets.

Characteristic	BC (n = 16)	DL (n = 15)	DLO (n = 17)	AO (n = 13)
Total farm size (NGE [1])	177 (106)	98 (68)	124 (127)	127 (68)
Share of laying hens in total farm size (mean % of NGE)	76 (24)	77 (34)	57 (32)	76 (21)
Mean number of hens (SD)	25944 (18142)	7295 (5204)	12771 (7996)	19953 (8009)
Farmer's age (years)	42 (12)	49 (14)	47 (13)	43 (9)

[1] NGE = Dutch Size Unit (ww.lei.wageningen-ur.nl), based on Standard Gross Margin, a unit used for determining economic size and type of agricultural holdings (EEC, 1985)

5.2.4 Statistical analysis

For a continuous SI, Levene's test ($\alpha = 0.05$) was used to test for homogeneity of variance. In case the variance was not homogeneous, we applied a suitable transformation to obtain homogeneity. Subsequently, we used analysis of variance to analyze the influence of housing system on the scores of an SI. When the influence of housing system was significant, we assessed differences among individual housing systems by pairwise comparison with the post-hoc test of Bonferroni.

For a discrete SI, we used Fisher's exact test to analyze the influence of housing systems on the scores of an SI. In case categories were not mutually exclusive, we tested each category separately as a yes/no category. All statistical analyses were performed using SAS (SAS Institute Inc., 1999).

5.3 Results and discussion

5.3.1 Animal welfare

Average ANI scores ranged from 37 points for BC to 114 points for AO, with all mutual differences among housing systems being significant ($P < 0.001$; Table 5.3). Higher scores for DLO and AO were determined mainly by the availability of an outdoor run. Other important determinants for differences among housing systems were the number of hens per square meter (categories locomotion and social; Table 5.3), and availability of facilities like litter, perches and nestboxes (categories resting, comfort, and nest). The high score for battery-cage systems on the category social was caused by group size, which was rewarded because in small groups hens are able to establish the pecking order (social hierarchy). In general, scores for BC were overestimated, due to the fact that ANI was not developed for cage systems (Sundrum and Andersson, 1994). Therefore, BC got zero points for several aspects, although negative scores would have been justifiable. This means that the difference among BC and other systems, as estimated in this study, was still conservative (Mollenhorst et al., 2005b). Results corresponded well with expert judgement from Fiks-van Niekerk (2003), who also evaluated the opportunities for performing behaviour in different systems.

Table 5.3. Results of the Animal Needs Index for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO). Data are given for each category and total per systems. Standard deviations are given between brackets.

Category	**BC (n = 16)**	**DL (n = 14)**	**DLO (n = 17)**	**AO (n = 13)**
Locomotion	0.0 (0.0)	2.3 (2.1)	13.6 (3.2)	19.4 (1.9)
Feeding & drinking	5.2 (1.9)	8.7 (3.2)	12.4 (2.3)	14.5 (2.6)
Social	6.9 (1.0)	3.0 (2.0)	5.6 (1.9)	11.8 (1.7)
Resting	3.0 (0.0)	10.6 (4.3)	11.1 (3.7)	11.1 (2.8)
Comfort	0.0 (0.0)	4.3 (2.4)	15.8 (1.9)	14.3 (1.8)
Nest	0.0 (0.0)	9.5 (1.5)	9.9 (1.7)	9.5 (1.1)
Hygiene	8.7 (1.7)	10.0 (3.2)	14.1 (2.7)	17.8 (3.0)
Care	13.1 (2.1)	11.3 (2.4)	14.2 (1.6)	16.0 (2.5)
ANI	36.9^{a} (4.5)	59.7^{b} (9.3)	96.7^{c} (9.4)	114.4^{d} (8.9)

^{a,b,c,d} ANI with different superscripts differ significantly ($P < 0.001$; Bonferroni)

Mortality rates differed considerably within and among housing systems (Figure 5.1). They were log-transformed before analysis to approach a distribution with equal variances. The geometric mean (n^{th} root of the product of n data points) of mortality rates ranged from 5.5% for BC to 10.6% for DLO (Figure 5.1). Because the variation within housing systems was high, only BC and DLO differed significantly ($P < 0.05$). That most differences were not significant corresponds with literature, which is also ambiguous on this subject. Some studies report that mortality rates are lowest in battery cages, higher in deep-litter systems, and highest in systems with outdoor run and in organic systems, with mortality rates up to 30% (van Niekerk and van Horne, 2000; Fiks-van Niekerk et al., 2003; KWIN, 2003; Hermansen et al., 2004), whereas others report that systems with outdoor run have lower mortality rates compared to deep-litter systems (Anonymous, 2004; von Borell and Sørensen, 2004), or that aviary systems without outdoor run had similar (Bosch and van Niekerk, 1995; Aerni et al., 2005) or even lower (van Horne, 1996) mortality rates compared to cage systems. Extremely high mortality rates are caused mostly by cannibalism, which was also the case for the three highest values in DL in Figure 5.1. Lower mortality rates in systems with outdoor runs could be caused by better opportunities to escape from attacks. This was not supported by our data.

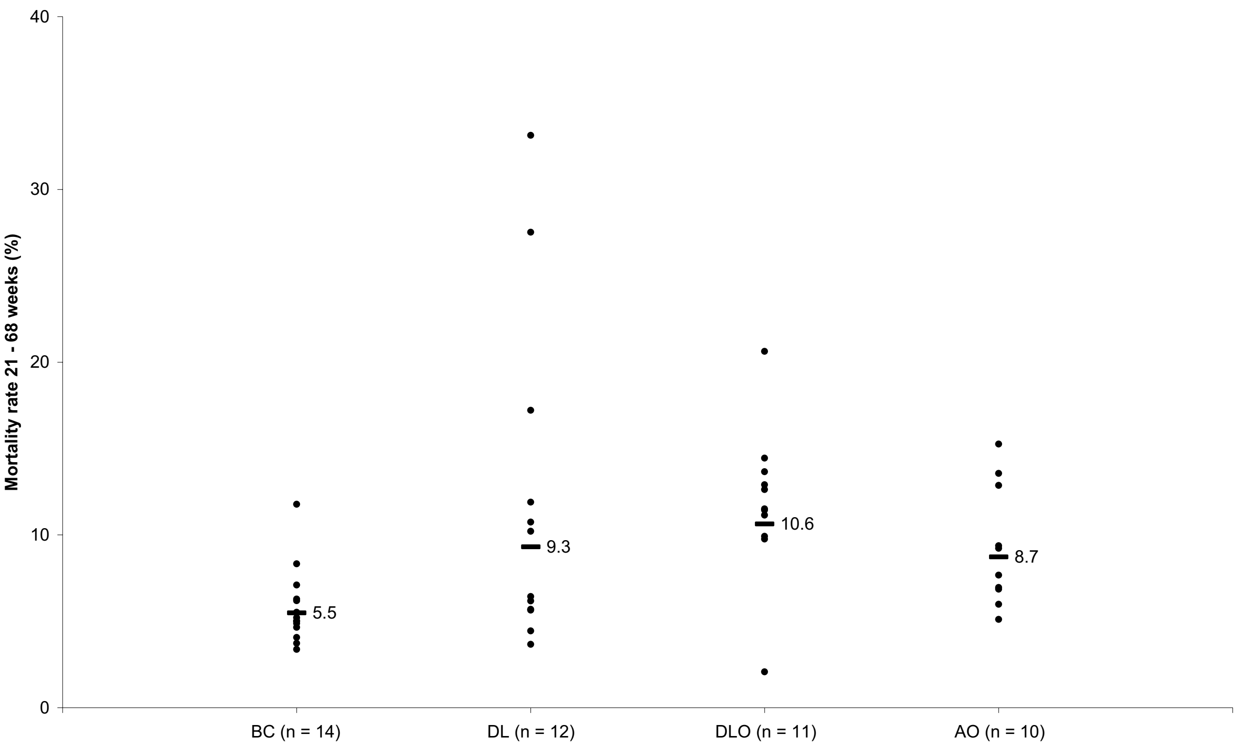

Figure 5.1. Mortality rates (21 – 68 weeks) for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO). Individual flocks are represented with dots and geometric means for the different systems with bars.

Concerning 'deviations from the egg production curve', DLO performed worse than the other systems, with on average more than three weeks with weight zero, compared to less than one for all other systems (Table 5.4). Because the number of weeks with weight zero differed considerably among individual flocks, the incidence of flocks with a high number of weeks with weight zero was low. Therefore, flocks with and without deviations were distinguished, and analysis was performed on the resulting variable. This resulted in 73% of the flocks having deviations in DLO and 27% or less in all other systems (Table 5.4). Herewith, the influence of housing system on the percentage of flocks with deviations from the production curve was significant (Fisher's exact test: $P < 0.05$).

Table 5.4. Deviations in production curves for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO).

	BC (n = 14)	**DL (n = 12)**	**DLO (n = 11)**	**AO (n = 11)**
Average number of weeks given weight zero	0.36	0.33	3.18	0.73
Flocks with deviations (%) [1]	14	25	73	27

[1] Fisher's exact test: $P < 0.05$

No medicines were used in BC and DL in respectively 81% and 73% of the flocks, compared to 41%, respectively 31% in DLO and AO (Table 5.5). Anthelmintics caused the differences in medicine use, whereas other medicines were used in similar amounts. The relationship between housing system and 'using no medicine' ($P < 0.05$) and between housing system and 'using anthelmintics' ($P < 0.001$) was significant (Fisher's exact test). Anthelmintics were used in more than 50% of all flocks that had access to an outdoor run. Risk of contamination with helminthes can be higher outdoors than indoors, because helminthes have a broad range of hosts (Ruff and Norton, 1997), and risk of contamination from wild birds is, therefore, plausible. Other medicines were used in less than 20% of all flocks in all housing systems. This is in agreement with Rougoor et al. (1994), who mentioned that only few medicines were used in laying hens, because of the risk of residues in the egg.

Table 5.5. Medicine use for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO).

	BC (n = 16)	DL (n = 15)	DLO (n = 17)	AO (n = 13)
No medicine use (%) [1]	81	73	41	31
Anthelmintics (%) [2]	0	20	53	62
Others (%) [3]	19	13	18	15

[1] Fisher's exact test: $P < 0.05$

[2] Fisher's exact test: $P < 0.001$

[3] Most common were medicines against E. coli.

The results on animal welfare, which were confirmed by literature, showed that prerequisites for performing behaviour were better in non-BC systems and in systems with access to an outdoor run. On the other hand, these systems could implicate some extra risks, e.g., increased mortality due to cannibalism or higher diseases incidence. The better farms, however, showed that there are possibilities to reduce these risks effectively.

5.3.2 Economics

Labour income per FTE differed considerably among housing systems, as shown by the differences in averages, as well as within housing systems, as shown by the high standard deviations (last line of Table 5.6). Results of AO (86 thousand euros per FTE per year) were significantly better than of all other housing systems ($P < 0.001$). Most important determinants were higher revenues, due to higher (standard) sales prices of eggs from systems with outdoor run, higher numbers of hens per FTE in AO compared to DL and DLO, and lower housing costs per hen compared to DL and DLO. Feeding costs were lowest for BC, which corresponded well with lower feed conversion ratios (Hermansen et al., 2004; von Borell and Sørensen, 2004; Aerni et al., 2005). In addition, almost all other costs were lowest for BC. These low costs, however, could not compensate for the lower revenues due to lower egg prices (difference BC vs. AO was 1.75 eurocent per egg, i.e., 39%).

Table 5.6. Economic results for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO). Data are given in euros per round or per year, per 100 housed hens, except for the last line, which is per FTE. Standard deviations are given between brackets.

	BC (n = 15)	**DL (n = 13)**	**DLO (n = 14)**	**AO (n = 11)**
		Euros per round		
Eggs	1476 (147)	1744 (170)	1915 (112)	1961 (125)
Old hens	28 (1)	26 (4)	25 (3)	27 (1)
Total revenues	**1504 (147)**	**1769 (172)**	**1940 (113)**	**1987 (125)**
Feed	849 (87)	891 (117)	897 (48)	883 (55)
Young hens	314 (0)	334 (0)	349 (0)	349 (0)
Other variable costs [1]	121 (28)	115 (24)	117 (15)	136 (28)
Total variable costs	**1284 (97)**	**1340 (130)**	**1364 (52)**	**1368 (56)**
Gross margin per round	**220 (87)**	**429 (126)**	**576 (80)**	**619 (112)**
Length of round (days)	416 (38)	425 (23)	425 (23)	423 (23)
		Euros per year		
Gross margin per year	192 (73)	368 (106)	495 (76)	533 (79)
Depreciation and maintenance of buildings	147 (5)	215 (4)	212 (1)	177 (9)
Interest on buildings	41 (1)	74 (1)	73 (0)	47 (2)
Control levies	0 (0)	4 (1)	4 (1)	3 (0)
Interest on land	0 (0)	0 (0)	84 (61)	55 (27)
Total fixed costs (excl. labour)	**187 (6)**	**292 (5)**	**373 (61)**	**282 (29)**
Labour income	**4[a] (72)**	**75[ab] (106)**	**123[b] (92)**	**251[c] (83)**
Hens per FTE (#)	44322 (33863)	16871 (9987)	19429 (9175)	32862 (14310)
Labour income per FTE [2]	**2855[a] (32596)**	**15576[a] (22600)**	**22828[a] (19149)**	**86041[b] (54016)**

[1] Other variable costs: costs of electricity, water, veterinarian service, bedding material, levies, disposal of dead animals, other services, interest on animals, and manure disposal.

[2] Assumption of equal variances is not appropriate for labour income per FTE ($P = 0.035$).

[a,b,c] Results with different superscripts differ significantly ($P < 0.05$)

It must be noted that the assumption on equality of variance was not totally appropriate for labour income per FTE (Levene's test P = 0.035). Analysis with a non-parametric test (Kruskal-Wallis), however, resulted in the same level of significance for the overall housing system effect, which showed that the assumption seemed to be appropriate. Large variation in labour income per FTE was caused partly by variation in number of hens per FTE. Labour income per 100 hens, however, showed more or less the same housing system effect as labour income per FTE (Table 5.6). When the results per 100 hens were multiplied with the normative number of hens per FTE (KWIN, 2003), also only AO performed significantly better than all other systems. Levels of and differences in economic results corresponded well with results discussed by experts in The Netherlands (Anonymous, 2003; KWIN, 2003).

5.3.3 Environmental impact

Table 5.7 shows LCA results of each impact category for all housing systems. Per impact category, the main on-farm and off-farm contributor are shown also. Production of concentrates contributed most to the total impact of all categories, except for acidification. Differences in impact of concentrate production among housing systems were mainly determined by differences in feed conversion ratio. The final differences among housing systems, however, were mainly determined by differences in on-farm contributions.

Acidification potential was highest for DL and DLO, and intermediate for AO, due to higher ammonia emission from manure, present in the house, storage facility, or outdoor run.

Eutrophication potential was highest for DLO, and intermediate for DL and AO. DL and DLO had a higher eutrophication potential due to higher ammonia emission, whereas systems with outdoor run had a higher eutrophication potential due to leaching from the manure in the outdoor run. This factor, however, could be overestimated, because we assumed that all nutrients (N and P) dropped in the outdoor run that did not volatilize, leached to the groundwater. Depending on the spread of manure over the outdoor run, grass takes up part of the minerals and, consequently, leaching decreases.

Global warming potential was highest for DLO and lowest for BC. Differences, however, were small. The main contributor was N_2O-emission during the growing of concentrate ingredients (part of concentrate production) and from manure on the farm. Differences in contribution of concentrate production to the total impact, mainly determined by differences in feed conversion ratio, were most clearly shown on this impact category, but were present in all impact categories.

Land use was highest for DLO and AO, mainly caused by the outdoor run, which was the only contributor to on-farm land use.

Differences in energy use were not significant, because differences in the contribution of concentrate production were counteracted by differences in direct energy use. DL and DLO use less direct energy, because, usually, they do not have manure drying facilities.

Table 5.7. Results of environmental impact assessment for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO). Per impact category totals and two main contributors are shown. Standard deviations are given between brackets.

	BC (n = 15)	DL (n = 13)	DLO (n = 14)	AO (n = 11)
Acidification potential (SO_2-eq. / kg egg)	0.032[a] (0.013)	0.057[c] (0.012)	0.065[c] (0.003)	0.042[b] (0.006)
- emissions from manure	0.011 (0.012)	0.031 (0.010)	0.037 (0.002)	0.019 (0.007)
- concentrate production	0.017 (0.001)	0.018 (0.003)	0.019 (0.002)	0.018 (0.001)
Eutrophication potential (NO_3^--eq. / kg egg)	0.25[a] (0.04)	0.31[b] (0.04)	0.41[c] (0.03)	0.35[b] (0.02)
- emissions from manure	0.02 (0.02)	0.06 (0.02)	0.14 (0.01)	0.10 (0.01)
- concentrate production	0.21 (0.03)	0.22 (0.03)	0.23 (0.02)	0.22 (0.02)
Global warming potential (CO_2-eq. / kg egg)	3.9[a] (0.3)	4.3[bc] (0.5)	4.6[c] (0.3)	4.2[ab] (0.3)
- emissions from manure	0.3 (0.1)	0.4 (0.2)	0.4 (0.0)	0.3 (0.2)
- concentrate production	3.2 (0.2)	3.4 (0.4)	3.6 (0.3)	3.4 (0.2)
Land use (m^2 / kg egg)	4.5[a] (0.3)	4.8[ab] (0.5)	5.7[c] (0.6)	5.1[b] (0.4)
- on-farm land use	0.0 (0.0)	0.0 (0.0)	0.5 (0.4)	0.3 (0.1)
- concentrate production	4.1 (0.3)	4.4 (0.5)	4.7 (0.4)	4.3 (0.3)
Energy use (kJ / kg egg)	1.30 (0.14)	1.34 (0.19)	1.39 (0.15)	1.37 (0.11)
- direct energy use	0.13 (0.06)	0.09 (0.07)	0.06 (0.03)	0.12 (0.05)
- concentrate production	1.03 (0.11)	1.10 (0.18)	1.17 (0.14)	1.09 (0.10)

[a,b,c] Totals with different superscripts differ significantly ($P < 0.05$)

5.3.4 Ergonomics

The average percentage of farmers with complaints ranged from 46% to 71% and did not differ significantly among housing systems (Table 5.8). Also the number of farmers with complaints ascribed to working in the laying hen house did not differ significantly among housing systems. In the questionnaire we asked specifically for complaints at neck or shoulders, arm or hand, lower back, and leg or foot. Neck or shoulders and lower back contributed mostly to the total number of complaints. These specified complaints, however, also did not differ significantly among housing systems. Ellen et al. (2002) performed a larger survey among poultry farmers and also compared their results with earlier studies in other agricultural sectors. Due to differences in reporting, results can be compared in broad outlines only. The overall incidence of physical complaints and its division over body regions, as noticed in our study, corresponded with the other studies and sectors. The difficulty to ascribe complaints to a specific task, as noticed by Ellen et al. (2002), could explain the low percentages of complaints related to

poultry. Furthermore, also psycho-social factors play an important role in causing complaints (Ellen et al., 2002).
The average percentage of farmers with coughing and sneezing fits ranged from 8% to 24%, and also did not differ significantly among housing systems (Table 5.8). This, again, corresponded with results from Ellen et al. (2002), who found an overall percentage of 11%. Concentrations of dust and endotoxins, however, are higher in non-cage systems (Seedorf et al., 1998; Takai et al., 1998; Drost et al., 2002; Whyte, 2002; Fiks-van Niekerk et al., 2003). That this was not reflected in our results could be due to the overall low incidence of complaints about coughing and sneezing fits, or was due to too low levels or short durations of exposure to cause complaints.

Table 5.8. Results of ergonomics for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO). Percentage farmers with physical complaints, percentage farmers with complaints related to poultry, and percentage farmers with coughing and sneezing fits.

	BC (n = 16)	DL (n = 15)	DLO (n = 17)	AO (n = 13)
Complaints (%)	56	53	71	46
Complaints related to poultry (%)	6	20	6	15
Coughing and sneezing fits (%)	13	13	24	8

5.3.5 Product quality

The average percentage of second grade eggs ranged from 6.1% to 7.9% and did not differ significantly among housing systems (Table 5.9). The number of flocks with useable records on second grade eggs, however, was quite low (43 out of 61) due to lack of information from egg packaging stations. For 52 flocks, however, it was possible to determine whether they exceeded 10% second grade eggs. Also this indicator did not differ significantly among housing systems (Fisher's exact test, $P = 0.08$; Table 5.9). This corresponded with Tauson et al. (1999), who reported similar, or better egg quality in floor systems compared to cage systems. Others (van Niekerk, 1992; Leyendecker et al., 2001), however, reported worse egg quality in non-cage systems compared to cage systems. This was attributed mainly to a higher percentage of dirty eggs due to floor eggs, while the percentage of cracked and broken eggs was higher for cage systems. Within our study, however, the percentage of floor eggs was low (only 2 flocks above 3%), which resulted in similar levels of second grade eggs for all systems.

There was only one SE contaminated flock in this study, which resulted in no significant differences among housing systems (Table 5.9). Only 31% of the flocks in BC was vaccinated, while more than 75% was vaccinated in all other systems. This resulted in a significant ($P < 0.01$) difference among housing systems. Whether this preventive measure was really necessary is doubtful, because Mollenhorst et al. (2005a) showed that the risk of contamination with SE is only higher in DL compared to BC when there are hens of different ages on a farm.

Table 5.9. Results of product quality for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO). Average percentage of second grade eggs (standard deviations are given between brackets) and percentage flocks exceeding 10% second grade eggs for external egg quality, and percentage *Salmonella enteritidis* (SE) contaminated and vaccinated flocks for internal egg quality.

	BC	DL	DLO	AO
	Second grade eggs			
	(n = 10)	(n = 9)	(n = 13)	(n = 11)
Average (%)	7.9 (1.8)	6.9 (2.9)	6.1 (3.0)	6.5 (1.8)
	(n = 12)	(n = 12)	(n = 16)	(n = 12)
Flocks > 10% (%) [1]	33	17	6	0
	SE status			
	(n = 16)	(n = 14)	(n = 17)	(n = 13)
Contaminated (%)	0	0	6	0
Vaccinated (%) [2]	31	79	76	85

[1] Not significant: Fisher's exact test: $P > 0.05$

[2] Fisher's exact test: $P < 0.01$

5.4 General discussion

The objective of this study was 1) to select SI for different EES issues, and 2) to analyze the performance on selected SI of different egg production systems. SI have to be a) relevant, b) simple, and c) sensitive and reliable. Furthermore, d) it must be possible to determine a target value or trend, and e) data have to be accessible. These criteria should guarantee a clear selection process. In general, many possible SI do not meet all these criteria. This is a well-known problem in SI literature, as phrased by de Kruijf and van Vuuren (1998): 'The search for indicators and indicator systems is an evolutionary process, and one has to realize that indicators are needed now, despite all scientific problems of developing them'. In the current study also many possible SI were not selected due to not meeting one or more criteria. Accessibility and reliability of data were sometimes problematic, especially because we gathered historical farm data by questionnaire. Data, on which no regular records are kept, like second grade eggs, or physical complaints of the farmer, were less reliable or even sometimes not available. This resulted in a lower number of farms on some SI. We also omitted some possible SI, because they needed expert judgement while the hens were present. Therefore, results from SI studies may not be considered as all-embracing assessments of SusD, but must be considered as the best possible assessment under the studied circumstances. A possible solution to increase accessibility and reliability of data, e.g., could be to contract farmers to collect data of a present flock. This is, however, expensive and time consuming.

Differences in results among housing systems can be confounded with other farm characteristics, like the type of farmers, degree of specialization, or farm size. Table 5.2 shows that the DL housing system is present on relatively small farms and DLO on less specialized farms. For DLO, e.g., this means that laying hens are not the only source of income, which means that the farmer has to divide his time, knowledge and expertise, over other activities as well. Small farms, as in DL, can point at some older farmers in this group that will quit farming within a couple of years, as reflected also by the somewhat higher average age of DL farmers. These farms are possibly not technically up to date anymore. These farm characteristics can explain why DL and DLO performed worse than what could be expected to be technically feasible, on, e.g., feed conversion ratio and mortality rate.

Farmers with AO are probably quite progressive farmers, as these systems are relatively new (Rogers, 1995). In general, their farms are technically up to date, and are probably also more up to date with regard to management. This can be a reason for the better technical performance on, e.g., feed conversion ratio and mortality rate, compared to DLO.

The stage of development is also an aspect that must be taken into account when interpreting results from this study. Battery-cage systems are developed since the 1950's, whereas aviary systems are developed only since the late 1980's, and even much later used commercially. For some farmers with deep-litter systems, this system is also quite new, because they changed quite recently from cages to deep-litter systems, due to the adoption of the ban on battery cages (EC, 1999). Deep-litter systems, however, are not new and some farmers even never have had battery cages. For systems of young age, there are still opportunities to develop on technical and managerial aspects, whereas the battery-cages system can be considered to be developed fully. This means that most improvement can be expected for aviary systems, which will make it an even better substitute for battery-cage systems.

5.5 Conclusions

A clear set of criteria for indicators is necessary when selecting SI for on-farm assessment of SusD. Although some SI have practical constraints or are not yet developed, selection of available SI and subsequently quantifying them, gives a good indication of the strengths and weaknesses of different systems. From this analysis it appears that AO is a good alternative for BC, with better scores for AO on animal welfare and economics, but with worse scores on environmental impact. DL and DLO perform equally or worse than AO on all SI.

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Chapter 6
Assessment of sustainable development of animal production systems: an ethical reflection

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Abstract

A major issue in discussions about the future of (intensive) animal production is the concern about sustainability. Scientists can provide reliable information on different aspects that affect sustainable development (SusD) using indicator based methods. In order to apply an indicator based assessment of SusD to animal production systems, a four-step methodology was developed: 1) description of the situation, 2) identification and definition of relevant economic, ecological, and societal issues, 3) selection and quantification of suitable sustainability indicators (SI) for each issue, and 4) final assessment of the contribution to SusD. As many decisions during the four-step methodology, e.g., decisions on which stakeholders to involve, or how to aggregate information, are based on implicit value judgements, it is important to elucidate these judgements when applying this methodology. Therefore, the objective of this paper was to explicate the main value judgements in the methodology. When these value judgements are considered, it becomes clear that there is not one way to aggregate SI results into a final index of SusD. Also the feature of SusD that it is context specific with regard to time and space, contributes to the diversity of possible results. When presenting final results, therefore, the whole process has to be taken into account, which means that all choices have to be explicated.

6.1 Introduction

A major issue in discussions about the future of (intensive) animal production is the concern about sustainability (SSP, 2003; LNV, 2005). The probably most often quoted definition of sustainable development (SusD) is from the World Commission on Environment and Development (WCED): "SusD meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations" (Brundtland, 1987). The term SusD is used instead of sustainability, because "SusD is not a fixed state of harmony, but rather a process of change … consistent with future as well as present needs" (Brundtland, 1987). Many other definitions are elaborated that fit better the priorities of certain groups or organizations, or fit better in certain circumstances. Almost everybody has a notion of what SusD means in his or her context (Bell and Morse, 2003), although not many people can define it. That makes it difficult to determine whether a production system contributes to SusD. But still people need to make a choice between different products or between different production methods, e.g., between eggs produced in a battery-cage system and eggs produced in an organic system. In literature, it is generally agreed that SusD encompass economic, ecological, and societal (EES) issues (e.g., Brundtland, 1987; Fresco and Kroonenberg, 1992; Spedding, 1995; Park and Seaton, 1996; Hardi and Zdan, 1997; de Boer and Cornelissen, 2002; Bell and Morse, 2003). This means that a system has to be economically viable, environmentally sound, and socially acceptable.

Scientists can provide reliable information on different aspects that affect SusD through indicator based methods. This is the most popular approach to assess SusD of a production process (Bell and Morse, 2003). An indicator is a tool to quantitatively represent an issue (Mollenhorst et al., 2005a). In order to apply an indicator based assessment of SusD to animal production systems, a four-step methodology is developed (Bell and Morse, 1999; Mollenhorst and de Boer, 2004): 1) description of the situation, 2) identification and definition of relevant EES issues, 3) selection and quantification of suitable sustainability indicators (SI) for each issue, and 4) final assessment of the contribution to SusD. During the first step, a production system, with its context, is depicted. This step determines the scope of the study and influences the selection of stakeholders. During step two, stakeholders are implicated in a participatory approach to identify EES issues. The stakeholders involved and methods used during this step influence which EES issues are identified. During the third step, identified EES issues are made measurable by selecting SI, which are, subsequently, quantified. Criteria for selecting SI and available resources for quantification determine the finally selected SI. During the fourth step, results from step three are integrated into a final assessment, or directly presented.

An essential point, which has to be considered when presenting results, is for whom it must be useful (Wefering et al., 2000). Morse (2004) uses a picture of a pyramid, originally developed by Braat (1991), to illustrate the process of aggregation (Figure 6.1a). At the base of this pyramid there is the total amount of information, i.e., the actual situation. The higher we climb in the pyramid, the higher the level of aggregation. Scientists, who want to know the background of the differences in performance, are most interested in transparent, single indicators or raw data. For policy makers and managers, among which we can also encompass farmers, we have to reduce complexity, because most often they do not have the time and tendency to study a large amount of data. For farmers, however, it is important to maintain the possibility to utilise data at a lower level of aggregation, in order to adjust their management (Häni et al., 2003). The public, at the apex of the pyramid, generally prefers highly aggregated indices. With regard to animal welfare, for example, consumers do not consider the details, but are only concerned with improved animal health and living conditions (Frewer et al., 2005). When we extrapolate this to SusD, we end up with one or only a few indices.

As many decisions during the four-step methodology, e.g., decisions on which stakeholders to involve, or how to aggregate information, are based on implicit value judgements, it is important to elucidate these judgements when applying this methodology. These decisions are inherent in the methodology and determine the final results. The social relevance of SusD entails these value judgements, because SusD is time and context specific. This demands that the scientific methodology is embedded in society. For clear scientific reporting, subsequently, we have to explicate these decisions. Therefore, the objective of this paper is to explicate the main value judgements in the methodology. We illustrate this with a case study on egg production systems in The Netherlands. Triggered by the ban on battery-cage systems in 2012 in the European Union (EC, 1999), a change in egg production systems is urgent, and, therefore, an assessment of the different alternatives is necessary.

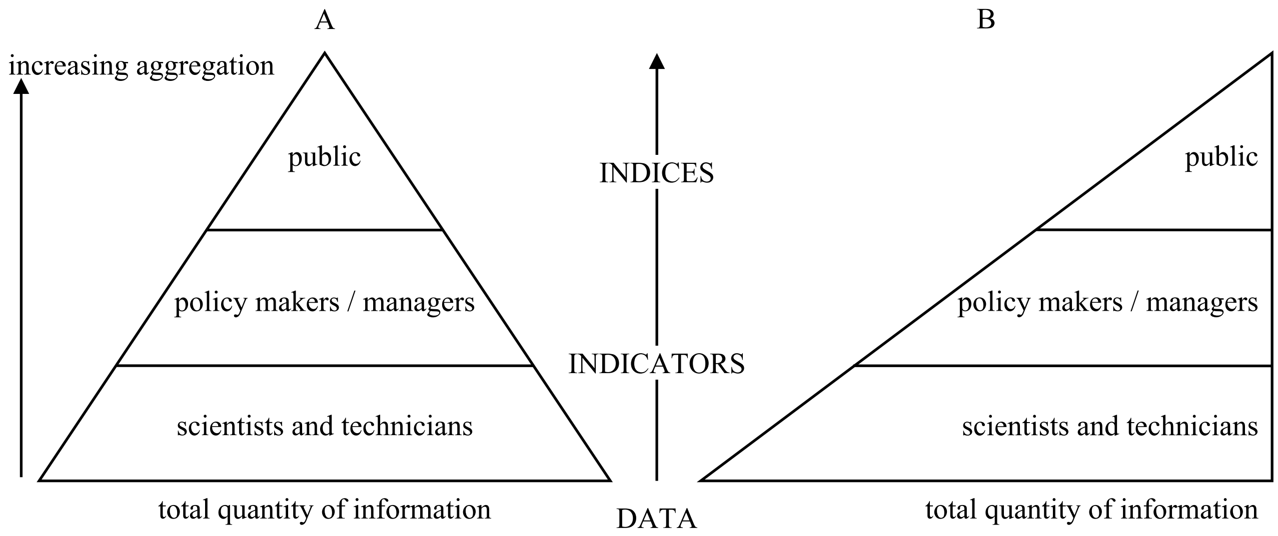

Figure 6.1. Relationship between indicators, data and information.
Source: Braat, 1991; Morse, 2004 [1]

6.1.1 Outline of the paper

Within this paper, the four-step methodology is reduced to three steps, which frame the outline of this paper. The first two steps of the four-step methodology are discussed together. Every section starts with a theoretical overview, in which different possibilities from literature are presented. This is followed by a description of the practical application, i.e. the choices made in this specific study, and a discussion of the value judgements. The first two steps of the methodology are taken together in the selection of EES issues and are already described by Mollenhorst and de Boer (2004). Mollenhorst et al. (2005a) described the selection of SI (step 3). Therefore, the first two sections focus mainly on the theoretical overview and value judgements, while referring to the mentioned papers for the application. The third section, about aggregation methods, also fully describes two potential applications, followed by a discussion of value judgements. The paper ends with a general discussion in which main ethical theories are taken into account.

6.2 Selection of EES issues

6.2.1 Theoretical overview

As SusD is more of a broad statement of philosophy than a clearly defined concept (Bell and Morse, 2003), the issues mentioned with regard to SusD are context and time specific. Selection of EES issues (step 2), therefore, depends strongly on the system under study, the demarcation of the system, and the way in which issues are identified (step 1). Two ways of identifying issues are distinguished: top-down and bottom-up (Rubenstein, 1993; Mitchell, 1996). The top-down approach, also referred to as 'omniscient modelling' or 'based on published work', leans heavily on 'technical' perspectives and possibly neglects the values and needs of people in the specific context. This has led to much effort being paid to defining SusD and developing tools to measure it, i.e., sustainability as a 'science', while actually 'doing' something with the outcomes is neglected (Bell and Morse, 2003). The bottom-up approach, on the other hand, is based on stakeholder or public participation. With this approach there is a risk of neglecting global issues (Mitchell, 1996). Furthermore, it is difficult to determine the stakeholders and the level of participation.

Different types of stakeholder participation are distinguished (Pretty, 1995; Bell and Morse, 2003), ranging from 'passive participation', which means that stakeholders are only informed about the process, to 'self-mobilization', which means that stakeholders take initiatives themselves. Intermediate forms are interactive participation, which means that stakeholders are actively involved in the project, and informative or consultative participation, which means that stakeholders are asked for specific information or views. Participation can mean that all stakeholders are present, however, more often only 'representatives' are involved. In case of representation, special attention is needed to ensure the best possible representation in order to assure that all stakeholders still feel owner of the project (Bell and Morse, 2003).

6.2.2 Practical application and value judgements

Within the case study on egg production systems, the researchers defined the production system and its context themselves, with the system boundary around the primary farm, and only one level of in- and outputs around it (Figure 1 in Mollenhorst and de Boer, 2004). They made these choices, because a change in housing system particularly influences the primary farm and the stakeholders closely related to it. As a result, all selected stakeholders had a close relationship with the primary farm or represented parts of the farm, like an animal welfare organisation that represented the interests of the chicken (for a complete list of stakeholders see Mollenhorst and de Boer, 2004). This has influenced the selected EES issues, as different stakeholders will address different issues. For the egg packaging industry egg quality, including food safety, is the most important aspect, whereas for the animal protection organisations and organic agriculture animal welfare is more important. Furthermore, the formulation of the subject for the participatory meeting could have influenced the selected EES issues, as it was about SusD of the egg production sector, thus not questioning, e.g., the future existence of egg production in itself.

Because the group of potential stakeholders within the case study on egg production systems was large, as it encompasses a whole sector, it was only possible to include representatives as stakeholders. We can consider the participation within the case study as consultative participation, as stakeholders were involved only in the identification of EES issues, using a brainstorming session and a participatory SWOT analysis (Mollenhorst and de Boer, 2004). Because they were not involved in the final definition of the EES issues, literature review and expert consultation were performed additionally to validate the issues before the final list was determined.

6.3 Selection of sustainability indicators (SI)

6.3.1 Theoretical overview

Criteria are needed for selecting SI for the identified EES issues. There are different lists of criteria available in literature, which all encompass more or less the same items. Mollenhorst et al. (2005b) formulated criteria for selecting indicators based on Mitchell et al. (1995). Indicators have to be a) relevant, i.e., they have to say something about the issue, b) simple, i.e., they have to be understandable for users, and c) sensitive and reliable, i.e., they have to react on changes in the system, and different measurements must lead to the same outcome. Furthermore, d) it must be possible to determine a target value or trend, and e) data have to be accessible.

Some SI already aggregate information, while other SI consist of directly measured data. Besides the above mentioned criteria, it is important for such aggregated SI that data can be expressed in the same units, there is a general agreement on the SI, or that the SI is tested on its validity.

6.3.2 Practical application and value judgements

Mollenhorst et al. (2005a) selected and quantified SI for the following EES issues: animal welfare, economics, environmental impact, ergonomics, and product quality. They searched possible SI for all issues in literature. Due to the availability of resources, only existing SI could be selected. Subsequently, they selected final SI, based on the mentioned five criteria. By using a list of criteria, they already explicated most value judgements in this phase. The judgement of SI against these criteria by the researchers, however, still involves value judgements, as the determination whether an indicator is suitable, moderately suitable, or unsuitable is not always unequivocal. Furthermore, the circumstances, like availability of money and time, determine also whether an SI that is more relevant, but also more expensive, prevails over a less relevant, but cheaper SI. Finally, Mollenhorst et al. (2005a) quantified fourteen SI for four different egg production systems, characterized by differences in housing system: the battery-cage system (BC), the deep-litter system (DL), the deep-litter system with outdoor run (DLO), and the aviary system with outdoor run (AO).

Within the case study, different SI were formulated at different levels of aggregation, as sometimes directly measurable data were used, e.g., mortality rate, whereas, most times, aggregated indicators were used, e.g., the animal needs index (ANI), acidification potential or labour income. The main reason for aggregation was that information could be expressed in the same units, e.g. SO_2-equivalents or euros. Within the ANI, however, different units were converted to points in order to add them together. Therefore, this SI was tested on its validity beforehand in a separate study (Mollenhorst et al., 2005b). When aggregated SI are used, one must realise that this contains value judgements also.

Within the case study, the researchers selected SI for on-farm quantification, because the primary farm was the studied system. With on-farm quantification, other indicators are important than when quantification takes place at the national level. For economics, e.g., labour income is the most important SI at farm level, whereas at the national level the contribution of egg production to the gross national product is probably more important.

6.4 Integration methods

6.4.1 Theoretical overview

In an ideal situation, indicators and indices give a good presentation of ‘reality’, as depicted by the symmetric triangle (Figure 6.1a). This means that every step upwards is a compromise, still representing the ‘centre’ of the information. It can happen easily, however, that each step upwards drives away from the centre, resulting in an, unintentionally, loaded picture of reality (Figure 6.1b, Morse, 2004). There are several reasons for distortion of the pyramid, of which some are already mentioned in this paper, like selection of EES issues and SI. Also the way of aggregation (e.g., is compensation allowed and are SI weighed or not) can distort the pyramid, because certain SI influence the final index too much. These constraints of aggregation must be considered when presenting final results to different end-users.

Many different methods to integrate SI results are proposed (for a review see, e.g., Mitchell, 1996; Hanley et al., 1999; Morse, 2004). In general, these methods can be distinguished in two categories: 1) integral or visual presentation, and 2) numerical aggregation methods (de Kruijf and van Vuuren, 1998; Bell and Morse, 2003). The first category does not aggregate information from different SI into an overall judgement of SusD, whereas the second category does.

An often used example of integral presentation, of which many modifications are made, is the AMOEBA (ten Brink, 1991), in which SI results are depicted graphically against reference values. This method was adapted by de Boer and Cornelissen (2002) and is referred to as 'modified AMOEBA'. Another way of presentation is the 'dashboard of sustainability' (http://www.iisd.org/cgsdi/dashboard.asp), as it depicts the different SI in colours, representing the performance per indicator.

The 'barometer of sustainability' (Prescott-Allen, 1997) aggregates all SI into two dimensions of SusD, namely human and ecosystem well-being, which are then depicted graphically. This method already aggregates information on a higher system level before depicting it graphically, which makes it an intermediate form of integration (between visual presentation and numerical aggregation).

Most numerical aggregation methods for SusD are founded on monetary valuation (Bell and Morse, 2003), usually incorporating ecological aspects in economic indicators, e.g., in Green Net National Product (Hartwick, 1990) or Genuine Savings (Pearce and Atkinson, 1993), but sometimes also incorporating social aspects, like unemployment, e.g., in the Genuine Progress Indicator (Cobb et al., 1995). Other aggregation methods are restricted to ecological aspects only, e.g., the ecological footprint (Wackernagel and Rees, 1996). All above mentioned indicators are developed for quantification at the national or regional level, although some are applied also at farm level, e.g. the ecological footprint of dairy production systems (Thomassen and de Boer, 2005). In order to break through the solely economic comparisons of farming systems, different on-farm assessment methods for SusD are developed (e.g., Taylor et al., 1993; Gomez et al., 1996; Heitschmidt et al., 1996; Rigby et al., 2001). However, even though they are called assessments of SusD, they are mainly directed at ecological aspects, some incorporating economic aspects, but generally neglecting social aspects.

Methods used, or at least proposed, to integrate EES issues into a single index are mathematical approaches, like calculating the weighted arithmetic mean (average) of SI results (de Boer and Cornelissen, 2002), fuzzy set theory (Zadeh, 1965; Cornelissen et al., 2001), and different types of multiple criteria decision making (Rehman and Romero, 1993), like weighted goal programming (Manyong and Degand, 1997) and multi-attribute utility theory (Keeney and Raiffa, 1976; van Calker et al., 2005). The weighted arithmetic mean and weighted goal programming methods aggregate the weighted deviations from reference values for all SI. Although there are some fundamental and technical differences between the other methods, the main steps are comparable. All methods start with expressing SI on a dimensionless scale and then aggregating them in a procedure with different factors for weighing and degree of compromise.

6.4.2 Practical application

To illustrate the different approaches and explicate the underlying value judgements, two approaches are elaborated in this paper, one integral presentation and one aggregation method. We selected the modified AMOEBA, because this approach is most widely used, and is already applied to animal production systems (de Boer and Cornelissen, 2002). As the value judgements are not essentially different for the aggregation methods, we chose the application of just one of them, fuzzy set theory (Cornelissen et al., 2001). In order to keep the example in this paper orderly and simple, we selected only five SI to illustrate the effects of the different integration methods. We selected SI that showed a housing-system effect, and that represented three different EES issues. The selected SI are: the ANI and mortality rate for the issue animal health and welfare, acidification and eutrophication potential for the issue environmental impact, and labour income for the issue economics (Table 6.1).

Table 6.1. Average data for selected sustainability indicators (SI, data originating from Mollenhorst et al., 2005a) and reference values for integral presentation for battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO).

SI	BC	DL	DLO	AO	Reference
Animal Needs Index (points)	37	60	97	114	100
Mortality rate (%)	5.5	9.3	10.6	8.7	5.5
Acidification potential (SO_2-equivalents per kg egg)	0.032	0.057	0.065	0.042	0.032
Eutrophication potential (NO_3^--equivalents per kg egg)	0.25	0.31	0.41	0.35	0.25
Labour income (euro per FTE [1])	2855	15576	22828	86041	45900

[1] FTE = Full-time Equivalent

6.4.3 Description of applied integration methods

Integral presentation

De Boer and Cornelissen (2002) used the modified AMOEBA in their study on egg production systems. In this approach, SI are expressed as a percentage relative to a baseline or reference value, and depicted graphically. Reference values are most often based on political goals, scientific knowledge, or expert judgement, however, there are no generally agreed criteria. Other possibilities, as mentioned by Bell and Morse (2003), are historical or geographical references, and references assessed by stakeholders. Tyteca (1996) distinguishes between ‘ideal’ and ‘target’ values. For example, for labour income, a standard income can be the ‘target’, whereas maximum income can be considered to be ‘ideal’. Ideal reference values will never be reached in practice for any of the SI.

Within the case study, (target) reference values (Table 6.1) were based on literature or on the battery-cage system, which is a historical reference. Bartussek (1999) states that animal welfare is ‘fairly suitable’ above 50% of the points of the ANI, which means 100 points or more. As no generally agreed reference values are available for mortality rate, acidification, and eutrophication potential, we chose the values of the battery-cage system. As a farmer has to earn an income from his farm, we chose the normative (gross) income per full-time equivalent (FTE) as reference for labour income (KWIN, 2003).

Aggregation methods

Cornelissen et al. (2001) utilised fuzzy set theory to aggregate data of individual SI into an overall judgement of SusD. It starts with assessing membership functions. Membership functions transform base variables (SI results) into variables with a homogenous unit of measure, ranging from 0 to 1 (Figure 6.2). The rate of transition from 0 to 1 and the fate of an indicator when it scores below or above a certain threshold, are both influenced by the choice of the basic shape of the function. In fuzzy set theory, an S-shaped curve is used generally. This originates from the property of the unit of measurement that it is a degree of membership ranging from 0 to 1. Classical set theory is based on two-valued logic, i.e, the value is either 0 or 1, in the example unsustainable or sustainable. Fuzzy set theory enables intermediate assessment, i.e., a degree of sustainability (Kosko, 1992). In the example we adhere to this basic function, the S-shaped curve, in order to link up with the mathematical theory. Other types of functions, however, can be used also, e.g., a linear function representing relative deviations as used in the modified AMOEBA or a function of diminishing marginal utility (van Calker et al., 2005).

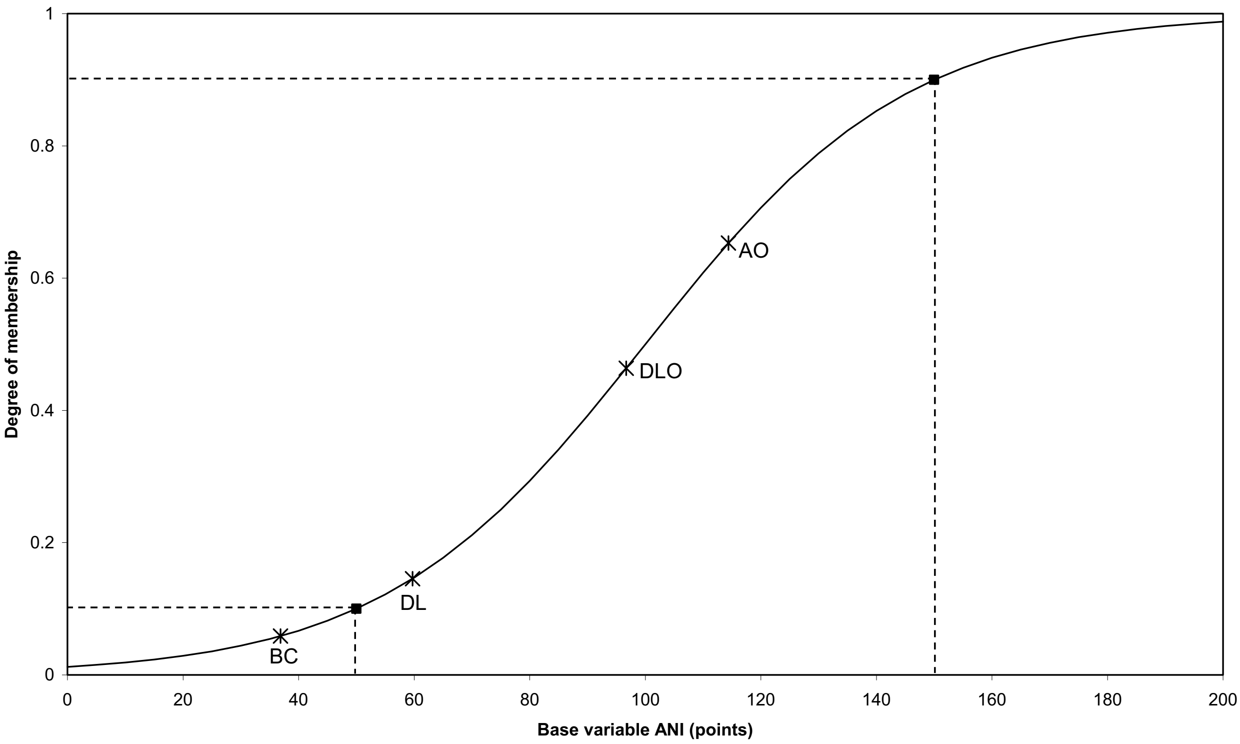

Figure 6.2. The membership function of the animal needs index (ANI; increasing SI; c = 0.044; d = 100), with dotted lines representing the 10 and 90% points, and stars marking the data points for the different housing systems (BC = battery cage; DL = deep litter; DLO = deep litter with outdoor run; AO = aviary with outdoor run).

Expert knowledge or stakeholder preferences can be used to assess the parameters that determine the final shape of the function. In the example we used the basic formula:

$\mu_{ij}(x_{ij}) = 1 - \frac{1}{1 + e^{c_j(x_{ij} - d_j)}}$ for increasing SI_j, and

$\mu_{ij}(x_{ij}) = \frac{1}{1 + e^{c_j(x_{ij} - d_j)}}$ for decreasing SI_j,

where $\mu_{ij}(x_{ij})$is the degree of membership (the contribution to SusD) of housing system i (i = 1,..,n) for SI_j (j = 1,..,m), x_{ij} is the base variable of housing system i for SI_j, c_j is a parameter representing the steepness of the curve for SI_j, and d_j is a parameter representing the inflexion point of the curve for SI_j. An increasing SI means that the contribution to SusD increases with higher values of the base variable (e.g., ANI), whereas a decreasing SI means that the contribution to SusD decreases with higher values of the base variable (e.g., mortality rate). In the example the inflexion point (d_j) for each SI_j (m = 5) is equal to the reference value used in the modified AMOEBA, and parameter c_j is chosen in such a way that 90% membership is reached when the base parameter has improved with 50%. Table 6.2 shows all parameters (c_j and d_j), and the values of the base parameters at which 10 and 90% membership is reached.

Table 6.2. Parameter values (c and d) and 10% and 90% values of the membership functions.

SI	c	d	10% [1]	90% [1]
Animal Needs Index (points)	0.044	100	50	150
Mortality rate (%)	0.80	5.5	8.2	2.7
Acidification potential (SO_2-equivalents per kg egg)	139	0.032	0.047	0.016
Eutrophication potential (NO_3^--equivalents per kg egg)	17	0.25	0.38	0.13
Labour income (euro per FTE [2])	0.000096	45900	22950	68850

[1] Values of the base variable where 10 or 90% membership is reached

[2] FTE = Full-time Equivalent

When degree of membership (μ_{ij}) is calculated for each housing system i and each SI_j, a formula aggregates all μ_{ij}'s to determine the total contribution of housing system i to SusD ($SusD_i$). This step includes weighing different SI against each other. This can be done at once, so all SI are directly weighed into SusD, or stepwise, by first weighing SI within a certain category, e.g., the three EES categories, and subsequently weighing the different categories. The researcher, experts, or stakeholders can determine weighing factors, and different methods can be used to aggregate the preferences of different experts or stakeholders (van Calker et al., 2005). Furthermore, a degree of compromise (α) can be included in the formula used for aggregation, which determines whether, and to what extent, SI may compensate each other

(Cornelissen et al., 2001). For the example we used the following aggregation function (Cornelissen et al., 2001):

$$\text{SusD}_i = \left[\frac{\sum_{j=1}^{m} (w_j \mu_{ij}(x_{ij}))^{\alpha}}{\sum_{j=1}^{m} w_j} \right]^{1/\alpha},$$

where w_j is a weighing factor for SI_j, and α the degree of compromise. If $\alpha = 1$ this formula results in the arithmetic mean, if $\alpha \rightarrow 0$ this formula results in the geometric mean, if $\alpha \rightarrow -\infty$ this formula results in the minimum, and if $\alpha \rightarrow \infty$ this formula results in the maximum. For the example, SI_1 is the ANI (x_{i1}, points), SI_2 is the mortality rate (x_{i2}, %), SI_3 is the acidification potential (x_{i3}, SO_2-equivalents per kg egg), SI_4 is the eutrophication potential (x_{i4}, NO_3^--equivalents per kg egg), and SI_5 is the labour income (x_{i5}, euros per FTE) (Table 6.1), with i = 1 = BC, i = 2 = DL, i = 3 = DLO, i = 4 = AO.

6.4.4 Effects of choices with respect to integration

Figure 6.3 shows results of the modified AMOEBA, i.e., deviations from the reference values in percentage terms, for the five SI, based on data from Table 6.1. Figure 6.3 shows no bars for mortality rate, acidification and eutrophication potential for BC, because the value of BC was used as reference value for these SI. AO is the only system performing better than the reference values for ANI and labour income. Scores for DL and DLO are in between or lower than BC and AO.

Table 6.3 shows the contribution to SusD (μ_{ij}) of the different housing systems for individual SI, based on the parameters from Table 6.2. When all SI are given equal weight and $\alpha = 1$, SusD_i is the arithmetic mean of the five SI for housing system i. The first row in Table 6.4 shows that AO ($\text{SusD}_4 = 0.41$) performs best, followed by BC ($\text{SusD}_1 = 0.31$). In the following paragraphs, we show the influence of changes in different parameters. All examples start from the basic situation, as shown in Figure 6.3 or the first row in Table 6.4.

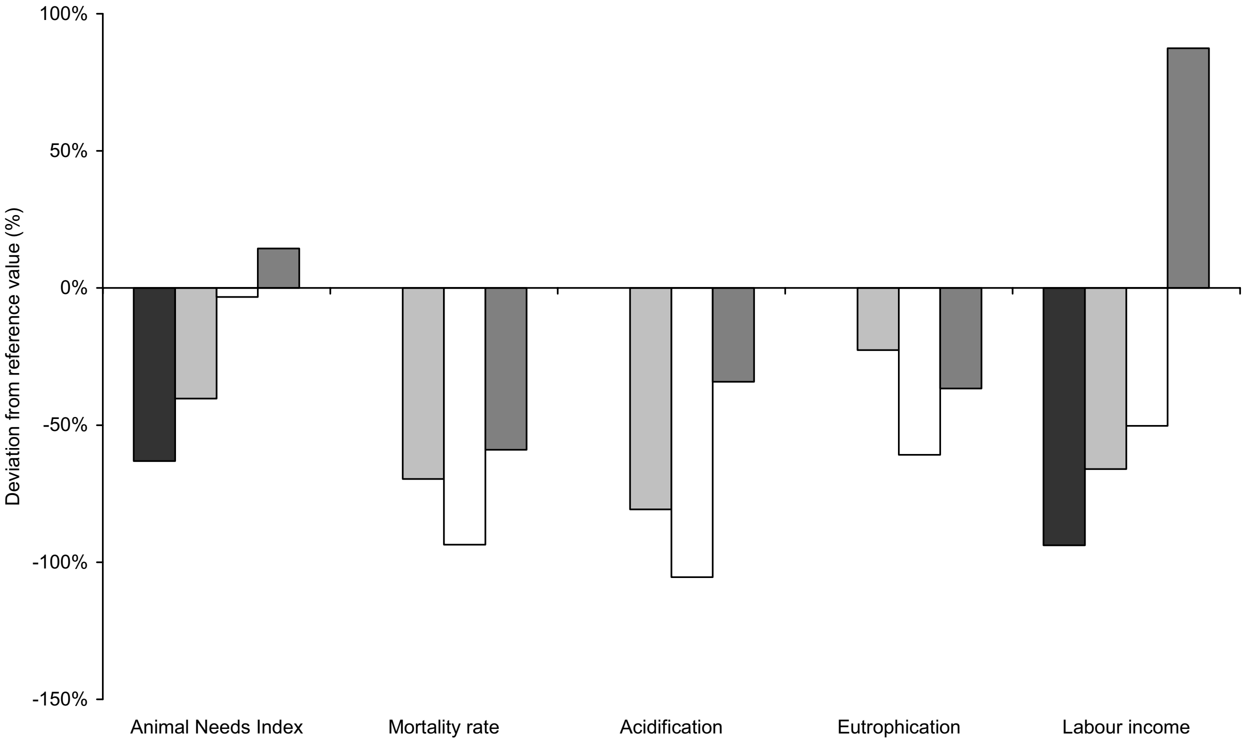

Figure 6.3. Integral presentation with all indicators relative to their reference values (Table 6.1), i.e., for mortality rate, acidification and eutrophication potential relative to battery-cage system (black = battery cage; light grey = deep litter; white = deep litter with outdoor run; dark grey = aviary with outdoor run).

Table 6.3. Contribution to SusD ($\mu_{ij}(x_{ij})$) of battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO) for the different SI.

SI	BC	DL	DLO	AO
Animal Needs Index	0.06	0.15	0.46	0.65
Mortality rate	0.50	0.04	0.02	0.07
Acidification potential	0.50	0.03	0.01	0.18
Eutrophication potential	0.50	0.27	0.06	0.17
Labour income	0.02	0.05	0.10	0.98

Table 6.4. Contribution to SusD of battery cage (BC), deep litter (DL), deep litter with outdoor run (DLO), and aviary with outdoor run (AO) in different situations. All changes in situations are relative to the basic situation (first row).

Situation	BC	DL	DLO	AO
Basic situation	0.31	0.11	0.13	0.41
Reference values at national average	0.40	0.16	0.16	0.49
Changed shape of membership function (c's doubled)	0.30	0.03	0.09	0.37
Weight of labour income doubled	0.27	0.10	0.13	0.50
No compensation ($\alpha \rightarrow \infty$)	0.02	0.03	0.01	0.07

Reference values

When we present SI results, we first have to decide on which scale the results will be presented. This decision can be split into two; at first, the level of the reference value, and second, the relation between deviations and the reference value. Figure 6.4 shows the influence of the choice of the level of the reference values. For mortality rate, acidification and eutrophication potential, we changed the reference values from best performing system to the average situation in 2002. These reference values were calculated on basis of the proportion of eggs produced in the different systems in 2002 (Anonymous, 2004), i.e. 73% BC, 14% DL and 13% from systems with an outdoor run, which we divided equally over DLO and AO with 6.5% each. As a result the general picture becomes less negative, and for some systems other SI become the most negative, like labour income for DL, which has now a larger (negative) deviation than mortality rate and acidification potential. This shows that the level of the reference value strongly influences whether a system is evaluated positively or negatively on a certain SI. Therefore, it is important to consider which reference values to take. A similar influence of reference values can be shown for the parameter d, which determines the inflexion point of the membership function. All results become more positive (second row in Table 6.4). Furthermore, systems with degrees of membership closest to the inflexion point (BC and AO) change most.

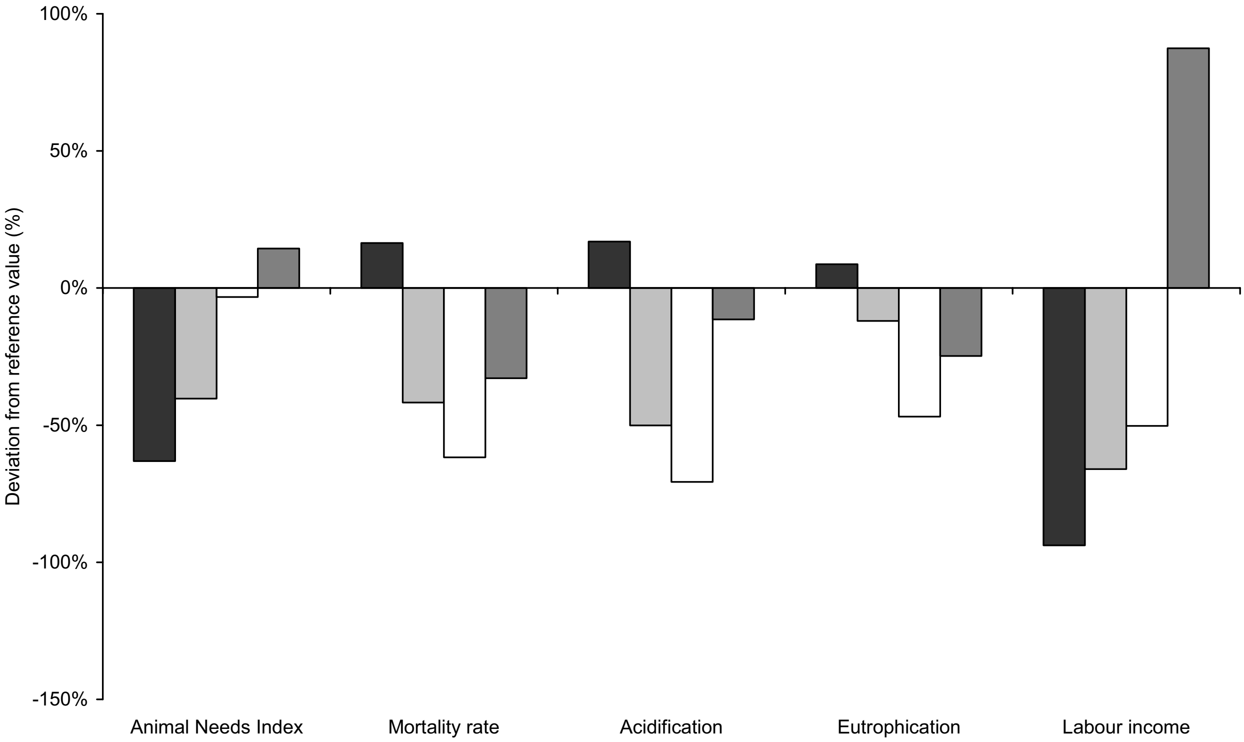

Figure 6.4. Integral presentation with animal needs index and labour income relative to their original reference values, and with mortality rate, acidification and eutrophication potential relative to the national average (black = battery cage; light grey = deep litter; white = deep litter with outdoor run; dark grey = aviary with outdoor run).

The third row in Table 6.4 shows the influence of the shape of the membership function, i.e., the relation between the original indicator and the reference value. The value of c_j is doubled, which results in halving the transition interval between the 10% and 90% membership. As a result, low degrees of membership ($\mu_{ij} < 0.50$) decrease and high degrees of membership ($\mu_{ij} > 0.50$) increase. Or, in other words, increasing the value of parameter c makes the SI more of a 0/1-indicator, with the reference value as threshold. The three values for BC ($\mu = 0.50$; Table 6.3) are exceptional, as they keep the same value. The number of SI with high membership now dominates the results, while differences in deviation from the reference values become less important. Results for DL and DLO decreased most, because they lacked an SI with $\mu_{ij} > 0.50$. AO ($SusD_4 = 0.37$) is still performing best, followed by BC ($SusD_1 = 0.30$). This shows that the relation between the deviation and the reference value determines whether large deviations from the reference value contribute more than small deviations. The consequence of assuming an S-shaped curve is that below a certain level, an SI can become much worse in actual value without really cutting down on its contribution to SusD. On the other hand, when deviations are expressed relative to the reference values, as in the modified AMOEBA approach, extreme deviations can influence the final outcome severely. Consequently, when we take the average of the results on several SI from both methods, the final outcome of both methods really gives another indication. Average degrees of membership indicate to what degree SI are acceptable, whereas average deviations indicate how far a system is away from the reference values. In this last approach one large positive deviation can compensate many small negative deviations. Point of discussion, therefore, can be whether only negative gaps must be addressed. This, however, will raise the risk of cutting back on SI with positive scores, in order to improve SI with negative scores (Bell and Morse, 2003). Whether trade-offs must be made between different SI and to which degree, also has to do with weighing and compensation, and will be discussed more thoroughly in the following paragraph.

Weighing and compensation

Weighing is only relevant when compensation is allowed. The degree of compensation (α in the case study) determines to which degree compensation is allowed, whereas the weight given to the different SI, together with the way in which an SI is expressed relative to its reference value, determines which SI has most influence on the final index. The fourth row in Table 6.4 shows the influence of weighing factors. Here the weighing factor for labour profit is doubled. This increases the difference between AO and the rest, but decreases the differences between BC, and DL and DLO. AO ($SusD_4 = 0.50$) is now performing far better than BC ($SusD_1 = 0.27$).

The fifth row in Table 6.4 shows the influence of excluding compensation. When $\alpha = 1$, low values on one SI can be compensated for by high values on another SI. In the end, the average of 0 and 1 is the same as the average of 0.45 and 0.55. In case $\alpha \rightarrow -\infty$, there is no compensation at all, and the SI with the lowest contribution to SusD determines the contribution to SusD of a housing system. In the case study, different SI determine the final result of the different housing systems. This results again in AO performing best ($SusD_4$ = 0.07), however, BC ($SusD_1$ = 0.02) is not the second best anymore, but DL ($SusD_2$ = 0.03).

In the modified AMOEBA approach, unacceptable scores can be shown by introducing an extra (bottom) reference line for some or all SI, e.g., at -50%. In the fuzzy set approach, a method to exclude systems with unacceptable scores on a certain SI is stopping the calculation for a housing system when a certain SI scores below a threshold. This can be done by including a logical operator in the calculation, like 'if ANI < 50 then 'no score''. In this way, some minimum criteria have to be fulfilled, while, for housing systems that comply with those criteria, still compensation is possible. When this example is used, BC would not get a score, and, consequently, must be considered as the worst performing system.

6.5 Discussion

Aggregation of SI implicates the ability to convert SI results into a commensurable unit, and to weigh SI against each other. This commensurable unit is interpreted the contribution to SusD, or, in other words, the degree to which a system scores 'sustainable' or 'unsustainable' on a certain SI. From this perspective the best system is the system with the most positive balance between 'sustainable' and 'unsustainable', or 'goods' and 'bads'. This perspective is reflected broadly in one of the prevailing ethical theories, i.e., utilitarianism (Beauchamp, 2001; Mepham, 2005). This perspective, however, shares two fundamental problems with utilitarianism: the problem of quantifying the 'goods' and the 'bads' in a common denominator, and the problem whether every 'bad' is open for compensation. Therefore, one might want to set limits on the extent to which compensation of certain 'bads' is allowed. Extreme infringements on animal welfare, for example, could be regarded as morally unacceptable, and, therefore, should not be open for compensation by other SI. This perspective is reflected in the ban on battery-cage systems (EC, 1999), and is illustrated by one of the situations in paragraph 6.4.4, when a minimum of 50 points for the ANI is set. The same applies to other SI, when, e.g., labour income drops below the social minimum, or environmental pollution exceeds certain limits. These minimum criteria or thresholds can be regarded as deontological constraints, which are part of deontological ethics (Beauchamp, 2001). Deontological ethics is based on rights and duties people have with respect to each other (Mepham, 2005). Within this theory, it is also possible to ascribe rights to animals, or at least state duties of humans towards animals. Problems, however, arise when all systems comply with the minimum criteria of all SI, because then, again a kind of weighing has to take place.

Utilitarianism and deontological ethics are based on rules and principles. The same applies to assessment of SusD that is based on EES performance only. Rules alone, however, are not sufficient, because in the application of rules there is always room for different interpretations. Therefore, the attitude and motivation of the actors involved must be taken into account also. This idea is reflected broadly in a third ethical theory, i.e., virtue ethics. This theory is not based on rules or principles, but 'puts emphasis on the person who performs the actions and makes the choices' (Mepham, 2005). This perspective results in a context dependent view on SusD, in which the virtuous person has to decide what is sustainable in his specific context (with regard to time and space). This means that weights of SI can be different for each individual, but also reference values can change, and even some SI can become irrelevant. In practice, the virtue-perspective becomes important when we want to transmit information to, e.g., farmers, in order to implement a more sustainable system. First, the human factor has to be taken into account, which means that the attitude of the farmer, e.g., whether he is an entrepreneur or a steward, plays an important role in his choice among EES issues. Within the boundaries of the legal requirements, an entrepreneur will choose for the system with the best market potential, whereas the steward will give priority to the issues environment and animal welfare. Secondly, there are different farms with the same housing system, which perform differently with regard to SusD due to different circumstances. These different circumstances cause that different issues become important. NH_3-emission, for example, is much more important for SusD of a specific farm when it is situated close to a nature reserve, because the reference value on this SI will be set lower. Thirdly, SusD is not a well defined concept, but a 'soft' problem, which means that objectives are unclear and solutions are not initially available. In the future, therefore, other issues will arise that have to be taken into account when assessing SusD, because ideas of people about SusD change. A virtuous person has internalised the idea of SusD and is, therefore, able to adjust his management to the new 'conception' of SusD. These three aspects plead for policy based on goals instead of rules, which gives those who have to implement the policy the opportunity to choose their own way to achieve the goals. When this is extended to the implementation of the results of the assessment of SusD in practice, this means that a farmer, with his own attitudes and motivation, will draw different conclusions within the specific context of his farm. This pleads for a participatory approach during the transmission of information from this type of study. This means that a researcher or consultant, together with the farmer, assesses the effect of different choices for that specific farm, while taking into account the context specific character of SusD. Based on this assessment, the farmer can make his own choices.

6.6 Conclusions

A methodology to assess SusD involves many implicit value judgements. When these value judgements are considered, it becomes clear that there is not one way to aggregate SI results into a final index of SusD. Also the feature of SusD that it is context specific with regard to time and space, contributes to the diversity of possible results. When presenting final results, therefore, the whole process has to be taken into account, which means that all choices have to be explicated. Therefore, all stakeholders that make decisions based on results from this kind of assessment have to be able, and are obliged, to justify the choices implied in the whole process.

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Chapter 7
General discussion

7.1 Introduction

The objective of this thesis was to develop a methodology to assess the contribution of various animal production systems to sustainable development (SusD) and to test the practical use of the methodology in a case study on egg production. The four-step methodology, as proposed in Chapter 1, was further developed and applied to four egg production systems in the Netherlands. These systems were characterized by the most common housing systems in the Netherlands, the battery-cage system, the deep-litter system with and without outdoor run, and the aviary system with outdoor run.

Many decisions during the four-step methodology are based on value judgements. As these value judgements, and therewith also the theoretical consequences of these choices, have been discussed already in Chapter 6, this chapter focuses on the practical implications for the case study on egg production systems.

7.2 Selection of issues

The first two steps of the methodology are the description of the situation, and the identification and definition of relevant economic, ecological, and societal (EES) issues (Chapter 2). A brainstorming session with a heterogeneous group of stakeholders provided an easy start for a strengths, weaknesses, opportunities and threats (SWOT) analysis, through quick listing of relevant aspects for SusD. During the brainstorming session, no discussion was allowed in order to give all stakeholders a chance to state their concerns regardless of their relative power. A participatory SWOT analysis, subsequently, appeared to be a useful tool to order and structure the listed aspects, and to identify relevant issues for SusD. Issues were mentioned in broad outlines during this workshop. Final selection of EES issues from the SWOT analysis, therefore, required additional reviewing of literature and consultation with experts from specific fields. EES issues selected for the case study of Dutch egg production included animal health and welfare, environment, quality, ergonomics, economics, consumer concerns, and knowledge and innovation. This result clearly emphasized that to assess the contribution of egg production systems to SusD many EES issues need to be considered.

The demarcation of the studied system (Chapter 2), including the context with regard to time and space within which the issues were determined, influenced the selection of EES issues strongly. In chapter 6 the influence of the demarcation of the system was discussed already. Although no consumers or consumer organisations were present at the workshop, even though the latter were invited, the main consumer concerns, i.e., price, product quality, animal welfare and environment (SER, 2003; LNV, 2005b), were taken into account. The main reason was that also for the farmer and his (direct) partners, i.e., the egg packaging station, it is important to guarantee product quality at reasonable costs. Furthermore, NGOs advocating, e.g., animal welfare and environmental issues were present. Because the workshop was meant for collecting issues only, and not for ranking their importance, the absence of some stakeholders did not influence the results significantly.

Besides the demarcation of the system, a second aspect, i.e., the date at which the workshop was held, had a strong influence on the selection of issues. Circumstances, and therewith opinions, change over the years. An incident such as the outbreak of Avian Influence (AI) in 2003, for example, puts some issues in a different perspective, such as the influence of an outdoor run on the risk of spreading a disease. Another important change was the shift in market potential for eggs from battery-cage to non-battery-cage systems, due to the disappearance of cage eggs from supermarkets. This shift was enforced by campaigns of one animal welfare organisation. The results of this project, therefore, must be considered in its time and space specific context, i.e., the years 2001/2002 in the Netherlands.

7.3 Selection and quantification of indicators

The third step of the methodology is the selection and quantification of suitable sustainability indicators (SI) for each EES issue. A clear set of criteria for indicators is necessary when selecting SI for on-farm assessment of SusD. In Chapter 3 criteria for selecting SI are formulated, based on Mitchell et al. (1995). SI have to be a) relevant, i.e., they have to express something about the issue, b) simple, i.e., they have to be understandable for users, and c) sensitive and reliable, i.e., they have to react to changes in the system, and different measurements must lead to the same outcome. Furthermore, d) it must be possible to determine a target value or trend, and e) data have to be accessible.

For one aspect of the issue animal welfare, i.e., the opportunity to express normal behaviour, we performed a validation study (Chapter 3), because on-farm assessment on a large number of farms was possible only with an indirect, environment-based method, i.e., the animal needs index (Striezel, 1994). An environment-based method describes features of the environment (dimensions of the house and facilities) and management, which can be considered prerequisites for welfare. An animal-based method, on the other hand, records animals' responses to that particular environment and management more directly, and, therefore, can be used to validate the former one. This study resulted in the conclusion that the animal needs index is valid and sensitive enough to show differences in animal welfare between housing systems for laying hens, whereas differences in welfare within systems cannot be shown. Furthermore, the animal needs index performs better than the animal-based methods for the other criteria for SI, such as simplicity, data accessibility, and possibility to set a target value. This led to the selection of the animal needs index as final SI within this thesis. This example illustrates clearly that final SI are not ideal SI. When a new SI becomes available for an issue, therefore, the process of selecting SI should be done again.

Instead of visiting farms to quantify SusD, an alternative approach was used in Chapter 4, namely using an existing data set. Advantages of this approach are that data are already available, and that the number of records in the data set can be much higher, e.g., because data are collected on all farms in a country over a longer period of time. A higher number of records makes it possible to assess differences more precisely, and opens the opportunity to perform a risk analysis. Disadvantages, however, are that data sets are not yet available on all issues, and that the cooperation of the owners of the data sets is required. Furthermore, it is not possible to analyze relations between different SI, because data on different SI are not collected on the same group of farms.

Selection and quantification of SI gave a good indication of the strengths and weaknesses of different systems, but also of the variation within these systems. Chapter 5 shows that within the boundaries of this study, the aviary system with outdoor run is the best alternative for the battery-cage system. The aviary system performed better on animal welfare and economics, however, worse on environmental impact. No significant differences were found for other SI. Deep litter with and without outdoor run performed equally or worse than aviary with outdoor run on all SI. This is the result of an assessment based on EES issues defined in 2001 for the Dutch situation, and quantified with available SI for on-farm assessment. In the following paragraphs some issues or aspects that were neglected during this quantification are discussed.

As mentioned before, we focused on quantification of SI on commercial farms. This resulted in the exclusion of the issue consumer concerns, because quantification of this issue requires data collection in society, a higher system level. On-farm quantification results in a technical analysis of the actual situation, whereas the consumer’s perception can be different (Aarts et al., 2001). When a certain system has a good image, it can be difficult to influence the purchasing behaviour by information. In the Netherlands, for example, eggs from an alternative system (deep litter or aviary) without outdoor run, in Dutch called ‘scharreleieren’, have a good image. In the end, this could lead to better market opportunities for a product with a good image, but perhaps produced in a system that performs worse than another system on several other SI.

Furthermore, within the scope of this thesis, it was not possible to develop SI, so we had to rely on already available ones. This resulted in neglecting the issue knowledge and innovation, because no SI was readily available. As mentioned in Chapter 2, there is much more knowledge about managing a battery-cage system than an alternative system, because farmers have much longer experience with the battery-cage system. However, due to the large-scale introduction of alternative systems, knowledge and experience of these systems is gained rapidly. As currently alternative systems are less developed than the battery-cage system, there are still more opportunities for innovation left.

Of some issues only one aspect was taken into account, because other aspects could not be quantified. For example, with regard to food safety, contamination of the hens with *Salmonella enteritidis* was taken as indicator. Even though *Salmonella enteritidis* is the most important microbiological threat regarding food safety in eggs (Chapter 4), food safety also encompasses chemical and physical contaminations (Codex Alimentarius Commission, 2001; Swabe et al., 2001). Physical contaminations can be neglected in eggs, because they are visually checked before leaving the farm. Chemical contaminations can originate from residues of, e.g., medicines, or from the environment, e.g., dioxins. The risk on residues from medicine is low, due to the low use of medicine, and legally prescribed and adhered waiting periods (Ministerie van Landbouw en Visserij and Ministerie van Welzijn Volksgezondheid en Cultuur, 1985). The risk on dioxins is higher for systems with outdoor run, than for systems without outdoor run (e.g., Schuler et al., 1997; Lovett et al., 1998; Harnly et al., 2000). This is an important aspect that could not be quantified within this thesis, because analysis on dioxins in eggs was too expensive. For eggs, a reference value of 3 pg WHO-TEQ (Toxic EQuivalent, as defined by the World Health Organization) per g fat is set (EC, 2001b), which corresponds with about 18 pg per egg. It is, however, questionable whether this reference value, which is based on attainable levels, must be regarded as a hard threshold, or whether weighing a (slightly) higher level of dioxins against increased animal welfare must be considered (Meijer, 2005). The Scientific Committee on Food (SCF) of the European Commission stated a tolerable weekly intake for dioxins and dioxin-like PCBs of 14 pg WHO-TEQ per kg body weight (SCF, 2001), which corresponds with a tolerable daily intake of 2 pg per kg body weight. Uncertainty and safety margins surround these norms. Freijer et al. (2001) conclude that 8% of the Dutch population exceeded this limit and that only 4% of the average intake came from eggs, while 27% came from dairy products, 23% from meat products, and 16% from fish. Furthermore, the intake decreased by about 90% over the last 25 years (Baars et al., 2004). A small increase of dioxin-levels in eggs, therefore, will only minimally increase the health risk for consumers. Therewith, the importance of dioxin contamination as an SI diminishes, but it still has to be monitored, in order to notice the development of dioxin-levels.

Some aspects that were mentioned in the workshop can be considered as general problems of the egg production sector, rather than of one specific production system. As these aspects do not differ between the studied systems, they were not further taken into account. The lifespan of a laying hen, for example, is about seventy weeks in all systems, whereas the male chicks are killed immediately after hatching. Feather pecking and cannibalism are implicitly taken into account in the SI for animal health and welfare, the animal needs index and mortality rate. The ban on beak trimming (LNV, 1996; 2004), however, likely increases the effects of feather pecking and cannibalism. The influence of this ban in the different housing systems could not be assessed, because all farms had beak-trimmed hens. Also the full vaccination program during the rearing period is a fragile spot for the sector, especially when new diseases emerge. These are all aspects that arise at a higher system level, namely the sector, and, therefore, do not cause any difference between the studied housing systems. They must, however, be taken into account when new housing systems are developed and policy is made, because they are relevant with regard to SusD of the whole egg production sector.

7.4 Final assessment

The fourth step of the methodology is the final assessment of the contribution to SusD. The most important question, which is dealt with in Chapter 6, is to whom the results must be presented. Or, in other words, who are the users of the results. Scientists and technicians can deal with rather detailed information. For farmers and policy makers, a certain level of aggregation of the data would be convenient, e.g., aggregation at the level of the identified issues, such as animal health and welfare or environment. This gives them the opportunity to quickly assess the strong and weak points of the different systems. Furthermore, it is necessary for them to have a look at detailed data, in order to adjust their management or policy. Both groups, however, sometimes have different objectives, and, therefore, the reference values and method of aggregation can differ. The public wants the most aggregated data, because most people do not want to consider all the details. Whether such an aggregated index is desirable, however, is highly questionable.

Chapter 6 shows that choices made with regard to aggregation of data, but also during the preceding steps of the methodology, have to be explicated, when presenting final results. Choices made with regard to reference values, and weighing and compensation factors influence the final results considerably when data are aggregated. A simple labelling method for consumer-products, e.g., the points or stars systems, indicating origin, freshness, animal welfare, safety, and environmental pollution, as proposed by the Dutch minister of agriculture (LNV, 2003), is, therefore, very difficult to accomplish. The minister also realized this after consultation with several stakeholders, and decided to refrain from his initiative. It is, however, broadly recognised that 'active communication of reliable, uniform information about product quality and sustainability' is essential (LNV, 2005a). Practical problems emerge, because most consumers do not want detailed information (Frewer et al., 2005), which makes aggregation necessary. There is, however, also no consensus among consumers on which issues to cover and how to weigh them. Furthermore, this kind of information is questionable, because the choice of the consumers in front of the shelves is determined more by factors like quality, safety, convenience, and price, than by, e.g., animal welfare and environmental issues (LNV, 2005b). A good marketing strategy, therefore, is necessary to sell eggs produced in a system that contributes more to SusD, even though they are more expensive than eggs produced in another system.

As mentioned before, SusD is highly context specific with regard to time and space. The proposed methodology, therefore, must be considered as an iterative process. This means that after the final assessment, and subsequent actions, the process starts again with reconsidering the identified issues and selected SI. For the Dutch egg production sector, but probably broader in the European Union, current concerns about low egg prices and dust emissions are examples of new issues that need to be considered.

7.5 Studied systems

Due to the choice to quantify all selected issues on-farm, we were only able to select the four systems that were most common in The Netherlands at that time. Other housing systems, such as enriched cages, aviary without outdoor run and organic systems were rare, and, therefore, not enough data were available. Enriched cages are rare in the Netherlands, probably caused by a long uncertainty about a ban on these systems. The lack of market potential for eggs from an aviary system without outdoor run was the most probable reason why farms with aviary without outdoor run were rare. Eggs from aviary with outdoor run, on the other hand, had a good market potential, because they were sold as free range eggs. Since the legislation changed (EC, 2001a), there is no difference between eggs from aviary and deep litter without outdoor run, which opens opportunities for the aviary system. The number of organic farms that were large enough to compare with other commercial farms, was too low to get a representative group. Extending the results from this study is risky, because many changes influence more than one indicator and there are possibly many interacting features. When we want to assess the contribution to SusD of these systems, therefore, we have to apply (at least the last two steps) the methodology again.

The methodology used in this thesis can be applied also to new systems at different stages of development. First, a new concept can be assessed, based on assumptions. The results from the research project ‘Laying hen husbandry’ are examples of such new concepts (Wageningen UR project team 'Houden van Hennen', 2004). Two designs for “socially responsible laying hen husbandry systems” were developed in cooperation with farmers and citizens. These concepts must not be considered as blue prints, but as inspirational examples. Secondly, a (new) concept can be assessed when it is tested at a research station, like Munniksma (2005) did for two organic production systems at the experimental farm of the Animal Sciences Group, ‘Het Spelderholt’. Thirdly, a new concept that is developed and introduced in practice on a commercial farm can be assessed. Developments like the use of mobile units, which can be placed in the outdoor run (see, e.g., www.huehnermobil.de or www.ringadvies.nl/PIMeng.htm) are at this stage.

7.6 Examples of assessment methods

Approaches that are to a certain extent comparable with our methodology are the 'sustainability scan' (Boone and ten Pierick, 2005) , RISE (Response-Inducing Sustainability Assessment, Häni et al., 2003) or 'Koeien en Kansen' (Aarts, 2003). The project 'EkoPluim', which focuses on organic poultry (www.biologischpluimvee.nl/projecten/ekopluim), has a similar approach as the latter project.

The 'sustainability scan' is developed as a self-analysis tool for companies in order to formulate their sustainability strategy. The scan is applicable to all links and sectors in the agribusiness, but, until now, mainly applied to larger companies (at least 5 employees) and not on primary farms. At this moment, the scan does not encompass issues that are specific for a certain type of production system, but the developers mentioned this already as a possibility.

RISE is a tool to assess sustainability, covering ecological, economic, and social aspects, of single farms and induce changes to improve sustainability. It is applicable for different farm types and in different countries. A trained analyst must complete an in-depth farm assessment, which is followed by a discussion with the farmer on possible changes in the farm management (Häni et al., 2003). Because RISE is applicable to a broad range of farms and circumstances, it does not consider the context specific character of SusD, and, therefore, also does not encompass issues that are specific for a certain type of production system.

In the 'Koeien en Kansen' project, dairy farms are analyzed in their current situation and compared with objectives for "ecological, agricultural-technical, and social-economic sustainability". Subsequently, researchers and farmers together develop a plan to implement changes in order to reach the objectives of the farmers and the project. The effects of the implemented changes are monitored and adapted if necessary (Aarts, 2003). This approach is more directed to the individual farm, and really uses a bottom-up approach during quantification and implementation phases of the project. The selection of issues in the 'Koeien en Kansen' project, however, was in first instance characterised by a top-down approach, because no consultation with stakeholders took place during this phase. During the project, only participating farmers influenced the studied issue, which resulted in a vision that focused mainly on on-farm issues, instead of encompassing all issues necessary to assess SusD.

Ideas and experiences from these examples can be used when implementing our methodology in practice.

7.7 Recommendations

Farmers who still have a battery-cage system have to choose for a different system in the near future, at least before 2012. They have to make their choice based on their own vision and circumstances. From this thesis, it is clear that aviary with outdoor run performed better or equal on all quantified indicators compared to deep litter with outdoor run. A better performance on animal welfare was caused by the ability to move in vertical direction, lower environmental impact was caused by manure drying and removal, and higher income was generated due to the possibility to keep more hens in a similar stable. Most of these features, however, can also be implemented in deep-litter systems, e.g., by making two floors in a house. Some farmers implemented this system already, but it was not taken into account in this study as a separate group. We could not assess the opportunities for enriched-cage systems, as there were not sufficient farms with this system available. This choice, therefore, has to be made on basis of other research results or practical experiences.

Further research can aim at assessment of issues at other system levels, like consumer concerns. As stated before, this requires data collection in society, with an inquiry among a large group of consumers. Other issues or aspects that were not taken into account in this thesis are the ban on beak trimming, the full vaccination scheme, and the concerns about the short lifespan. These aspects can be considered as general problems of the egg production sector, rather than of one specific production system. Further research can aim at developing possibilities to deal with these problems in different systems.

In order to really effectuate a process of SusD, it is necessary to consider the developed methodology not as a linear, but as a circular, iterative process. After the evaluation of a system for the selected indicators, changes have to be implemented in order to improve. When these are effectuated, a new assessment can start. This can be done on basis of the same list of indicators, but it is also possible that the context changes and new issues have to be selected, or that better indicators have become available. Furthermore, stakeholders, and especially farmers, can be stimulated to effectuate SusD by involving them more in the whole process of assessment, instead of only during the identification of issues. This will make them more owner of the project (Bell and Morse, 2003), because their farms are not only subject of study, but they become a partner in the project contributing with their own knowledge and experience (Aarts, 2003). An additional advantage is that due to the participation of the farmers, it is possible to collect actual data during the production round, which are more reliable than historical data that are collected after the production round has ended. Furthermore, in a participatory approach, a farmer can be supported in his decisions on SusD, taking into account the specific context of his farm.

7.8 Conclusions

- A systems approach is necessary to assess sustainable development of (animal) production systems in its specific context with regard to time and space.
- The four-step methodology, proposed to assess sustainable development of egg production systems, is suitable for practical application.
- Assessment of sustainable development is not a linear process with an end-point, but a circular, iterative process.
- Participation of stakeholders is a useful approach to elucidate the general perception of sustainable development in a specific situation.
- In order to assess the contribution of egg production systems to sustainable development, many economic, ecological and societal issues need to be considered. These issues are not only defined at the farm level, but also at higher system levels.
- Within the boundaries of the performed study, the aviary system (with outdoor run) proved to be the best alternative for the battery-cage system.
- The variation between farms with the same housing system shows that improvements can be achieved within a housing system as well.
- Choices made during the application of the methodology are value based and, therefore, have to be explicated, in order to understand the background of the results. These choices have to be taken into account when results are communicated or used in practice.

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Summary

Sustainability or sustainable development (SusD) is stated as a core element of many government policies, research projects, and corporate strategies. Due to the widespread use and the different meanings given to the term 'sustainability', it is discarded as a buzz-word sometimes. There is, however, a common essence in using the term, which originates from the most often quoted definition from the World Commission on Environment and Development (WCED): "Sustainable development meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations". Subsequently, in scientific literature many authors gave their own definition, with the result that there is no generally agreed definition. Therefore, it is necessary to first define SusD in broad terms, and, subsequently, come to a more precise and context specific definition.

In order to define SusD, two core elements have been identified. The first element is that SusD is not a fixed state of harmony, but rather a process of change, consistent with future as well as with present needs. This means that we cannot define a sustainable system or product, but that it is necessary to monitor SusD of a process. The second element is that SusD relates to economic, ecological, and societal (EES) issues. Within the domain defined by these core elements, researchers have to find out what people think about SusD in a specific situation. A participatory approach can help to obtain people's opinions, which means that all relevant stakeholders of a certain system are involved.

The objective of this study was to further develop and apply a methodology to assess the contribution of animal production systems to SusD. Here, a methodology means not a fixed method, which always will lead to a certain type of outcome. It is a general approach, in which different methods are applied. The practical use of the methodology is tested in a case study on egg production systems, because the upcoming ban on the battery-cage system in 2012 forces farmers to change to an alternative, more animal-friendly production system in the near future. A decision to introduce a new production system should not be based on one single issue, e.g., animal welfare, as was the case with the ban on the battery cage. In order to prevent future shortcomings on other aspects, the selection of new production systems must consider all EES issues, which together determine the contribution to SusD.

Assessment of the contribution of animal production systems to SusD implies four steps: (1) description of the situation; (2) identification and definition of relevant EES issues; (3) selection and quantification of suitable sustainability indicators (SI); and (4) final assessment of the contribution to SusD. The first step requires that you have to define and describe the system that is subject of study, in our case the egg production system. Stakeholders, who represent the internal and surrounding components (i.e., the context) of a system, were identified. These stakeholders were involved in the second step, the identification and definition of relevant EES issues. This step was supplemented with information from literature. During the third step, issues were made measurable by selecting SI, which were quantified. For the case study, this

meant that data had to be collected in the field, i.e., on the farm, from different egg production systems, characterized by differences in housing system. The fourth step encompassed the final assessment, which meant that all information was combined to determine the final contribution of the system to SusD.

Chapter 2 describes the first two steps of the methodology, the description of the situation, and the identification and definition of relevant EES issues. It demonstrates how participatory strengths, weaknesses, opportunities and threats (SWOT) analysis can be used to identify relevant EES issues for the assessment of SusD. Participatory methods were used to facilitate the exchange of ideas, experiences and knowledge of all relevant stakeholders and to create a basis for implementation of the final results. We concluded that the combination of a brainstorming session and SWOT analysis with a heterogeneous group of stakeholders constituted a useful tool to order and structure these listed aspects and to identify relevant issues for SusD. Final selection of EES issues from the SWOT analysis, however, required additional reviewing of the literature and consultation with experts from specific fields. Final EES issues selected in the case study of Dutch egg production included animal health and welfare, environment, egg quality, ergonomics, economics, consumer concerns, and knowledge and innovation.

Chapter 3 describes an example of step three of the methodology, i.e., the selection of appropriate SI. Before selection can take place, a clear set of criteria for indicators must be defined. SI have to be a) relevant, i.e., they have to express something about the issue, b) simple, i.e., they have to be understandable for users, and c) sensitive and reliable, i.e., they have to react to changes in the system, and different measurements must lead to the same outcome. Furthermore, d) it must be possible to determine a target value or trend, and e) data have to be accessible. This chapter describes the selection of SI for one aspect of the issue animal welfare, i.e., the opportunity to express normal behaviour, because this aspect cannot be assessed easily on a large number of commercial farms.

Methods available to assess opportunities to express normal behaviour at farm level are based on a range of welfare parameters, which can be divided into two categories, environment-based and animal-based parameters. The first category describes features of the environment (dimensions of the house and facilities) and management, which can be considered prerequisites for welfare. The second category records animals' responses to that particular environment and management more directly. The objective was to validate a mainly environment-based method, i.e., the animal needs index (ANI), with animal-based methods, i.e., behavioural observations and feather condition scores. The study was conducted on 20 commercial laying hen farms; 10 farms with battery cages and 10 farms with deep-litter systems. The results showed that ANI is valid and sensitive enough to show differences in animal welfare between housing systems, whereas differences in welfare within housing systems cannot be shown. For the other criteria, simplicity, data accessibility, and possibility to set a target value, the animal needs index performed better than the animal-based methods. We concluded that ANI is an appropriate method for assessment of this aspect of laying hen welfare on a large number of farms with different housing systems.

Because of the outbreak of Avian Influenza in the Netherlands during spring and summer 2003, it was not allowed to visit farms to quantify all SI. Therefore, we resorted to the use of an existing data set. From the screening of *Salmonella enteritidis* (SE) infections in laying hens, a data set of regularly collected blood samples was available for analysis. Chapter 4 describes an in-depth study on the incidence of SE infections in laying hens, which is the main threat regarding food safety in egg production. Various risk factors exist for infection with and spreading of SE on a farm. The objective of the analysis was to identify risk factors associated with SE infection in laying hens. Results showed that bigger flocks increased the chance of infection with SE in all housing systems. The system with the lowest chance of infection was the cage system with wet manure. An outdoor run increased the chance of infection only at farms with all hens of the same age. The presence of hens of different ages on a farm was a risk factor for deep-litter systems only. This resulted in the highest chance of infection for a deep-litter system on a farm with hens of different ages. On a farm with all hens of the same age, however, a deep-litter system did not increase the chance of infection with SE compared with a cage system. The main risk factors associated with SE infection, therefore, were flock size, housing system, and farm with hens of different ages.

Chapter 5 describes the third step of the methodology, the selection and quantification of suitable SI, for all issues. The objective was to select SI for all EES issues, and to analyze the performance of different production systems on the selected SI. We compared four egg production systems, characterized by different housing systems, which were most common in the Netherlands: the battery-cage system, the deep-litter system with and without outdoor run, and the aviary system with outdoor run. We showed that on-farm quantification of SI was an appropriate method to identify strengths and weaknesses of different systems, and the variation within these systems as well. From this analysis it appeared that, within the boundaries of this study, the aviary system with outdoor run was the best alternative for the battery-cage system. The aviary system performed better on animal welfare and economics, however, worse on environmental impact. No significant differences were found for other SI. Deep litter with and without outdoor run performed equally or worse than aviary with outdoor run on all SI.

Chapter 6 presents an ethical reflection on the whole methodology, with special emphasis on the fourth step of the methodology, the final assessment of the contribution to SusD. Many

decisions during the four-step methodology, e.g., decisions on which stakeholders to involve, which reference values to choose, or how to aggregate information, are based on implicit value judgements. These value judgements influence the final results of the assessment, which makes it important to elucidate them when applying this methodology. Therefore, the objective was to explicate the main value judgements in the methodology. From this reflection it became clear that different users require a different level of aggregation and that there is not a generally accepted way to aggregate SI results into a final index of SusD. The feature of SusD that it is context specific with regard to time and space, also contributes to the diversity of possible results. When presenting final results, therefore, the whole process has to be taken into account, which means that all choices have to be explicated.

The final conclusions from this thesis are:

- A systems approach is necessary to assess sustainable development of (animal) production systems in its specific context with regard to time and space.
- The four-step methodology, proposed to assess sustainable development of egg production systems, is suitable for practical application.
- Assessment of sustainable development is not a linear process with an end-point, but a circular, iterative process.
- Participation of stakeholders is a useful approach to elucidate the general perception of sustainable development in a specific situation.
- In order to assess the contribution of egg production systems to sustainable development, many economic, ecological and societal issues need to be considered. These issues are not only defined at the farm level, but also at higher system levels.
- Within the boundaries of the performed study, the aviary system (with outdoor run) proved to be the best alternative for the battery-cage system.
- The variation between farms with the same housing system shows that improvements can be achieved within a housing system as well.
- Choices made during the application of the methodology are value based and, therefore, have to be explicated, in order to understand the background of the results. These choices have to be taken into account when results are communicated or used in practice.

Samenvatting

De doelstelling van dit onderzoek was het verder ontwikkelen en toepassen van een aanpak om duurzame ontwikkeling van (dierlijke) productiesystemen te beoordelen. De gekozen aanpak is toegepast op de leghennensector in Nederland, waarbij verschillende huisvestingssystemen met elkaar vergeleken zijn. De keuze voor de leghennensector is vooral ingegeven door het verbod op legbatterijen in de Europese Unie na 1 januari 2012.

Voordat duurzame ontwikkeling beoordeeld kan worden, is het noodzakelijk dit begrip te definiëren. Twee aspecten van duurzame ontwikkeling zijn in het kader van dit proefschrift van belang. Ten eerste heeft duurzame ontwikkeling geen vaststaand einddoel, maar is het een proces van verandering, een ontwikkeling. Ten tweede gaat duurzame ontwikkeling over zowel economische, ecologische, als ook sociaal-maatschappelijke ontwikkeling. In een workshop met belanghebbenden van de leghennensector hebben we bepaald welke onderwerpen beoordeeld moeten worden in het kader van duurzame ontwikkeling van de sector. Dit proces is beschreven in hoofdstuk 2. Tijdens de workshop zijn de verschillende onderwerpen aan de hand van een sterkte-/zwakteanalyse bediscussieerd en uitgewerkt. Voordat de definitieve lijst met onderwerpen vastgesteld werd, zijn experts en literatuur geraadpleegd. Dit proces heeft de volgende lijst met onderwerpen opgeleverd: diergezondheid en –welzijn, milieu, eikwaliteit, arbeidsomstandigheden, economie, consumentenbelangen, en kennis en innovatie.

Om een vergelijking van verschillende systemen te kunnen maken zijn bovenstaande onderwerpen omgezet in meetbare indicatoren. Voor één aspect van dierenwelzijn, de mogelijkheid om normaal gedrag uit te voeren, is eerst een studie gedaan om te bepalen of de beoogde indicator voldeed. Dit is beschreven in hoofdstuk 3. Het betrof een dierenwelzijnsindex die een beoordeling geeft op basis van stalafmetingen en inrichting. Deze index is getoetst aan indicatoren die gebaseerd zijn op waarnemingen aan de dieren zelf, namelijk gedragswaarnemingen en verenkleedscores. Deze studie is uitgevoerd op 20 leghennenbedrijven, 10 met batterijkooien en 10 met scharrelhuisvesting. De conclusie van deze studie was dat de gebruikte dierenwelzijnsindex voldeed voor het aantonen van verschillen tussen huisvestingssystemen. Daarnaast was deze index, voor studies op een groot aantal bedrijven, eenvoudiger toepasbaar dan de indicatoren waarbij waarnemingen gedaan worden aan de dieren.

Een literatuurstudie naar verschillende aspecten van voedselveiligheid leverde twee belangrijke aandachtspunten op, namelijk dioxine- en salmonellabesmettingen. Doordat al enige jaren een verplichte controle op salmonellabesmetting van leghennen plaatsvindt, was een dataset met uitslagen van bloedtesten beschikbaar. Aan de hand van deze dataset hebben we de belangrijkste risicofactoren voor salmonellabesmetting bepaald. Dit is beschreven in hoofdstuk 4. De belangrijkste risicofactoren waren koppelgrootte, huisvestingssysteem en meerleeftijdenbedrijf. Grotere koppels verhogen het risico op besmetting. De invloed van verschillende huisvestingssystemen hing af van het feit of er hennen van verschillende leeftijden op een bedrijf aanwezig waren (meerleeftijdenbedrijf). Hierdoor kan geen algemene uitspraak gedaan worden over een verhoogd risico in scharrelsystemen of in systemen met buitenuitloop ten opzichte van batterijhuisvesting.

Hoofdstuk 5 beschrijft een analyse van indicatorscores op praktijkbedrijven. Doordat we ons beperkt hebben tot bestaande indicatoren en de kwantificering op praktijkbedrijven plaatsvond, hebben we alleen onderwerpen geanalyseerd die op bedrijfsniveau meetbaar waren. Dit resulteerde in indicatoren voor de onderwerpen diergezondheid en –welzijn, milieu, eikwaliteit, arbeidsomstandigheden en economie. De vier in Nederland meest voorkomende huisvestingssystemen zijn onderzocht; het legbatterijsysteem, het scharrelsysteem met en zonder uitloop, en het volièresysteem met uitloop. Andere huisvestingssystemen, bijvoorbeeld de verrijkte kooi, zijn niet meegenomen, omdat daarvan te weinig bedrijven beschikbaar waren. Een dergelijke analyse van indicatorscores geeft, ten eerste, inzicht in de sterke en zwakke punten van de verschillende systemen. Met andere woorden de verschillen tussen de systemen. Ten tweede, geeft het inzicht in de variatie in prestaties binnen de systemen, waardoor mogelijke verbeteringen binnen systemen zichtbaar worden. Binnen de randvoorwaarden van dit onderzoek bleek het volièresysteem met uitloop het beste alternatief voor de legbatterij te zijn. Het volièresysteem presteerde beter op dierenwelzijn en economie, maar slechter op milieu. Met betrekking tot de overige indicatoren werden geen duidelijke verschillen waargenomen. Scharrelsystemen met en zonder uitloop presteerden gelijk of slechter dan het volièresysteem met uitloop op alle indicatoren.

In hoofdstuk 6 wordt een aantal methoden besproken die gebruikt kunnen worden om de resultaten van een duurzaamheidsanalyse te presenteren of samen te voegen. Het samenvoegen van indicatorscores tot een eindcijfer (duurzaamheisscore) is, net als vele andere beslissingen in de gevolgde aanpak, gebaseerd op impliciete waardeoordelen. Dit houdt in dat keuzes (mede) bepaald worden door de achtergrond van de belanghebbenden. Bijvoorbeeld, ten opzicht van welke referentiewaarden, waarden die aangeven wat wel en wat niet acceptabel is, worden systemen vergeleken. Daarnaast zullen belanghebbenden verschillende onderwerpen belangrijk vinden en daardoor verschillende wegingsfactoren toekennen aan de daarbij behorende indicatoren. Daardoor is het niet mogelijk om een algemeen geldend eindcijfer voor duurzame ontwikkeling te berekenen. Bij de presentatie van resultaten van onderzoek naar duurzame ontwikkeling moeten daarom altijd de verschillende (impliciete) waardeoordelen aangegeven worden.

Dankwoord

Aan het einde gekomen wil ik een woord van dank richten aan alle mensen die een bijdrage geleverd hebben aan het tot stand komen van dit proefschrift. Dit is misschien wel het gevaarlijkste onderdeel van een proefschrift, omdat het nooit mogelijk is om iedereen persoonlijk te noemen. Toch wil ik in ieder geval een aantal personen bij naam noemen.

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List of publications

Papers in refereed journals

Mollenhorst, H., van Woudenbergh, C.J., Bokkers, E.G.M., de Boer, I.J.M., 2005. Risk factors for Salmonella enteritidis infections in laying hens. Poultry Science 84, 1308-1313. (Chapter 4)

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de Boer, I.J.M., Smits, M.C.J., Mollenhorst, H., van Duinkerken, G., Monteny, G.J., 2002. Prediction of ammonia emission from dairy barns using feed characteristics. Part I: Relation between feed characteristics and urinary urea concentration. Journal of Dairy Science 85, 3382-3388.

Monteny, G.J., Smits, M.C.J., Mollenhorst, H., van Duinkerken, G., de Boer, I.J.M., 2002. Prediction of ammonia emission from dairy barns using feed characteristics. Part II: Relation between urinary urea concentration and ammonia emission. Journal of Dairy Science 85, 3389-3394.

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Other publications

Mollenhorst, H., de Boer, I.J.M., 2003. Identifying sustainability issues for egg production systems. PhD Retreat "Gateway to the Future", 12-13 December 2002, Nunspeet, The Netherlands. s.n., pp. 19.

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Training and Supervision Plan		Graduate School WIAS
Name: Erwin Mollenhorst		
Group: Animal Production Systems		
Daily supervisor: Dr ir I.J.M. de Boer		
Supervisor: Prof. dr ir A.J. van der Zijpp		
Period: October 2000 - June 2005		
	Year	**Cp**
The Basic Package (minimum 2 cp)		
WIAS Common Course (mandatory)	2001	2.0
WIAS Course on philosophy of science and ethics (mandatory)	2001	1.0
SUBTOTAL		**3.0**
Scientific Exposure (minimum 5 cp)		
International conferences		
11th European Poultry Conference, Bremen, Germany (poster presentation)	2002	1.3
27th Poultry Science Symposium 'Welfare of the laying hen', Bristol, UK	2003	0.7
6th Int. Livestock Farming Systems Symposium, Benevento, Italy (oral presentation)	2003	1.0
22nd World's Poultry Congress, Istanbul, Turkey (poster presentation)	2004	1.3
Seminars and workshops		
WIAS seminar 'Organic farming: a challenge for animal production systems research', Wageningen (poster pres.)	2000	0.8
WIAS/APS 'Sustainable development in practice: methodologies and applications', Wageningen (oral pres.)	2000	0.6
WIAS workshops 'Supervising PhD students' 2000/2001, Wageningen	2000-1	0.2
WIAS Science Day 2001-2004, Wageningen (2004 oral presentation)	2001-4	1.3
Scientific meeting 'Grenzen aan welzijn & dierlijke productie', Lelystad (poster presentation)	2001	0.6
'Kenniseenheid Dierendag', Rhenen	2002	0.2
Veterinary Science Day 2002, Garderen	2002	0.2
WPSA study day 2002, Wijchen	2002	0.1
Sector study day Laying hens 2002/2003, Ede	2002-3	0.2
PhD retreat 'Gateway to the Future', Nunspeet (oral presentation)	2002	0.9
'Environmental systems analysis: environmental research at the edge of science and society', Ede	2003	0.1
'Possibilities of Fuzzy Logic', Wageningen	2003	0.1
NWO symposium 'Grenzen aan welzijn en dierlijke productie', Utrecht (poster presentation)	2003	0.9
'The National Poultry debate', Utrecht, The Netherlands	2003	0.2
WPSA Symposium 'Pluimveehouderij als kenniseconomie? De rol van Nederland internationaal', Wageningen	2004	0.2
Farewell symposium Wiebe Koops 'Choices for the future', Wageningen (oral presentation)	2005	0.7
SUBTOTAL		**11.6**
In-Depth Studies (minimum 4 cp)		
WIAS advanced statistics course 'Design of animal experiments'	2000	1.0
WIAS course 'Biology underpinning animal sciences: Broaden your horizon'	2001	0.8
PE&RC/WIAS course 'How to manage diversity in living systems?'	2002	1.0
CERES course 'Complex dynamics in and between social and ecosystems' (incomplete)	2004	1.2
WIAS/VLAG course 'Nutrition and Sports'	2005	1.0
SUBTOTAL		**5.0**
Professional Skills Support Courses (minimum 2 cp)		
WIAS course 'Techniques for writing and presenting a scientific paper'	2001	0.7
OWU course 'Supervising MSc thesis work'	2001	0.5
OWU course 'Hoorcollege geven' (oral presentations)	2003	1.0
WGS course 'Time Planning and Project Management'	2003	0.5
WIAS/LTP Midterm Job Assessment	2003	0.5
NWO 'Talentendag', Zeist	2004	0.2
SUBTOTAL		**3.4**
Didactic Skills Training (optional)		
Supervising a group of 'Boerderijproject' 2001/2002	2001-2	1.6
Supervising MSc theses Lotte van de Ven, Yvette Koedijk, and Kees van Woudenbergh	2002-4	2.5
Guest lecture 'Systems approach in animal science'	2004	0.3
SUBTOTAL		**4.4**
Management Skills Training (optional)		
Chairman WAPS (WIAS Associated PhD students) council	2001-3	9.0
Organisation WIAS Science Day 2002/2003	2002-3	2.0
Organisation WIAS Introduction Course 2003	2003	0.5
SUBTOTAL		**11.5**
TOTAL		**38.9**

One credit point equals a study load of approximately 40 hours

Curriculum vitae

Herman (Erwin) Mollenhorst werd geboren op 24 juli 1977 op een boerderij in Den Ham (Ov.). In 1995 behaalde hij zijn VWO-diploma aan de Christelijke Scholengemeenschap 'Het Noordik' te Almelo. In datzelfde jaar begon hij aan de studie Zoötechniek aan de toenmalige Landbouwuniversiteit Wageningen, met als specialisatie Dierlijke Productiesystemen. Eind 1998 deed hij een afstudeervak bij de leerstoelgroep Agronomie, sectie gewas- en graslandkunde naar de verteerbaarheid van Engels raaigras, witte klaver en paardebloem. Aansluitend ging hij op stage naar het Danish Institute of Agricultural Sciences te Foulum in Denemarken, waar hij het mineralenmanagement in de Deense landbouw heeft bestudeerd. Tijdens zijn laatste afstudeervak bij de leerstoelgroep Dierlijke Productiesystemen, in samenwerking met het toenmalige Instituut voor Milieu- en Agritechniek (IMAG), deed hij onderzoek naar de invloed van rantsoenkenmerken op de ammoniakemissie uit melkveestallen. Voor het resultaat van dit afstudeervak ontving hij in 2001 de Schothorstprijs voor de beste scriptie over een veevoedkundig onderwerp. Hij studeerde in augustus 2000 *cum laude* af en is vervolgens in oktober 2000 aangesteld als assistent in opleiding bij de leerstoelgroep Dierlijke Productiesystemen van Wageningen Universiteit op het in dit proefschrift beschreven onderzoek. Dit project maakte deel uit van het NWO/LNV-prioriteitsprogramma 'Grenzen aan welzijn en dierlijke productie' en werd ondersteund door Technologiestichting STW. Tijdens zijn promotieonderzoek heeft hij het onderwijsprogramma van de onderzoekschool WIAS doorlopen en het bijbehorende onderwijscertificaat behaald. Daarnaast heeft hij zich, als voorzitter van de AIO-raad, ingezet voor de belangen van de promovendi binnen genoemde onderzoekschool.

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