Assessing the sustainability of egg production systems in The Netherlands

[E. D. van Asselt](http://ps.oxfordjournals.org/search?author1=E.+D.+van+Asselt&sortspec=date&submit=Submit)[\*](http://ps.oxfordjournals.org/content/94/8/1742.full#aff-1),[1](http://ps.oxfordjournals.org/content/94/8/1742.full" \l "corresp-1),

[L. G. J. van Bussel](http://ps.oxfordjournals.org/search?author1=L.+G.+J.+van+Bussel&sortspec=date&submit=Submit)[\*](http://ps.oxfordjournals.org/content/94/8/1742.full#aff-1),[2](http://ps.oxfordjournals.org/content/94/8/1742.full#corresp-2),

[P. van Horne](http://ps.oxfordjournals.org/search?author1=P.+van+Horne&sortspec=date&submit=Submit)[†](http://ps.oxfordjournals.org/content/94/8/1742.full#aff-2),

[H. van der Voet](http://ps.oxfordjournals.org/search?author1=H.+van+der+Voet&sortspec=date&submit=Submit)[‡](http://ps.oxfordjournals.org/content/94/8/1742.full#aff-3),

[G. W. A. M. van der Heijden](http://ps.oxfordjournals.org/search?author1=G.+W.+A.+M.+van+der+Heijden&sortspec=date&submit=Submit)[‡](http://ps.oxfordjournals.org/content/94/8/1742.full#aff-3) and

[H. J. van der Fels-Klerx](http://ps.oxfordjournals.org/search?author1=H.+J.+van+der+Fels-Klerx&sortspec=date&submit=Submit)[\*](http://ps.oxfordjournals.org/content/94/8/1742.full#aff-1)

[+](http://ps.oxfordjournals.org/content/94/8/1742.full) Author Affiliations

\*RIKILT–Wageningen UR, P.O. Box 230, 6700 AE Wageningen, The Netherlands

†LEI–Wageningen UR, P.O. Box 29703, 2502 LS The Hague, The Netherlands

‡Biometris–Wageningen UR, P.O. Box 100, 6700 AC Wageningen, The Netherlands

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-corresp-1-1)1Corresponding author: [esther.vanasselt@wur.nl](mailto:esther.vanasselt@wur.nl)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-corresp-2-1)2Current address: Plant Production Systems Group, Wageningen University, P.O. Box 430, 6700 AK, Wageningen, The Netherlands

Revision received October 15, 2014.

Accepted May 7, 2015.

[Next Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-1)

Abstract

Housing systems for laying hens have changed over the years due to increased public concern regarding animal welfare. In terms of sustainability, animal welfare is just one aspect that needs to be considered. Social aspects as well as environmental and economic factors need to be included as well. In this study, we assessed the sustainability of enriched cage, barn, free-range, and organic egg production systems following a predefined protocol. Indicators were selected within the social, environmental, and economic dimensions, after which parameter values and sustainability limits were set for the core indicators in order to quantify sustainability. Uncertainty in the parameter values as well as assigned weights and compensabilities of the indicators influenced the outcome of the sustainability assessment. Using equal weights for the indicators showed that, for the Dutch situation, enriched cage egg production was most sustainable, having the highest score on the environmental dimension, whereas free-range egg production gave the highest score in the social dimension (covering food safety, animal welfare, and human welfare). In the economic dimension both enriched cage egg and organic egg production had the highest sustainability score. When weights were attributed according to stakeholder outputs, individual differences were seen, but the overall scores were comparable to the sustainability scores based on equal weights. The provided method enabled a quantification of sustainability using input from stakeholders to include societal preferences in the overall assessment. Allowing for different weights and compensabilities helps policymakers in communicating with stakeholders involved and provides a weighted decision regarding future housing systems for laying hens.

Key words

[sustainability](http://ps.oxfordjournals.org/search?fulltext=sustainability&sortspec=date&submit=Submit&andorexactfulltext=phrase)

[egg](http://ps.oxfordjournals.org/search?fulltext=egg&sortspec=date&submit=Submit&andorexactfulltext=phrase)

[The Netherlands](http://ps.oxfordjournals.org/search?fulltext=The+Netherlands&sortspec=date&submit=Submit&andorexactfulltext=phrase)

[enriched cages](http://ps.oxfordjournals.org/search?fulltext=enriched+cages&sortspec=date&submit=Submit&andorexactfulltext=phrase)

[free-range](http://ps.oxfordjournals.org/search?fulltext=free-range&sortspec=date&submit=Submit&andorexactfulltext=phrase)

[Previous Section](http://ps.oxfordjournals.org/content/94/8/1742.full#abstract-1)[Next Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-2)

INTRODUCTION

Battery cages were developed in the 1930s and accepted on a widespread basis in the 1950s. However, over the years, this housing system for laying hens has increasingly been criticized in northern Europe for animal welfare reasons (Mench et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-24)). Public concern resulted in an adjustment of European legislation favoring production systems, which allowed hens to express their natural behavior (Mollenhorst and de Boer, [2004](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-28)). Starting in 2012, the conventional cage has been banned and only enriched cages with a minimum space of 750 cm2 per laying hen or alternative housing systems, such as barn, free-range, and organic systems are allowed in the European Union (Directive 1999/74/EC). In The Netherlands, a further ban is implied for enriched cages starting in 2021 (Legkippenbesluit, [2004](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-19)). Clearly, egg production systems are changing as a result of public concern on animal welfare. However, when policymakers have to decide upon changes in a production system, their choice should be based on a sustainability assessment incorporating not only animal welfare, but also environmental impacts, food safety, and economic vitality of the producer (De Boer and Cornelissen, [2002](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-5); Mench et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-24); Swanson et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-31)). In other words, each of the 3 sustainability dimensions (social, environmental, and economic dimensions) should be incorporated in an overall sustainability assessment.

As sustainability is a broad issue, usually indicators are used for quantification. Previous sustainability assessments provide an assessment of individual indicators, but they either do not establish an overall sustainability score for the various egg production systems (Mollenhorst et al., [2006](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-27); Dekker et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6)) or their overall score is based on equal weighting of the indicators (De Boer and Cornelissen, [2002](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-5)). In a previous study, a protocol was developed to come to an overall sustainability assessment of agri-food production systems enabling weighting of selected indicators (van Asselt et al., [2014](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-32)). The protocol starts with the selection of indicators that are linked to themes and subthemes within the social, environmental, and economic dimension. Selected indicators are then scaled based on sustainability limits. Comparison of agri-food production systems is finally based on weights attributed to the indicators using the opinion of policymakers and/or stakeholders as well as their opinion on compensability (to what extent a good score for one indicator can compensate a bad score for another indicator).

The aim of the current study was to evaluate the usefulness of the established protocol for assessing the sustainability of enriched cage, barn, free-range, and organic egg production systems.

[Previous Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-1)[Next Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-5)

MATERIALS AND METHODS

Sustainability Assessment

The sustainability of the 4 egg production systems was assessed using the protocol as described in Van Asselt et al. ([2014](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-32)).

The protocol consists of the following steps:

Definition of the case study in which geographic and time scale boundaries are described as well as precise definitions of the housing systems to be studied.

 In this case study, the following research question was formulated: “What are the consequences for sustainability in case conventional egg producing farmers (enriched cage) switch to barns, organic farming or free range farming”? The case study was further defined by using data for the Dutch situation. The following housing systems were assumed for the four egg production systems: enriched cages with forced air drying of manure at 0.7 m3/hen/h were assumed for the battery cage housing system [i.e., Housing Type E 2.5.5 (Ministry of Infrastructure and the Environment, [2012](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-26))]; for barn and free-range systems, it was assumed that 50% of the floor was slatted in 2 or more tiers and a manure belt was present [i.e., Housing Type E 2.11.1 (Ministry of Infrastructure and the Environment, [2012](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-26))]. The difference between barn and free-range is that in the latter case, hens have outdoor access. For organic production, a housing system with 1/3 littered floors and 2/3 slatted floors was assumed [i.e., Housing Type E 2.7 (Ministry of Infrastructure and the Environment, [2012](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-26))] and hens have outdoor access.

Establishment of a gross list of indicators based on literature and expert opinions. Indicators are included in the gross list if they fulfill the following criteria: the indicator should be measurable, sensitive to variations between housing systems, relevant to the case study, and directly linked to the subtheme.

Establishment of a core list of indicators most relevant for the case study based on the following criteria: data availability, every dimension should have at least one indicator, profitability and societal support should be included, and indicators should preferably be as broad as possible (umbrella indicators).

Evaluation.

 The established core list is discussed with a policy maker to ascertain that all important indicators are included.

Sustainability limits.

 Sustainability, midsustainability, and nonsustainability limits are set for each of the selected indicators based on legislation, policy targets, or best practices.

Data collection.

 Data are collected for the selected indicators based on literature, expert opinion.

Weighting tool.

 Results of Steps 5 and 6 are incorporated in a weighting tool that allows for assigning weights and compensabilities for each of the indicators. The weighting tool calculates sustainability scores on a scale from 0 to 100% at various levels: an overall sustainability score, scores for the 3 dimensions, scores for the various themes within the dimensions and scores per indicator (van der Voet et al., [2014](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-33)). In case the sustainability limit is reached, a factor of 100 is assigned. On the other hand, when the nonsustainability limit is reached the indicator gets a value of 0. When the indicator is in between the sustainable and nonsustainability limit, it is weighed against the predefined limits resulting in a value between 0 and 100. The weighting tool allows policymakers and/or stakeholders to define the importance of the individual indicators as well as their compensability within their themes. In case there is no compensation possible between indicators, compensability is set at 0. On the other hand, when the lack in sustainability in one indicator can be compensated by compensability is set at 1. Compensability can also be set at 0.5 if a tradeoff between indicators is possible meaning that a lower indicator score on a sustainability indicator can to some extent be compensated by higher scores on other indicators using linear weighting (van Asselt et al., [2014](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-32)). Further details on the method can be found in Van der Voet et al. ([2014](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-33)).

Communication.

 In this final step, the outcome of the overall sustainability assessment is visualized based on the entered weights and compensabilities. The weighting tool allows for a quick analysis of the effect of different weights and compensabilities on the outcome of the overall sustainability assessment.

Questionnaire on Importance of the Indicators

A questionnaire was established to obtain stakeholders’ perceptions towards the importance of the various indicators. For this purpose, 36 stakeholders were asked to participate in the study. Stakeholders were selected among the network of the researchers involved and based on their expertise related to the case study. The stakeholders represented 4 different stakeholder groups: industry (11 people), nongovernmental organizations (7 people), policymakers (8 people), and scientists (10 people). Scientist had expertise in animal welfare, nutrition, food safety, supply chain management, housing systems, and ethics; policymakers were from the Ministry of Economic Affairs and the Dutch Food Safety Authority; nongovernmental organizations included consumer organizations, environmental organizations, and animal welfare organizations; and people from industry were from farmers’ associations, wholesale, and the egg processing industry. Participants were asked to first distribute 100 points over the social, economic, and environmental dimension, and then to distribute 100 points over the indicators within each dimension. Questionnaires were sent by e-mail to facilitate the response.

[Previous Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-2)[Next Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-6)

RESULTS

A gross list of indicators was established based on consultation with 6 scientific experts and based on a literature review (Table [1](http://ps.oxfordjournals.org/content/94/8/1742.full#T1)). In total 48 indicators were selected using the criteria described in Step 2 of the protocol. Criteria described in Step 3 were used to derive a core list of indicators (Tables [2](http://ps.oxfordjournals.org/content/94/8/1742.full#T2) and [3](http://ps.oxfordjournals.org/content/94/8/1742.full#T3)). Dioxins and percentage Salmonella-positive farms were selected to evaluate food safety as these hazards are most commonly reported in eggs (Holt et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-17)). For animal welfare, various factors can be included such as disease, skeletal and foot health, pest and parasite load, natural behavior, stress, nutrition, and genetics. Housing systems score differently on these factors. However, information on these aspects is usually qualitative (EFSA, [2005](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-7); Lay et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-18)), indicating, for example, that larger environments are more difficult to clean and may thus result in higher probability of spreading diseases (Lay et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-18)), or semi-quantitative using scores to evaluate various aspects (Shimmura et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-30)). In our study, we aimed to quantify animal welfare as objectively as possible using indicators that are measurable and preferably have a unit. Hence, we used the approach of the Welfare Quality Monitor. This approach indicates criteria based on 4 principles: good feeding, good housing, good health, and appropriate behavior (Botreau et al., [2007](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-2), [2009](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-3)). The number of square meters per hen was selected as core indicator for good housing. Although other factors may also be relevant with regard to good housing (such as the presence of perches and ability to potter about and build nests), these factors are less quantifiable. Furthermore, it was assumed that the amount of square meters per hen indirectly covered these factors. As a measure for animal health, the percentage mortality was chosen as this was seen as the most objective indicator within this subtheme for which data were readily available as well.

View this table:

[In this window](http://ps.oxfordjournals.org/content/94/8/1742/T1.expansion.html)

[In a new window](http://ps.oxfordjournals.org/content/94/8/1742/T1.expansion.html)

Table 1.

Gross list of themes, subthemes, and indicators for assessing the sustainability in egg production systems (bold indicators were selected for further assessment).

View this table:

[In this window](http://ps.oxfordjournals.org/content/94/8/1742/T2.expansion.html)

[In a new window](http://ps.oxfordjournals.org/content/94/8/1742/T2.expansion.html)

Table 2.

Sustainability limits for the core indicators indicated in Table 11.

View this table:

[In this window](http://ps.oxfordjournals.org/content/94/8/1742/T3.expansion.html)

[In a new window](http://ps.oxfordjournals.org/content/94/8/1742/T3.expansion.html)

Table 3.

Parameter values for the core indicators.

As indicator for consumer involvement, we selected the percentage increase in turnover per housing system. Consumers’ preferences for a certain housing system (enriched cage, barn, free-range, or organic eggs) are reflected in the sales numbers of the specific eggs. An increase in turnover per year will give an indication of the trend in these preferences.

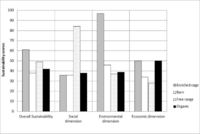
Environmental aspects are usually evaluated using lifecycle analysis (LCA) (De Boer and Cornelissen, [2002](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-5); Mollenhorst et al., [2006](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-27); Dekker et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6)). We selected the most common indicators from such an LCA: global warming potential (CO2 equivalents/kilogram egg), energy use, and direct and indirect land use for assessing environmental sustainability. Additionally, ammonia emission was included in the list as this was also seen as a relevant issue related to egg production (Xin et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-34); Leinonen et al., [2012](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-22)).

Farmer income was seen as the most important factor in the economic dimension, which coincides with other studies on the sustainability of egg production systems (De Boer and Cornelissen, [2002](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-5); Mollenhorst et al., [2006](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-27); Dekker et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6)). We characterized farmer income by cost price and farmer revenue price as there are no independent reliable data regarding farmer income and furthermore, this income fluctuates largely between farms and years. Cost price and farmer revenue price were thus seen as more robust indicators.

Sustainability limits were set based on legislation, on policy targets, or on best practices. In some cases, the midsustainability limit was set as the geometric mean of the other 2 limits. Geometric means were used because the lower limit was often close to 0, and linear interpolation at the logarithmic scale therefore seemed more appropriate (Table [2](http://ps.oxfordjournals.org/content/94/8/1742.full#T2)). Parameter values were primarily based on literature (Table [3](http://ps.oxfordjournals.org/content/94/8/1742.full#T3)). For dioxins and Salmonella prevalence no specific data for The Netherlands were available for all 4 housing systems, and therefore European data were used for these indicators. Although we realize that these data are averages of several European countries, the data will provide insight in the differences between housing systems.

For number of square meters per laying hen, no data were available and it was assumed that the amount of square meters per laying hen was equal to the legal limits. The obtained data presented in Tables [2](http://ps.oxfordjournals.org/content/94/8/1742.full#T2) and [3](http://ps.oxfordjournals.org/content/94/8/1742.full#T3) were incorporated into the weighting tool (Step 7 of the protocol).

Assuming equal weights for all indicators and compensability factors of 0.5 showed that enriched cage egg production had the highest sustainability score (61) and barn egg production the lowest (39). Free-range and organic egg production gave in-between scores of 49 and 42, respectively. The high score for enriched cage egg production is mainly due to a high score in the environmental dimension (Figure [1](http://ps.oxfordjournals.org/content/94/8/1742.full#F1)). Within the social dimension, free-range egg production had the highest score (Figure [1](http://ps.oxfordjournals.org/content/94/8/1742.full#F1)), due to a high score on food safety, animal welfare, and human welfare (Table [4](http://ps.oxfordjournals.org/content/94/8/1742.full#T4)).

[](http://ps.oxfordjournals.org/content/94/8/1742/F1.expansion.html)

View larger version:

[In this page](http://ps.oxfordjournals.org/content/94/8/1742/F1.expansion.html)

[In a new window](http://ps.oxfordjournals.org/content/94/8/1742/F1.expansion.html)

[Download as PowerPoint Slide](http://ps.oxfordjournals.org/powerpoint/94/8/1742/F1)

Figure 1.

Overall sustainability scores and scores in the social, environmental and economic dimension for enriched cage egg production (grey bars), barn egg production (white bars), free-range egg production (dotted bars), and organic egg production (black bars). Scores were obtained using a sustainability assessment assuming equal weights for the 3 dimensions and the various indicators.

View this table:

[In this window](http://ps.oxfordjournals.org/content/94/8/1742/T4.expansion.html)

[In a new window](http://ps.oxfordjournals.org/content/94/8/1742/T4.expansion.html)

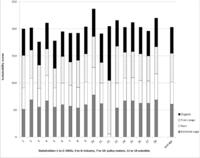
Table 4.

Results of the sustainability assessment assuming equal weights for the various dimensions and indicators.

In order to assess the effect of uncertainty in the indicators, data on global warming potential (in CO2 equivalents/kilogram egg), direct and indirect land use and energy use from an alternative Dutch study (Hilkens and Klein Swormink, [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-16)) were used for the parameter values. In comparison to the initial sustainability scores based on data from Dekker et al. ([2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6)) (Figure [1](http://ps.oxfordjournals.org/content/94/8/1742.full#F1)), this resulted in a comparably high score in the environmental dimension for enriched cage egg production (score of 98), but a much lower score for organic egg production (score of 8). Barn and free range egg production scored slightly higher with 57 and 55 compared with the initial scores (46 and 37 respectively, Figure [1](http://ps.oxfordjournals.org/content/94/8/1742.full#F1)).

Sustainability scores are not only dependent on parameter values, but also on the compensability and weights assigned to the 3 sustainability dimensions and the selected indicators. Initially, compensability factors were set to 0.5 and all indicators were equally weighted (Figure [1](http://ps.oxfordjournals.org/content/94/8/1742.full#F1)). When compensability was set at 0 (all indicators had to reach the sustainability limits), the overall scores for the 4 egg production systems was 0. Within the social dimension, the free-range egg production system had a score of 30, whereas the other egg production systems scored 0 in this dimension. For the environmental dimension, the enriched cage egg production system scored 92, barn egg and free-range egg production scored 21, and organic farming scored 0. In the economic dimension all 4 production systems scored 0.

Apart from compensability, the weights of the indicators may also influence the sustainability assessment. Thus, various stakeholders were asked to fill in a questionnaire on the weights of the 3 dimensions as well as the weights of the various indicators within these dimensions. In total, 18 people filled in the questionnaire (4 policymakers, 8 scientists, 2 nongovernmental organizations, and 4 people from industry); a response rate of 50%. Results showed that, on average, the social dimension was seen as more important (average weight of 43%; SD was 20) than the environmental (average weight of 31% and SD of 12) and economic dimension (average weights of 26% and SD of 14). Within the social dimension, the number of square meters per hen was seen as the most important indicator with an average weight of 24%. Percentage Salmonella-positive farms, levels of dioxins, percent mortality, and percent increase in annual turnover had average weights of 22, 21, 19, and 15%, respectively. Within the environmental dimension, CO2-equivalents had the highest average score of 27%. Land use, ammonia emission, and energy use were scored with average weights of 25, 24, and 24%, respectively. Within the economic dimension, farmer revenue price was seen as more important (average weight 55%) than cost price (average weight 45%). Figure [2](http://ps.oxfordjournals.org/content/94/8/1742.full#F2) presents the results of attributing different weights to the 3 dimensions and the indicators, showing large individual differences. Different stakeholders may have different opinions about the importance of various indicators, which have an effect on the overall sustainability score. For 3 stakeholders, free-range egg production gave the highest sustainability score. In general, however, enriched cage egg production had the highest overall sustainability score and barn egg production the lowest, which coincides with the results assuming equal weights.

[](http://ps.oxfordjournals.org/content/94/8/1742/F2.expansion.html)

View larger version:

[In this page](http://ps.oxfordjournals.org/content/94/8/1742/F2.expansion.html)

[In a new window](http://ps.oxfordjournals.org/content/94/8/1742/F2.expansion.html)

[Download as PowerPoint Slide](http://ps.oxfordjournals.org/powerpoint/94/8/1742/F2)

Figure 2.

Overall sustainability scores for enriched cage egg production (grey bars), barn egg production (white bars), free-range egg production (dotted bars), and organic egg production (black bars). Scores were obtained using a sustainability assessment using weights for the 3 dimensions and indicators as provided by 18 individual stakeholders (Nos. 1 and 2 were nongovernmental organizations, Nos. 3 to 6 industry, Nos. 7 to 10 policymakers, and Nos. 11 to 18 scientists) and based on the average weights of these stakeholders.

[Previous Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-5)[Next Section](http://ps.oxfordjournals.org/content/94/8/1742.full#ack-1)

DISCUSSION

Currently, developments in laying hen industry are primarily guided by animal welfare issues. When only this factor is taken into account, our case study showed that free-range egg production is beneficiary as this system had the highest scores for the indicators related to animal welfare (65 compared with 50, 40, and 28 for organic, enriched cage, and barn housing systems, respectively). However, our study included only a limited number of indictors to assess animal welfare. Various studies have been described to assess animal welfare. For example, Shimmura et al. ([2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-30)) performed an overall welfare assessment based on the 5 freedoms as developed by the Animal Welfare Council (FAWC, [2009](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-12)): freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury, and disease; freedom to express normal behavior; and freedom from fear and distress. Various indicators were used to assess these freedoms ranging from feather condition to animal handling. These indicators were evaluated using scores between 0 and 1. Most of these indicators were qualitative or semiquantitative rather than quantitative. We preferred to use indicators that were as objective as possible and therefore chose to use the core indicators “housing density” and “percent mortality > 20 wk.” Results showed that the outcome of the animal welfare assessment is comparable to Shimmura et al. ([2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-30)): cages score better on freedom from pain, injury, and disease, whereas noncage systems score better on expressing normal behavior (amongst other things expressed in housing density).

Animal welfare is only one aspect contributing to sustainability. Apart from this, also other social aspects need to be included, as well as environmental and economic aspects in order to evaluate the overall sustainability of the various egg production systems. In our approach, sustainability was evaluated based on core indicators within each of the 3 sustainability dimensions.

Previous sustainability assessments provide data on various indicators, but they do not compare these indicators to come to an overall sustainability assessment (Mollenhorst et al., [2006](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-27); Dekker et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6); Leinonen et al., [2012](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-22)). The approach described in this paper is a valuable addition to the sustainability assessments currently available as it enables weighting and comparing various indicators. A comparable approach using indicators and target values is presented by de Boer and Cornelissen ([2002](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-5)). In their study, indicators for economic, environmental, and societal impacts were selected and quantified, and an overall assessment of sustainability was obtained assuming equal weights for all indicators. One advantage of our approach is that different weights can be attributed to the various indicators. A second advantage is that indicators can be combined per dimension enabling a comparison between environmental, economic, and social dimensions regardless of the number of indicators within each dimension.

When equal weights were attributed to our indicators, this resulted in a highest sustainability score for enriched cage egg production systems, which is in line with the assessment of de Boer and Cornelissen ([2002](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-5)). Overall scores ranged between 38 for barn housing systems and 61 for enriched cage housing systems, meaning that some improvement on sustainability is still possible in order to arrive near the ideal score of 100.

A limited number of stakeholders were asked to weigh the dimensions and indicators in order to evaluate the effect of including societal concerns in the overall assessment. Due to this small sample size, SD values were high, resulting in different outcomes of the overall sustainability when individual weights of stakeholders were used (Figure [2](http://ps.oxfordjournals.org/content/94/8/1742.full#F2)). This was also found by Castellini et al. ([2012](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-4)). However, the outcome of the individual scores in most cases is comparable to the overall assessment meaning that enriched cage systems had the highest sustainability score and barn egg system the lowest. One stakeholder (No. 12) attributed rather extreme scores to the indicators and the 3 dimensions resulting in deviating sustainability scores for the 4 housing systems. The advantage of using the weighting tool is that such different opinions can easily be visualized allowing discussions between policymakers and stakeholders.

Apart from weights, compensabilities can also be set for the 3 dimensions and indicators. When it is assumed that no compromise is possible (compensability is 0: all indicators should reach their sustainability levels), none of the 4 egg production systems managed to obtain an overall score above 0. This means that it is impossible to reach all sustainability limits; in other words: a low score on one indicator needs to be compensated with a high score on another indicator within the same dimension. In our case we set compensability factors at 0.5: indicators can be compensated to some extent.

The outcome of the sustainability assessment is also influenced by the parameter values and sustainability limits used in the assessment. Comparing various LCA shows that scores on global warming potential, energy use, and land use differ between countries (Dekker et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6); Leinonen et al., [2012](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-22)), which may be due to the use of different production systems. However, LCA within a country may differ as well depending on the input parameters used (Dekker et al., [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6); Hilkens and Klein Swormink, [2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-16)). Using data from these 2 cited LCA resulted in large differences in the sustainability score for organic egg production in the environmental dimension. It is thus essential to select the most relevant data for the sustainability assessment. In our study, data from Dekker et al. ([2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-6)) were used for further analysis, as the LCA provided by Hilkens and Klein Swormink ([2011](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-16)) was neither clearly substantiated nor subjected to peer review.

Scientists are responsible for providing objective information for the first 6 steps of the protocol. In this case selected indicators, parameter values and sustainability limits were specific for the Dutch situation. For other countries, other indicators may be more relevant. However, the same protocol may be used to come to an overall sustainability assessment. Once parameter values and sustainability limits are set, they can be included in the developed weighting tool (van der Voet et al., [2014](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-33)). Then, it is up to the policymaker to attribute compensability and weight factors for the various dimensions and indicators. These values can be based on his/her own opinion, but should preferably be set using various stakeholders to reflect societal concerns (Gómez-Limón and Riesgo, [2009](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-14)). The weighting tool then allows for evaluating the effect of different weights and compensabilities on the overall sustainability scores. This facilitates discussions between stakeholders involved and may help in the decision-making process regarding the choice for the most sustainable egg production system.

[Previous Section](http://ps.oxfordjournals.org/content/94/8/1742.full#sec-6)[Next Section](http://ps.oxfordjournals.org/content/94/8/1742.full#ref-list-1)

Acknowledgments

Stakeholders participating in this study are kindly thanked for their valuable contributions. The financial support from the Dutch Ministry of Economic Affairs has been highly appreciated.

© 2015 Poultry Science Association Inc.

[Previous Section](http://ps.oxfordjournals.org/content/94/8/1742.full#ack-1)

REFERENCES

Bokkers E. G. M.

Bespaar uzelf een boete: Actieplan Salmonella eiersector 2001+. De Pluimveehouderij 2002;32:8-9.

[Google Scholar](http://scholar.google.com/scholar_lookup?title=Bespaar%20uzelf%20een%20boete%3A%20Actieplan%20Salmonella%20eiersector%202001%2B&author=E.%20G.%20M.%20Bokkers&publication_year=2002&journal=De%20Pluimveehouderij&volume=32&pages=8-9)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-2-1)

Botreau R.,

Veissier I.,

Butterworth A.,

Bracke M. B. M.,

Keeling L. J.

Definition of criteria for overall assessment of animal welfare. Anim. Welf. 2007;16:225-228.

[Web of Science](http://ps.oxfordjournals.org/external-ref?access_num=000246382400030&link_type=ISI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=Definition%20of%20criteria%20for%20overall%20assessment%20of%20animal%20welfare&author=R.%20Botreau&author=I.%20Veissier&author=A.%20Butterworth&author=M.%20B.%20M.%20Bracke&author=L.%20J.%20Keeling&publication_year=2007&journal=Anim.%20Welf.&volume=16&pages=225-228)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-3-1)

Botreau R.,

Veissier I.,

Perny P.

Overall assessment of animal welfare: Strategy adopted in Welfare Quality®. Anim. Welf. 2009;18:363-370.

[Web of Science](http://ps.oxfordjournals.org/external-ref?access_num=000271513500006&link_type=ISI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=Overall%20assessment%20of%20animal%20welfare%3A%20Strategy%20adopted%20in%20Welfare%20Quality%C2%AE&author=R.%20Botreau&author=I.%20Veissier&author=P.%20Perny&publication_year=2009&journal=Anim.%20Welf.&volume=18&pages=363-370)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-4-1)

Castellini C.,

Boggia A.,

Cortina C.,

Dal Bosco A.,

Paolotti L.,

Novelli E.,

Mugnai C.

A multicriteria approach for measuring the sustainability of different poultry production systems. J. Clean Prod. 2012;37:192-201.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.1016/j.jclepro.2012.07.006&link_type=DOI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=A%20multicriteria%20approach%20for%20measuring%20the%20sustainability%20of%20different%20poultry%20production%20systems&author=C.%20Castellini&author=A.%20Boggia&author=C.%20Cortina&author=A.%20Dal%20Bosco&author=L.%20Paolotti&author=E.%20Novelli&author=C.%20Mugnai&publication_year=2012&journal=J.%20Clean%20Prod.&volume=37&pages=192-201)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-5-1)

De Boer I.,

Cornelissen A.

A method using sustainability indicators to compare conventional and animal-friendly egg production systems. Poult. Sci. 2002;81:173-181.

[Abstract/FREE Full Text](http://ps.oxfordjournals.org/cgi/ijlink?linkType=ABST&journalCode=poultrysci&resid=81/2/173)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-6-1)

Dekker S. E. M.,

de Boer I. J. M.,

Vermeij I.,

Aarnink A. J. A.,

Koerkamp P. W. G. G.

Ecological and economic evaluation of Dutch egg production systems. Livest. Sci. 2011;139:109-121.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.1016/j.livsci.2011.03.011&link_type=DOI)[Web of Science](http://ps.oxfordjournals.org/external-ref?access_num=000292443100012&link_type=ISI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=Ecological%20and%20economic%20evaluation%20of%20Dutch%20egg%20production%20systems&author=S.%20E.%20M.%20Dekker&author=I.%20J.%20M.%20de%20Boer&author=I.%20Vermeij&author=A.%20J.%20A.%20Aarnink&author=P.%20W.%20G.%20G.%20Koerkamp&publication_year=2011&journal=Livest.%20Sci.&volume=139&pages=109-121)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-7-1)

EFSA

. Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to the welfare aspects of various systems of keeping laying hens. J. EFSA 2005;197:1-23.

EFSA

. Report of the Task Force on Zoonoses Data Collection on the analysis of the baseline study on the prevalence of Salmonella in holdings of laying hen flocks of Gallus gallus. J. EFSA 2007;97:1-85.

EFSA

. Update of the monitoring of dioxins and PCBs levels in food and feed. J. EFSA 2012;10:2832. doi:10.2903/j.efsa.2012.2832.

EL&I. Derde Convenant Marktontwikkeling Biologische Landbouw. The Hague, The Netherlands: Ministery of Economic Affairs, Agriculture, and Innovation; 2008.

EL&I. Convenant Marktontwikkeling Verduurzaming Dierlijke Producten. The Hague, The Netherlands: Ministery of Economic Affairs, Agriculture, and Innovation; 2009.

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-12-1)

FAWC

. Farm Animal Welfare in Great Britain: Past, Present and Future. London, UK: Farm Animal Welfare Council; 2009.

Fiks-van Niekerk T. G. C. M.

Gezondheid van Biologische Leghennen. Lelystad, The Netherlands: ASG; 2008.

[Google Scholar](http://scholar.google.com/scholar_lookup?title=Gezondheid%20van%20Biologische%20Leghennen&author=T.%20G.%20C.%20M.%20Fiks-van%20Niekerk&publication_year=2008)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-14-1)

Gómez-Limón J. A.,

Riesgo L.

Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain. J. Environ. Manage. 2009;90:3345-3362.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.1016/j.jenvman.2009.05.023&link_type=DOI)[Medline](http://ps.oxfordjournals.org/external-ref?access_num=19560250&link_type=MED)[Google Scholar](http://scholar.google.com/scholar_lookup?title=Alternative%20approaches%20to%20the%20construction%20of%20a%20composite%20indicator%20of%20agricultural%20sustainability%3A%20An%20application%20to%20irrigated%20agriculture%20in%20the%20Duero%20basin%20in%20Spain&author=J.%20A.%20G%C3%B3mez-Lim%C3%B3n&author=L.%20Riesgo&publication_year=2009&journal=J.%20Environ.%20Manage.&volume=90&pages=3345-3362)

Haverkort A. J.,

Bindraban P. S.,

Conijn J. G.,

de Ruijter F. J.

A crop production ecology (CPE) approach to sustainable production of biomass for food, feed and fuel. Outlook Agric. 2009;38:249-258.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.5367/000000009789396801&link_type=DOI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=A%20crop%20production%20ecology%20%28CPE%29%20approach%20to%20sustainable%20production%20of%20biomass%20for%20food%2C%20feed%20and%20fuel&author=A.%20J.%20Haverkort&author=P.%20S.%20Bindraban&author=J.%20G.%20Conijn&author=F.%20J.%20de%20Ruijter&publication_year=2009&journal=Outlook%20Agric.&volume=38&pages=249-258)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-16-1)

Hilkens W.,

Klein Swormink B.

Duurzaamheid in Eieren en Kippenvlees. ABN AMRO 2011. Available at: <http://www.abnamro.nl/agrarisch>.

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-17-1)

Holt P. S.,

Davies R. H.,

Dewulf J.,

Gast R. K.,

Huwe J. K.,

Jones D. R.,

Waltman D.,

Willian K. R.

The impact of different housing systems on egg safety and quality. Poult. Sci. 2011;90:251-262.

[Abstract/FREE Full Text](http://ps.oxfordjournals.org/cgi/ijlink?linkType=ABST&journalCode=poultrysci&resid=90/1/251)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-18-1)

Lay D. C.,

Fulton R. M.,

Hester P. Y.,

Karcher D. M.,

Kjaer J. B.,

Mench J. A.,

Mullens B. A.,

Newberry R. C.,

Nicol C. J.,

O'Sullivan N. P.,

Porter R. E.

Hen welfare in different housing systems. Poult. Sci. 2011;90:278-294.

[Abstract/FREE Full Text](http://ps.oxfordjournals.org/cgi/ijlink?linkType=ABST&journalCode=poultrysci&resid=90/1/278)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-19-1)

Legkippenbesluit

. Besluit van 27 mei 2003, houdende regels voor de huisvestiging en verzorging van legkippen. Staatsblad 2004;40:1-20.

LEI Wageningen UR

. Agrarische Prijzen (Agricultural Prices). 2013a. Wageningen UR, LEI, Available at: [http://www.wagen-ingenur.nl/nl/Expertises-Dienstverlening/Onderzoeksinstituten/lei/Sector-in-cijfers/Agrarische-prijzen.htm](http://www.wageningenur.nl/nl/Expertises-Dienstverlening/Onderzoeksinstituten/lei/Sector-in-cijfers/Agrarische-prijzen.htm).

LEI Wageningen UR

. Monitor Duurzaam Voedsel 2012. The Hague, The Netherlands: LEI; 2013b.

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-22-1)

Leinonen I.,

Williams A. G.,

Wiseman J.,

Guy J.,

Kyriazakis I.

Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Egg production systems. Poult. Sci. 2012;91:26-40.

[Abstract/FREE Full Text](http://ps.oxfordjournals.org/cgi/ijlink?linkType=ABST&journalCode=poultrysci&resid=91/1/26)

Livestock Reserach Wageningen UR

. Handboek Kwantitatieve Informatie Veehouderij (Quantitative Information Animal Husbandry Handbook), 6th ed. The Netherlands: Lelystad; 2011.

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-24-1)

Mench J. A.,

Sumner D. A.,

Rosen-Molina J. T.

Sustainability of egg production in the United States—The policy and market context. Poult. Sci. 2011;90:229-240.

[Abstract/FREE Full Text](http://ps.oxfordjournals.org/cgi/ijlink?linkType=ABST&journalCode=poultrysci&resid=90/1/229)

Ministry of Infrastructure and the Environment

. Besluit Ammoniakemissie Huisvesting Veehouderij (Decision Ammonia Emission of Housing Systems in Animal Husbandry). The Hague, The Netherlands: Ministry of Infrastructure and the Environment; 2005. Accessed 27-9-2013, Available at:<http://wetten.overheid.nl/BWBR0019211/>.

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-26-1)

Ministry of Infrastructure and the Environment

. Regeling Ammoniak en Veehouderij (Regulation Ammonia and Animal Husbandry). The Hague, The Netherlands: Ministry of Infrastructure and the Environment; 2012. Available at: <http://wetten.overheid.nl/BWBR0013629/>.

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-27-1)

Mollenhorst H.,

Berentsen P. B. M.,

De Boer I. J. M.

On-farm quantification of sustainability indicators: An application to egg production systems. Br Poult. Sci. 2006;47:405-417.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.1080/00071660600829282&link_type=DOI)[Medline](http://ps.oxfordjournals.org/external-ref?access_num=16905466&link_type=MED)[Web of Science](http://ps.oxfordjournals.org/external-ref?access_num=000240120500004&link_type=ISI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=On-farm%20quantification%20of%20sustainability%20indicators%3A%20An%20application%20to%20egg%20production%20systems&author=H.%20Mollenhorst&author=P.%20B.%20M.%20Berentsen&author=I.%20J.%20M.%20De%20Boer&publication_year=2006&journal=Br%20Poult.%20Sci.&volume=47&pages=405-417)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-28-1)

Mollenhorst H.,

de Boer I. J. M.

Identifying sustainability issues using participatory SWOT analysis: A case study of egg production in the Netherlands. Outlook Agric. 2004;33:267-276.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.5367/0000000042664747&link_type=DOI)[Web of Science](http://ps.oxfordjournals.org/external-ref?access_num=000225975300007&link_type=ISI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=Identifying%20sustainability%20issues%20using%20participatory%20SWOT%20analysis%3A%20A%20case%20study%20of%20egg%20production%20in%20the%20Netherlands&author=H.%20Mollenhorst&author=I.%20J.%20M.%20de%20Boer&publication_year=2004&journal=Outlook%20Agric.&volume=33&pages=267-276)

PVE

. Poultry Board of Livestock, Meat, and Eggs (PVE). The Netherlands: Zoetermeer; 2008. Actieplan Salmonella in de Eiersector.

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-30-1)

Shimmura T.,

Bracke M. B. M.,

De Mol R. M.,

Hirahara S.,

Uetake K.,

Tanaka T.

Overall welfare assessment of laying hens: Comparing science-based, environment-based and animal-based assessments. Anim. Sci. J. 2011;82:150-160.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.1111/j.1740-0929.2010.00834.x&link_type=DOI)[Medline](http://ps.oxfordjournals.org/external-ref?access_num=21269374&link_type=MED)[Google Scholar](http://scholar.google.com/scholar_lookup?title=Overall%20welfare%20assessment%20of%20laying%20hens%3A%20Comparing%20science-based%2C%20environment-based%20and%20animal-based%20assessments&author=T.%20Shimmura&author=M.%20B.%20M.%20Bracke&author=R.%20M.%20De%20Mol&author=S.%20Hirahara&author=K.%20Uetake&author=T.%20Tanaka&publication_year=2011&journal=Anim.%20Sci.%20J.&volume=82&pages=150-160)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-31-1)

Swanson J. C.,

Mench J. A.,

Thompson P. B.

Introduction—The Socially Sustainable Egg Production project. Poult. Sci. 2011;90:227-228.

[Abstract/FREE Full Text](http://ps.oxfordjournals.org/cgi/ijlink?linkType=ABST&journalCode=poultrysci&resid=90/1/227)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-32-1)

van Asselt E. D.,

van Bussel L. G. J.,

van der Voet H.,

van der Heijden G. W. A. M.,

Tromp S. O.,

Rijgersberg H.,

van Evert F.,

Van Wagenberg C. P. A.,

van der Fels-Klerx H. J.

A protocol for evaluating the sustainability of agri-food production systems—A case study on potato production in peri-urban agriculture in The Netherlands. Ecol. Indic. 2014;43:315-321.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.1016/j.ecolind.2014.02.027&link_type=DOI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=A%20protocol%20for%20evaluating%20the%20sustainability%20of%20agri-food%20production%20systems%E2%80%94A%20case%20study%20on%20potato%20production%20in%20peri-urban%20agriculture%20in%20The%20Netherlands&author=E.%20D.%20van%20Asselt&author=L.%20G.%20J.%20van%20Bussel&author=H.%20van%20der%20Voet&author=G.%20W.%20A.%20M.%20van%20der%20Heijden&author=S.%20O.%20Tromp&author=H.%20Rijgersberg&author=F.%20van%20Evert&author=C.%20P.%20A.%20Van%20Wagenberg&author=H.%20J.%20van%20der%20Fels-Klerx&publication_year=2014&journal=Ecol.%20Indic.&volume=43&pages=315-321)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-33-1)

van der Voet H.,

van der Heijden G. W. A. M.,

Kruisselbrink J. W.,

Tromp S.-O.,

Rijgersberg H.,

van Bussel L. G. J.,

van Asselt E. D.,

van der Fels-Klerx H. J.

A decision support tool for assessing scenario acceptability using a hierarchy of indicators with compensabilities and importance weights. Ecol. Indic. 2014;43:306-314.

[CrossRef](http://ps.oxfordjournals.org/external-ref?access_num=10.1016/j.ecolind.2014.02.022&link_type=DOI)[Google Scholar](http://scholar.google.com/scholar_lookup?title=A%20decision%20support%20tool%20for%20assessing%20scenario%20acceptability%20using%20a%20hierarchy%20of%20indicators%20with%20compensabilities%20and%20importance%20weights&author=H.%20van%20der%20Voet&author=G.%20W.%20A.%20M.%20van%20der%20Heijden&author=J.%20W.%20Kruisselbrink&author=S.-O.%20Tromp&author=H.%20Rijgersberg&author=L.%20G.%20J.%20van%20Bussel&author=E.%20D.%20van%20Asselt&author=H.%20J.%20van%20der%20Fels-Klerx&publication_year=2014&journal=Ecol.%20Indic.&volume=43&pages=306-314)

[↵](http://ps.oxfordjournals.org/content/94/8/1742.full#xref-ref-34-1)

Xin H.,

Gates R. S.,

Green A. R.,

Mitloehner F. M.,

Moore P. A.,

Wathes C. M.

Environmental impacts and sustainability of egg production systems. Poult. Sci. 2011;90:263-277.

[Abstract/FREE Full Text](http://ps.oxfordjournals.org/cgi/ijlink?linkType=ABST&journalCode=poultrysci&resid=90/1/263)